PHOTONS

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Canada celebrates photonics excellence
Le Canada célèbre l'excellence en photonique

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EDITORIAL / ÉDITORIAL

Let's celebrate photonics in Canada!

It is with great pleasure that CIPI announced this winter its extension of NCE funding until 2012. By developing and supporting collaborative projects between universities and Canadian industry, CIPI has demonstrated its importance and has had an impact stimulating the transfer of knowledge and technology.

In 2009, CIPI is celebrating its 10th anniversary, while the Centre d'optique, photonique et laser (COPL) at Université Laval celebrates its 20th anniversary. Furthermore, with the support of many stakeholders, the Canadian Photonic Consortium (CPC) has completed the survey on the status of photonics in Canada producing a very useful report which demonstrates the strategic value of photonics for the Canadian economy.

In this issue of PHOTONS, our objective is to celebrate our achievements in photonics and therefore, we begin with an overview of the document Illuminating a World of Opportunity. It is followed by articles on the history of CIPI and COPL, and the story of three start-ups which are related to CIPI projects. Also, this issue includes an example of what may become one of CIPI's legacy: a resume of a workshop called the Canadian Laser Application Network (CLAN) which intends to initiate the development of a new network focusing on laser processing.

On the more scientific side, we have state-of-the-art scientific articles from Canadian researchers with their contexts: new technologies which are applicable in the medical field and in high-speed communications, the development of new photonics components and processes. Last but not least, the winning article of our scientific popularization contest, explaining the capability of lasers to move particles, completes this issue.

Since industries are in the midst of a significant economic crisis, technology is the best lifebelt for them and photonics is a strategic enabler for improved productivity and growth. Therefore, let's celebrate photonics while we continue to focus on the new needs of Canadian industry.

Robert Corriveau
President and CEO
Canadian Institute for Photonic Innovations

Célébrons la photonique au Canada!

C'est avec un grand plaisir que l'ICIP a annoncé au début de l'hiver le prolongement du support financier du RCE jusqu'en 2012. Grâce au développement et au support de projets de collaboration entre les universités et l'industrie canadienne, l'ICIP a démontré son utilité et son impact dans le transfert de la connaissance et de la technologie vers l'industrie.

Au cours de l'année 2009, l'ICIP célébrera son dixième anniversaire tandis que le Centre d'optique, photonique et laser (COPL) de l'Université Laval célèbrera son vingtième anniversaire. Par ailleurs, grâce à l'appui de plusieurs organismes en photonique, le Consortium photonique canadien (CPC) a complété une enquête sur l'état de la photonique au Canada et a produit un document très utile qui démontre la valeur stratégique de la photonique pour l'économie canadienne.

Dans ce numéro de PHOTONS, notre objectif est de célébrer la photonique et donc, nous débutons avec une revue du document Faire la lumière sur une multitude de débouchés. Suivent des articles sur l'histoire de l'ICIP et du COPL, et l'histoire de trois entreprises photoniques en démarrage qui sont fortement liés à des projets de l'ICIP. Nous continuons avec un exemple d'héritage de l'ICIP, soit un résumé de l'atelier Canadian Laser Application Network (CLAN) qui a pour but d'initier le développement d'un nouveau réseau axé sur le traitement laser.

Du côté scientifique, PHOTONS publie plusieurs articles d'avant-garde provenant de chercheurs canadiens, ainsi que leurs contextes : de nouvelles technologies applicables au domaine médical et en communication haute vitesse, le développement de nouveaux composants et procédés photoniques. Pour finir en beauté, l'article gagnant de notre concours de vulgarisation scientifique, qui explique la capacité de déplacer des particules par faisceau laser.

En temps de crise économique importante, la technologie reste la meilleure bouée de sauvetage de l'industrie. Et la photonique est une technologie habilitante stratégique pour améliorer la productivité et la croissance des entreprises. Ainsi, célébrons la photonique tandis que nous continuons à adapter nos projets aux nouveaux besoins de l'industrie canadienne.

Robert Corriveau
Président-directeur général
Institut canadien pour les innovations en photonique

Making Light Work for Canada

Michael G Scott, MA. PhD

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ABSTRACT - The Canadian Photonics Consortium has recently completed a survey of the status and impact of photonics in Canada. The survey identifies the numbers of photonics companies in the country, their size and market sectors. It looks at investment in photonics R&D and education and its effectiveness. The report concludes with some recommendations as to how Canada can best position itself to benefit from the photonics revolution.

1. INTRODUCTION

Canada has a long history of investment and innovation in photonics. Among Canadian photonic firsts are the charge coupled device, drugs for photodynamic therapy, the fiber Bragg grating and the solid-state laser range finder. During the telecom bubble of the late 1990's/early 2000's Canadian companies led the world in optical communications equipment and components. Since that time the industry has consolidated and diversified and many sectors of Canada's economy have become users of photonics technologies. Yet, despite the size of the global photonics market and its impact on almost every sector of the Canadian economy, knowledge of photonics and its significance is lacking amongst many decision makers and the general public. Furthermore, extracting data about photonics is often difficult since it is rarely tracked as a separate industry category.

To gain a clearer perspective, in 2007 the Canadian Photonics Consortium commissioned a wide ranging survey of photonics in Canada [1]. The aims were to;

- assess the status of photonics in Canada from the science base to producers,
- examine the extent of the application of photonics in major sectors of the economy,
- assess the impact of training and education in creating a workforce that is adequately photonics literate, and
- recommend how Canada can maximize its benefits from a "photonics world."

This paper summarizes the findings of that study

2. METHODOLOGY

Our methodology was very similar to that used two years earlier by the UK Department of Trade and industry to prepare their strategic document on photonics [2]. Data collection was through a mix of surveys and workshops. Provincial level surveys had already been started in Quebec [3] and Ontario [4] and by agreeing to a common methodology we were able to leverage and supplement their data. We also commissioned additional surveys in the Prairies, British Columbia and the Atlantic Provinces. The surveys were conducted by a mix of questionnaires and face to face or telephone interviews. We also held a series of 5 industry – led sector based workshops to establish business and technical trends and to undertake a Strengths/ Weaknesses/ Opportunities/ Threats analysis for the sectors.

It was important that for maximum credibility the study had wide endorsement. Therefore, we assembled an Advisory Group, representing a broad cross section of photonics producers and users in Canada and the academic community. All of the findings were discussed with this group and the recommendations were endorsed by them.

3. RESULTS

3.1 Photonics producers

We identified about 370 photonics companies in Canada (Table 1). We have used a broad definition to include any company, or division of a large company, whose primary business is to supply goods or service that depend on photonics. Not unexpectedly a large proportion of these companies are in Quebec and Ontario where there are well established and formalized clusters, together with a healthy concentration in the Vancouver/Victoria area. A surprise is the significant number of companies in the Prairie Provinces, particularly in the Edmonton area. Collectively these companies employ about 20,000 people and generate annual revenues of around $4.5bn, of which 85% is from exports.

	Companies	Employees	Revenues
Quebec	104	4,750	$600M
Ontario	117	10,200	$3000M
Prairies	95	2,990	$330M
BC	50	2,010	$430M
Atlantic	8	310	$36M
TOTAL	**374**	**20,260**	**$4,400M**

***Table 1**. Photonics companies in Canada*

The Canadian photonics industry is dominated by SMEs and start-ups. Though there are a few major players such as Dalsa and Elcan, 70% of Canadian photonics companies have under $10m in revenues (fig.1) and less than 50 employees (fig.2). Indeed, 25% have less than 10 employees and in many cases are pre-revenue. As a result the companies are R&D intensive with over 40% of employees engaged in this activity. A significant amount of assembly and manufacturing is also conducted in Canada.

Canadian photonics companies are predominantly integrators of optical and electronic components, which are often imported (fig.3). Over two-thirds list subsystems or systems as their end product. With the exception of consumer goods, Canadian companies now provide photonic solutions for all sectors of the economy. The industry has diversified significantly since the beginning of the century, with less than 20 % of companies now claiming to address the communication sector (fig.4).

3.2 User sectors

Every sector of the Canadian economy uses photonics. In some cases Canadian solutions are being used for Canadian applications but often the technology is imported. This is particularly true in the manufacturing sector; Canada no longer has an indigenous high power laser industry, yet such devices are used extensively for cutting and joining in the auto, bus and aerospace industries. The oil and gas industry is an extensive user of photonics, from the machining of bore tubes to temperature and pressure monitoring and detection of leaks and flaws in pipelines. The lumber and paper industry utilizes laser sizing of logs, for quality control and for treating and

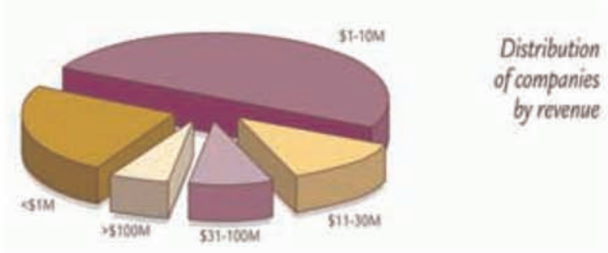

Fig.1. Revenues of Canadian photonics companies

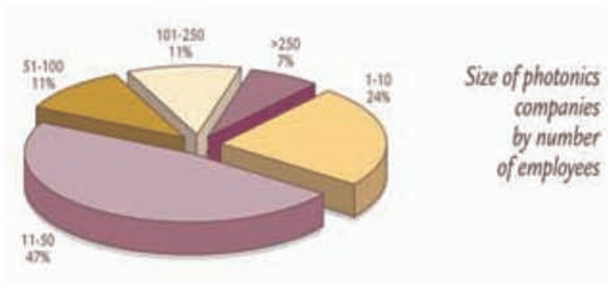

Fig.2. Canadian photonics companies by number of employees

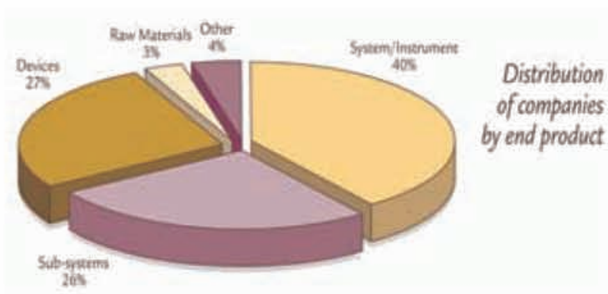

Fig.3 Distribution of companies by end product

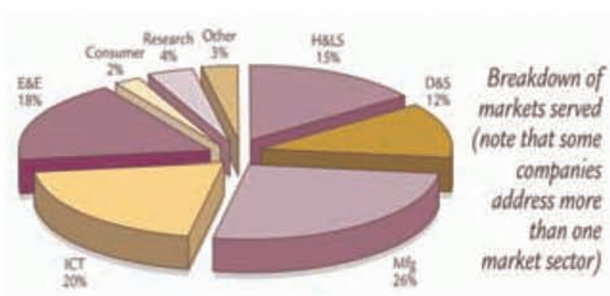

Fig. 4. Sectors served by Canadian photonics companies

finishing wood. The food processing industry uses photonic based quality monitoring systems. One particularly novel Canadian solution is the use of photonics to size fish filets in Newfoundland!

3.3 Research

The federal and provincial governments invest about $150m annually in broadly photonics based research. Much of this is spent in government facilities of which the National Research Centre (NRC) and Defence Research and Development Canada (DRDC) are the biggest beneficiaries. The government has invested strongly in photonics facilities, notably the Canadian Photonics Fabrication Facility (CPFC) in Ottawa, National Optics Institute (INO) in Quebec City, Advanced Laser Light source (ALLS) near Montreal and the Canadian Light source (CLS) in Saskatoon.

We estimate that about $30m is spent annually on photonics related research in universities with much of this coming from the National Science and Engineering Research Council (NSERC). There are currently over 30 holders of Canada Research Chairs who list photonics or optics as a major part of their research activities. Over 20 universities in Canada have active photonics research groups. There is a high degree of collaboration and networking, driven by organizations such as CIPI which brings together over 90 researchers and 300 graduate students in 20 universities. In recent years there has been an increasing emphasis on encouraging university industry partnerships to improve technology transfer and commercialization. CIPI has been at the forefront of this with its Technology Exchange and Networking Programme (TEN) and its Innovative Photonics Applications Programme (IPA) for which approximately two thirds of the cost is covered by cash or in kind from industrial partners. Ontario Centres of Excellence commits over $3m annually to university / company projects in photonics. It has also recently launched an accelerator fund to assist early stage companies to exploit university developed technology. CMC Microsystems has developed a national infrastructure that facilitates the design and testing of micro-system concepts. Photonics is a key platform within CMC's programme.

3.4 Training

Most training in photonics in Canada occurs at the PhD or Masters level through hands-on research. There are a handful of taught courses specializing in photonics but collectively these generate fewer than 50 students per year. For most students at the Bachelors level their exposure to photonics is limited to one or two modules, often as electives. One of our surprises was how little exposure to photonics the average engineer receives.

Ontario has paid particular attention to the training of photonics engineers and technicians. In response to comments from companies about the lack of trained photonics professionals, OCE established the Ontario Photonics Education and Training Association. One outcome was the establishment of a Bachelor in Photonics at Algonquin College and Diploma courses at Algonquin, Niagara and Brock Colleges.

3.5 Some observations

The photonics community in Canada has recovered well from the "meltdown" and has diversified. We have world leading companies in areas such as imaging technologies and vision based systems. There is a growing capability and startup community addressing health care and life sciences. We are developing a strong capability in sensing particularly for the oil industry and gas industry .We have a number of companies that are developing novel lighting and energy solutions - so called "green photonics". And despite the downturn there are a number of companies with a significant market presence in key areas of optical communications such as network management and fibre to the home.

Canada has some world leading research, for example in short pulse laser technology. However, from a commercial perspective the significant investment in research has led to mixed results in the direct creation and transfer of exploitable technology. INO and NRC have been successful in technology transfer and in spinning out a number of companies. Both CIPI and OCE can point to successes. The CPFC is providing a valuable bridge between innovation and commercialization and has attracted and spawned several companies in the Ottawa area. However, our surveys suggested there was often scope for improvement in the interaction between universities and industry.

Canada needs a broader photonics workforce. There is no doubt we produce some of the best photonics PhDs in the world; we need to supplement these with graduates and technicians who are familiar with and trained in photonics and its applications. If we are to encourage industries to adopt photonic solutions we need to ensure that engineers have a better understanding of photonics so that they consider photonics solutions to problems. There is also a need for better dissemination of information between industries and companies and between producers and users. For example we need to ensure that those involved in a traditional industry such as lighting know how to adopt innovative solutions such as LEDs rather than feel threatened by them.

4. RECOMMENDATIONS

Canada has an outstanding track record and a strong global brand in photonics. We have an excellent workforce, world class universities, a strong commitment to research and an innovative and entrepreneurial culture. By focusing our efforts and channeling our research efforts into providing solutions for major Canadian industries which we can then export to the world we can leverage our position beyond where we are today and gain a bigger share of the $700 billion pie. The report made the following recommendations;

The photonics producer community should engage more strongly with the user community to develop solutions that provide leadership to key Canadian industries and generate potential export opportunities.

Establish information portals similar to the UK Knowledge Transfer Networks to facilitate transfer of information between companies and from universities to companies.

Improve awareness and education in photonics. Photonics should be an integral part of all engineering courses and there should be an increase in the number of photonics technician courses.

Increase commercialization of photonics technology, leveraging initiatives such as CIPI and collaborative programmes along the lines of those used by the EU Framework.

Establish an industry-academic steering group to focus research on areas of strategic importance to Canada such as energy, the environment and healthcare.

Expand the cluster model, successful in Ontario and Quebec to other locations such as BC and Alberta where there are emerging photonic sectors.

CIPI SUPPORT

The Canadian Photonics Consortium would like to thank CIPI for their financial and technical support of this study.

OTHER ACKNOWLEDGEMENTS

The CPC would also like to thank the following organizations that contributed to this report;

- Institute for Microstructural Studies and the Canadian Photonics Fabrication Centre of the National Research Council,
- Réseau Photonique du Quebec,
- Ontario Centres of Excellence, Centre for Photonics,
- Institute national d'optique,
- Defence Research and Development Canada – Valcartier,
- Atlantic Canada Opportunities Agency,
- Industry Canada (BC),
- Department of Foreign Affairs and International Trade
- CMC Microsystems
- National Research Council Industrial Research Assistance Programme,
- TRLabs – Edmonton,
- NanoBC.

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L'ICIP: au cœur de l'excellence en photonique…depuis 10 ans

Nathalie Kinnard, coordonnatrice des communications

Le portrait de la recherche en photonique a bien changé depuis 10 ans. À la fin des années 90, elle se faisait de façon isolée : d'un océan à l'autre, les chercheurs étudiaient la lumière et ses applications, chacun dans leur laboratoire. Puis, grâce à la vision de Michel Têtu et William A. van Wijngaarden, les scientifiques ont réalisé que l'union fait la force. Ils ont commencé à sortir de leurs laboratoires, à rencontrer leurs pairs et à établir des liens avec les gens de l'industrie de la photonique. L'ICIP était né ! 10 ans plus tard, l'Institut pour les innovations en photonique (ICIP) est plus actif que jamais, et vient même de voir sa subvention renouvelée pour les 3 prochaines années.

La petite histoire de l'ICIP débute en 1997. Michel Têtu, alors professeur et directeur au Centre d'optique, photonique et laser (COPL) de l'Université Laval, caresse le rêve de réunir tous les chercheurs canadiens du domaine de la photonique. Dans la province voisine, William A. van Wijngaarden, professeur et chercheur à l'Université York, a la même ambition. Mis au courant l'un et l'autre de leurs projets respectifs, ils décident de combiner leurs efforts et de présenter une demande de financement au programme fédéral des Réseaux des centres d'excellence (RCE). Malheureusement, les RCE n'ont pas assez de budget pour financer le projet lors du concours de 1998. Mais les bases sont jetées, et les deux scientifiques à la tête du projet n'abandonnent pas leur idée pour autant. Heureusement, car convaincus du bien-fondé d'un institut en photonique, les RCE débloquent finalement en 1999 le montant nécessaire pour financer l'ICIP!

Débute alors un travail acharné pour mettre sur pied une structure administrative fonctionnelle comprenant un Conseil d'administration (C.A.), un centre administratif, un comité exécutif et un programme de recherche scientifique. L'Université Laval devient l'hôte de l'Institut, codirigé par Michel Têtu et William A. van Wijngaarden, alors que Claude Desaulniers s'occupe de la gestion administrative. Le mot d'ordre : développer et valoriser la photonique au Canada. « Nous avons mis beaucoup d'effort pour monter un bon programme de recherche, qui tournait alors autour de cinq thèmes, soit la métrologie, les composants photoniques, les télécommunications / fibres optiques, les nanotechnologies et les lasers à impulsions ultrabrèves », raconte Michel Têtu, nouvellement en poste à la tête du Réseau photonique du Québec (RPQ). L'ICIP part en force, la bulle des télécommunications aidant beaucoup sa cause.

Un logo qui parle

Dès sa création, l'ICIP se dote d'un logo toujours utilisé aujourd'hui. Les « parenthèses » évoquent l'une la recherche universitaire, l'autre l'industrie. Les cinq points de couleurs représentent les thèmes de recherche, alors que l'espace entre les « parenthèses » rappelle la cavité de résonance d'un système laser.

CHANGER POUR MIEUX ÉVOLUER

En 2000, l'ICIP organise sa première assemblée annuelle à Québec. Peu de temps après, en partie grâce à des fonds de l'ICIP, le codirecteur de l'ICIP Michel Têtu fonde Dicos, un premier essaimage de l'ICIP, offrant une expertise en contrôle et stabilisation de fréquence optique qui sera vite reconnue mondialement. Le professeur Michel Piché, chercheur au COPL, assure la relève comme codirecteur de l'institut, et le Conseil d'administration nomme le premier président, Elmer Hara, qui a le rôle de diriger le centre administratif de l'ICIP. Celui-ci arrive à point pour préparer le rapport de mi-étape de l'ICIP. Il faut savoir que le programme des RCE finance un réseau pendant 14 ans maximum, 13 pour l'ICIP étant donné sa création tardive. Durant la première phase de 6 ans, le réseau doit fournir un rapport de mi-étape pour continuer à recevoir la subvention. L'ICIP profite de ce renouvellement pour effectuer plusieurs changements. À la suite du départ de William A. van Wijngaarden, Michel Piché assure seul le rôle de directeur scientifique. Ian McDonald, alors membre et président intérimaire du C.A., quitte son poste pour prendre la relève en tant que président-directeur général de l'ICIP lorsque M. Hara quitte. Dès la fin de 2002, Robert Fedosejevs, chercheur à l'Université de l'Alberta est nommé directeur scientifique de l'ICIP. Douglas James, dirigeant d'entreprise impliqué dans de nombreux C.A. de compagnies, est nommé par les RCE pour siéger au C.A. de l'ICIP. Ensemble, ils travaillent à remodeler le programme scientifique qui passe de 5 thèmes à 3 axes orientés vers les applications : Information et télécommunications, Santé, environnement et sécurité, et Frontières de la photonique. « Nous avons dès lors instauré un processus de compétition entre les projets de recherche, pour savoir lesquels seraient financés ou non, explique Michel Piché. Nous avons également créé le programme valorisation technologique et de réseautage (VTR) pour encourager des projets de recherche visant des applications de la photonique à court terme, ayant un grand potentiel de commercialisation ». Selon Denis Faubert, vice-président du C.A. de l'ICIP de 1999 à 2005, le programme VTR est un grand coup de l'ICIP. « Ce programme démontre bien la volonté de l'ICIP d'appliquer la recherche et de transférer les technologies, et de se rapprocher de l'industrie qui fait et qui utilise la photonique », pense le directeur principal du Centre de recherche d'Hydro-Québec.

Présidents-directeurs généraux de l'ICIP

Elmer Hara	2000-2002
Ian McDonald	2002-2005
Robert Corriveau	2005-

Présidents du C.A. de l'ICIP

Michael Steinitz	1999-2002
Ian McDonald	été 2002
Douglas James	2002-

Un changement n'attend pas l'autre. Sous recommandation de Michel Piché, l'étudiante Claudine Allen et quelques collègues, fondent l'association étudiante ICIP-É en 2002 afin d'impliquer d'avantage les étudiants dans la structure de l'ICIP. « Notre première mission a été de recruter des étudiants de l'Ouest pour les impliquer et leur faire connaître l'ICIP-É et l'ICIP, se rappelle Claudine Allen, aujourd'hui professeure et chercheure au COPL. Nous avons ensuite organisé des ateliers et des visites industrielles ; nous avons également créé un site Internet ». Leur premier atelier s'est tenu à Montréal en février 2003 et a regroupé pas moins de 84 participants de partout au Canada. Une des récentes activités organisées par l'association étudiante est un atelier sur la biophotonique, tenu à Toronto le 23 avril 2009, auquel ont participé quelque 45 étudiants.

Logo de l'ICIP-É

L'ICIP accorde une grande place aux étudiants : le président de l'ICIP-É siège sur le C.A. de l'ICIP alors que le vice-président siège sur le comité du programme de recherche. « L'expérience de faire partie du C.A. est extraordinaire, note Mme Allen. On acquiert une bonne vision de la recherche canadienne, on voit les dessous de la recherche ». Même son de cloche de la part de Trinh Nguyen, actuelle présidente de l'ICIP-É.

Au fil du temps, l'ICIP-É est également devenue l'instigateur de plusieurs activités sociales pour favoriser les échanges entre étudiants et chercheurs. Selon Alain Villeneuve, membre du comité du programme de recherche de l'ICIP entre 1999 et 2005 et de nouveau depuis 2009, le réseau étudiant est l'un des grands succès de l'ICIP : « La création de l'ICIP-É a permis d'augmenter les collaborations de recherche grâce aux échanges d'étudiants entre les différents laboratoires », rapporte celui qui dirige présentement la compagnie Optav, et qui a travaillé avec l'ICIP dès ses débuts.

L'ICIP-É 2008
Arrière: Melanie Burger, Arvind Chandrasekaran, Noah Puskas, Hooman Hosseinkhannazer
Avant: Trinh Nguyen (présidente), Nazanin Morbrhan-Shafiee. Absente: Geneviève Taurand

L'ICIP AU CŒUR DE LA PHOTONIQUE CANADIENNE

Un autre succès de l'ICIP : la participation à la création en 2004 du Laboratoire international de source de rayonnement laser ultrarapide (Advanced Laser Light Source ou ALLS). Dirigé par le professeur et directeur général de l'INRS, Jean-Claude Kieffer, également chercheur de l'ICIP, le projet ALLS est l'aboutissement d'une collaboration exceptionnelle entre les chercheurs réunis initialement dans le cadre de projets de l'ICIP. Aujourd'hui, ALLS regroupe 14 universités canadiennes (INRS, U. Alberta, UBC, U. Calgary, U. Laval, U. McGill, U. Sherbrooke, U. Toronto, etc.), 3 laboratoires gouvernementaux (CNRC-Steacie, CNRC-IMI, DRDC) et 17 institutions internationales (notamment Max Plank (Allemagne), École Polytechnique (France), SUNY (É-U), Kansas State Univ. (É-U), LLNL (É-U), UCLA (É-U), Imperial College (UK), Riken (Japon), etc.).

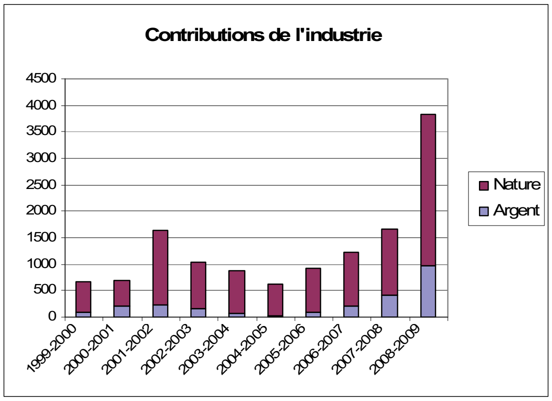
Ligne attoseconde montée à ALLS

Le laboratoire est situé au centre de recherche sur l'Énergie, les matériaux et les télécommunications de l'Institut national de la recherche scientifique, à Varennes en banlieue de Montréal. Il permet aux scientifiques qui y travaillent de redéfinir les frontières de la physique et de la chimie, et de multiplier les découvertes en biologie grâce aux nouvelles applications des technologies du laser femtoseconde susceptibles de mener à une compréhension accrue des systèmes biologiques infiniment petits et complexes. Les installations laser et les outils d'imagerie uniques profitent aux travaux de plusieurs chercheurs de l'ICIP et mettent en évidence à l'échelle internationale l'excellence de leurs activités scientifiques. « L'ICIP a permis de réunir toutes les parties impliquées dans ce projet, note Michel Piché. Il a même instauré un programme de bourses pour permettre aux étudiants d'aller passer un séjour dans ces laboratoires de pointe ».

2005 fut une autre grande année pour l'ICIP. L'Institut célèbre le renouvellement de sa subvention pour une deuxième phase de 7 ans. Robert Corriveau, alors vice-président, développement des affaires chez Phasoptx, vient occuper le poste de président-directeur général à l'ICIP. Avec le C.A., il instaure le programme IPA et dote les chercheurs en photonique au Canada d'une nouvelle source de financement pour les aider à transférer vers l'industrie les technologiques photoniques qu'ils développent. Le programme d'innovation en photonique appliquée (IPA) vise à soutenir les projets de recherche mis sur pied pour répondre aux besoins des utilisateurs dans divers secteurs industriels. Ce type de collaboration réunit des chercheurs universitaires, des intégrateurs de technologie et des utilisateurs autour de projets à court terme où les technologies de la photonique seront utilisées pour répondre à des problèmes précis.

L'année suivante, M. Corriveau met sur pied un réseau de représentants qui feront le lien entre l'ICIP et l'industrie. « Leur rôle est d'aller rencontrer les industriels pour leur parler de la photonique, de l'ICIP, et leur faire voir comment la recherche universitaire en photonique pourrait les aider à régler certains problèmes, notamment de production ou de contrôle de qualité », explique Robert Corriveau. Pendant que les représentants basés à Montréal, Ottawa, Toronto, Edmonton et Vancouver visitent les industries canadiennes, l'ICIP commence à afficher sa présence dans diverses expositions scientifiques et industrielles en photonique, un peu partout dans le monde : Photonics West, Photonics North, LASER et des missions internationales…

L'impact des programmes TEN et IPA, ainsi que le réseau de représentants se fait rapidement sentir. L'industrie réalise que les chercheurs peuvent les aider à régler certains problèmes. La contribution en argent ou en nature des industriels augmente d'ailleurs d'année en année, tout comme les projets de collaborations. « 20% des compagnies photoniques canadiennes sont actuellement impliquées avec l'ICIP », souligne fièrement Robert Corriveau.



Contributions de l'industrie 1999-2008

UNE HISTOIRE À SUIVRE

Dans trois ans, la subvention des RCE se terminera. L'ICIP gardera-t-il sa structure actuelle ou changera-t-il de vocation ? Nul ne le sait encore. Mais il reste que l'ICIP aura été une histoire à succès du programme des RCE pense

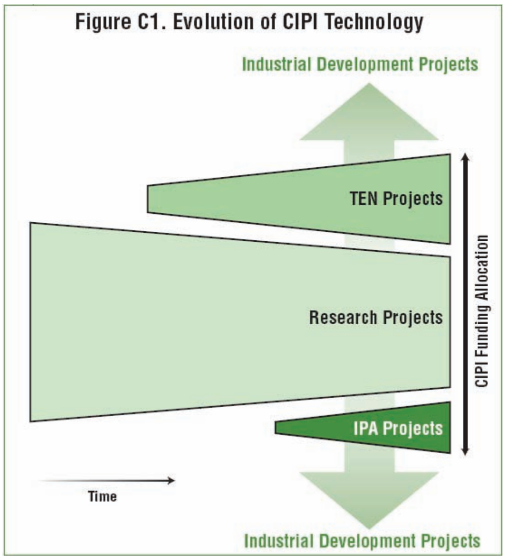
Michael Steinitz, professeur de physique à St. Francis Xavier University et président du C.A. de l'ICIP jusqu'en 2002. Opinion partagée par plusieurs. Robert Fedosejevs s'est notamment impliqué dans des projets de recherche qui n'auraient pas vu le jour sans l'ICIP. « L'ICIP a contribué à établir des liens entre les chercheurs de l'Est et de l'Ouest du Canada, fait-il remarquer. L'ICIP a de plus permis à la photonique d'émerger comme domaine de recherche d'importance au Canada, et à rapprocher les milieux universitaire et industriel ». Selon M. Fedosejevs, l'ICIP laissera en héritage une communauté photonique forte qui donnera probablement naissance à plusieurs réseaux plus pointus, comme le Réseau canadien des applications laser (CLAN) (voir article dans le présent numéro de PHOTONS), et de nombreux startups. « L'ICIP a aussi contribué à faire augmenter l'argent investi dans la recherche en photonique par les différents paliers de gouvernement, et a favorisé une nette augmentation de personnel hautement qualifié ! », d'ajouter Michel Têtu.

	2005-06	2006-07	2007-08
Étudiants gradués formés	261	291	271
Thèses complétées	42	46	33
Articles avec arbitrage	156	190	161
Brevets mis en filière	6	8	8

Statistiques des 3 dernières années

Sans contredit, l'ICIP a modifié la façon de faire la recherche, et ce, pour toujours. « L'ICIP permet aux chercheurs de se rencontrer, notamment lors des assemblées annuelles, note Sophie Larochelle, chercheure membre de l'ICIP. Par exemple, Mme Larochelle a rencontré lors d'une assemblée annuelle des chercheurs spécialisés dans la modélisation des modes de fibres optiques. Grâce à cette rencontre, son projet de recherche a pris de l'ampleur et continue de se diversifier même si son principal collaborateur est maintenant en Australie. La chercheure reconnait aussi l'impact du programme TEN qui permet de répondre rapidement à un besoin industriel, ainsi que l'opportunité pour les étudiants d'échanger avec les différents partenaires de recherche.

En 2012, l'ICIP aura élevé ses enfants, se plaît à imager Alain Villeneuve. Comme bien des parents, l'ICIP devra les laisser voler de leurs propres ailes. Reste à voir comment la famille évoluera alors.



Évolution des programmes de recherché de l'ICIP

CIPI: putting excellence at the heart of photonics for the past 10 years

Nathalie Kinnard, Communications Coordinator

Photonic research has greatly evolved and changed over the past decade. In the late nineties, researchers worldwide studied light and its applications, isolated in their individual laboratories. The joint vision of Michel Têtu and William A. van Wijngaarden changed photonic research forever. The concept of 'strength in numbers' was embraced by the scientific community and, leaving the confines of their laboratories, researchers met with their peers, creating unique interaction among those in the photonics industry. CIPI was born! Ten years later, the Canadian Institute for Photonic Innovations (CIPI) is more involved and active than ever and has recently been awarded renewed funding for an additional three years.

CIPI began in 1997 as an ambitious idea shared by two men. Michel Têtu, at the time Professor and Director at the Centre d'Optique, photonique et laser of Université Laval (COPL), dreamed of uniting all Canadian photonic researchers; whereas, in another province, William A. van Wijngaarden, Professor and researcher at York University, shared the same ambition. They united forces and jointly applied for federal financing through the Networks of Centres of Excellence (NCE) federal program and although NCE lacked the funds to finance the project in the 1998 funding competition, both scientists held on to their convictions that a photonic institute was necessary and successfully convinced NCE to find funding for CIPI in 1999!

Michel Têtu and William A. van Wijngaarden work relentlessly at establishing a functional administrative organization which includes a Board of Directors, Administrative Centre, Executive Committee, and Scientific Research Program. Université Laval becomes host to the Institute which is co-directed by Michel Têtu and William A. van Wijngaarden, whereas Claude Desaulniers is in charge of Administrative management. Their goal: to develop and promote photonics in Canada. "A lot of effort was invested into developing a good research program revolving around five main themes : metrology, photonic components, telecommunications/optic fibers, nanotechnology, and ultrashort pulse lasers," states Michel Têtu, recently appointed as President and General Manager of the Quebec Photonic Network (QPN). CIPI begins strong and solid, aided by the full force of the telecommunications bubble.

A logo which speaks volumes

CIPI's original logo has not changed. The brackets refer to both industry and university research; the five colored dots represent the five original research themes, whereas the space between the brackets represents a resonant cavity laser system.

CHANGING IN ORDER TO BETTER EVOLVE

In the year 2000, CIPI organized its first annual meeting in Quebec City. Shortly afterwards, thanks in part to CIPI funding, the co-director, Mr. Michel Têtu, creates Dicos, CIPI's first spin-off company. Dicos provides expertise in the control and stabilization of optical frequencies and does not take long in becoming recognized worldwide. Professor Michel Piché, researcher at COPL, takes over as co-director of the Institute and the Board of Directors names its first President, Mr. Elmer Hara, to manage the CIPI's Administrative Centre. Mr. Hara's arrival is opportune in preparing the CIPI's required mid-term report for the upcoming NCE review. The NCE program finances a network for a maximum of 14 years, 13 in the case of the CIPI due to its late set-up. During the first 6-year phase, the network is required to produce a mid-term report in order to continue receiving funds. This renewal period provides the opportunity to make many changes within CIPI. Michel Piché becomes the sole Scientific Director following the departure of William A. van Wijngaarden. Ian McDonald resigns as member and Acting President of the Board of Directors to take on the position of President and CEO after Mr. Hara's departure. CIPI names Robert Fedosejevs, a researcher at the University of Alberta, as Scientific Director at the end of 2002. The NCE names Douglas James, a corporate director involved in various corporate boards, as Chair on the CIPI Board of Directors. This new team will work towards restructuring the scientific program, changing the former 5 themes to 3 thrust areas focused on the following applications: Information and Telecommunications, Health, Safety and Environment, and Frontier Photonics. “From there, we established competition procedures between research projects to determine which projects would benefit from funding,” explains Michel Piché. “We also created the Technology Exploitation and Networking (TEN) Program which is designed to promote short-term photonic application research projects with strong commercial prospects.” According to Denis Faubert, CIPI Vice-President of the Board of Directors, the TEN Program constitutes one of CIPI's great successes. “This program aptly portrays CIPI's desire to apply research and technology transfer and to create close ties within the photonics industry,” suggests the director of Hydro Quebec's research center.

Presidents of CIPI Board of Directors	
Michael Steinitz	1999-2002
Ian McDonald	summer of 2002
Douglas James	2002-

Presidents-CEOs of CIPI	
Elmer Hara	2000-2002
Ian McDonald	2002-2005
Robert Corriveau	2005-

Change is the order of the day. The CIPI Student Network (CIPI-S) was founded in 2002 by a student, Claudine Allen, and colleagues following the recommendations of Michel Piché. The goal of this network was to promote student interaction within the existing CIPI framework. “Our initial mission consisted in recruiting students from Western Canada, introducing them to CIPI-S and CIPI, and getting them involved in our network,” remembers Claudine Allen, now a professor and researcher at COPL. “We then organized workshops and industrial visits, and created an official web site.” Their first workshop was held in February 2003 in Montreal and successfully attracted 84 participants nationwide. One of the student network's more recent activities consisted in the organization of a biophotonic workshop in Toronto this past April 23, where 45 students participated.

CIPI-S logo

Much importance is given to students within CIPI: the President of CIPI-S sits on the CIPI Board of Directors whereas the Vice-President sits on the Research Program Committee. “There is invaluable experience to be gained as part of the Board,” states Ms. Allen. “We acquire a true picture of what Canadian research is and are introduced to the underlying facets of research.” Trinh Nguyen, President of CIPI-S, could not agree more.

CIPI-S has since become the instigator of various social activities promoting the interaction and networking between students and researchers. According to Alain Villeneuve, member of the Research Program Committee, 1999 to 2005, and 2009, CIPI's student network is one of its major accomplishments. Involved in CIPI since its beginnings and presently in charge of Optav, Mr. Villleneuve states, “The creation of CIPI-S and its encouragement of networking and exchanges among students have resulted in increased collaborative research between different laboratories.”

CIPI-S 2008
Back row: Melanie Burger, Arvind Chandrasekaran, Noah Puskas, Hooman Hosseinkhannazer
Front row: Trinh Nguyen (President), Nazanin Morbrhan-Shafiee. Absent: Geneviève Taurand

CIPI AT THE HEART OF CANADIAN PHOTONICS

Another of CIPI's accomplishments is its active participation in the creation, in 2004, of the International Advanced Laser Light Source (ALLS) Laboratory. Headed by Jean-Claude Kieffer, Professor and Director at INRS (Institut National de la Recherche Scientifique), the ALLS project is the fruit of successful networking and partnership among researchers brought together initially for collaboration on CIPI projects. ALLS has grown to become a consortium of 14 Canadian universities (INRS, Universities of Alberta, British Columbia, Calgary, Laval, McGill, Sherbrooke, Toronto, etc.), 3 government laboratories (NRC-Steacie, NRC-IMI, DRDC) and 17 international institutions (notably Max Plank (Germany), École Polytechnique (France), SUNY (USA), Kansas State U (USA), LLNL (USA), UCLA (USA), Imperial College (UK), Riken (Japan), etc.).

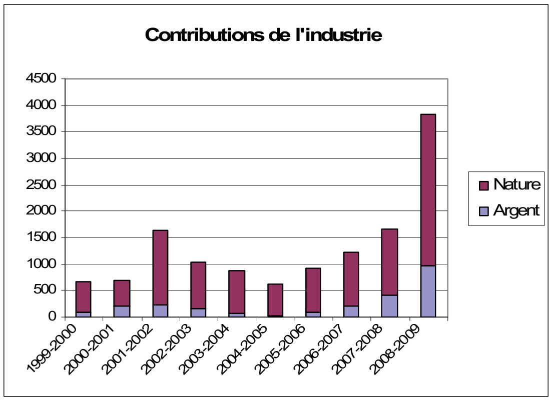
Attosecond technology at ALLS

The laboratory is located at the INRS-EMT (Energy, Materials and Telecommunications) centre in the Montreal suburb of Varennes. The Centre provides scientists with the opportunity to make breakthroughs in the fields of physics and chemistry and to multiply discoveries in biology using technological innovations such as femtosecond laser technology applications in the hope of advancing knowledge pertaining to infinitely small and complex biological systems. Not only are the laser facilities and unique imaging tools greatly beneficial to the work of CIPI scientists but the state-of-the-art facilities provide international recognition to the excellence of their scientific activities. "CIPI has given everyone implicated in this project a platform on which they can work and collaborate together. Additionally, its bursary program has even allowed students to spend valuable time in its high-tech facilities," adds Michel Piché.

CIPI made great strides once again in 2005. The Institute celebrated the renewal of its second-phase funding for a 7-year period. Robert Corriveau, then Vice-President, Business Development at Phasoptx, joins CIPI as President and CEO and, with the Board of Directors, founded the IPA (Innovative Photonic Applications) Program and provides a new source of financing for Canadian photonic researchers, allowing them to finally apply the photonic technologies they are developing to the industry. The objective of the Innovative Photonic Applications Program is to support research projects which address the needs of various industrial sectors. This program brings together university researchers, technology implementers and end-users to work on short-term projects destined to optimize photonic technologies to resolving specific problems.

The following year, Mr. Corriveau established a network of representatives to foster interaction between CIPI and the industry. "Their role is to meet with industrial leaders, talk about photonics and CIPI, and point out how photonic university research can help solve problems such as quality control or production," explains Robert Corriveau. While representatives based in Montreal, Ottawa, Toronto, Edmonton and Vancouver interact with Canadian industries, CIPI works on displaying a strong presence in various worldwide scientific and industrial photonic exhibitions: Photonics West, Photonics North, LASER and international missions...

The joint impact of the arrival of the TEN and IPA programs as well as the strong presence of the representatives is quickly felt by the industry which recognizes the potential researchers have to help resolve certain problems. Cash or in-kind contributions from industrial leaders increase over the years, as do collaborative projects. Robert Corriveau is proud to state that 20% of Canadian photonic companies are presently involved with CIPI.



Contributions from the industry 1999-2008

A FUTURE WORTH FOLLOWING

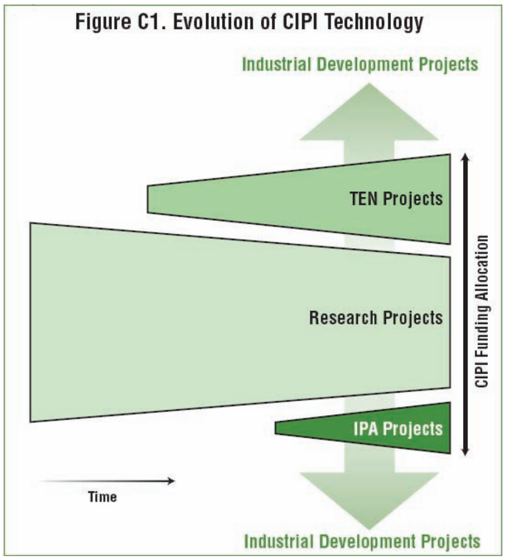
NCE funding will end in three years. It is uncertain whether CIPI will maintain its original structure or if changes are on the horizon. Whatever the outcome, CIPI will always be seen as one of NCE Program's success stories believes Michael Steinitz, Physics Professor at St. Francis Xavier University and President of the Board of Directors until 2002. His opinion is shared by many. Robert Fedosejevs, who was involved in research projects which would never have seen the light of day were it not for CIPI, states, "CIPI has been detrimental in establishing collaboration and partnerships among researchers across Canada. Not only has CIPI placed photonics at the forefront of Canadian research, it has been central in fostering close interaction between universities and the industry." M. Fedosejevs is confident that CIPI will leave a strong heritage to the photonics community, possibly leading to the creation of highly specialized networks such as the Canadian Laser Application Network (CLAN) (refer to the article in the current issue of PHOTONS) and numerous start-ups. "CIPI has contributed to an increase of government funding in photonic research and has also generated a marked increase in highly qualified personnel! » adds Michel Têtu.

	2005-06	2006-07	2007-08
Graduate students with training	261	291	271
Thesis completed	42	46	33
Work involving arbitration	156	190	161
Patents	6	8	8

Statistics of the 3 last years

CIPI has, without a doubt, forever changed the way research is done. "CIPI provides unique opportunities, notably through its annual assemblies, for researchers to meet," comments Sophie Larochelle, researcher and member of CIPI. During such an occasion, Ms. Larochelle met researchers specialized in optical fiber modelling; this encounter led to the evolution and progression of her research project even though her main collaborator is presently in Australia. The benefits of the TEN program are well-known to Ms. Larochelle. The program enables rapid responses to industrial needs and provides students with the possibility to exchange with various research partners.

In 2012, CIPI will have brought up its children, muses Alain Villeneuve. Like many parents, CIPI will have to let go, let them spread their wings. Time will tell how the family will evolve.



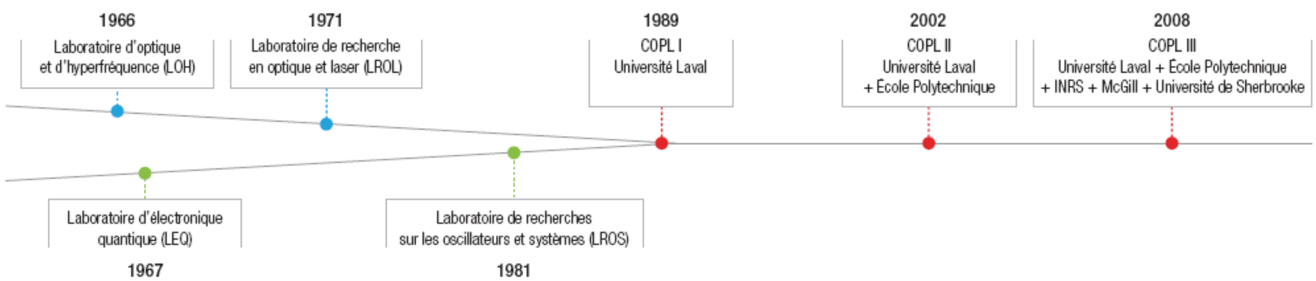
Evolution of CIPI research programs

Le COPL : 20 ans de recherche concertée en optique-photonique

Diane Déziel, chargée de communications, COPL

Partager savoir et ressources dans le but de former la prochaine génération de spécialistes en optique-photonique, faire avancer l'état des connaissances et contribuer au développement socio-économique, voilà ce qui caractérise le Centre d'optique, photonique et laser (COPL), depuis maintenant 20 ans.

Le COPL voit le jour le 5 mai 1989 lors d'une séance du conseil de la Faculté des sciences et de génie de l'Université Laval. La résolution alors adoptée concrétise la volonté des chercheurs en optique-photonique du département de physique et du département de génie électrique de se regrouper en une seule et même entité. D'entrée de jeu, mentionnons que l'optique-photonique à l'Université Laval était un domaine d'études et de recherche déjà bien établi et structuré depuis les années 60 (voir la ligne du temps ci-dessous). En effet, au cours des deux décennies précédant la création du COPL, l'Université formait plus de la moitié des chercheurs en optique au Canada, une réalisation fort appréciable. S'ajoute à cela le rôle déterminant qu'ont joué, au milieu des années 80, certains de ses professeurs dans la fondation de l'Institut national d'optique (INO), qui allait devenir le plus important centre de compétences en optique-photonique appliquée au Canada. La mise sur pied du COPL constitue donc un jalon de plus dans une tradition d'excellence bien enracinée à l'Université Laval. Au moment de sa création, il compte 14 professeurs-chercheurs, 80 étudiants diplômés et 5 stagiaires postdoctoraux. Son premier directeur était le regretté Roger Lessard.



COPL – Ligne du temps

LE COPL EN CONSTANTE ÉVOLUTION

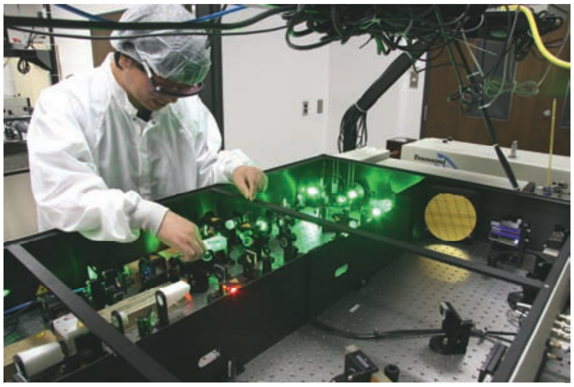
Pendant la décennie 90, le COPL consolide son rôle et sa renommée comme centre de recherche d'envergure nationale et internationale. Les efforts déployés en ce sens par plusieurs de ses chercheurs, sous l'habile direction de Michel Têtu, se traduisent par l'établissement d'un Réseau de centres d'excellence, l'Institut canadien pour les innovations en photonique (ICIP), dont l'Université Laval demeure l'institution hôte. L'entrée en scène de l'ICIP contribue grandement au développement du COPL lui ouvrant la voie à de nouvelles collaborations avec l'industrie et avec d'autres universités canadiennes.

Les directeurs depuis 20 ans

Roger Lessard (89-94)
Marguerite-Marie Denariez-Roberge (94-97)
Michel Têtu (97-99)
Réal Vallée (2000-)

L'essor de la photonique ainsi que son énorme potentiel motivent le COPL à se diversifier et à intégrer de nouvelles expertises afin de bien remplir son mandat de centre de recherche et de formation de pointe. Sous l'impulsion de son nouveau directeur, Réal Vallée, le COPL élargit son cadre en 2001 afin d'inclure des chercheurs de génie physique de l'École Polytechnique de Montréal ainsi que des chimistes de l'Université Laval.

À la même époque, le directeur du COPL coordonne différentes demandes de subvention dont une de 46 M$ présentée à la Fondation canadienne pour l'innovation afin de doter l'Université Laval d'un pavillon de recherche avant-gardiste en optique-photonique, une première au Canada. Mis en service à l'automne 2006, le pavillon d'Optique et de photonique (POP) positionne désormais le COPL parmi les grands centres de recherche et de formation au monde (voir encadré Le POP).



Stagiaire postdoctoral au laboratoire de la science du laser ultrarapide et intense

Évoluant au rythme de son domaine, le COPL amorce en 2008 sa plus grande expansion à ce jour afin de devenir, à l'instar de l'ICIP au Canada, le réseau des experts en optique-photonique au Québec. Ainsi, le Centre s'adjoint de nouveaux collaborateurs non seulement de Laval et de Polytechnique, mais aussi de McGill, de l'INRS et de l'Université de Sherbrooke. Une douzaine de professeurs-chercheurs deviennent membres du COPL lui insufflant une énergie nouvelle et l'assurant de bien répondre aux besoins variés d'une société innovante.

Ce sont donc 20 années de recherche concertée qui ont vu le COPL se transformer en un centre multi-institutionnel et multidisciplinaire comptant aujourd'hui 32 professeurs-chercheurs, 4 professeurs associés, 200 étudiants diplômés et 30 stagiaires postdoctoraux.

LE COPL SE DÉMARQUE

Depuis 20 ans, le COPL remplit chaque jour sa mission et se démarque par plusieurs réalisations. Sa plus grande fierté: la formation des étudiants, le volet prépondérant de la mission du COPL. La qualité des installations de recherche et la masse critique d'expertises offrent aux jeunes une formation universitaire exceptionnelle en optique-photonique.

La mission du COPL

- Former des étudiants et du personnel hautement qualifié
- Effectuer de la recherche fondamentale et appliquée
- Contribuer à l'essor socio-économique

Fournissant de la main-d'œuvre spécialisée à la quasi-totalité des entreprises et des centres de recherche du milieu de la photonique au Québec ainsi qu'à de nombreux organismes des secteurs industriel et universitaire au Canada et à l'étranger, le COPL est très conscient du rôle de premier plan qu'il joue dans la chaîne de l'innovation. C'est pourquoi il veille à former non seulement de la main-d'œuvre hautement qualifiée pour satisfaire aux besoins des entreprises existantes, mais également les entrepreneurs de demain.

La formation de PHQ depuis 1989

313 diplômes de maîtrise
163 diplômes de doctorat
122 stagiaires postdoctoraux

Les étudiants du COPL : source de grande fierté

Autre point fort du COPL : sa programmation scientifique. En optique-photonique, la recherche appliquée et la recherche fondamentale sont interdépendantes et se rejoignent à une vitesse phénoménale. Des percées scientifiques majeures dans le domaine des impulsions laser ultrabrèves, par exemple, se répercuteront de façon significative dans les différents domaines d'application dont la biophotonique, l'environnement, l'aérospatiale, les procédés industriels et les télécommunications. Convaincu d'offrir un programme de recherche de calibre international, le COPL a choisi d'articuler sa programmation scientifique autour de sept axes de développement scientifique et technologique susceptibles d'avoir, dans un avenir rapproché, un impact socio-économique majeur pour le Québec, soit :

- l'optique guidée et les fibres optiques ;
- les lasers et les phénomènes ultrarapides ;
- les communications optiques ;
- la biophotonique ;
- l'instrumentation, la métrologie et l'imagerie ;
- les matériaux photoniques ;
- l'optique quantique.

Le COPL est également fier de compter dans ses rangs six titulaires de chaires de recherche. Ces chaires contribuent à sa renommée et à son rayonnement, non seulement grâce aux activités de recherche qui leur sont rattachées, mais également grâce à la formation d'étudiants dans des domaines de pointe.

Les chaires de recherche

- Chaire de recherche du Canada en science du laser ultrarapide et intense (See Leang Chin, Université Laval)

- Chaire de recherche du Canada en biophotonique (Daniel Côté, Université Laval)

- Chaire de recherche du Canada sur les systèmes photoniques futurs (Raman Kashyap, École Polytechnique de Montréal)

- Chaire de recherche du Canada en communications et composants à fibre optique (Sophie LaRochelle, Université Laval)

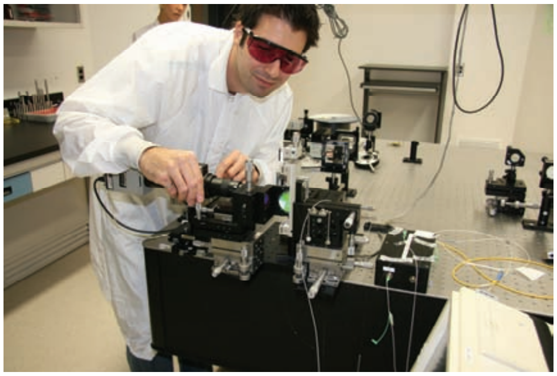
- Chaire de recherche du Canada sur la théorie, la fabrication et les applications des cristaux photoniques (Maksim Skorobogatiy, École Polytechnique de Montréal)

- Chaire de recherche industrielle du CRSNG en conception optique (Simon Thibault, Université Laval)

La recherche est appelée à jouer un rôle prépondérant dans la création de nouvelles entreprises et dans le maintien du positionnement avantageux des compagnies déjà établies. Au Québec, le COPL se situe au cœur de l'industrie de l'optique-photonique et ses chercheurs entretiennent des liens étroits avec elle. Cette proximité avec le milieu industriel permet aux chercheurs du COPL de demeurer à l'affût des tendances et des besoins émergents, de bien évaluer la pertinence de leurs travaux d'enseignement et de recherche et de les adapter à la chaîne de l'innovation.

UN AVENIR BRILLANT

Comme regroupement stratégique fermement implanté dans un secteur en forte croissance, le COPL détient une position unique pour coordonner à l'échelle du Québec les activités de recherche dans son domaine. Grâce à ses chercheurs qui, au fil des ans, ont développé des relations fructueuses avec la communauté internationale de l'optique-photonique, le COPL continuera d'accroître son rayonnement à l'échelle internationale, ce qui ne peut qu'avoir un impact positif sur la réalisation de sa mission.



Le COPL joue un rôle de premier plan dans la chaîne de l'innovation.

Les membres réguliers du COPL

ÉCOLE POLYTECHNIQUE DE MONTRÉAL
Caroline Boudoux
Sébastien Francoeur
Nicolas Godbout
Raman Kashyap
Suzanne Lacroix
Maksim Skorobogatiy

INRS-ÉMT
Jose Azana
Roberto Morandotti

UNIVERSITÉ McGILL
Lawrence R. Chen
Martin Rochette

UNIVERSITÉ DE SHERBROOKE
Paul Charette
Yves Bérubé Lauzière

UNIVERSITÉ LAVAL
Claudine Allen
Ermanno Borra
Denis Boudreau
See Leang Chin
Daniel Côté
Yves De Koninck
Tigran Galstian
Jérôme Genest
Sophie LaRochelle
Nathalie McCarthy
Thanh-Tung Nguyen-Dang
Michel Piché
Simon Rainville
Anna-Marie Ritcey
Leslie Ann Rusch
Yunlong Sheng
Simon Thibault
Pierre Tremblay
Réal Vallée
Bernd Witzel

Les membres associés du COPL

Henri-H. Arsenault, Université Laval
Pierre-André Bélanger, Université Laval
Pierre Galarneau, INO
Romain Maciejko, École Polytechnique

Le POP

Les chercheurs du COPL disposent du plus imposant parc d'équipement en optique-photonique au Canada. Ils ont de plus accès à une infrastructure de recherche d'avant-garde : le POP (pavillon d'Optique-photonique) qui est, à bien des égards, unique au monde, et qui leur permet de travailler en synergie. Ce pavillon offre des conditions incomparables pour la recherche en optique-photonique. Un soin rigoureux est apporté au contrôle des paramètres de température, d'humidité, d'empoussièrement et de vibration.

Le POP en chiffres

- Un investissement de 46 M$ (FCI, Gouvernement du Québec, Université Laval)
- Une superficie totale de 10 400 m^2, dont 5 000 m^2 sont des laboratoires
- 45 bureaux de professeurs et de chercheurs
- 150 espaces de bureau pour étudiants de 2e et 3e cycles
- 100 laboratoires

Caractéristiques particulières du POP

- Température : variation de ± 0,5 o C.
- Humidité : taux variant entre 40 et 50 %.
- Les 2 sections du pavillon reposent sur des dalles de béton séparées.
- Un espace de 10 cm sépare les 2 sections afin d'éviter que les vibrations causées par les différents systèmes de ventilation, de chauffage, de filtration d'air, de contrôle de température et d'humidité ne se communiquent aux laboratoires.
- La section des laboratoires est contenue dans un édifice au volume aplati.
- La structure de béton présente une dalle gaufrée qui absorbe les vibrations.
- Murs de béton et talus autour de l'édifice coupent les vibrations en provenance de la rue.
- La cage d'escalier et le puits de l'ascenseur à l'intérieur de la section laboratoires sont désolidarisés du reste de l'édifice.
- La plupart des laboratoires du POP sont de classe 100 000. Les laboratoires de microfabrication et de microcaractérisation sont de classe 100.
- Le volume d'air est complètement filtré toutes les 3 minutes. L'air circule dans les laboratoires par des diffuseurs à flux laminaire qui éliminent les perturbations causées par les courants d'air qui risquent d'altérer les expériences en cours sur les tables optiques.

Autre particularité du POP: la section laboratoires est en réalité un immeuble de 4 étages, mais seulement 2 d'entre eux servent à la recherche. Les 2 autres étages sont des étages de service où se trouvent les conduits d'aération, les fils électriques, et les tuyaux de gaz pour alimenter les laboratoires au-dessous. Ces services proviennent donc du plafond.

Le pavillon d'Optique-photonique, Université Laval

Les équipements de pointe du POP

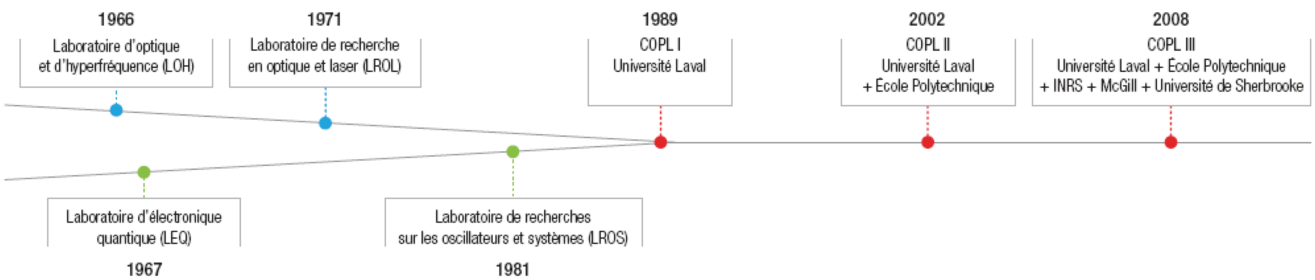
- Laboratoire de fabrication et de caractérisation de fibres optiques de silice et de verres exotiques
- Chaîne laser femtoseconde 12 mJ à 1kHz
- Laboratoire d'écriture de réseaux de Bragg
- Laboratoire d'écriture de masques de phase
- Laboratoire de tests et mesures en communications optiques
- Chaîne laser Ti:Saphir amplifiée (RegA)
- Chaîne laser Ti:Saphir femtoseconde terawatt
- Laboratoire de caractérisation des matériaux photoniques
- Laboratoire de déposition de couches minces
- Faisceaux focalisés d'ions-électrons

COPL: 20 years of collaborative research in optics and photonics

Diane Déziel, Communications Manager, COPL

Sharing knowledge and resources for the purpose of training the next generation of optics and photonics specialists, enriching the field with new scientific contributions and fostering socio-economic development, this has been the focus of the Centre for Optics, Photonics and Lasers' (COPL) activities for the past twenty years.

The COPL was created on May 5, 1989 when management of Université Laval's Faculty of Science and Engineering passed a resolution recognizing the collective will of optics and photonics investigators in two departments, Physics and Electrical Engineering, to join forces and form a single research entity. The Faculty's decision was the outcome of energetic lobbying by the late Roger Lessard who became the COPL's first Director. It must be mentioned at the outset that optics at Laval had been a well established and well structured research field and academic program since the 60's (see timeline). In fact, in the two decades preceding the COPL's creation, the university was turning out over half of Canada's optics researchers, quite a noteworthy achievement. To this must be added the decisive role played in the early 80's by some Laval professors in establishing the National Optics Institute, which was to become Canada's largest centre of expertise in applied optics and photonics. The creation of the COPL was yet another milestone in Université Laval's long tradition of excellence in optics. At the time of its foundation, the Centre consisted of 14 professor-researchers, 80 graduate students and 5 post-doctoral fellows.



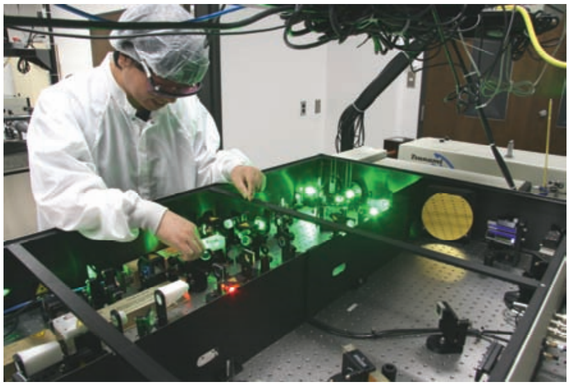
COPL – Timeline

CONSTANTLY EVOLVING

In the 90's, the COPL consolidated its role and reputation as a research centre of national and international status. Under the deft guidance of Michel Têtu, COPL researchers contributed to the establishment of the Canadian Institute for Photonic Innovations (CIPI), a Network of Centres of Excellence, whose administrative centre is located at Université Laval. CIPI has been instrumental in the further development of the COPL by facilitating valuable collaborations with industry and other Canadian universities.

COPL Directors
Roger Lessard (89-94) Marguerite-Marie Denariez-Roberge (94-97) Michel Têtu (97-99) Réal Vallée (2000-)

The tremendous growth and potential of photonics compelled the COPL to diversify and integrate new expertise. In 2001, led by its new Director, Réal Vallée, the COPL expanded by adding physical engineers from École Polytechnique de Montréal and chemists from Laval. At the same time, Dr. Vallée coordinated various grant applications, including a $46 M application to the Canada Foundation for Innovation for the construction on the Laval campus of a state-of-the-art research facility totally dedicated to optics and photonics research, a first in Canada! Completed in 2006, the Pavilion of Optics and Photonics (POP) now positions the COPL among leading academic and research institutions in the world (see below).



Post-doctoral fellow in the ultra-fast intense laser science lab

In order to keep pace with the field's extraordinary development, the COPL underwent its most ambitious expansion to date in 2008 to become, much like CIPI across Canada, Quebec's network of experts in optics and photonics. With a dozen new collaborators joining, not only from Laval and Polytechnique but also from McGill, INRS and Sherbrooke, the Centre has been rejuvenated and will ensure that the numerous needs of today's knowledge-based economy are addressed.

These 20 years of collaborative research have seen the COPL transform into a multi-institutional and multi-disciplinary research organization now numbering 32 professor-researchers, 4 associate professors, 200 graduate students and 30 post-doctoral fellows.

LEADING THE WAY

For 20 years, the COPL has been successful in fulfilling its mission. Student training is its top priority and the facet of its mission that elicits the most pride. Because of its world-class research facilities and the critical mass of high-level expertise available, the COPL offers an exceptional environment for graduate students wishing to specialize in optics and photonics.

COPL's mission

- To train highly qualified personnel

- To perform fundamental and applied research

- To contribute to socio-economic development

A major player in the innovation chain, the COPL has provided specialized manpower to virtually every photonics company and research centre in Quebec as well as countless others in Canada and abroad. The Centre endeavours to train not only the next generation of scientists but also of high-technology entrepreneurs.

HQP training since 1989

313 MSc degrees
163 PhD degrees
122 Post-doctoral fellows

COPL students: a source of great pride

Another of the COPL's strengths is its research program. In the field of optics and photonics, applied and fundamental research merge at astonishing speed. Major scientific breakthroughs, in the field of ultrafast laser pulses for example, will have significant impact on applications in biophotonics, the environment, aerospace, industrial processes and telecommunications. For this reason, the COPL has chosen to organize its world-leading research program around seven major themes (see below) where scientific and technological development are likely to produce major socio-economic benefit for Quebec in the near future.

Research Themes

- Guided wave optics and fibre optics
- Lasers and ultrafast phenomena
- Optical communications
- Biophotonics
- Instrumentation, metrology and imaging
- Photonics materials
- Quantum optics

The COPL is proud to have within its ranks six research chair holders. The research and training activities associated with these chairs contribute to the Centre's reputation and standing worldwide.

Research Chairs associated with COPL

- Canada Research Chair in Ultrafast and Intense Laser Science (See Leang Chin, Université Laval)

- Canada Research Chair in Biophotonics (Daniel Côté, Université Laval)

- Canada Research Chair in Future Photonic Systems (Raman Kashyap, École Polytechnique)

- Canada Research Chair in Communications and Optical Fibre Components (Sophie LaRochelle, Université Laval)

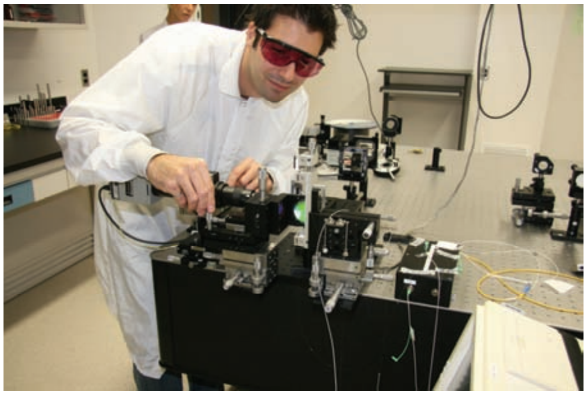
- Canada Research Chair in the Theory, Manufacturing and Applications of Photonic Crystals (Maksim Skorobogatiy, École Polytechnique)

- NSERC Industrial Research Chair in Optical Design (Simon Thibault, Université Laval)

Research spurs the creation of new businesses while supporting existing ones in their quest to maintain their competitive edge. The COPL has played a pivotal role in shaping Quebec's photonics industry. Linkages to industry have enabled COPL researchers to keep on top of developing needs and trends, evaluate the relevance of their work and adapt research directions and course content to the cycle of innovation.

A BRIGHT FUTURE

The COPL is confident and optimistic about its future having gathered the resources necessary to contribute to the development of new knowledge and technologies and to the training of the next generation of highly skilled scientists in optics and photonics. As a strategic cluster of investigators firmly established in a constantly evolving sector, the COPL is uniquely positioned to coordinate Quebec's research activities in the field. Furthermore, the productive partnerships forged over the years with the international research community will have a positive impact on the COPL's ability to carry out its mission.



The COPL is a major player in the innovation chain.

COPL Regular Members

ÉCOLE POLYTECHNIQUE DE MONTRÉAL
Caroline Boudoux
Sébastien Francoeur
Nicolas Godbout
Raman Kashyap
Suzanne Lacroix
Maksim Skorobogatiy

INRS-EMT
Jose Azana
Roberto Morandotti

McGILL UNIVERSITY
Lawrence R. Chen
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UNIVERSITÉ DE SHERBROOKE
Paul Charette
Yves Bérubé Lauzière

UNIVERSITÉ LAVAL
Claudine Allen
Ermanno Borra
Denis Boudreau
See Leang Chin
Daniel Côté
Yves De Koninck
Tigran Galstian
Jérôme Genest
Sophie LaRochelle
Nathalie McCarthy
Thanh-Tung Nguyen-Dang
Michel Piché
Simon Rainville
Anna-Marie Ritcey
Leslie Ann Rusch
Yunlong Sheng
Simon Thibault
Pierre Tremblay
Réal Vallée
Bernd Witzel

COPL Associate Members

Henri-H. Arsenault, Université Laval
Pierre-André Bélanger, Université Laval
Pierre Galarneau, INO
Romain Maciejko, École Polytechnique

The POP

COPL researchers are equipped with the latest in state-of-the-art laboratory systems and devices. They also have access to arguably the most impressive facilities to be found on a university campus anywhere in Canada. The Pavilion of Optics and Photonics (POP) is, from several standpoints, unique in the world and was designed to allow scientists to work in synergy. The building provides an incomparable environment for research as parameters such as temperature, humidity, dust and vibration are perfectly controlled.

The Pavilion of Optics and Photonics, Université Laval

POP fast facts

- A total investment of $46 M
- The building covers an area of 10,400 m^2, of which 5,000 m^2 is laboratory space.
- 45 offices for professors and researchers
- 150 graduate student office cubicles
- 100 laboratories

Special features

- Temperature variation : ± 0,5^o C
- Humidity range : 40 - 50 %
- The building is comprised of 2 sections built on separate concrete slabs
- A 10 cm gap between both sections ensures that vibration caused by the ventilation, heating, filtration, humidity and temperature control systems does not impair laboratory experiments.
- Laboratories are housed in a low-rise structure.
- The concrete waffle-like structure absorbs vibrations
- Concrete walls and slopes around the exterior of the building minimize vibration coming from the street
- The staircase and elevator well inside the laboratory section are detached from the building
- The POP's laboratories are class 100,000 except for the micro-fabrication and micro-characterization labs that are class 100
- The total air volume is filtered every 3 minutes. The air passes through laminar flow scrubbers eliminating disturbances that could alter ongoing experiments on the optical tables below

Another noteworthy feature: the laboratory section is actually a 4-storey building, of which only 2 are used for research. The other 2 storeys are service floors where air ducts; electrical cabling and gas pipes are laid out in order to service the laboratories below through the ceiling.

State-of-the art equipment

- Fabrication and characterization facilities for silica and exotic glass fibres
- 12 mJ @ 1kHz femtosecond laser system
- Bragg grating laboratory
- Phase-mask etching laboratory
- Optical communication test and measurement laboratory
- Amplified Ti :Sapphire laser system (RegA)
- Ti :Sapphire femtosecond terawatt laser system
- Photonic material characterization laboratory
- Thin film deposition laboratory
- Dual-focussed ion beam

Attodyne: the Next Generation of Picosecond Lasers

Michael Cowan and Darren Kraemer
Attodyne Inc. 60 St. George St., Toronto, ON, Canada
www.attodynelasers.com

ABSTRACT – Attodyne was founded to commercialize picosecond laser and Cold Ablation technology developed at the University of Toronto. This technology evolved from a unique perspective on the interaction of ultrafast-pulsed lasers with water, and the parallel development of a highly stable and compact picosecond laser suitable for a range of industrial and surgical applications. We have successfully launched our first product, and continue to expand upon this next generation of industrial and surgical lasers.

1. OVERVIEW

Attodyne Inc. was founded to commercialize picosecond laser technology developed in the labs of Prof. Dwayne Miller at the University of Toronto. This technology came about through our work on the nature of the interaction of ultrafrast-pulsed lasers with water [1]. From this work we gained insight into fast laser ablation dynamics and realized that "Cold Ablation" of biological tissue could be achieved using a picosecond laser in the mid-IR [2]. Conventional lasers deliver the laser light in long pulses that let energy from the pulse dissipate as heat and shockwaves into the surrounding tissue before ablation occurs, resulting in burning and damage which has ultimately limited the widespread use of lasers as surgical tools. Ultrafast lasers can achieve clean ablation cuts, but are complicated and expensive, and the resulting multiphoton ionization produces harmful free-radicals that have been found to delay healing [3]. In contrast, our Cold Ablation method enables a precise and powerful laser scalpel or drill that will not leave any damage.

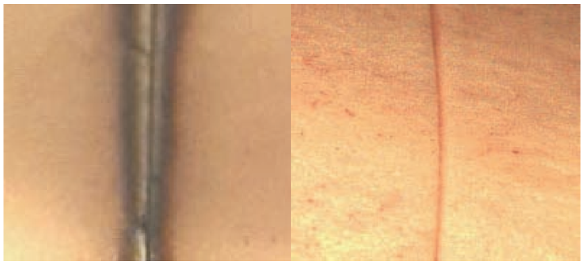


Figure 1. (left) *Laser cut in bone using a conventional laser, showing burning and damage.* ***(right)*** *Laser cut in bone using Attodyne's mid-IR picosecond laser.*

Once the potential of this advance was realized, a compact, robust and affordable picosecond mid-IR laser was developed, using CIPI funds. It is based on a novel solid-state laser amplifier and optical parametric amplifier [4,5]. Using this approach, a picosecond laser platform has been developed that has the additional advantage that it can generate wavelengths from the UV to the mid-IR at a significant cost advantage. Our uniquely compact, robust and inexpensive picosecond laser platform has many surgical, micromachining and industrial applications.

Attodyne has now successfully launched its first product out of a line of high energy picosecond lasers at a wavelength of 1 micron. These lasers are primarily intended for micromachining and industrial applications where precise and reliable cutting and drilling are required. These products will be used as core components of the mid-IR surgical lasers to be launched at a later date.

CIPI funding has been critical in the early stages of Attodyne's development, through research grants, market research support and Linkages Fellowships.

2. TECHNOLGY

Cold Ablation technology for tissue cutting results in the majority of the absorbed laser energy being ejected along with the ablated material. To achieve Cold Ablation we use a unique combination of a strongly absorbed mid-IR wavelength tuned to vibrational modes of water and a picosecond pulse duration. This is illustrated in Fig. 2. The water is rapidly superheated by the laser pulse, and vaporizes, forcing the ejection of the enclosing tissue before heat and shockwaves have had a chance to propagate out of the excited volume. There is thus minimal damage to the surrounding tissue.

Ablation of both soft tissue and hard tissue with minimal damage to the surroundings has been demonstrated. The images in Fig. 2 show microscale and macroscale cuts in bone, and both show no sign of heat or shock-wave damage to the surrounding tissue.

Detailed analysis shows negligible damage to the surrounding tissue beyond the first cellular layer. Without damage, a much higher degree of precision can be achieved with laser surgery. This precision far exceeds that of a mechanical tool and enables faster healing, improved recovery rates and outcomes. Further animal studies using Attodyne's mid-IR picosecond laser are proceeding.

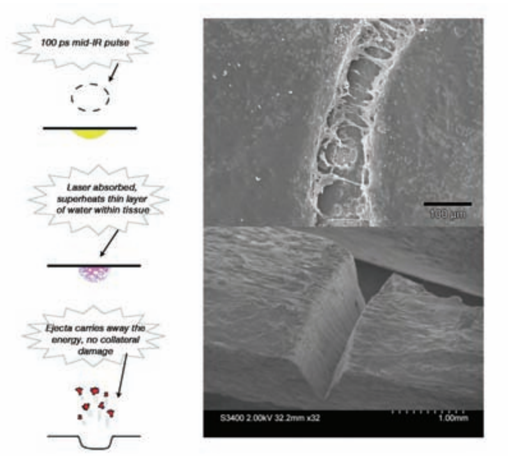


Figure 2. ***(top)*** *SEM picture of a narrow (<100 µm) Attodyne laser cut in bone.* ***(bottom)*** *Larger (mm) cut in bone. In both cases there is no evidence of tissue damage.*

For industrial and micromachining applications, Attodyne's short pulse duration 1 micron lasers ablates with a quality and precision that is equivalent to ultrafast femtosecond lasers. This is illustrated in Fig. 3, where before and after pictures show our ability to selectively remove metal and insulating layers precisely in a TFT circuit.

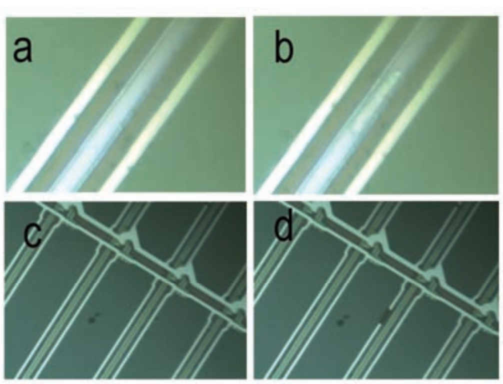
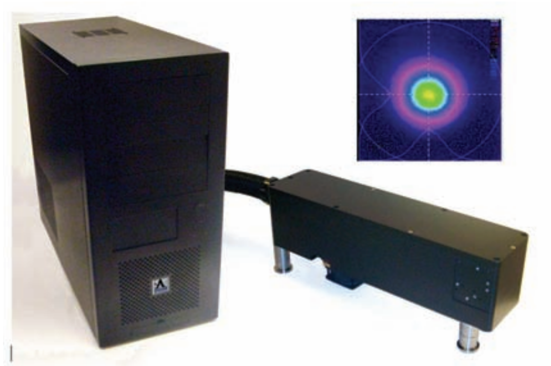


Figure 3. ***(a)*** *Before picture of a TFT circuit.* ***(b)*** *The transparent insulating layer protecting the circuit is removed, without removing the metal below.* ***(c)*** *Before picture.* ***(d)*** *A portion of a metal trace is cleanly removed.*

3. PRODUCTS

Attodyne's full range of 1 micron products is shown in Fig. 4. The top photograph shows the laser head (right) and control unit (left) of the APL-500-1064, a 0.5W, 20 µJ laser meant for low-throughput micromachining applications. The laser head is uniquely compact at 10x13x44 cm. Attodyne's product range extends up to a 1mJ >10W laser for scribing, dicing and drilling. Applications include TFT and memory repair, semiconductor dicing, thin-film machining, laser deposition, microscopy, non-linear optics and spectroscopy. All of these lasers are turn-key systems engineered for continuous use in an industrial environment, yet come in a compact and cost-effective package.



SHORT PULSED NEAR-IR

	LOW POWER	HIGH POWER	HIGH ENERGY
WAVELENGTH	1064 nm	1064 nm	1064 nm
PULSE DURATION	5-10 ps	5-10 ps	5-10 ps
PULSE ENERGY	< 20 µJ	< 5 µJ	< 1 mJ
REPETITION RATE	0-100 kHz	0.1-30MHz	0-10 kHz
DIMENSIONS [cm]	10x10x40	10x20x40	10x20x40

HIGH ENERGY NEAR-IR

	HIGH POWER	LOW REP. RATE
WAVELENGTH	1064 nm	1047 nm
PULSE DURATION	50-500 ps	50-500 ps
PULSE ENERGY	1-10mJ	< 50 mJ
REPETITION RATE	0-5 kHz	100 Hz
DIMENSIONS [cm]	10x30x40	10x40x40

Figure 4. *Attodyne's current product line*

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3. B. Girard, et al, *Laser. Surg. Med.* **39**, 458 (2007).
4. D. Kraemer, R. Hua, M.L. Cowan, K. Franjic & R.J.D. Miller, *Optics Letters*. **31**, 981 (2006).
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The Startup of Inometrix Inc.

Michael Galle, President, Inometrix Inc.
Email: michael.galle@inometrix.com,Web: www.inometrix.com

In May 2006, a Master's student in the photonics research group at the University of Toronto's Edward S. Rogers Sr. Department of Electrical and Computer Engineering is given the task of characterizing the dispersion of short lengths of fiber. He considers using commercial dispersion measurement equipment but soon discovers that none of them are capable of performing the measurement. The only method sensitive enough involves setting up a device called an interferometer in the lab. The problem is that it involves the use of expensive temperature stabilization and monitoring equipment and it requires calibration. Calibration introduces an error into the measurement that can be larger than the measurement itself so it is not a good option for measuring short lengths. Unsatisfied with the current state of the art, the inexperienced student decides that it might be better to develop a new technique to make the measurement rather than to set up a conventional interferometer. Little did he know that it would take him almost three years and several inventive steps before he would realize this dream.

From idea to company

The research group in this story is that of Professor Li Qian and the name of our naive student is Michael Galle. During his work as a Master's student, Michael worked with his supervisor and a post-doctoral fellow named Dr. Waleed Mohammed to develop several unconventional methods for measuring dispersion. One of the devices they would develop was a Single Arm Interferometer that used the two reflections from the facets (front and back) of an optical channel to measure dispersion (2 Wave SAI). Another device developed by the group was a Single Arm Interferometer that used three reflections, two from the facets of an optical channel and one from a third reflection at a 'balanced' point (3 Wave SAI). The core value proposition of these new technologies was the capability for the high accuracy characterization (10^{-4} ps/nm) of short length optical channels ($<10^{-3}$ ps/nm) without the high costs and calibration error associated with standard interferometers. These inventions would form the basis of Inometrix Inc. (www.inometrix.com).

Inometrix was founded after a meeting between Michael and Lino DeFacendis, Director of Commercialization - ICT at The Innovations Group, University of Toronto (TIG) in October 2007 (www.innovations.utoronto.ca). Lino immediately saw the commercial viability of the technology and worked with Michael to lay the foundation for Inometrix Inc. Michael and Lino worked with law firm Miller Thomson on several patent applications which would form the basis of the company's IP portfolio.

Michael Galle, president of Inometrix

Dream meets challenges

November 2007 was one of the most critical times in the company's history. If this new company Inometrix was to survive it would require funding to transform the technology into a commercial product and ultimately engage potential customers. It was at this point that Lino introduced Michael to Marc Castel a Business Development Officer with both the Canadian Institute for Photonic Innovations (CIPI) and the Ontario Centres of Excellence (OCE). Lino also introduced Michael to Kurtis Scissons a Commercialization Manager with TIG. With the help of Lino, Kurtis and Marc, Inometrix applied for and was granted critical initial seed funding and support from CIPI, OCE and the Ontario Research Commercialization Program (ORCP).

The funding from CIPI was crucial to the company during the first year as it allowed Inometrix to perform a marketing study, develop a commercial prototype, engage potential customers (including some of the top photonics and optics companies in the world), attend and exhibit at various conferences and trade shows and develop our web presence. Just as important as the funding, however, were the people that CIPI helped us to work with. CIPI business development officer Marc Castel also provided critical guidance on the steps necessary for success in business. The CIPI project also allowed us to continue to work with Professor Li Qian and to start work with a post-doctoral fellow at the University of Toronto named Dr. Wen Zhu who both played a central role in the construction and development of our first product based on Single Arm Interferometer technology. The product is now ready for demonstration to potential clients.

Inometrix continues to strive to improve its technology and to strengthen its IP portfolio. Recently we have developed another breakthrough technology based on a new kind of interferometer. This new technology is called Virtual Reference Interferometry (VRI) because it completely eliminates the need for a reference arm in an interferometer. The core value proposition of Virtual Reference Interferometry is similar to Single Arm Interferometry - high accuracy dispersion characterization (10^{-4} ps/nm) of short length optical channels ($<10^{-3}$ ps/nm) without the high costs and calibration error associated with standard interferometers – but it has two more advantages. The first is that it reduces costs by eliminating the reference path. The second is that it increases the speed of the experiment by producing the points in the dispersion parameter plot all at once. With this new very disruptive product, a multi-point experiment can be conducted within 1 minute (limited only by data transfer and laser set up time). Details of this new product will be coming soon on our website.

INOMETRIX INC.
INNOVATION AT ITS BEST

Nouveau startup pour l'ICIP

Le 17 mars 2009 a eu lieu la signature de la constitution d'une nouvelle société dérivée de l'Université Laval et de l'ICIP. La société commercialisera une technologie en instance de brevet qui permet l'inscription de réseaux de Bragg dans des fibres de verre fluoré. Développée grâce à un appui de 100 000 $ du programme de valorisation technologique et de réseautage de l'ICIP, la technologie ouvre la voie à une nouvelle génération de produits possédant des plages de longueurs d'onde dans l'infrarouge moyen et le visible qui ne pouvaient être exploitées couramment à ce jour. Les premières applications visent le domaine médical, plus précisément la dentisterie, la chirurgie esthétique et, à plus long terme, la cytométrie. Les produits dérivés de la technologie pourraient éventuellement s'appliquer aux domaines de la défense et sécurité, de l'environnement et de la recherche fondamentale.

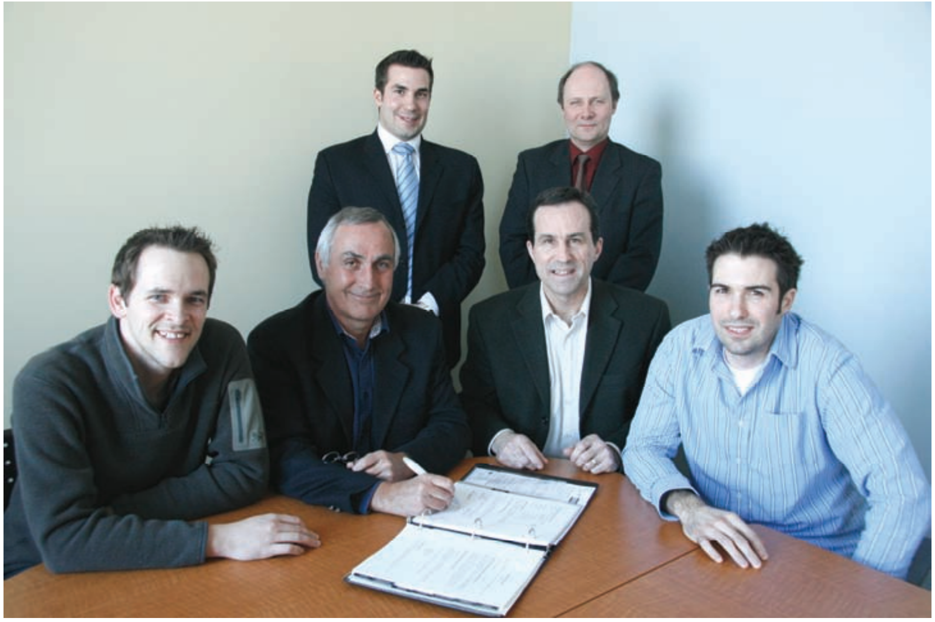
Le projet a aussi bénéficié d'un soutien financier de 32 000 $ de la société de valorisation Sovar et de près de 390 000 $ du ministère du Développement économique, de l'Innovation et de l'Exportation.

.

New spin-off for CIPI

On March 17, 2009, a spin-off company from CIPI and Université Laval was founded. The company will market a patent pending technology that will enable Bragg gratings to be inscribed in fluoride glass fibres. The technology was developed with the support of a $100 k CIPI TEN grant and will spawn a new generation of products operating at mid-infrared and visible wavelengths never before accessed until now. Applications will first target the biomedical sector, namely dentistry, plastic surgery and, in the longer term, cytometry. Eventually, further applications could be deployed for defence and security, the environment and basic research.

The project also benefited from a $32 k contribution from Sovar, a research enhancement corporation, as well as a $390 k grant from the Quebec Ministry of Economic Development, Innovation and Export Trade



Debout, de gauche à droite : Me Jean-Raymond Castelli du cabinet BCF et M. Yves Matte de la société de valorisation Sovar.
Assis, de gauche à droite, les cofondateurs de la société : Messieurs Dominic Faucher, Gary Vail, Réal Vallée et Martin Bernier.

Standing, from left to right: Jean-Raymond Castelli from the law firm BCF and Yves Matte from Sovar.
Sitting, from left to right, the company's co-founders: Dominic Faucher, Gary Vail, Réal Vallée and Martin Bernier.

CLAN Workshop: a Summary

Canadian researchers from academic, government institutions and industry met on March 11 and 12, 2009, at the Marriot hotel in downtown Toronto for the first 'CLAN' Workshop. CLAN is the **C**anadian **L**aser **A**pplication **N**etwork, a new initiative led by Peter Herman (University of Toronto) to forge industry-academic cooperation in laser material processing and laser characterization activities in Canada. A new network which might be part of CIPI'S legacy…

The CLAN Workshop was a very active meeting of more than one-hundred researchers and business leaders examining the scope for Canada to accelerate research and development activities in targeted laser application sectors of our economy. The CLAN program opened with a German Forum led by five academic and industry leaders. Panel discussions included models for education, research and development in Germany, where giant laser research centres and research networks are long established and have a strong history of academic-industry cooperation and economic benefit. There was enthusiastic support amongst Canadian participants to emulate many aspects of the German success, but focussed in key sectors where Canadian researchers and industry have critical mass and promising know-how for growing world leadership positions.

A key discovery during the many Canadian presentations was the diverse research and industry activities already existing in our country. Thirty presentations came from Canadian Universities, Colleges and Institutions, including the National Research Council (NRC), the National Optics Institute (INO) and many current CIPI members. A total of 35 Canadian Industry participants contributed to 11 presentations and many ideas in panel discussions. Companies included ELCAN, WDI, TeraXion, Dofasco, CorActive, ROFIN-BAASEL, Magna, and MPB Communications. Eight more presentations came from companies outside Canada including TRUMPF, IPG Photonics, Amplitude Systemes, and Imra America.

The Canadian presentations were strong and often represented world leading research or state-of-the-art commercial products. Indeed, our renowned German visitors were surprised by our high level of activity and overall strength—they were further convinced that the critical mass is already here on which to build world leading laser application programs like those in Germany. But equally apparent was a fragmented community, disconnected across Canada and often focussed on niche markets or overly narrow research disciplines. In this context, highly enthusiastic panel discussions generated numerous ideas for thrust areas, international networking, and education. These discussions further revealed major untapped opportunities for research and technology cooperation in our country by linking existing areas of strength along academic-industry axes. What was clear in the end was the crucial need for an active CLAN association that with clear objectives and management can drive a transformation of our field and economy in laser applications. The workshop clearly showed that as a whole, Canada has the broad spectrum of expertise and receptor bases to be world leaders in key sectors of this field.

Going forward, far more analysis and discussion is required. And wider participation from industry will be sought. Please join in regional workshops and site visits that will be held during the spring and summer. International Partnership Workshops are being planned for Munich Germany (June) and Tokyo Japan (July). CLAN will hopefully be invited to submit a full proposal in the current competition for new Networks of Centres of Excellence. This and other networking, partnership, and workshop programs are going to be tapped.Together, these activities underpin CLAN's mission to drive world leading science, technology innovation, and business practices that gives Canada a strong international recognition in our field and major economic benefits. Please participate and help shape a cohesive national program for Canada.

For further information, to volunteer or to offer ideas for CLAN, please contact:

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Graham Salt (Magna consultant) makes a point during the panel discussion "Strategic Areas for Industry Benefits" while panel members (left to right) look on: James Chen (Siemens Power Generation), Robert Mueller (NuTech), Norman Zhou (U. Waterloo), Elliot Biro (ArcelorMittal Dofasco), Lijue Xue (NRC), and Peter Herman (U. Toronto).

RADIO-OVER-FIBER TECHNOLOGY

With the growing demand for increased bandpass communication systems, it becomes evident that a concept such as Radio-over-Fibre would be a suitable solution. The main advantage of that technology is the flexibility of such optical network and the reduction of noise by avoiding the optic-to-electric conversion. Researchers from Ryerson University have demonstrated that it is possible to demultiplex the RF signal by using a sub-picometer Fibre Bragg grating bandstop filter. This approach simplifies the demultiplexing of multimedia radio signals.

READ THE ARTICLE ON PAGE 34

TECHNOLOGIE DE RADIO-SUR-FIBRE

Avec l'accroissement des besoins en bande passante dans les systèmes de communication, il semble évident que le concept de radio-sur-fibre devient une solution enviable. Le grand avantage d'une telle technologie réside dans la flexibilité du réseau optique et la réduction du bruit en évitant le transfert du signal de l'optique à l'électronique. Les chercheurs de la Ryerson University ont démontré que le multiplexage d'un signal radiofréquence était possible en utilisant un filtre bloquant une bande de fréquence par un réseau de filtre de Bragg souspicométrique. Cette approcha simplifie le multiplexage des signaux radio multimédia.

VOIR L'ARTICLE À LA PAGE 34

ALL OPTICAL WRITING OF MICROFLUIDIC SENSOR SYSTEMS

Lasers hold the promise of all optical, "green", processing of MEMS and microfluidic devices eliminating many steps of mask making, resist coating and etching. Such laser processing makes use of the tremendous degrees of control that one has to interact at any point within a transparent dielectric material using various intensities, polarizations, wavelengths and pulse shapes. The University of Toronto group under the guidance of Professor Peter Herman has demonstrated a further step towards such all optically written devices. In the article by Grenier *et al.*, we read that they have developed a microfluidic sensor system based on the penetration of the evanescent field from a femtosecond-laser-written waveguide Fibre Bragg Grating (FBG) into a microfluidic channel, also laser written, located only microns away from the FBG. Small refractive index changes in the fluid in the channel result in shifts in the peak reflectance wavelength of the FBG allowing sensitive detection of changes in the composition of the fluid. Being all optically written, this can be used as a building block and can easily be integrated with other optically written sensor techniques in a sequence for complete analysis within a given fluid system.

READ THE ARTICLE ON PAGE 38

INSCRIPTION TOUT OPTIQUE DE CAPTEURS MICROFLUIDIQUES

Les lasers pourrait un jour simplifier la fabrication de dispositifs micro-électromécaniques et microfluidiques et la rendre beaucoup plus écologique en éliminant les étapes de préparation de masques, de revêtement de résine et de gravure. Le contrôle des paramètres d'utilisation du laser, comme l'intensité, la polarisation, la longueur d'onde et la forme d'impulsions, permet une inscription extrêmement précise à l'intérieur d'un matériau diélectrique transparent. Sous la direction du professeur Peter Herman, une équipe de l'Université de Toronto a fait un pas de plus vers la réalisation de dispositifs photo-inscrits. Dans l'article de Grenier *et al.*, on rapporte la mise au point d'un capteur microfluidique réalisé par la pénétration, à l'intérieur d'un canal microfluidique gravé par laser, du champ évanescent provenant d'un réseau de Bragg également inscrit par laser femtoseconde et situé à quelques microns à peine du canal. De légers changements de l'indice de réfraction du liquide dans le canal font décaler la longueur d'onde maximale de réflexion du réseau de Bragg, ce qui permet de détecter de subtils changements dans la composition du liquide. Cette technique tout optique ouvre la voie à l'intégration d'une séquence de capteurs dans un même système qui permettrait l'analyse complète d'un liquide donné.

VOIR L'ARTICLE À LA PAGE 38

ROLL OUT THE LASERS

Integrating optical sources and micro lasers onto silicon photonic systems has been a tough challenge that researchers have been struggling with for over a decade. A number of techniques have been proposed but many suffer from difficulties in fabrication or limited functionality. In the article by Mi *et al.*, the group at McGill University presents a novel micro laser source based on hollow tube, quantum dot lasers that are rolled up from a thin bilayer of InGaAs and GaAs. The bilayer is grown under a controlled stress condition so that when released by etching from the growth substrate it naturally rolls up into an unattached 5 micron diameter tube. By embedding quantum dots in the GaAs layer the sheet becomes a laser amplifying medium. Subsequently, it can be transferred to a silicon substrate using the capillary force of a solvent layer on the silicon surface and bonded in place by van der Waals forces. Such micro lasers exhibit the same family of precise frequency laser modes as their much bigger macroscopic laser cousins. By aligning these with silicon photonic waveguides and sensors in the future it should be possible to use them as source lasers for optical processing and sensor applications.

READ THE ARTICLE ON PAGE 43

DES LASERS EN TUBE

Intégrer des sources optiques et des microlasers à des systèmes photoniques à base de silicium constitue un défi de taille auquel s'attaquent les spécialistes depuis une dizaine d'années. Quelques techniques ont été avancées, mais certaines présentent des difficultés de fabrication et des contraintes de fonctionnalité qui en limitent l'emploi. L'article de Mi *et al.* présente les travaux d'une équipe de l'Université McGill qui a réalisé une microsource laser novatrice sous forme d'un tube creux fait à partir d'une bicouche mince de InGaAs et de GaAs intégrant des points quantiques. Une contrainte est imposée lors de la production de la bicouche. Ainsi, lorsque la bicouche est dégagée de son substrat par gravure, elle s'enroule sur elle-même pour former un tube de 5 microns de diamètre. En incorporant des points quantiques dans la couche de GaAs, on crée un milieu d'amplification laser. Le tube peut par la suite être transféré sur un substrat de silicium par la force capillaire d'une couche de solvant et maintenu en place au moyen de la force de van der Waals. Les modes de fréquence de ces microlasers sont similaires à ceux que présentent les macrolasers beaucoup plus gros. En alignant ces microdispositifs avec des capteurs et des guides d'onde photonique en silicium, il serait possible de les utiliser à l'avenir comme lasers sources dans des applications de traitement optique et de détection.

VOIR L'ARTICLE À LA PAGE 43

NOVEL HIGH NUMERICAL APERTURE POLYMER-BASED FIBER

When applying some techniques of glass optical technology to the lower cost plastic optical fibres, you get novel components which can find many new applications. A team of researchers from l'École polytechnique de Montréal has demonstrated that is it possible to get microstructured plastic optical fibres with excellent guiding capabilities. This type of fibre has a 520 um core surrounded by an air gap which improves the light guidance. They have also demonstrated that the loss of light in the material is equivalent to the one lost through the bridges. Such polymer fibre could be used to develop new types of fibre sensors with enhanced device sensibility and therefore, short range fibre sensors operating in a high numerical aperture are now feasible.

READ THE ARTICLE ON PAGE 46

FIBRES OPTIQUES POLYMÉRIQUES MICROSTRUCTURÉES

Lorsqu'on adapte les techniques utilisées pour la technologie des fibres de verre aux fibres optiques de plastique, on obtient de nouveaux composants qui débouchent sur plusieurs nouvelles applications. Une équipe de chercheurs de l'École polytechnique de Montréal a démontré qu'il était possible de produire des fibres optiques de plastique microstructurées ayant d'excellentes propriétés de guidage. Ce type de fibre utilise un cœur plein de 520 micromètres entouré d'un espace vide, ce qui améliore le guidage de lumière. Les scientifiques ont aussi démontré que la perte de signal par absorption dans le matériel est équivalente à celle perdue par les ponts qui maintiennent l'espace d'air. Ainsi, ces fibres optiques polymériques peuvent être utilisées pour développer de nouveaux types de capteurs à fibre ayant une sensibilité accrue. Les capteurs à fibre de petite dimension et à grande ouverture numérique peuvent maintenant être développés.

VOIR L'ARTICLE À LA PAGE 46

CARS MICROSCOPY MADE SIMPLE

The advent of new imaging modalities such as Coherent Anti-Stokes Raman Scattering (CARS) microscopy has paved the way to extracting information not only about the structure of a biological sample but also about its molecular content. CARS microscopy relies on a nonlinear interaction between pump and Stokes beams whose difference in frequency is matched to the frequency of a vibrational Raman mode from a specific chemical species. By scanning the frequency difference between the pump and Stokes beams one can determine the composition of a sample. Most CARS setups involve a pair of mode-locked lasers; such laser systems are expensive and their performance must meet stringent requirements. In their work, a group of scientists from the Steacie Institute of NRC has introduced a novel approach to CARS microscopy where a single femtosecond laser is used to provide the pump beam; the Stokes beam is generated by propagating the femtosecond pulses in a photonic crystal fibre. The group has demonstrated how the frequency difference between the pump and Stokes beams can be tuned by chirping and delaying appropriately the two beams. The method was shown to produce high resolution images with excellent contrast and low noise.

READ THE ARTICLE ON PAGE 50

LA MICROSCOPIE CARS SIMPLIFIÉE

L'apparition de nouveaux types d'imagerie, dont la microscopie CARS (Coherent Anti-Stokes Raman Scattering), a ouvert la voie à l'extraction d'information sur la structure d'un échantillon biologique ainsi que sur son contenu moléculaire. La microscopie CARS est basée sur une interaction non linéaire entre des faisceaux pompe et Stokes dont la différence de fréquence est accordée à la fréquence d'un mode vibrationnel Raman d'un composé chimique. Le balayage de la différence de fréquence entre les deux faisceaux permet de déterminer la composition d'un échantillon. La plupart des montages de microscopie CARS comprennent deux lasers à impulsions brèves coûteux qui doivent satisfaire des critères de performance fort exigeants. Dans leur article, des scientifiques de l'Institut Steacie du CNRC introduisent une nouvelle approche à la microscopie CARS, où un seul laser femtoseconde sert de faisceau pompe; le faisceau Stokes est généré en propageant les impulsions femtosecondes dans une fibre de type cristal photonique. Ces chercheurs ont montré comment la différence de fréquence entre les faisceaux pompe et Stokes peut être accordée par le glissement de fréquence et la synchronisation de ces faisceaux. La méthode produit des images de haute résolution ayant un excellent contraste et un faible bruit.

VOIR L'ARTICLE À LA PAGE 50

PULSE COMPRESSION AND SHAPING OF INFRARED SUB-20 FS LASER PULSES AT ALLS

Many experiments in fundamental sciences require the availability of ultrashort pulses whose duration is as close as possible of the single-cycle limit. The generation of few-cycle optical pulses has been achieved at 800 nm by compressing the pulses from femtosecond Ti:sapphire laser systems. The most common compression scheme proceeds in two steps: propagation of the pulses in a hollow core fiber filled with a noble gas followed by dispersion compensation with specially designed mirrors (i.e. chirped mirrors). Propagation in the fibre generates new frequencies that are synchronized by the chirped mirrors. This approach cannot be used in the infrared beyond 1 µm since chirped mirrors are not available in that part of the spectrum. The INRS group has shown how to generate few-cycle pulses at 1300 nm using an Acousto Optic Programmable Dispersive Filter for dispersion compensation. The group has implemented the method using the 100-Hz Optical Parametric Amplifier beam line at the ALLS facility in Varennes; 20-fs laser pulses were produced with an energy close to 20 µJ. The group is now working on a new compression scheme to further reduce the pulse duration.

READ THE ARTICLE ON PAGE 53

COMPRESSION ET FORMATION D'IMPULSIONS OPTIQUES ULTRABRÈVES

Plusieurs expériences en recherche fondamentale exigent la disponibilité d'impulsions laser ultrabrèves dont la durée s'approche de la limite d'un seul cycle optique. La formation d'impulsions optiques de quelques cycles a été réalisée à 800 nm en comprimant les impulsions provenant de systèmes Ti:saphir femtosecondes. Le schéma de compression usuel utilise une fibre optique creuse remplie d'un gaz rare et la réflexion sur des miroirs spéciaux dits "chirpés" qui fournissent une compensation de dispersion. La propagation dans la fibre génère de nouvelles composantes spectrales qui sont synchronisées par les miroirs "chirpés". Cette approche ne peut être utilisée dans l'infrarouge au-delà de 1 µm puisqu'il n'y a pas de miroirs "chirpés" disponibles dans cette plage spectrale. L'équipe de l'INRS a montré comment un filtre dispersif programmable constitué par un élément acousto-optique peut être utilisé pour la compensation de dispersion à 1300 nm. En utilisant les impulsions d'un amplificateur paramétrique du laboratoire ALLS à Varennes, cette équipe a produit des impulsions de 20 fs avec une énergie tout près de 20 µJ. L'équipe étudie présentement un nouveau schéma de compression qui devrait mener à des impulsions encore plus courtes.

VOIR L'ARTICLE À LA PAGE 53

All Optical Demultiplexing of RF Signals for Radio-Over-Fiber Communication Systems

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ABSTRACT – Due to the tremendous growth in the multimedia communication and the rapid development in optical transmission technologies, the Radio-Over-Fiber technology is approaching its golden stage and it will become indispensable as the need for cheap, and high-quality broadband wireless communication increase. Implementation of this technology is still in its infancy because broadband wireless standards are just emerging. These multimedia radio signals over fiber need to be demultiplexed in the optical domain to avoid loss and noise due to the optical-to-electrical conversion but it is challenging to optically isolate signals in subgigahertz range with low insertion loss and noise. We have developed a subpicometer all-optical bandstop filter by using fiber Bragg grating technology. This FBG filter has a bandwidth of 30 to 34 picometer at –3 dB. This filter demultiplexes RF signals without significant distortion. This paper investigates the scenario where this filter will be used with a wireless local area network and cellular wireless radio signals.

1. INTRODUCTION

As the demand of broadband, interactive and multimedia services increase over wireless medium, much attention has been paid to large capability and high-speed mobile communication systems. Current wireless communication systems are challenged by the demand for high capacity with the rapidly growing interest to provide multimedia services, such as voice, data and video. The subcarrier multiplexing (SCM) technique has the potential to multiplex a radio signal in a single optical fiber. In such systems, a single central base station can be connected to many radio access points, which provide multiple services to the portable units via SCM radio over fiber (ROF) networks. Each radio access point can support cellular CDMA, WLAN or CATV services as required (Fig. 1). Moreover, these services can be of high quality because of short air range [1].

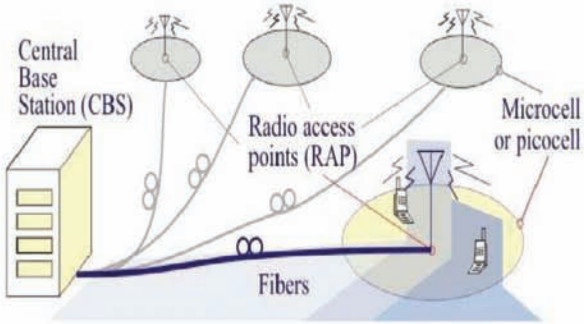

Figure 1: *Radio-Over-Fiber basic architecture*

In radio over fiber systems, multiple subcarriers are multiplexed to transmit different signals over a single fiber. Therefore, SCM technique is a simple and cost effective solution to increase the capability of radio over fiber systems. In ROF system, demultiplexing of such subcarrier signals can be done either in the optical domain or electrical domain. Previous research has shown that isolation of radio signal in the optical domain can offer a more advantageous performance than in the electrical domain. The main advantages of all optical demultiplexing are [9]:

- Flexibility of the optical networks or links
- Less noise and distortion by avoiding the optical-to-electrical conversion
- Wavelength selective and Passive
- Cost effective
- Easier technical requirements on the optical receiver

There are many approaches to demultiplex the subcarriers in the optical domain by using FBGs filters, but these filters are not narrow enough for subgigahertz range. A FBG based filter can play an effective role to demultiplex in the subgigahertz range but it must satisfy the following criteria:

- Low insertion loss
- Inherently fibre-compatible
- Robust
- Linear and Passive

Therefore, the continuous development of such a device allows the subcarrier multiplexed fiber systems to benefit from optical signal processing.

In this paper, we investigate the characteristics of a newly and recently developed sub-picometer fiber Bragg grating based optical filter. This filter has narrow bandwidth and we were able to experimentally demultiplex signals in the sub GHz range.

2. NARROW BANDSTOP FBG FILTER

Since the invention of the fiber Bragg grating, the development of the FBG technology has been continuous. This has led to FBGs to be actively investigated and employed in a wide range of applications in fiber optic communications and sensor systems. One type of FBG that has evolved over the last few years is a narrow band fibre optic filter and they have the key characteristics such as high reflectivity, very stable after annealing, transparent to through wavelength signals and easily integrated with other optical devices [5]. There are many applications that need ultra narrow bandwidth filters such as fiber lasers, high resolution spectroscopy, EDFA pump laser stabilizer, optical amplifier gain flattening filter, laser diode wavelength lock filter, tunable filter, remote monitoring, and channel selection in multi-channel systems. Adopting FGBs as an optical filter provides a valuable and cost effective approach.

There are four main types of fiber Bragg gratings, that is reflecting gratings, long period gratings, chirped fibre Bragg gratings, and slanted fibre gratings.

Figure 2 shows the transmission and reflection of a FBG based optical filter. We can easily understand such transmission and reflection properties of the fiber Bragg gratings. When the grating period is half of the input light wavelength, the signal is reflected coherently to make a large reflection.

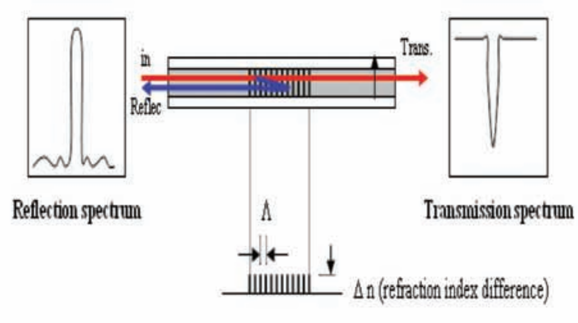

Figure 2: *The transmission and reflection Characteristics of FBG Filter*

The fabricated FBG filter used in this experiment was written on an H_2 loaded SMF-28 fibre and apodized with a sinc function. The n_{eff} (effective refractive index) is 1.4467. The grating wavelength is 1550.20 nm and has reflection and transmission of 51% and 3 dB respectively (Fig. 3).

Since high reflectivity FBGs between -20 to -40 dB can be easily fabricated, the bandwidth of the spectrum in picometer can be realized.

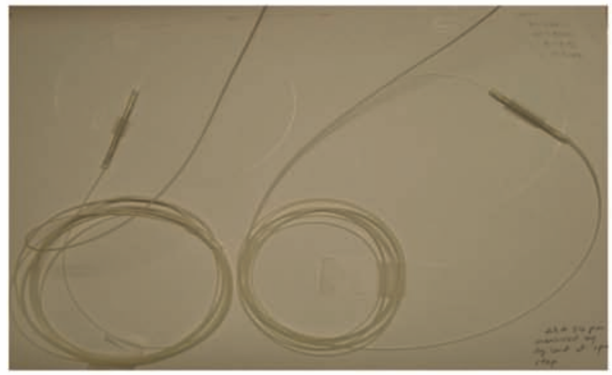

Figure 3: *Photograph of bandstop FBGs*

3. RESULTS AND DISCUSSIONS

To determine how well the output optical power at the filter could follow the input RF power at 2.4 GHz, and to characterize the demultiplexer, a large number of experiments were performed. In this section the performance of the designed sub-picometer filter with an optical circulator in extracting 2.4 GHz from Subcarrier multiplexing is studied.

An RF signal generator was used to create a microwave signal in binary phase shift keying format at 2.4 GHz. The optical modulation of the SCM radio signal was realized using a Mach-Zehnder intensity modulator, which was biased at a DC voltage corresponding to the MZM linear region of operation. Figure 4 shows the carrier spectrum of 2.4 GHz signal without sidebands. As a result of the intensity modulation an optical signal consisting of the carrier and the corresponding upper and lower sidebands of the microwave signals was generated at the MZM output. Figure 5 shows the MZM output when the DC bias voltage of the modulator was set at a non-linear region. Note that due to limited resolution bandwidth of the optical spectrum analyzer (OSA), only the sideband of 2.4 GHz can be seen from the carrier. As the modulating subcarrier frequency is decreased to 1.0 GHz, the sideband appears to be embedded within the carrier spectrum and hence not visible. Figure 5 also represents the MZM out under the same condition when the DC bias was tunned to linear region of operation. Still both sidebands of the subcarriers are there, and quite well visible.

The fabricated bandstop filter was positioned to coincide with a central wavelength of 1549.9 nm with 1 nm span. Note that the carrier should not be completely removed to avoid clipping distortion in the RF signal [3]. A Carrier-to-Sideband ratio of ~3dB was obtained. The CSR with modulating signal after filtering could not be measured directly due to the resolution constraint of the optical spectrum analyzer.
The problem with SCM multiplexing is non-linear distortion, which includes intermodulation and in-band distortion, is a major problem with Cable TV Systems. On the other side, in-band distortions are of concern for radio-over-fiber systems [4].

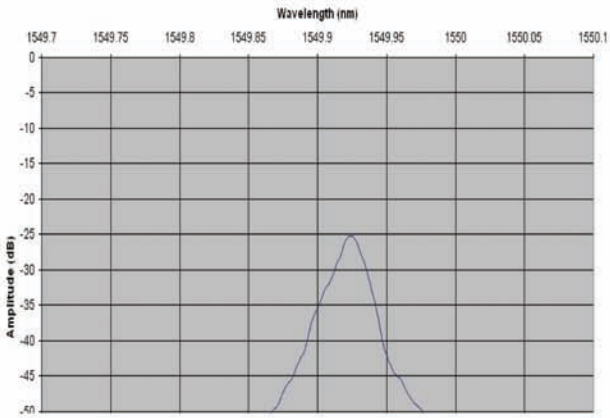

Figure4 : *Carrier spectrum of 2.4 GHz RF Signal without sidebands*

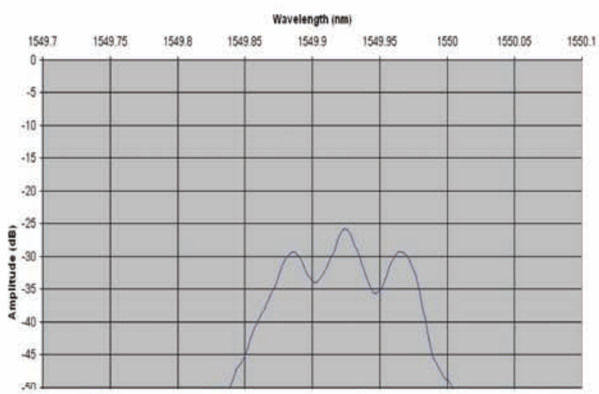

Figure 5: *Modulation spectrum of 2.4 GHz RF Signal with sidebands*

4. CONCLUSIONS

In this paper, the characteristics of newly designed sub-picometer fiber Bragg grating based optical bandstop filter was provided. Our result shows that with the narrow filter bandwidth in the picometer range and low insertion loss, it was possible to recover the filtered RF signal. But because of the environmental effects such as temperature, the FBG peak may shift slightly and it is well known that the Bragg wavelength shifts by 10 pm per 1°C variation of the temperature. This requires the laser to be adjusted accordingly.

The main focus of this experiment was to investigate optical demultiplexing of RF signal at 2.4 GHz transmitted over an extremely modulated ROF link. To achieve this, we fabricated a novel sub-picometer fiber Bragg grating bandstop filter. This filter has a bandwidth of 34 pm and a fairly low insertion loss of 3dB. We experimentally verified that this filter could be applied as an optical bandstop filter and has a linear response. In our experiment, excess dc power resulting from externally modulating optical carrier was reduced significantly. Also, the results show that the fabricated filter is a promising candidate for demultiplexing multimedia radio signals in a sub GHz range in optical domain. It is evident that the ultra narrow bandwidth of the filter allows demultiplexing of closely spaced subcarriers effectively. By using this filter that has low insertion loss and low distortion, demultiplexing of multimedia radio signals is possible.

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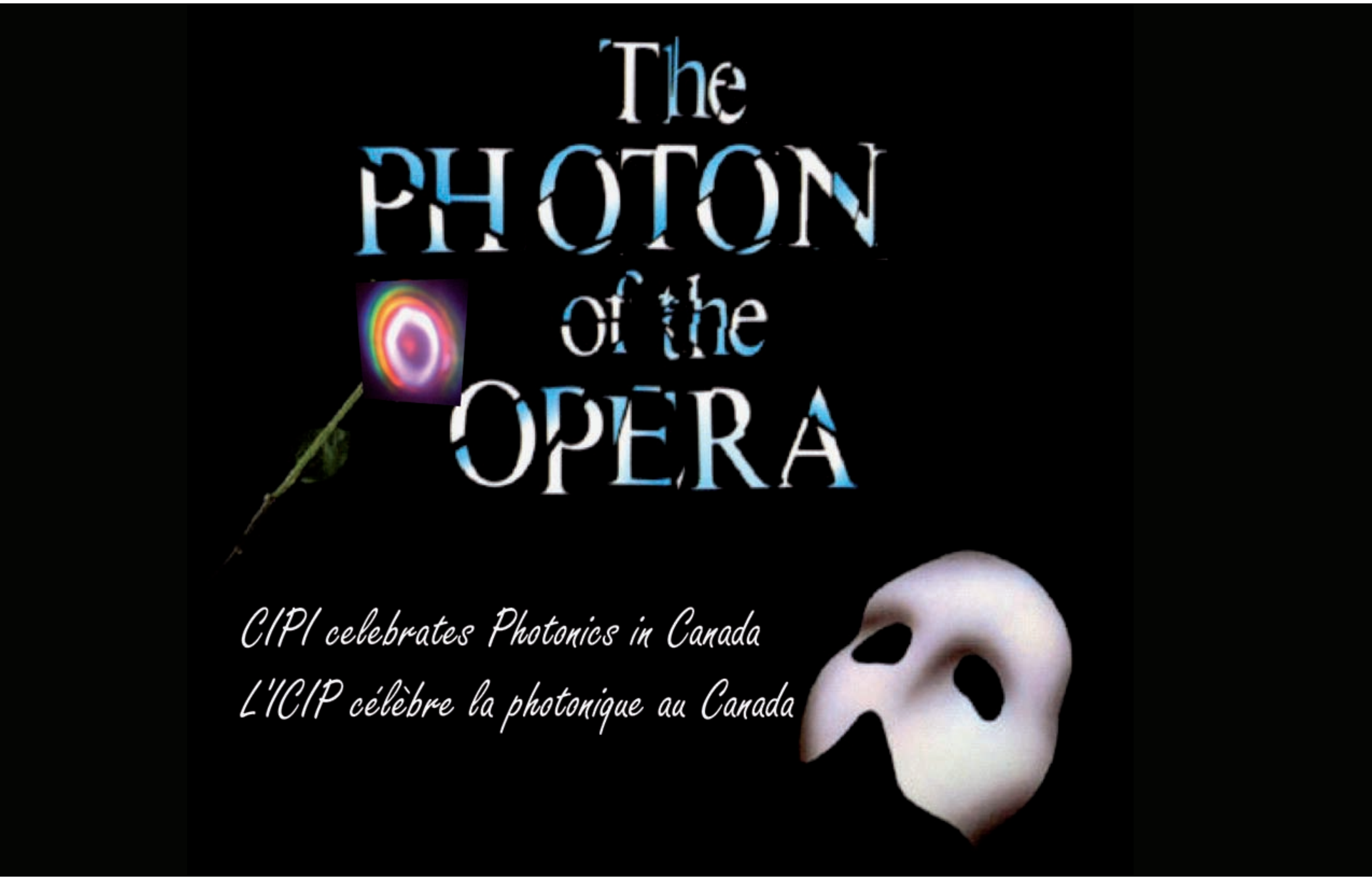

Integration of Microfluidic Channels and Bragg Grating Waveguides for Optofluidic Sensing

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ABSTRACT – Femtosecond laser direct writing in bulk glass materials presents an attractive single-step means for generating three-dimensional (3D) optical circuits that cannot be constructed with traditional fabrication techniques. In this work, Bragg grating waveguides and microfluidic channels are combined to create sensors that occupy minimal area and can probe sub-nanoliter sample volumes, and are therefore suitable for lab-on-chip devices. The strong evanescent probing of a 1560 nm waveguide mode into the liquid-filled microchannel medium induced sufficient shift in the Bragg resonance for characterization of refractive index in the 1 to 1.452 range. This article will report on the engineering efforts to increase the device sensitivity and the ability to improve device accuracy by employing reference gratings for temperature and strain compensation. The results present a new direction for optical sensing in biochips, chemical reactors, and general fluidic applications by novel 3D optofluidic microsystems made available by new femtosecond laser processes.

1. INTRODUCTION

The increasing demand to miniaturize the systems in which chemical and biological samples can be manipulated and analyzed, has stimulated the use of optical techniques for probing and analysis. This development has provided motivation and direction for the emerging field of optofluidics, which is attempting to combine concepts from optics and microfluidics [1]. The high integration, fast response time, low sample size and portability of these highly reconfigurable optofluidic systems are resulting in novel devices that can be integrated on a lab-on-chip platform.

In this regard, the use of femtosecond laser processing presents unique capabilities for the three-dimensional, sub-wavelength processing of transparent materials [2], which can be attractive platforms on which optofluidic systems can be fabricated. When femtosecond laser pulses are focused to micron-sized spots the resulting intensity in the focal volume is on the order of terawatts per square centimeter – a level where simultaneous absorption of two or more photons can induce multi-photon absorption inside a laser focal volume positioned inside transparent materials. Femtosecond lasers are used today to drive refraction index modification in the bulk of glass which enables fabrication of optical components such as optical waveguides, which was first demonstrated in 1996 by Hirao and colleagues [3]. More recently, femtosecond laser irradiation has been shown to form nanogratings [4] which, when followed by wet chemical etching in hydrofluoric (HF) acid, have been used to create three-dimensional microfluidic channels in glass [5,6]. The differential etch rate between the exposed and unexposed regions of the glass allows for the exposed region to be etched away much more quickly, resulting in a structure in the shape of the laser exposed region.

In a previous CIPI Photons review, we reported the three-dimensional femtosecond laser writing of Bragg grating waveguides (BGW) in bulk glasses, and the primary extension for distributed optical sensing of strain and temperature [7]. In this paper, femtosecond laser writing was optimized in fused silica to integrate BGWs and microfluidic channels to form three-dimensional optofluidic sensing microsystems. Using a single-step laser exposure, BGWs were simultaneously formed alongside modification tracks that were successfully etched into microfluidic channels without breaking into the laser-formed waveguide. Close side-by-side placement of the waveguide and channel enabled strong evanescent field penetration of the waveguide mode into the microfluidic channel as illustrated in Figure 1. Devices are presented for refractive index characterization in the 1 to 1.452 range of the fluidic medium inside the microfluidic channel.

2. EXPERIMENTS

Fused silica was chosen as the substrate because of its attractive optical properties, relative inertness, hydrophilicity, low adsorption and its ability to withstand high temperatures and pressures [8]. The fused silica substrate is 50 mm x 25 mm x 1 mm in length, width and height, respectively. The BGW is written from one side of the sample to the other and is thus 25 mm in length. The microfluidic channel fabricated alongside the BGW is 10 mm in length and is placed in the middle of the sample, 7.5 mm from each end. Both structures are fabricated 75 μm below the surface.

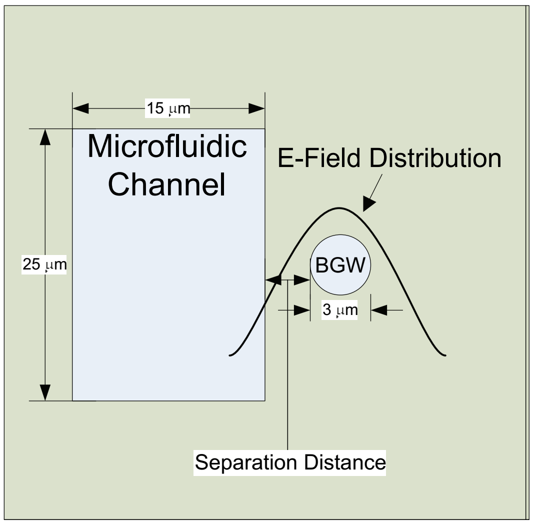

Figure 1: *Schematic drawing of the end view of the proposed optofluidic sensor that combines a BGW alongside of a microfluidic channel.*

A top view of the sensing device is illustrated in Figure 2. The BGW contains three segments; each is tuned to a different Bragg resonance: 1530 nm, 1560 nm, and 1550 nm for λ_{B1}, λ_{B2} and λ_{B3}, respectively. The segment of the BGW that is located in front of the microfluidic channel (λ_{B2}) is the sensing wavelength while λ_{B1} and λ_{B3}, which do not interact with the microfluidic channel, are reference gratings that are used to compensate for temperature and strain.

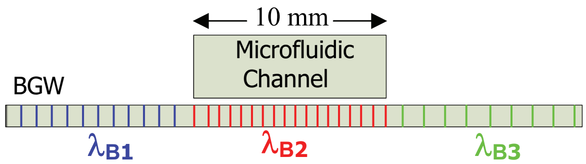

Figure 2: *Schematic drawing of the top view of the proposed optofluidic sensor that combines a BGW alongside of a microfluidic channel.*

An essential component for the fabrication of the optofluidic sensor is the novel fiber-amplified laser. The laser (IMRA America; μJewel D-400-VR) is a Yb:fiber chirped pulse amplified (FCPA) system, with a variable repetition rate of 100 kHz up to 5 MHz with an average power of 500 mW at a fundamental wavelength of 1045 nm. The pulse width is measured to be approximately 300 fs (FWHM of a Lorentzian fit). The laser beam is directed into an acousto-optic modulator (AOM; NEOS 23080-3-1.06-LTD) which is used to create burst trains of laser pulses (when fabricating Bragg Grating Waveguides) or as a fast switch to deflect the laser beam and prevent overexposure or damage when writing three-dimensional structures with high resolution. After passing through the AOM, the laser beam is focused into a 3 mm thick lithium triborate (LBO) crystal for second harmonic generation (522 nm) which offers stronger interaction in fused silica than the fundamental wavelength [9]. Since the conversion process is approximately 50% efficient, a short-pass filter is used to remove the fundamental beam. Turning mirrors steer the beam to the sample which is mounted on an air-bearing motion stage (Aerotech ABL1000 with 2.5 nm resolution and 50 nm repeatability) and translated with respect to the laser beam.

2.1 Bragg Grating Waveguide Fabrication

To fabricate the BGWs the laser was set to a pulse repetition rate of 500 kHz, pulse energy of 150 nJ and focused to 75 μm below the surface using a 40X objective lens with a 0.55 NA. The sample was translated with respect to the laser beam which was linearly polarized parallel to the direction of motion of the motion stages. The desired Bragg reflection is determined according to:

$$\lambda_B = 2 \cdot n_{eff} \cdot \Lambda \qquad (1)$$

where λ_B is the reflected Bragg wavelength, n_{eff} is the effective index of the waveguide mode and Λ is the grating period, which is controlled by the ratio of the scan velocity to the AOM modulation frequency [7]. For a reflected wavelength of 1550 nm, the scanning velocity was set to 0.26815 mm/s and the AOM was modulated using a 500 Hz square wave with a duty cycle of 0.6. The reflection and transmission spectra of a BGW fabricated using this method and measured using an optical spectrum analyzer (OSA; Ando AQ6317B) with 0.01 nm resolution is shown in Figure 3.

2.2 Microfluidic Channel Fabrication

To create microfluidic channels of the desired cross-sectional height and width, a 5 x 5 array of modification tracks were combined to create a larger volume of laser modified region. The array was formed starting from the bottom and used a layer-to-layer separation of 1 μm and 2 μm in the horizontal and vertical directions, respectively.

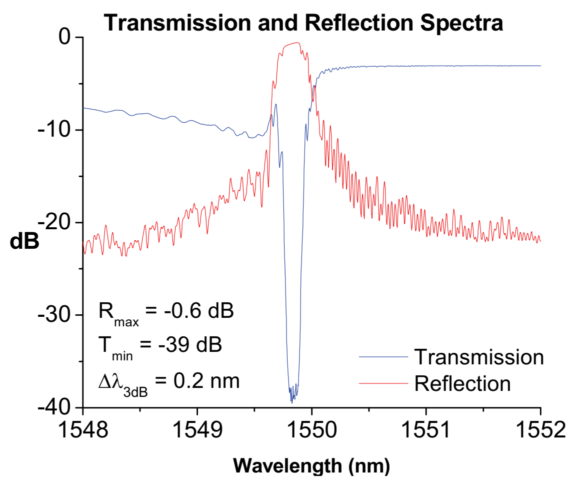

Figure 3: *Reflection and transmission spectra of a BGW fabricated by femtosecond laser irradiation.*

To prevent the microfluidic channel from tapering in the middle during the etching process, modification tracks from the glass surface to the top of the microfluidic channel were placed every 100 μm along the 10 mm long microfluidic channel. This increased the total number of entry points for etching the buried channel, thereby decreasing the required etching time and ensuring a uniform microfluidic channel over long distances of 10 mm. Given that the microfluidic channels were fabricated in the same laser process as the BGWs, only the pulse energy, laser polarization and AOM modulation were changed. A lower pulse energy (~80 nJ) and perpendicular laser polarization resulted in smoother side walls. While fabricating the microfluidic channels the AOM was only used to deflect the beam from the sample to prevent overexposure of the ends of the microfluidic channel during the turn-around periods preventing stress and cracks from forming. The entire sample was etched in 10% HF acid for 2.5 hours producing channels that were 10 mm, 15 μm, and 20 μm in length, width and height respectively. An optical microscope picture of the combined BGW fabricated alongside a microfluidic channel is shown in Figure 4 after the HF etching step. To improve the device sensitivity, the waveguide-to-channel separation was decreased until breakthrough due to the HF etching occurred.

3. RESULTS

The optical characterization of the optofluidic sensor followed the procedure previously described in [7]. Briefly, a broadband infrared light source (Thorlabs; ASE-FL7002, 1530 nm to 1610 nm) was passed through an optical fiber circulator and coupled to and from the BGW under test using end-coupled single mode fibers with index matching oil to reduce the Fresnel reflections and Fabry-Perot effects.

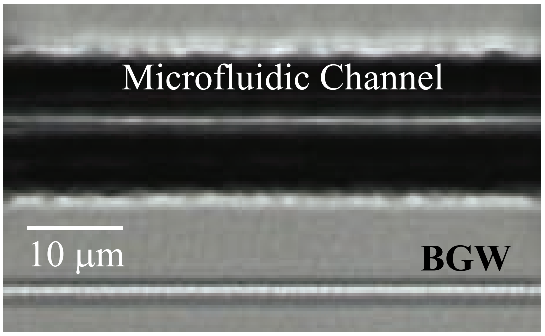

Figure 4: *Optical microscope picture providing a top view of a BGW fabricated alongside a microfluidic channel (post-etching).*

The transmitted and reflected signals were recorded using an optical spectrum analyzer (OSA; Ando AQ6317B, with 0.01 nm resolution). The microfluidic channel was filled, using the same access holes that facilitated uniform etching, with air (n = 1.00), vinegar (n = 1.33) and various index oils from Cargille (n = 1.402 to 1.452).

The evanescent field penetration of the waveguide mode into the microfluidic channel increases the effective index and hence, according to Equation 1, will shift the Bragg resonance and allow the refractive index to be measured. Given that the amount of evanescent field that penetrates into the microfluidic channel affects the effective index change, fabricating the BGW as close to the microfluidic channel as possible was essential. The objective of increasing the amount of evanescent field that penetrates into the microfluidic channel led to the idea of fabricating microfluidic channels on both sides of the BGW to further increase the change in the Bragg resonance. The Bragg grating results for both the single and double channel topology are shown in Figure 5 for refractive index in the 1 to 1.452 range. For a change in index of refraction from 1.448 to 1.452, the resulting change in Bragg wavelength was 0.22 nm and 0.32 nm for the single and double channel topology, respectively. The change in Bragg resonance per unit change in the refractive index yields a maximum demonstrated sensitivity of 81 nm per refractive index unit (RIU), achieved using the double channel topology which compares favorably to the 55 nm/RIU obtained for the single channel topology.

The reflection spectra in Figure 6 show the sensing wavelength (1560 nm) increasing with the index of refraction of the medium inside the microfluidic channel, while the reference grating (1550 nm) does not shift within the 0.01 nm resolution of the OSA. This reference BGW segment does not probe the microfluidic channel. Any shift in this reference grating would therefore indicate a change in temperature or strain [10], in which case the sensing grating would need to be compensated by the amount of this shift. Such diagnostics are powerful new tools for distributed sensing in microfluidic and lab-on--chip devices as well as microreactors.

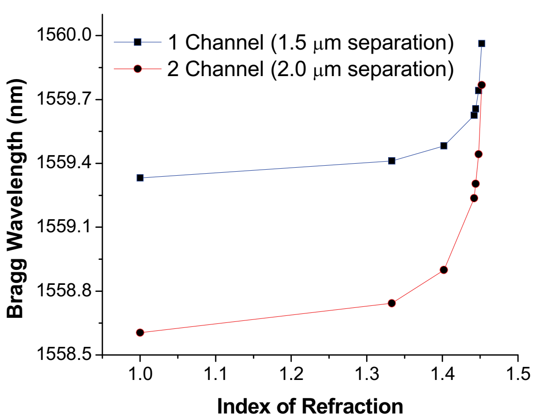

Figure 5: *Results showing the shift in the Bragg resonance versus the refractive index of the media inside the microfluidic channel(s).*

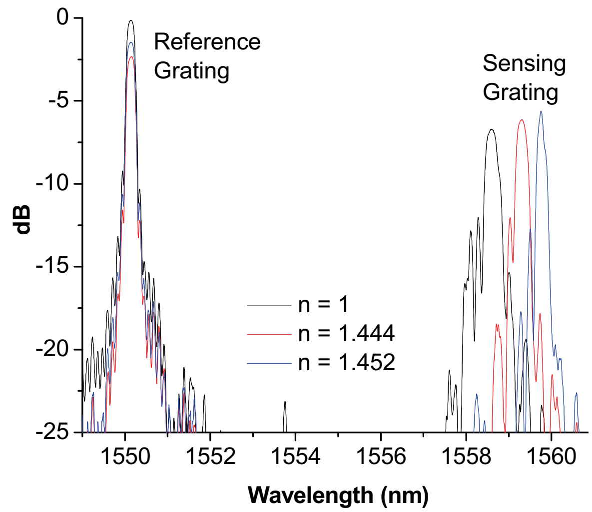

Figure 6: *Reflection spectra of a reference BGW and sensing BGW with a microfluidic channel on both sides.*

4. CONCLUSIONS

In conclusion, we present a femtosecond laser fabrication technique for the three-dimensional integration of BGW with microfluidic channels for optofluidic sensing in a single laser writing step followed by chemical etching in HF acid. Sampling the refractive index of the medium carried inside a microfluidic channel provides a new direction for optical sensing of gases, liquids, and biological media in three-dimensional optofluidic microsystems. Future work includes writing multiple BGW along a microfluidic channel for distributed sensing of a media that is flowing through the microfluidic channel as well as temperature and strain sensing inside microreactors and biochips.

CIPI SUPPORT

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ACKNOWLEDGEMENTS

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Self-Assembled InGaAs/GaAs Quantum Dot Microtube Coherent Light Sources on GaAs and Si

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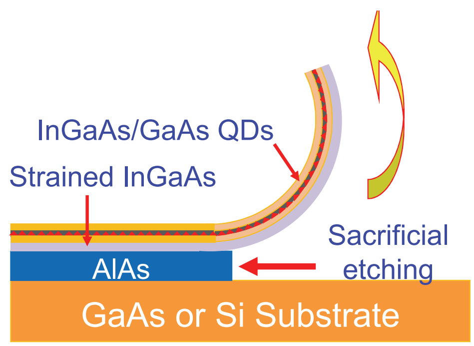
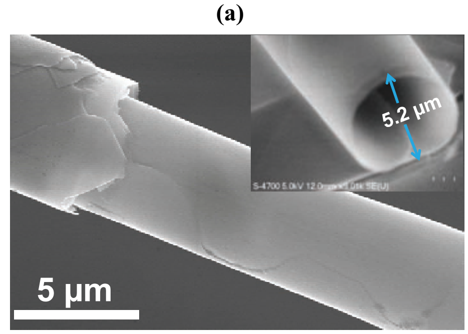
ABSTRACT – We report on the growth, fabrication, and characterization of InGaAs/GaAs quantum dot microtube optical ring resonators on GaAs substrates as well as the achievement of such unique devices directly on Si using a simple but controllable substrate-on-substrate transfer technique. Three dimensionally confined optical modes, with wavelengths in the range of 1.1 – 1.3 µm and an intrinsic Q-factor of ~ 3,000, are measured at room temperature in microtube ring resonators with an engineered surface geometry.

1. INTRODUCTION

A critical, yet missing technology for future chip-level optical communications is a high performance and highly reliable laser on Si. In this regard, III-V semiconductor lasers on Si as well as the monolithic integration with Si-based waveguide devices have been extensively investigated [1-3]. However, their practical applications have been limited, to a large extent, by the generation and propagation of dislocations, due to the large lattice and thermal mismatches between III-V materials and Si [4]. We have recently developed free-standing InGaAs/GaAs quantum dot microtube coherent light sources that may fundamentally eliminate such problems [5]. Such microtubes are formed by self-rolling of coherently strained InGaAs/GaAs quantum dot heterostructures through controlled release from their host substrates [5-7]. We have developed a substrate-on-substrate transfer process and realized nearly defect-free quantum dot microtubes on Si that were not possible before [5]. We have further achieved, for the first time, coherent emission from single rolled-up quantum dot microtubes, with emission wavelengths in the spectral range of 1.1 ~ 1.3 µm and an intrinsic linewidth of less than 0.4 nm at room temperature. Moreover, the 3-dimensionally confined optical modes can be exactly tailored by varying the microtube geometry.



(a)



(b)

Figure 1. *(a) Illustration of the formation of InGaAs/GaAs quantum dot microtube ring resonators; (b) Scanning electron microscopy image of a quantum dot microtube transferred on a Si substrate, wherein an engineered surface geometry can be seen. The cross-sectional view of a microtube is shown in the inset.*

2. METHODOLOGY

The InGaAs/GaAs bilayer heterostructure was grown on a 50 nm AlAs layer on GaAs substrates by molecular beam epitaxy. The heterostructure consists of a 20 nm $In_{0.18}Ga_{0.82}As$ and 30 nm GaAs layer as well as two $In_{0.5}Ga_{0.5}As$ quantum dot layers embedded in the GaAs matrix. Illustrated in Fig. 1(a), by selectively etching the AlAs sacrificial layer, the InGaAs/GaAs quantum dot layer can roll into nano- or micro-tubes, due to the relaxation of strain [5,6]. The tube diameter is determined by the bilayer thicknesses and compositions. The number of revolutions and, consequently, the tube wall thickness is controlled by the etching time. In this study, quantum dot microtubes with one or two revolutions, corresponding to wall thicknesses of 50 – 100 nm, were fabricated.

Such high quality microtubes can be grown and fabricated directly on Si substrates or transferred reliably from the host substrate to any foreign ones using a newly developed substrate-on-substrate transfer technique [5]. In the latter process, the thin AlAs sacrificial layer is completely etched and the fully released quantum dot microtubes then register on the GaAs substrate. Subsequently, the GaAs wafer is placed directly on top of a Si substrate with the presence of an appropriate solvent. When the GaAs wafer is removed, freestanding microtubes preferentially stay on the Si substrate due to the gravitational force induced by the solvent in and around the tube. Upon drying up, such microtubes can be attached to the Si wafer by van der Waals force through surface tension. Figure 1(b) shows the scanning electron microscopy (SEM) image of a quantum dot microtube on Si. The cross-sectional view of a microtube is also illustrated in the inset of Fig. 1(b), showing a tube diameter of ~ 5.2 µm.

3. RESULTS

Emission characteristics of InGaAs/GaAs quantum microtubes on GaAs and Si were studied using micro-photoluminescence spectroscopy at 300 K. The devices were optically excited using a semiconductor laser operating at 0.64 µm through an objective lens (100×, 0.7 NA). Emission from the microtube resonators were analyzed by a high resolution spectrometer and detected using an InGaAs detector with lock-in amplification. The measured spectrum at a pump power of 30 µW is shown in Fig. 2(a). Six groups of sharp optical modes, with the dominant modes of each group spaced apart by approximately 24 meV, can be clearly observed. For an ideal optical ring resonator, the emission spectrum is generally characterized by a regular sequence of optical modes, whose spacing can be calculated, in the simplest case by $c/n_{eff}l$ by modeling the microtube as a planar dielectric waveguide, where n_{eff} is the effective refractive index and l is the microtube circumference. The calculated azimuthal mode numbers (m = 25 to 30) are shown in Fig. 2(a).

Additionally, associated with each azimuthal mode is a group of at least three spectral eigenmodes separated by ~ 8 meV, detailed in Fig. 2(b). To understand the origin of these optical modes, it is important to note

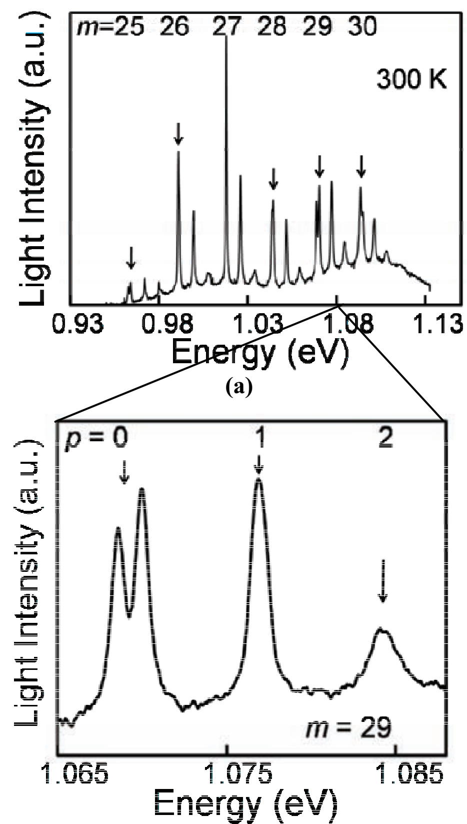


Figure 2. *(a) Emission spectrum of a freestanding InGaAs/GaAs quantum dot microtube at an excitation power of 30 µW. The corresponding azimuthal mode numbers (m = 25 – 29) are illustrated; (b) A detailed view of the eigenmodes associated with the azimuthal mode number m = 29. The axial mode numbers (p) are also identified.*

that, while photons circulate around the tube periphery and establish optical resonance, they are also strongly confined along the tube axial direction by the intentionally introduced corrugations on the tube surface, as shown in Fig. 1(b). Therefore, for each azimuthal mode, there may exist several field distributions along the tube axial direction. The resulting axial field dispersion also implies that the wavevector of each confined photon is not only determined by the azimuthal mode (m) but also directly related to an additional axial mode (p), illustrated in Fig. 2(b).

Detailed studies also confirm that each optical resonance mode consists of two non-degenerate modes, as shown Figs. 2(a) and (b). For a perfect optical ring resonator, confined photons may circulate around the tube periphery either clockwise or counterclockwise, with degenerate eigenmodes. However, this degeneracy is lifted in a rolled-up microtube, due to the spiral asymmetry, *i.e.* the presence of inside and outside edges around the tube [8]. Based on this consideration, we have derived a minimum intrinsic linewidth of ~ 0.4 nm, which corresponds to a maximum Q-factor of ~ 3,000. Further improvement in the Q-factor can be achieved by optimizing the optical confinement along the tube axial direction.

4. CONCLUSIONS

In summary, combining both top-down and bottom-up approaches, we have developed high performance quantum dot microtube based coherent light sources on Si substrates. Such unique nanoscale devices, with exactly tailored properties, may emerge as an enabling technology for future on-chip optical communications, biosensing, and quantum information processing.

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High Numerical Aperture Polymer Microstructured Fiber with Three Super-Wavelength Bridges

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ABSTRACT: The transmission properties of a novel high numerical aperture polymer-based fiber are detailed. The proposed fiber features a large core 520µm suspended in air by three bridges of 3µm thickness. Unlike in existing high NA fibers featuring a large number of subwavelength supports, the bridge size in our fiber is not subwavelength. However, as there are only three such bridges and the core diameter is large, our fiber still confines light efficiently in the inner core. High NA operation was registered for fiber pieces of less than 1m in length. We believe that the proposed fiber has a potential for short range applications such as evanescent sensing due to the fiber simple fabrication methodology, wide unobstructed air channels, relatively low loss and high NA.

Polymer materials offer wide material diversity and flexible processing, enabling cost-effective fabrication of complex fiber geometries for a broad range of applications Ref. 1. Among others, high numerical aperture (NA) microstructured polymer optical fibers (MPOF) promise solutions in high bandwidth data communications (Ref. 2) and optical sensors (Refs. 3-4). When designing fibers with high numerical aperture (Refs. 2, 5), one usually faces the problem of a lack of material combinations with high enough refractive index contrast. The use of an air-filled porous cladding is one way of achieving such a high refractive index contract; however, great care should be taken to avoid leakage of light through the material bridges that support fiber core in air (Refs. 6-7). A common solution to this problem is making support bridges subwavelength, thus preventing the light from escaping, while placing many of such bridges in close proximity to each other for structural support. Fabrication of such fibers is typically challenging (Refs. 8-9) and requires several drawing steps.

In this paper, we report fabrication of a novel all-polymer high NA fiber that consists of a large core suspended in air by only three relatively thick-walled (several wavelengths in size) bridges (see Fig. 1). If the sum of thickness of all the bridges is much smaller than the circumference of the fiber core, then the light is still going to be well confined inside of the core (assuming that the fiber length is not too long). The relatively thick walls of the support structure guarantee a good structural integrity with only a few bridges. Additionally, the presence of only few support bridges makes the large air channel surrounding the core relatively unobstructed. This feature is important for sensing applications, which typically require filling the air channel with the analyte. The unique geometry of the proposed fiber offers a large interaction area, thus enhancing device sensitivity. Finally, the fabrication of the proposed fibers through stack and draw process is relatively simple and requires only a single drawing step without preform pressurization.

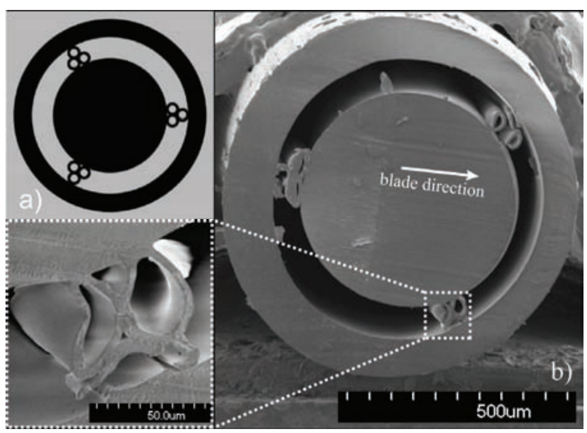

***Figure 1**: a) Schematic of the fiber preform. Solid PMMA core is suspended in the center of a hollow tube by means of three capillary-based bridges. b) SEM picture of the crossection of a drawn fiber. Wall thickness of the bridge capillaries is 3 m. Bridge geometry is distorted at the fiber crossection during cutting. Striation marks from the blade are also visible in the fiber core.*

Details of the fiber fabrication are as follows. The fiber was made of commercial polymethylmethacrylate (PMMA) tubing purchased from McMaster-Carr. The fiber preform consisted of a hollow tube of 31.75mm outside diameter (OD) and a solid rod of 12.70mm OD. This particular choice of dimensions was made mostly for availability reasons. Precaution was taken to choose the thinnest walled hollow tube in order to minimize the relative size of the supporting pillars. The PMMA tube and rod were degassed and annealed in vacuum oven at 90^{o}C for 48h prior to use. Capillaries of 1.8mm OD were drawn from one of the PMMA tubes. The tube, rod and capillaries were then stacked in a 30cm long preform with a crossection shown in Fig. 1(a). Prior to drawing, the preform was consolidated in the oven at 130^{o}C for 8h and then preheated in the draw tower furnace at the same temperature for 1h. The preform was drawn at 175^{o} C at a speed of 1m/min. The final fiber dimensions are 900µm for the fiber OD, 520µm for the inner core diameter, 75µm for the air channel width, and 45µm for the diameter of an individual bridge capillary of 3µm wall thickness.

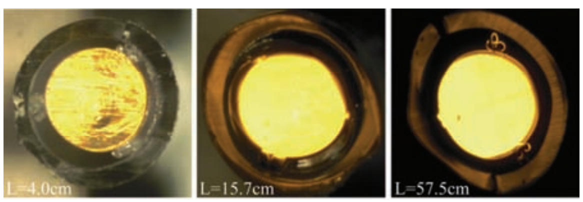

Figure 2: *Near field images of the fiber output face for the propagation lengths of a) 4.5cm, b) 15.7cm, and c) 57.5cm. Optical power slowly leaks into the cladding as light propagates along the fiber core.*

We now present the results of an optical characterization performed on the drawn fibers. We expect that the two main attenuation mechanisms in the proposed fibers are material absorption of the PMMA polymer and light leakage through the capillary bridges from the fiber core into the cladding. The simplest way of ascertaining the optical power leakage from the fiber core by way of bridges into the fiber cladding is by imaging the fiber output face for several increasing fiber lengths.

Fig. 2 shows photos of the near field intensity distributions at the fiber output face for the fiber lengths of 4.5cm, 15.7cm, and 57.5cm. Non-surprisingly, the fiber cladding becomes brighter as the fiber length increases. Moreover, in the longest fiber pieces one can also see light guidance by the bridges themselves.

The spectral attenuation of the fibers (solid blue curve in Fig. 3) was then measured using standard cut-back technique with the aid of a supercontinuum white-light source and a monochromator. In our measurements, we used a diaphragm to prevent the light that leaked from the fiber core into the cladding from passing into the monochromator. Thus, only the power guided in the core was considered for the fiber attenuation measurements. In every measurement, the broadband spectrum of a collimated supercontinuum source was focused at the center of the fiber core using a 10X, 0.25 NA microscope objective. Between measurements, the fiber was removed from the optical setup, cut to a shorter length (from the output end), and then re-installed into the setup. In order to minimize the effect of variations in the input coupling conditions, which is important for the multimode fibers, images of the fiber input face and position of the focused supercontinuum beam in the fiber crossection were recorded for every experiment. Every time the fiber was re-installed, the input coupling conditions were reproduced through comparison with a pre-recorded image. A separate detailed study demonstrated effectiveness of this technique in achieving reproducible transmission spectra of the large core multimode fibers. We would like to notice that, ideally, during cut-back measurements the input end of a fiber should stay fixed, while cutting would be done at the output end. In practice, when working with small fiber pieces it is difficult to achieve high quality cuts without removing the fiber.

As we have mentioned previously, several factors contribute to the total loss of the proposed fiber, namely, the material absorption of the PMMA polymer and light leakage through the capillary bridges. In order to estimate losses caused only by the leakage of light, the fiber transmission spectrum was compared to that of a PMMA rod of diameter equal to that of the fiber core (dashed red curve in Fig. 3). The PMMA rod was drawn from the same material as the one used for making fiber core, employing the same drawing parameters. Assuming that the fiber core and equivalent polymer rod have the same material loss and comparable interface roughness due to similar processing, the difference between the two corresponding transmission spectra should give the leakage loss. The proposed suspended core fiber exhibits a transmission loss close to 10dB/m for the whole visible spectral range. On the other hand, the lowest loss of the industrial grade PMMA rod in the visible is measured to be 5dB/m. Therefore, an important fraction of the proposed fiber loss can be attributed to poor optical quality of the PMMA raw material. Based on the stated assumption, we can note that leakage loss mechanism contributes about 5dB/m to the fiber global transmission loss. The use of optical grade PMMA could greatly improve the fiber performance as it can exhibit absorption loss as low as 0.16dB/m.

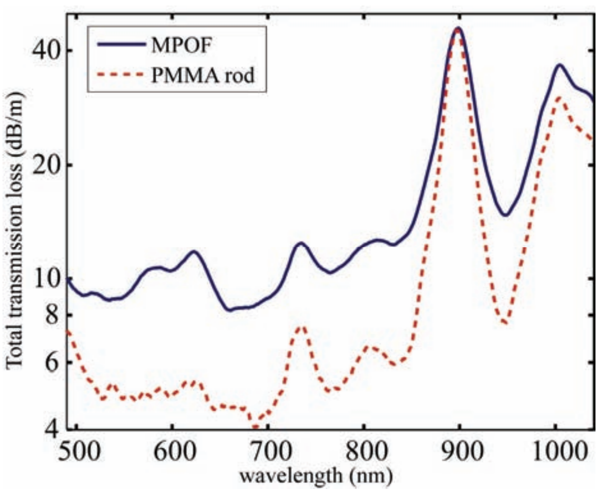

***Figure 3:** Transmission losses of the proposed fiber (solid blue), and a PMMA rod having the same diameter as the fiber core (dashed red). Losses of the PMMA rod are mostly due to polymer material absorption while losses of the suspended core fiber are due both to absorption and power leakage.*

Finally, the numerical aperture of the proposed fiber has been characterized as a function of the fiber length (see Fig. 4). Two types of microscope objectives 40X, 0.60NA, and 60X, 0.75NA were used for coupling light into the fiber. Numerical aperture of the fiber sample is defined as $NA=\sin\theta_{5\%})$, where $\theta_{5\%}$ characterizes the angular spreading of an outgoing beam, and is deduced from the beam-width at exp(-3)≈5% of the maximum in the output far field intensity distribution. Schematic of a NA measurement setup is presented at the top of Fig. 4. In our measurements, NA was averaged over the visible spectrum as we have used the collimated beam of an infrared filtered supercontinuum white-light source.

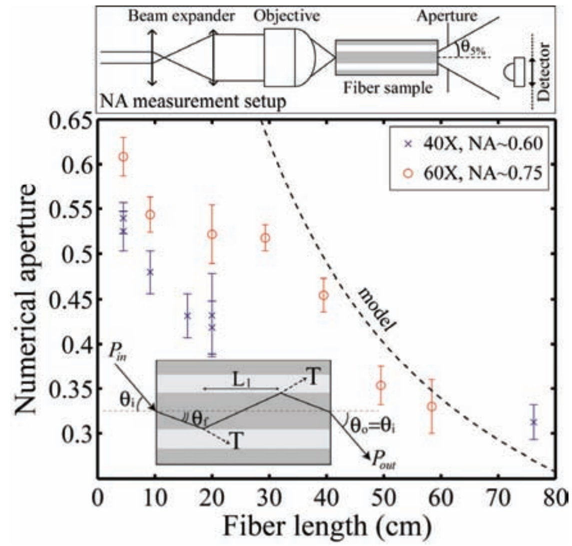

***Figure 4:** Numerical aperture as a function of fiber length. NA decreases with fiber length due to higher leakage loss for rays having steeper propagation angles θ_f.*

From Fig. 4 we see that fiber NA decreases as the fiber length increases. This behavior can be readily rationalized by employing ray picture for the propagation of light in the large core multimode fibers. Particularly, consider an external ray incident on the fiber input interface at an angle θ_i (inset in Fig. 4). Inside of the fiber core of refractive index n_f, such a ray will propagate at an angle η_f. The two angles are related by the Snell's law $\sin(\theta_i)=n_f$. Defining D_f to be the fiber core diameter, after a distance $L_1=D_f/\tan\theta_f)$ a ray will bounce off the core/air-clad interface; if L is the length of a fiber sample, before arriving to the fiber end a ray will exhibit L/L_1 bounces. Every time a ray strikes the core/air-clad interface the T portion of its power is leaking out through the bridges into the cladding. The amount of power leakage per bounce is proportional to the ratio of the total thickness of all the bridges to the total circumference of the cladding $T=\delta/(\pi D_f)$. By inspection of Fig. 1, the total thickness of six contact points between bridge capillaries and the fiber core is estimated to be $\delta\approx18$~m. In a fiber of length L, power loss due to leakage will then be $(1-T)^{L/L1}\approx\exp(-(T/L_1)L)$. Moreover, for a ray travelling at an angle, effective propagation length from one end of the fiber to the other will be $L/\cos\theta_f)$, therefore, total propagation loss due to material absorption will be $\exp(-(\alpha_{abs}/\cos\theta_f)L)$. Defining α_{abs}, and $\alpha_{lk}=\delta/(\pi D_f^2)$ to be the fiber absorption and leakage losses, for the power attenuation of the ray launched at θ_i we write:

$$\frac{P_{out}(\theta_o)}{P_{in}(\theta_i)} = \exp\left(-\left(\alpha_{lk}\tan(\theta_f) + \frac{\alpha_{abs}}{\cos(\theta_f)}\right)L\right), (1)$$

Angular beam spreading at the fiber output is characterized by the angle θ_o^{NA}. By definition, the ratio of intensities of an outgoing ray travelling with θ_o^{NA} to the ray intensity at zero propagation angle is $P_{out}\theta_o^{NA})/ \tilde{P}_{out})$=exp(-3). Numerical aperture of a fiber is then defined as NA=$\sin\theta_o^{NA}$). Using $\delta \approx 18\mu m$, D_f=520µm, and assuming isotropic launching conditions $P_{in}\theta_i^{NA}) = \tilde{P}_{in}$), we find that, for the steepest ray that defines NA, leakage loss dominates over absorption. This particular ray exhibits losses of α_{lk}=91dB/m and α_{abs}=10dB/m. In this limit (1) simplifies and fiber NA can be found analytically:

$$NA = n_f\left(1+(\alpha_{lk}L/3)^2\right)^{-1/2}. (2)$$

Finally, in dashed line in Fig. 4, we show the prediction of the theoretical model (2). We observe that, despite its very simple geometrical interpretation, it matches well experimental data for longer fiber pieces. For short fibers, however, measured NA might be limited by that of the coupling objective.

To summarize, novel air-clad polymer microstructured fiber with three super-wavelength supporting bridges was fabricated and characterized. It was established that in such fibers, loss due to material absorption was comparable to the loss due to leakage of light from the fiber core through the bridges. Each loss mechanisms contributed approximately 5dB/m over the whole visible PMMA transparency window, giving the fiber an overall 10dB/m transmission loss. A numerical aperture of over 0.60 was demonstrated and was shown to decrease rapidly for longer fiber spans, which was explained by the higher leakage rate of the rays propagating at sharper angles with respect to the fiber direction. Short range applications such as evanescent sensing can operate in the high numerical aperture regime of the proposed fiber.

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CARS Microscopy Made Simple

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ABSTRACT – We describe a very simple yet high performance version of multi-modal Coherent Anti-Stokes Raman Scattering (CARS) Microscopy, based upon a single fs Ti:Sapphire oscillator and a photonic crystal fibre. Simultaneous CARS, second harmonic and two-photon fluorescence microscopy of live cells and tissues are demonstrated at frame rates of $2s^{-1}$ and low light exposures (< 30 mW total).

1. INTRODUCTION

Coherent anti-Stokes Raman scattering (CARS) microscopy provides molecule specific yet label-free imaging of samples based on their Raman spectrum [1]. CARS has attracted significant interest for its applicability to imaging live cells and tissues. Most implementations of CARS microscopy are based on the use of a pair of transform-limited (TL) tunable ps pulses. The narrow linewidth of TL ps pulses ensures that the laser pulse linewidth falls within or matches the spectral linewidth of the Raman band of interest, thereby enhancing the contrast of resonant over nonresonant (background) CARS signals [2]. By contrast, nonresonant two-photon fluorescence (TPF) and second harmonic generation (SHG) signals benefit greatly from the use of shorter (fs) laser pulses. We recently showed that, for multimodal CARS microscopy, we could very successfully use fs laser pulses for high performance imaging of live cells and tissues [3]. Although fs pulses have poor spectral resolution, well known nonlinear optical methods exist for enhancing this, based upon the control over optical phase inherent to fs laser pulses. The simplest implementation is a quadratic spectral phase variation (linear chirp). By optimizing the degree of chirp in fs pulses, we obtained a very simple yet high performance CARS microscopy method that is robust and inexpensive yet stable enough for real time imaging of live cells over periods of days [3].

1.1 Optimally Chirped CARS Microscopy

In Fig.1, we show the chirped pulse CARS scheme. The degree of linear chirp is a variable parameter to be optimized under user control. The best performance (combination of signal and contrast) is achieved when the effective second order laser line width (the height $\Delta\Omega$ of the difference frequency ellipse) matches the width of the Raman resonance under study. As Raman line widths can vary considerably (5 - 400 cm^{-1}), the ability to easily tune the effective spectral width of the excitation pulses is a useful tool to put in the hands of the user.

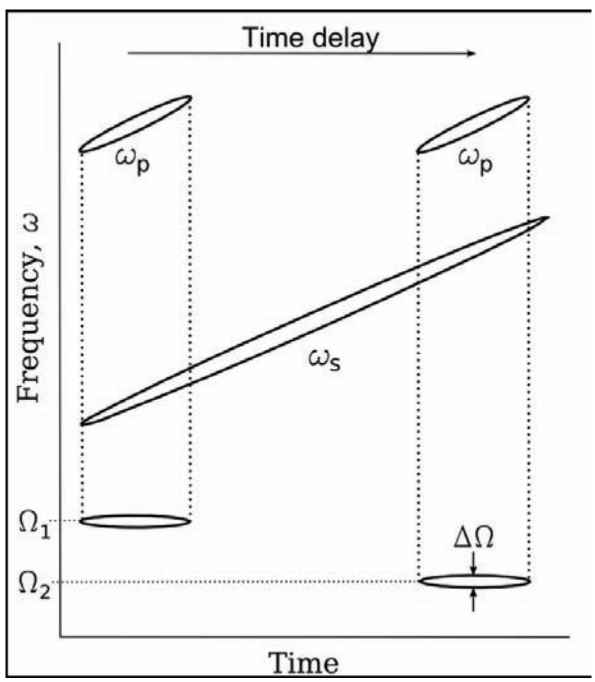

Figure 1: *Time-frequency plots of chirped Pump and Stokes pulses. The CARS spectral resolution $\Delta\Omega$ is determined by the height of the difference frequency ellipse $\omega_p - \omega_s$. Adjusting the chirp rates gives an adjustable instantaneous bandwidth and a user-variable spectral resolution. Changing the time delay of the Pump relative to the broadband Stokes scans this instantaneous difference frequency, probing different Raman modes (Ω_1 , Ω_2).*

We used a photonic crystal fiber (PCF) to generate the broadband synchronized Stokes light for broad Raman tunability (~2500-4100 cm^{-1}). Rapid tuning of the Raman resonance is obtained by varying the time delay between chirped pump and Stokes pulses, whereas the effective Raman resolution and signal level are controlled by varying the chirp of the two pulses. In Fig.2, we show CARS spectra of a drop of liquid methanol, showing the effect of chirp rate on spectral resolution. The approach we describe is general to all fs sources and can also be used, for example, with synchronized fs oscillators or a fs OPO. Overall, the optimally chirped system is a high performance, versatile multimodal CARS microscope allowing for microspectral imaging of live cells and tissues. We provide sample illustrations of this capability by imaging myelin in rat dorsal nerves and an atherosclerotic arterial sample (rabbit aorta).

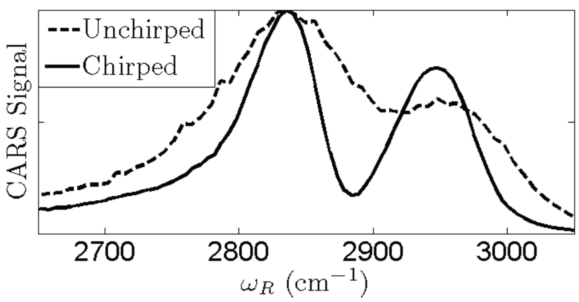

***Figure 2**: CARS spectra of methanol obtained by scanning the time delay between the pump and Stokes pulses shown in Fig.1. The dashed curve was for unchirped pulses, the solid for wich pulses width matched chirp rates.*

2. METHODOLOGY

2.1 A single Ti:Sa oscillator CARS source

An outline of the optical setup is given in Fig. 3. A Spectra Physics Tsunami Ti:Sapphire laser system produced pulses of 60 femtoseconds at 80 MHz with 550 mW total average power with a center wavelength of 800 nm. A Faraday isolator was used to avoid back reflections into the laser. To maximize performance of the PCF, the pulse train was sent through a prism compressor in order to have TL pulses at the input of the PCF. After the compressor, the beam was split by a 50:50 beam splitter into a pump and Stokes arm. The light in the Stokes arm was sent through the PCF. The pump was passed through a variable time delay stage and a variable neutral-density filter. To control the chirp in the simplest possible way, we used fixed length blocks of glass: one 3 cm block of SF6 glass was placed in the pump arm and a 5 cm block of SF6 glass was placed in the Stokes arm, to achieve nearly matched chirps. Typical powers before the microscope scan head were 7 mW in the Stokes and ~ 50 mW in the pump. These powers were attenuated by about a factor of two through the microscope system before reaching the back aperture of the objective lens inside the microscope.

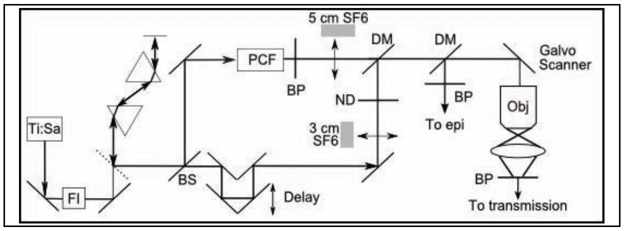

***Figure :** Simple CARS Microscope. A 50:50 beam splitter (BS) splits pulses from an isolated (FI), prism compressed Ti:Sa oscillator. One half went to a PCF and bandpass filter (BP) before being recombined on a dichroic mirror (DM). The other half was time delayed and attenuated (ND). Glass blocks (SF6) controlled the chirp rates. The recombined pulses were sent into the FV300 microscope for imaging.*

All imaging was performed on a specially modified Olympus Fluoview 300 (FV300) laser scanning system and IX71 inverted microscope using a 40X 1.15 NA objective lens, and a 0.55 NA condenser lens for forward collection (CARS and SHG). TPF signals were collected back through the objective lens (epi-detection). Filters were used to discriminate signals from each other and the input pump and Stokes beams. For imaging, light was directed to photomultiplier tubes (PMT).

3. RESULTS

In Fig. 4, we show measurements of rat spinal nerves, demonstrating the capability of using this system for CARS tissue imaging. The spinal nerves are approximately 300 μm in diameter and consist of bundles of roughly 100 myelinated axons, each about 15 μm diameter. The effective depth of field of the CARS signal was ~1.5 μm, necessary in order to see detail from this tissue. The pixel intensity profile of the indicated line is shown demonstrating the contrast achieved. It is clear that the signal intensity from the myelin is at least 60 fold greater than that from the axon and that fine detail in the myelin structure is clearly visible. The spectral response of the myelin (not shown) proved that the signals observed were due solely to resonant CARS and not due to changes in the non-resonant background.

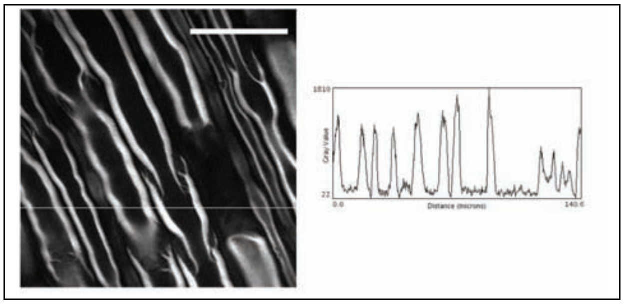

Figure 4: Forward detected FV300 CARS imaging of fixed rat dorsal root nerves at 2850 cm^{-1} (lipid C-H stretch). The lipid-rich myelin sheath surrounds the neuronal axon and generates a strong CARS signal. The pixel intensity profile of the indicated line is shown, revealing high contrast. The scale bar is 50 μm. The pixel dwell time was 8 μs. [3]

In Fig. 5, we show an atherosclerotic lesion from a rabbit aorta which was used as a test sample for label-free multimodal imaging. A 50 μm section of aorta was imaged showing lipids (CARS - red), collagen (SHG - blue) and smooth muscle elastin (TPF - green). Importantly, all three signals are endogenous to the sample and no dyes or stains were added to enhance contrast.

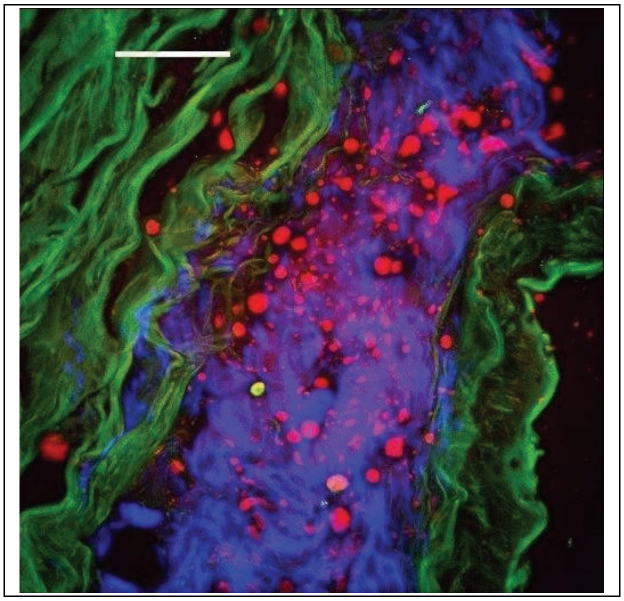

Figure 5: Label-free multimodal CARS microscopy of atherosclerotic rabbit aorta. A 50 micron slice was imaged at 2850 cm^{-1} for lipids (CARS - red), collagen (second harmonic - blue) and smooth muscle elastin (fluorescence - green). This image is a z-projection of a 50 image data set (1 μm apart) of a 3D scan through the sample. The scale bar is 50 μm. The pixel dwell time was 8 μs. [3]

This image is a projection of a 50 image data set recorded along the axial direction (1 μm interval between images). An extensive network of collagen surrounds the lipid rich tissues.

We have also performed extensive real time imaging (movies) of lipid trafficking in live human hepatocytes (liver cells), demonstrating that the arrangement shown in Fig.3 is stable on all time scales relevant to live cell microscopy [3].

4. CONCLUSIONS

We have presented an optimally chirped implementation of live cell CARS microscopy with the degree of linear chirp being an active user-controlled variable. The best performance is achieved when the effective pump and Stokes pulses spectral widths matches the Raman line width of interest. By using chirp as a control parameter, the microscope user can choose to optimize contrast in CARS imaging or enhance signals in various nonlinear optical processes (e.g. CARS, TPF, SHG, etc.) in a multimodal microscope. In our case, the Stokes pulse generated by the PCF has a much broader spectrum than the pump, permitting rapid multiplex CARS imaging by simply scanning the time delay between the pump and Stokes, avoiding the need to tune any lasers. The images and video presented here and elsewhere [3] demonstrate that this approach leads to a very simple, practical, yet high performance CARS microscope.

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Pulse compression and shaping of infrared sub-20 fs laser pulses at ALLS

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ABSTRACT - We report pulse shaping and compression of broadband Optical Parametric Amplifier laser pulses using the combination of nonlinear propagation in a hollow fiber filled with argon and an Acousto Optic Programmable Dispersive Filter (AODPF). Using this single device, we demonstrate compression, characterization and amplitude/phase control of sub-20 μJ 1300 nm 20 fs laser pulses. This novel infrared laser source is perfectly suitable for seeding successive OPA amplification stages and for time-resolved molecular spectroscopy. The experiments were performed at the Advanced Laser Light Source using the 100 Hz laser beamline.

1. INTRODUCTION

Generation of Titanium-Sapphire (800 nm) few-optical-cycle laser pulses is commonly achieved using the combination of self-phase modulation through nonlinear propagation of intense multi-cycle laser pulses in a hollow core fiber filled with a noble gas, like argon, followed by dispersion compensation using chirped mirrors [1,2]. At 800 nm, this approach is commonly used at ALLS for various applications: ultra-fast molecular imaging, studying recollision physics for atoms and molecules, high harmonic generation, and material ablation. In the visible spectral range, sub-8 fs laser pulses have been generated using the same approach as at 800 nm [3,4]. In the infrared, this approach is not yet possible since chirped mirrors are not available in this spectral range. We have recently demonstrated generation of broadband Optical Parametric Amplifier infrared laser pulses using the hollow core experimental setup, but instead of using chirped mirrors for dispersion compensation, we used an Acousto Optic Programmable Dispersive Filter (AODPF). Using the AODPF, we have demonstrated compression, pulse shaping, and characterization of sub-20 μJ 1300 nm 20 fs laser pulses [5].

2. METHODOLOGY

This novel infrared laser source has been integrated to the 100 Hz, 100 mJ, 25 fs, Ti-Sa laser beam line at ALLS. Using an Optical Parametric Amplifier (OPA) based on parametric superfluorescence (He-TOPAS, Light Conversion), we converted 6 mJ of Ti-Sa to 1300 nm (the signal frequency of the OPA). The typical signal pulse energy is 1.3 mJ with energy fluctuation of about 3% rms, and the pulse duration is sub-80 fs. After the OPA, the pulse energy is controlled using the combination of an achromatic half-waveplate with a Glan-Calcite polarizer. The signal laser beam is coupled into the hollow core fibre setup using an f=750 mm focusing lens. The fibre diameter is 400 μm and its length is 100 cm. This configuration favors the coupling into the fundamental EH_{11} spatial mode, which has the highest transmission and whose spatial profile is close to a Gaussian function (the exact function is the zeroth-order Bessel of the first kind [6]).The fibre is installed in a closed gas cell and supported on an aluminum V-groove. Typical pressure is 1.2 atm. We measured that the typical transmission efficiency was near 30%. At the output, the laser beam was collimated with an f=300 mm concave silver mirror to set its diameter to 3 mm being the input size of the AODPF. In addition to its function of spectral broadening, the hollow core capillary acts as an excellent spatial filter. We have recently demonstrated that spatial filtering with the hollow core fiber is known to improve significantly high harmonic generation [7].

Pulse compression and shaping was performed using the Acousto Optic Programmable Dispersive Filter (Dazzler[TM], WB45-1150-1600, Fastlite, France). To prevent damage of the AOPDF, input laser pulse energy was limited to 20 µJ. In principle, higher energy per pulse can be transmitted in the AODPF if they are chirped. At the output of the AODPF, there are two spatially separated beams; the purely transmitted beam and the diffracted one being shaped (there is no spatial chirp). By using the 45 mm TeO_2 crystal, we have been able to achieve 50% of the energy in the diffracted beam for ~200 nm of bandwidth (see figure 1(b)). Pulse compression is performed by recording the SHG spectra for a well defined sequence of $\phi^{(2)}(fs^2)$. The software generates the chirp sequence and uses the SHG spectra function of $\phi^{(2)}(fs^2)$ in order to retrieve the high order components of the spectral phase ($\phi^{(2)}(fs^2)$, $\phi^{(3)}(fs^3)$, $\phi^{(4)}(fs^4)$ and higher orders). This is possible due to the AODPF capability of a highly accurate control on the spectral phase.

We also used the AOPDF for pulse characterization after compression. With the AODPF, we can produce pulse replica at variable delays that are locked to the carrier frequency. This is exactly like a Michelson interferometer but using a pulse shaper controlled with precise electronics. In the spectral domain, this corresponds to the following phase filter: $H(\omega) = 1 + \exp(i(\omega - \omega_0)\tau + \phi_0)$, with the delay τ, ω_0 being the carrier frequency and ϕ_0 a phase shift. We measured the $\phi_0 = 0, \pi$ traces since their shapes are characteristic of the envelope of the interferometric autocorrelation trace.

3. RESULTS

In figure 1, typical spectra after the fibre as a function of output pulse energy are shown. At low output energy (30 µJ), the spectra remained identical to the one at the output of the OPA laser. At higher output energies (150 µJ and 225µJ), spectral broadening is observed and the amplitude modulations are related to the process of self-phase modulation in the noble gas (Ar@1.2bar). At 150 µJ output energy, the spectral bandwidth extended over ~200 nm and up to ~300 nm for 225 µJ. Assuming Fourier transform limited pulse duration; the corresponding durations (FWHM of temporal intensity) are (a) 43 fs, (b) 20 fs and (c) 11.5 fs.

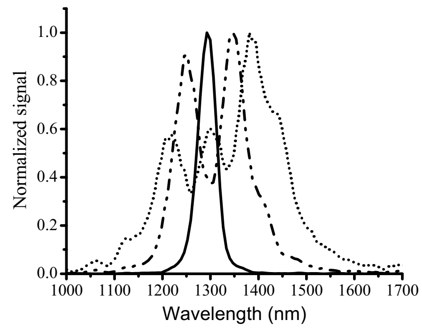

Figure 1: *OPA spectra after the hollow core fibre as a function of output energy; (a) 30µJ (full line), (b) 150µJ (dashed line) and (c) 225µJ (dotted line).*

In figure 2, we show the experimental autocorrelation traces for the spectra of figure 1(b), i.e. 20 fs Fourier transform limited pulse duration. We observed two types of oscillations in the experimental autocorrelation traces (see figure 2(b)). The low frequency modulations observed in both traces ($\phi_0 = 0, \pi$) are directly linked to the amplitude modulations observed in the spectral domain due to self-phase modulation (see figure 1(b)). The high frequency modulations, also observed for the unmodified spectra, are related to the 4% rms energy fluctuation of the OPA laser system. To confirm that we have compressed OPA laser pulses down to 20 fs duration (FWHM of temporal intensity), we have calculated the $\phi_0 = 0, \pi$ traces assuming flat spectral phase. The agreement between our measurements and the calculation confirmed pulse compression

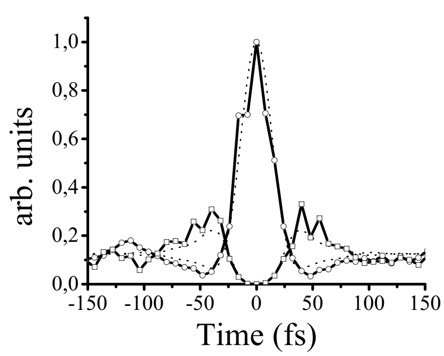

Figure 2: *Autocorrelation traces of the compressed sub-20 fs 1300 nm laser pulses; square $\phi_0 = 0$, circle $\phi_0 = \pi$. Dotted curves: traces assuming Fourier transform limited pulse duration.*

For compression, the AODPF has been used to correct the spectral phase. It can also control precisely the amplitude of the broadband spectra. For time-resolved spectroscopy, broadband laser pulses are highly valuable since multiple colors are available. Using the AOPDF, we can produce multiple laser pulses that have different carrier frequencies, with each of them having a well defined spectral phase, and we can control the delays between those pulses with attosecond precision.

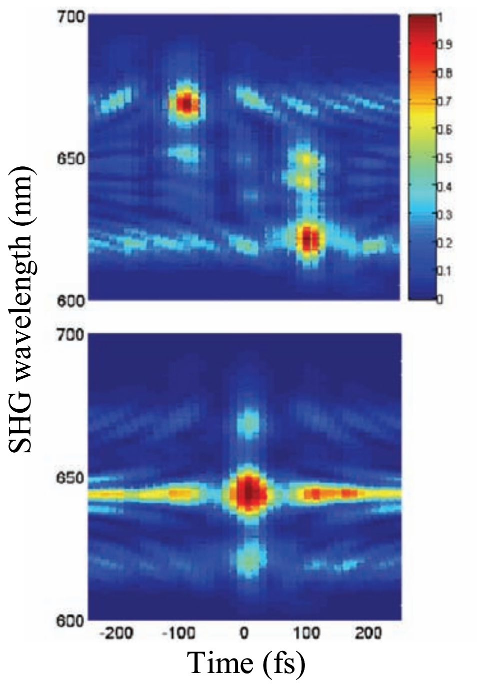

Figure 3. *SHG spectrogram as a function of τ_2 for fixed τ_1; $\tau = 200$ fs(top) and 0 fs (bottom).*

As a demonstration, we have applied amplitude filters such that we produced three laser pulses. The first amplitude filter selects the complete broadband spectra. The second and the third filters (6^{th} order supergaussian), with 50 nm of bandwidth, are applied at 1250 nm and 1350 nm. Second, the delay (τ_1) between those two laser pulses (1250 nm and 1350 nm) was fixed by applying a linear spectral phase. Third, we scanned the temporal delay (τ_2) between the broadband pulse and the two filtered pulses from –250 fs to 250 fs. In figure 3, we are showing the SHG spectra as a function of τ_2 for two different τ_1; 200 fs and 0 fs. For τ_1 equals to 200 fs, the SHG spectra as a function of τ_2 contain two distinct peaks that are located in two different spectral region, while the SHG spectra at τ_1 equals to 0 fs reflect the sum frequency of the three laser pulses.

4. CONCLUSIONS

By combining spectral broadening of intense OPA laser pulses into a hollow core fibre with an AODPF pulse shaper, we have demonstrated generation, compression, characterization and shaping of 20 μJ sub-20 fs 1300 nm laser pulses. For scaling up the energy to the millijoule level, it will be possible to use this novel laser source for seeding successive OPA amplification stages, similar to Vozzi et *al.* [8], but with a complete control over the amplitude and the phase of the broadband spectra.

Currently, we are limited to ~200 nm bandwidth due to limitations in the dispersion capability imposed by the AODPF. We have not been able to compress the ~300 nm broadband spectra presented in figure 1(c), but we are actively working on a new experimental scheme for pulse compression. We expect to generate sub-12 fs OPA laser pulses within the next year.

CIPI SUPPORT

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OTHER ACKNOWLEDGEMENTS

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Real-life tractor beams, is there anything light can't do?

Luc Charron, PhD Candidate, Medical Biophysics Department, University of Toronto

I think it is safe to say that there have been enough television satires and spoofs about *Star Trek* that most people are familiar with the famous tractor beam. This brilliant sci-fi technology enables its user to trap, pull, and push large objects with a single beam of energy or light. If my memory serves, this invention was especially useful from tugging broken down starships to moving an entire planet to its rightful orbit around a sun. While these feats are clearly the work of writers and make for great sci-fi television, tractor beam technology actually DOES exist and has been applied in the laboratory for over 20 years!

I won't lie to you, there are a few catches, or should I say certain restrictions with real life tractor beams. The fact is they have only been successfully applied at the microscopic scale to move tiny objects, like atoms and particles more than 100 times smaller than a grain of sand. But don't let that discourage you! Tractor beams, or in fancy physics speak, optical micromanipulation technology has lead us to many scientific breakthroughs. But first, let's look at how this tractor beam works, shall we?

Let there be light!

Light is a spectacular natural phenomenon. It's the reason why life started on earth, it may soon become one of our main energy sources to power our homes and cars, and it keeps us from bumping our knees on furniture at night. While light is often perceived as long, continuous rays, it's actually composed of many tiny little light particles called photons (the name's origin comes from ancient Greece). These photons interact with matter in many ways. For example, photons hitting a mirror will be reflected while those that collide with your black T-shirt on a sunny day will be absorbed and make you hot and sweat.

There is yet another neat type of interaction called refraction. A good example of refraction is shown in Figure 1. When light encounters a transparent substance such as water in a glass, it will slightly change direction, giving us the illusion that the straw is bent when it enters the water. This refraction phenomenon also applies to microscopic transparent particles and is the cornerstone of the theory behind our optical tractor beam.

Figure 1: Illusion of the bent straw. Source: www.andybrain.com/sciencelab

Consider the analogy of a game of pool. Like the cue ball striking the eight ball, the photons collide, and transfer some of their energy to the microscopic particle. The energy imparted is in the form of a force which propels our particle in a given direction. By changing the angle of impact of our photons, we create different types of tractor beam functions. The most popular function is that of the optical trap which, as stated in its name, allows us to trap particles simply using light! By creating a tightly focused beam of photons, the optical force will attract the particle to the focal spot of the beam. We can then move the beam and the particle will follow (see Figure 2a). Another useful function is the repulsive or pushing beam. This time we apply a straighter, less focused beam of light to the particle and the resulting force will push the particle away from the light source (see Figure 2b).

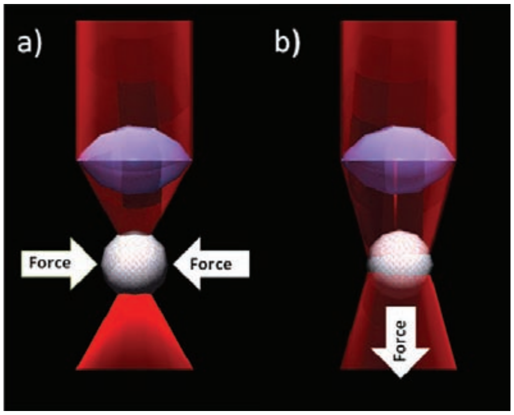


Figure 2: Various optical tractor beam functions. a) Optical trapping. b) Optical pushing

Now that we know how our optical tractor beam works, let's find out why it could never be used for day-to-day activities such as towing your groceries or levitating your pets (wouldn't that be fantastic?)

It's all about photon density

Every day, you are bombarded by trillions of photons, but because they are so infinitely small, you'll never feel the force when they collide with you (other than a great skin tan). In fact, in order to see the effects of photon pressure or force on a microscopic scale, scientists had to use lasers to achieve photon densities over 10 MILLION times higher than what we experience on a sunny day. Using such densities on a large scale would vaporise buildings, cars and you and I. Think of a magnifying lens and an ant, then trade places with the ant... You get the idea? Comparatively, the microscopic particles don't burst into flames. As you know, light comes in many colours, so the scientists simply need to select a colour that is not absorbed by the particle's material. Doing so, we minimize heating to our particle and maximize the photon force delivered through refraction.

Show me the apps

Optical micromanipulation techniques have a wide range of applications besides moving tiny particles. In 1995, an optical trap was designed to cool down atoms near absolute zero (that's -273 degree Celsius!) allowing scientists to prove the existence of a new state of matter called a Bose-Einstein condensate. This might not sound very impressive right now because there are no main stream applications using condensates. However, people thought the same way when scientists discovered the plasma state and because of that discovery we now have plasma screen TVs!

Optical tractor beams have also found a home in the life sciences. It is now possible to manipulate, sort, transport individual human cells like stem cells and cancer cells in order to study them. A new technology called "Lab-on-a-chip" is under development where a device no bigger than a credit card can be used to monitor the patient's health almost instantaneously. Figure 3 illustrates how a tractor beam is being used in a Lab-on-a-chip device to trap and transport a cancer cell to be analyzed. In the near future, devices like these will be used routinely in hospitals and pharmacies to personalize healthcare and cut down on waiting time. Can you imagine, no more 3-week wait for test results!

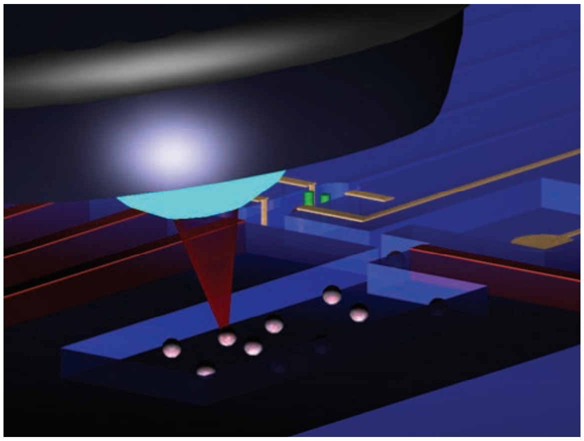


Figure 3: Microscope objective focusing light to optically trap a cancer cell in a Lab-on-a-chip device.

Finally, researchers have been working on using photon pressure from sunlight to propel satellites in space. The idea is to deploy solar sails to catch the light much like sails on a boat catch the wind (see Figure 4). No prototypes have yet been tested in space; however encouraging results have been achieved in vacuum chambers here on earth.

That's all folks

So now you know the truth, tractor beams do exist. And while they may not stand up to the ones in *Star Trek*, the concept of physically manipulating objects with light has lead us to many scientific discoveries in fundamental physics, biology and even space travel. In the years to come, many more applications will stem from optical tractor beams and who knows, perhaps in a few years with a little luck you'll see a personal dog levitating device selling at your local pet store.

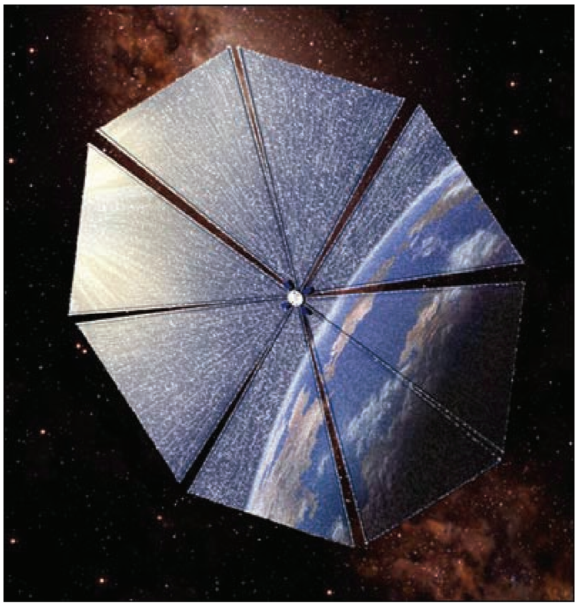
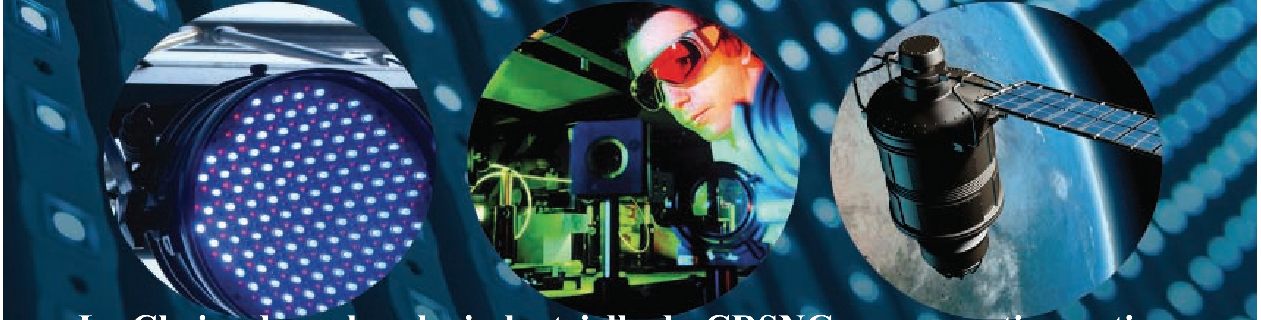


Figure 4: Space satellite with solar sails for propulsion Source: news.cnet.com/2300-1041_3-5754545-1.html).

The NSERC Industrial Research Chair in Optical Design
NEW CAPABILITIES FOR CANADA



La Chaire de recherche industrielle du CRSNG en conception optique
UN ATOUT POUR LE CANADA

Optical design has accelerated progress in imaging, microscopy, adaptive optics and LED lighting. It is an absolute requirement in the implementation of the photonic technologies that are rapidly revolutionizing our world. An NSERC Industrial Research Chair in Optical Design has recently been launched at Université Laval with the aim of supporting optics and photonics research in Canada, training highly qualified personnel and establishing productive linkages with industry. The Chair will provide new capabilities currently not found in Canada, and presently available only in a few universities in North America.

Research thrusts will focus on:

1- Development of efficient innovative imaging concepts for earth and space applications.

2- Development of novel, intelligent and green illumination systems based on light-emitting diodes (LEDs).

The Chair holder is Simon Thibault, the former head of optical design at INO from 2000 to 2005. Dr. Thibault has also worked as Senior Optical Designer for ImmerVision for three years. He is now a professor at the Department of Physics, Engineering Physics and Optics at Université Laval and a member of the Center for Optics, Photonics and Lasers.

The Chair is supported by ten industrial partners. The major funding partners are Dellux Technologies, ImmerVision, ABB Bomem, Hedzopt and Xeos Imaging. Over the next five years, the Chair will benefit from over $2 million in funding, including $1.1 million from industry. With this support, the Chair will be able to carry out its mission of stimulating productivity and innovation and introducing students to optics industry requirements.

La conception optique se situe au cœur des récents progrès en imagerie, en microscopie, en optique adaptative et en éclairage par DEL. Il s'agit d'une étape incontournable dans la mise en application des technologies photoniques qui sont en train de révolutionner nos vies. Dans le but de soutenir la recherche en optique-photonique au Canada, de former du personnel hautement qualifié et d'établir avec l'industrie des partenariats fructueux, une Chaire de recherche industrielle du CRSNG en conception optique vient d'être inaugurée à l'Université Laval. Cette chaire apporte de nouvelles compétences qu'on ne trouve présentement dans aucune université au pays et qui existent seulement dans quelques universités en Amérique du Nord.

La chaire poursuit ses activités selon deux axes précis :

1. le développement de concepts innovateurs d'imagerie efficaces pour les applications terrestres et spatiales ;
2. le développement de nouveaux systèmes d'illumination intelligents et écologiques basés sur l'utilisation de diodes électroluminescentes.

Le titulaire de la chaire, Simon Thibault, a été responsable du programme de conception optique à l'INO de 2000 à 2005 et a travaillé comme concepteur optique principal chez ImmerVision pendant trois ans. Maintenant professeur au Département de physique, de génie physique et d'optique à l'Université Laval et membre du Centre d'optique, photonique et laser, il s'est entouré de dix partenaires industriels, dont les principaux sont Dellux Technologies, ImmerVision, ABB Bomem, Hedzopt et Xeos Imagerie. Au cours des cinq prochaines années, la chaire pourra compter sur un financement de plus de 2 millions de dollars, dont 1,1 millions de l'industrie. Cet appui lui permettra de bien remplir sa mission de stimuler la productivité et l'innovation et d'initier les étudiants aux réalités de l'industrie de l'optique.

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TABLE OF CONTENTS
TABLE DES MATIÈRES

Technical Review of the Canadian Institute for Photonic Innovations
Revue technique de l'Institut canadien pour les innovations en photonique

Vol. 7 No. 1, Spring 2009 / Vol. 7 no 1, Printemps 2009

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