P.M. DUFFIEUX OPTICS DEPARTMENT

The optics department of FEMTO-ST has a long history and tradition in contributing to both fundamental advances and technological applications of optics and photonics. Its contributions are recognized both nationally and internationally, and its scientific production as measured by standard scientific metrics is at the highest level and comparable to larger national optics laboratories or consortia.

Research Context

The optics department consists of four groups that carry out theoretical and experimental research encompassing fundamental optics and photonics, proof-of-concept studies, system demonstrators, and components technology development supported by the local MIMENTO micro/nano fabrication platform.

1. The **Biophotonics Group** focuses on applications of optical metrology to biology and health. This includes fluorescence, plasmonic and evanescent sensors for, e.g., allergen detection, optofluidic lab-on-chips for in-vitro fertilization and cytomegalovirus screening, novel ultra-precise position-referenced microscopy and optical coherence tomography (OCT) systems.
2. The expertise of the **Nanooptics Group** covers the design, FDTD simulation, fabrication and characterisation of nanooptical devices. Specific areas of study include nanoantennas for local field sensing, smart photonic crystals (PCs) with electro-, acousto- and magneto-optical photonic bandgap tuning, plasmonic and metallic collective nanostructures with extraordinary optical transmission (EOT) and local field enhancement.
3. The activities of the **Nonlinear Optics Group** span basic research such as the spatial quantum properties of light, spatial optical solitons and slow light, photon-phonon coupling in microstructure fibres, to the development of new photonic technologies for all-optical processing such as novel supercontinuum light sources, fibre optical parametric amplifiers, mode-locked fibre Raman lasers, and 3-D light-induced waveguides in photorefractive crystals and chalcogenide glasses.
4. The **Optoelectronics, Photonics and Optical Telecommunications Group** (OPTO) focuses on both fundamentals and applications of future photonic technologies. Specific research areas include chaos-based and quantum information cryptographic systems, the application of nonlinear delay dynamics to ultrastable optoelectronic oscillators (OEO), and fundamentals and applications of ultrafast optics such as supercontinuum generation, nonlinear signal processing and femtosecond micro- and nano-machining.

Research is financed from a range of sources: European STREP and INTERREG projects; national MENRT, ANR, DGA, CNRS and industrial contracts; the Region and the University of Franche-Comté. The optics department is a partner in the French-Swiss LEA, the UMI GeorgiaTech-CNRS, has worldwide collaborations, and is active in national (GDRs) and European (COSTs) networks as well as in the scientific committees of major international conferences and journals. Industrial transfer projects include a common R&D platform with SmartQuantum SA for quantum cryptography, industry-linked ANR projects, industry partnerships in white light "laser" source, development and collaboration with the regional technology platform DISO on the Development and Integration of Optical Systems.

Selected Highlights 2006-2008

1. An INCA-funded partnership with biologists has begun on position-referenced microscopy to determine whether fragments of viral DNA from dead cancer cells are capable of reaching and infecting neighbouring cells. Original micro-scale pseudo-periodic reference patterns have been inserted on culture boxes which, together with the proper phase retrieval processing software, leads to an accuracy in repositioning cell culture images better than one tenth of the diffraction limit.

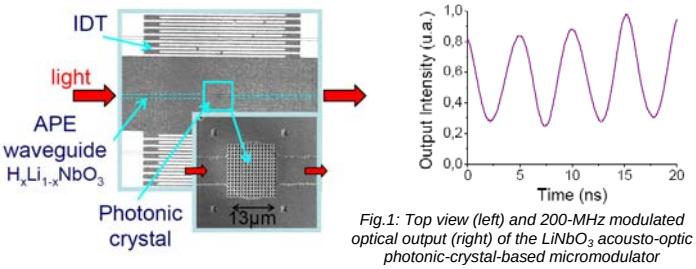

Fig.1: Top view (left) and 200-MHz modulated optical output (right) of the $LiNbO_3$ acousto-optic photonic-crystal-based micromodulator

2. Complementing our previous demonstration on slow-light-enhanced electro-optic photonic bandgap tuning in $LiNbO_3$ photonic crystals, the first acousto-optical 2D-PC-based micromodulator has been recently realised, with extinction ratio of -5.2 dB and driving power of -13 dBm. In addition, EOT using annular nano-aperture gold arrays has been theoretically and experimentally demonstrated for the first time in the optical domain, with a transmission as high as 90% in the visible.

RESEARCH HUMAN RESOURCES (Dec. 1st 2008)									
PR	DR	MCF	CR	Publ.	HDR	PEDR	RA	Doct.	IR
8	3	8	10	33	17	9	5	26	4
11		18							

3. In nonlinear optics, a significant achievement has been the measurement of sub-shot-noise quantum correlations of spatial fluctuations in $\chi^{(2)}$ parametric fluorescence, that are without subtraction of detection noise 7 standard deviations below the standard quantum limit. In addition, Raman-induced multicolour spatial solitons producing slow-light in Kerr planar waveguides have been modelled and experimentally observed for the first time.

4. Research on ultra-stable optoelectronic oscillators has reported state of the art phase noise performance of 155 dB.rad^2/Hz at 10 kHz from a 10 GHz carrier (collab. with Time & Frequency dept). Work in ultrafast photonics has made major contributions to the understanding of supercontinuum generation, with a highlight being the world ranking of our "Review of Modern Physics" invited article amongst the top 10 highest cited papers in physics since 2006 (*SCOPUS TopCited, Dec. 2008*).

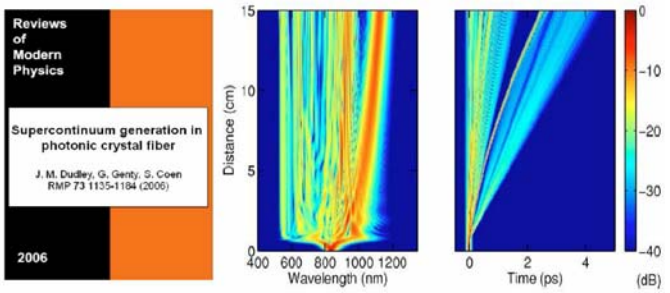

Fig.2: Accurate modelling of the evolution dynamics of a femtosecond octave-spanning supercontinuum in a short Photonic Crystal Fibre.

Perspectives

1. In Biophotonics, original lab-on-chips are being developed for areas such as newborn screening and blood transfusion safety. Our OCT setup recently reached µm axial resolution with 90 dB sensitivity. Industrial, national and international collaborations on endoscopic and optical biopsy systems are currently building up.

2. The Nanooptics group will study novel smart plasmonic-metallo-dielectric PCs and also phoXonic crystals (both elastic and photonic forbidden bandgaps, collab. with MN2S dept). Newly developed FIB-milled gold nanoantennas on SNOM probes will be applied to the discrimination of the electromagnetic vector components of the optical field, with important applications for exploring experimental nanodevices. Then metamaterials and time reversal will be explored in the visible.

3. In Nonlinear optics, we will develop novel distributed sensors based on Brillouin enhancement in PCFs (INTERREG IVA, collab. with MN2S) and also explore Raman-induced slow light in liquid-filled PCFs for tuneable optical delay lines. Work on 3-D waveguides will take profit of a newly developed time-dependent full three-dimensional photorefractive model and of our recent discovery of bright solitons in $LiNbO_3$ without external electric field. Finally, quantum imaging will tackle the entanglement properties of spatial fluctuations.

4. Future work from OPTO in nonlinear dynamics will miniaturize optoelectronic oscillators using MgF_2 disk resonators and develop novel and generic analyses of OEO dynamics. Work in quantum information will consolidate industrial transfer and explore new directions in quantum computing. Ultrafast optics research will focus on novel nanowire propagation effects and "rogue wave" fluctuations in nonlinear propagation. Femtosecond micromachining research will extend results on high aspect-ratio structures and further develop a recently-patented sample positioning technique.

Scientific production

SCIENTIFIC PRODUCTION (06-08)				
Int. PR art. & book chapters	Inv. Conf.	Int. PR Conf.	Pat.	PhDs & HDR
167 + 6	42	116	7	22 + 3

35% increase of yearly rate of peer-reviewed (PR) papers compared to the preceding contractual period. Average of 1.5 paper/person/year (all included).
PR papers in journals with impact factor > 2: 56%
PR papers with an international collaboration: 41%