Photonic Crystal Research in IST

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Abstract *An overview is given of research on photonic crystals and photonic crystal based devices in the 5th and 6th Framework Programme of the European Union. The projects are listed with some key data and highlights.*

Introduction

Modification of spontaneous emission by the surrounding dielectric structure has been studied throughout the second half of the 20th century following the initial work of (among others) Purcell (spontaneous emission in microcavities) in the late forties and Bykov (spontaneous emission in periodic structures) in the early seventies. The term "photonic bandgap" was incepted by Yablonovitch via his seminal paper on "Inhibited spontaneous emission in solid state physics and electronics" in 1987. The principles of Bragg reflection underlying a photonic bandgap were well known in the field, but Yablonovitch made the original step of connecting these to electronic bandstructure and its related language, which offered new insights into the operation of periodic structures in optics. The key property of interest was the suppression of light propagation through these structures, which led to initial research into novel light emitters and zero-threshold lasers based on the inhibition of unwanted spontaneous emission. The suppression of propagation leads to the strong confinement of light, which inspired Joannopoulos to champion photonic crystals for applications in integrated optics in the mid-nineties. This strong confinement enables high-density integration in photonics and thereby a new class of devices and circuits reminiscent of the large scale integration achieved by the microelectronics industry.

While most of the early research in the field of photonic crystals (PhCs) took place in the USA, the situation today shows a much more balanced geographical picture. Since 1999 there has been an International Symposium on Photonic and Electromagnetic Crystal Structures (PECS) which has rotated between the USA, Japan and Europe. PECS-6 will be organized in 2005 in Crete.

In Europe the IST-programme under the 5th Framework Programme (FP5) has definitely had a major impact on the development of a European photonic crystal research community and on the advancement of the field as a whole. This research is now maturing under the 6th Framework Programme (FP6) with an increase of the involvement of industrial partners and a broadening to new research topics in nanophotonics and molecular photonics. For more information on the IST-programma the reader is referred [1].

In this paper we provide a brief description of past and present research projects in the field of photonic crystals. This covers both projects on 2D and 3D photonics crystals. Research on photonic crystal fibers is not covered in this paper.

For a comprehensive bibliography on photonic crystals we refer to [2] and [3].

Past FP5 projects

PCIC (*Photonic Crystal Integrated Circuits*)

The purpose of the PCIC-project was to apply 2D Photonic Crystal (PhCs) concepts to Photonic Integrated Circuits (PICs) on InP, intended for telecommunication applications, because of three major advantages: (i) ultra high compactness, (ii) simple and low-cost fabrication routes, (iii) implementation of novel functionalities.

PCIC has successfully developed integrated-optics oriented PhC fabrication routes, losses of InP-based structures following a decreasing Moore's law of its own. It has combined them with validated PhC modelling tools to achieve several PhC-based building blocks: low-loss waveguides, bends, couplers, combiners and filters, and novel PhC-based lasers. Integrated systems consisting of active (lasers) and passive elements (combiners, mirrors,…) for WDM applications were demonstrated, as well as MOPAs-type PhC lasers, and a novel PhC based Add-Drop filter.

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PICCO (*Photonic Integrated Circuits using Photonic Crystal Optics*)

The aim of the PICCO-project was to explore the potential of 2D photonic crystals in GaAs- and SOI-based photonic integrated circuits for telecommunication applications as well as to advance the technology required for such circuits.
The key achievements of the PICCO-project are fourfold. It has achieved record low losses in both GaAs- and SOI-base photonic crystal waveguides and couplers as well as in photonic wire waveguides. The understanding of the loss mechanisms in PhC circuits has improved dramatically during the project. PICCO has also developed innovative ways to couple light between optical fibres and photonic crystal waveguides. A third achievement is to refine and extend commercial CAD-tools for use in PhC-structures. Finally the PICCO-project has demonstrated high quality PhC structures in SOI by means of deep-UV optical lithography as used in micro-electronics, thereby opening the way to cost-effective manufacturing.

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PHOBOS (*PHOtonic crystals Based on Opal Structure*)

The PHOBOS project has focussed on 3-dimensional photonic crystals – in particular opals and inverted opals - realised using a template method.
Selected achievements include:
- Synthesis of fine monodisperse particles of silica, latex and PMMA in the range from 100 to 1300 nm with a dispersion below 5% and crystallisation of bulk and thin film opals of pre-set thickness
- World first Si and Ge inverted opals with a complete 3-dimensional PBG and realisation of a complete PBG Sb_2S_3 inverted opal
- Experimental demonstration of emission directionality from opals explained in terms of the photon caustics model.
- Application of group theory to predict optical properties based on symmetry considerations.
- Development of a rigorous description of the superprism effect in opals and a multiple scattering algorithm for anomalous refractive properties in 2D and 3D photonic crystals.

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FP6 projects

PHAT (*PHotonic hybrid Architectures based on Two- and three-dimensional silicon photonic crystals*)
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The key objective of this project is to combine two complementary approaches, namely 2D Si-based PhCs and 3D Si-based PhCs templated on self-assembled matrices, to design, fabricate, characterize, study and model hybrid 2D-3D PhC platforms, offering routing and light emission functions on the same "chip".

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PICMOS (*Photonic Interconnect Layer on CMOS by Waferscale Integration*)

For future generation electronic circuits a severe bottleneck is expected on the global interconnect level. One of the most promising solutions is the use of an optical interconnect layer. The PICMOS-project will demonstrate the feasibility of adding a photonic interconnect layer on top of silicon ICs. This interconnect layer will be fabricated by a combination of wafer bonding and wafer-scale processing steps. It will be planar and will be built from a high-density passive optical wiring circuit integrated with InP-based sources and detectors using a wafer bonding approach.
The light sources in this application need to be both very efficient and very compact. The project will develop InP-membrane micro-lasers of various types bonded to SOI, including micro-cavity as well as micro-DFB lasers based on 2D photonic crystals.

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FUNFOX (*Functional Photonic Crystal Devices for Metropolitan Optical Networks*)

Compared with previous projects, and with most of the photonic crystal activity worldwide, FUNFOX aims at providing photonic crystal solutions for the real world of metropolitan optical networks. It focuses on InP-based devices exploiting advances made in the

FP5/IST projects PCIC and PICCO.
Example of active functions addressed are highly linear optical amplification and wavelength conversion. Also novel, passive functions exploit novel schemes permitted by photonic crystals, either for spectral selection, notably in relation with monitoring and multiplexing, or for polarisation management. Expected results are wavelength-stabilised laser sources, and easy-to-package devices. All these devices, with improved performance and high degree of integration, thus potentially low-cost, will contribute to future large scale deployment of metropolitan core and access networks for new services of "infotainment".

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Project duration : 2004 (fall)-2007
Web site : not available yet

ePIXnet (*European Network of Excellence on Photonic Integrated Components and Circuits*)

ePIXnet is a Network of Excellence with photonic integration as leading thread. The integration of complex or high performance photonic functions will become the key enabler for a cost-effective and ubiquitous deployment of photonics in a wide range of applications, including ICT, sensors and biomedical applications.
The technologies needed for photonic integrated components and circuits are characterised by high investment and exploitation cost. This calls for more integration of research at an international level.
Therefore the mission of the ePIXnet is three-fold. The first objective is to stimulate the restructuring of the photonic integration research community from a model of independent or collaborative research towards a model of integrated research. The second is to stimulate training activities as well as integration of educational programs. The third objective is to stimulate new opportunities for photonic integration in a wide range of application domains.
The NoE will focus on five major themes: photonic integration technology, nanophotonics, advanced semiconductor materials, ultrafast light sources and ultrafast signal processing. The backbone of the Network is formed by 14 activities. At least 3 of these activities focus on photonic crystal based components and crictuis. The network brings 34 academic and industrial actors and will contribute to the quality of education and research by stimulating long lasting partnerships and by providing access to unique facilities and knowledge in the field. The network will also develop an active program of exchange of researchers,of institutional collaboration agreements, web-based information exchange and dissemination etc.

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Web site : not available yet

PHOREMOST (*NanoPHOtonics to REalize MOlecular-Scale Technologies*)

PHOREMOST is a Network of Excellence with the objective to integrate, rationalise and dramatically enhance research in photonics in general and, in particular, in nanophotonics. Whereas traditional semiconductor materials are already in the market as part of opto-electronic components, and to a much smaller degree some organic materials, the same is not the case for molecular-based optical components, simply because the underpinning science and engineering has still to be developed. This Network intends to bridge that gap in order to establish a body of knowledge in the field from which a more direct route to applications can be followed.
The PHOREMOST network has ambitious objectives. These range from conceiving and testing methods and good practices to integrate and restructure the research efforts in the field at European level, to meeting the challenges of using single molecules for information processing, through setting up training measures to address the shortage of suitably qualified human resources.

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Project duration : 2004(fall)-2008
Web site : not available yet

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3. Y. Vlasov's Photonic Bandgap Links' website:
http://www.pbglink.com/.

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