



Proposal/ Contract No. 017160

Newton

**Enabling Technologies for 3D Nano Photonics: New Materials and Process Technology
for real 3D Integrated Optical Circuits, Photonic Band Gap Devices and Photonic
Crystals**

Instrument type: STREP (Special Targeted Research Project)
Activity Code: NMP-2004-IST-NMP-3

Publishable Final Activity Report

Period covered: January 1st, 2006 – December 31st, 2008 (36 month)



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Project coordinator organization: Laser Zentrum Hannover e.V. (Germany)

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1. Project Execution

1.1 Summary of project objectives



In this project, **new materials and production technologies for photonic band gap (PBG) devices and photonic crystals (PhCs)** are introduced.



The project goals were the realisation of real three-dimensional (3D) PhCs by adapted **nano-material** and **nano-process development** and the **smart synthesis** of **bottom-up** and **top-down approaches**; the development of a cost efficient process, capable of **high volume nano photonics production**, but also of flexible prototyping.




To meet these goals the project had the following key objectives.

- Development of materials and production technology for PhCs and 3D PBGs with defined defects.
- Design and simulation of 3D PBG optical components.
- Characterization of PhCs and 3D PBG optical components.
- Realization of prototype components with inherent real 3D PBGs with optical functions for operational wavelength bands 800 nm and 1280 to 1610 nm.

1.2 Contractors involved

 <small>LASER ZENTRUM HANNOVER e.V.</small>	Coordinator Laser Zentrum Hannover e.V. Hollerithallee 8 30419 Hannover Germany
	BASF Aktiengesellschaft Polymerforschung GKD/A Carl-Bosch-Strasse 38 67056 Ludwigshafen Germany
	DTU Fotonik Technical University of Denmark Department of Photonics Engineering Ørsteds Plads, Building 345V 2800 Kgs. Lyngby Denmark



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	Ecole Nationale Supérieure des Télécommunications de Bretagne Département Optique Technopole Brest-Iroise 29238 Brest France
	Photon Design LTD 34 Leopold Street Oxford OX4 1TW United Kingdom

1.3 Introduction to the topic

Photonic crystals and photonic band gaps (PBG) represent a new class of optical devices for guiding and processing light. Conventional optics relies on effects like reflection (mirrors, Bragg reflection), refraction (lenses, prisms) or diffraction (gratings). In PBG devices the interaction of light is based on “optical bandgaps” in crystals, suppressing the propagation of certain wavelengths in pre-determined directions. PBGs occur in volumes where the dielectric constant and thus the refractive index vary periodically. In analogy to electronic band gaps in semiconductor materials, PBGs prohibit the propagation of electromagnetic waves for a range of defined frequencies. By introducing defects into the crystal lattice, light at frequencies in the band gap may be confined to point defects or guided along lines of defects. Inherent structures of PhCs are in the order of ~100 nm to sub-micrometer, functional domains of the resulting components are in the order of several microns. With the implementation of photonic band gaps in optical systems, new applications for processing light are feasible, existing optical functions can be built up with much smaller dimensions (< 1 mm³), and higher integration densities can be achieved.

Although a variety of technological approaches for the fabrication of 3D photonic crystals have been demonstrated and investigated previously, by the time the project started in 2006, a cost effective technology for the industrial production of 3D PhC did not exist. Furthermore, the creation of defined defects in the volume of 3D PhC presented an even greater challenge. Emphasis has been given to planar (2D) structures, due to the lack of efficient production methods for 3D-PhCs with defined defects. However, in order to exploit the advantages offered by photonic crystals, real 3D PhCs with defined defects have to be realized.

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1.4 Work performed during the project

The efforts of the consortium were concentrated on the development of the complete process chain for the fabrication of 3D PBG photonic components. Theoretical modelling of 3D photonic crystals and light localization on point and linear defects in PhCs possessing a complete PBG was the basis for the decisions concerning the material systems and specific geometrical characteristics of the future 3D PBG devices. An analysis of the photonic components available on the market was performed by TAS in order to define the goals for the realization of specific optical components with competitive characteristics. As a result of this analysis the decision was made to realize a simple 3D PBG optical waveguide, a 3D PBG optical splitter, and a 3D PBG optical filter. The target applications for the newly developed 3D PBG components were defined in the area of fibre optic telecommunication systems operating in the 1.5 μm wavelength range.

For a cost effective, high volume production of real 3D PhCs with defined defects, expertise in bottom-up and top-down approaches was combined. The main project steps towards 3D PhCs optical components were template generation, defect inscribing and inversion of the inscribed template with a high refractive index material. The project explored colloidal templates of nano-spheres and holography as building blocks for bulk meta-materials, in which the defects were defined by intense laser radiation. Based on investigations carried out in the project colloidal templates of nano-spheres were selected as most suitable for realizing the project objectives. Two-photon polymerization (2PP) by femto-second laser pulses was applied for inscribing defects in the PhC template. Finally, silicon was identified as the material for inversion of the inscribed PhC template, since this material allows operation of the 3D PBG components in the selected wavelength range.

Monodisperse colloids of polystyrene produced by BASF were the basis for the templates. Their segregation out of a dispersion forms a face centred cubic (fcc) crystal lattice (Fig. 1). Infiltrated with a high refractive index (>2.9) material and inverted with air voids, such structures have a complete photonic band gap. From the theoretical modelling the spheres diameter was determined to be around 1000 nm in order to centre the band gap in the 1.5 μm wavelength range. The major challenge in increasing the size of the spheres was the increasing inhomogeneity of the sphere diameter, a maximum tolerance in the monodispersity of 1% was predicted by theoretical modelling. BASF developed the process of preparation of polystyrene monodisperse colloids with the required characteristics. Assembly of the monodispersed colloidal spheres into highly ordered three dimensional arrays (artificial opal) was achieved by a vertical deposition technique. The mechanical stability of the polystyrene opal template was improved by chemical or physical bonding of the polystyrene spheres. The bonding processes were developed by BASF.

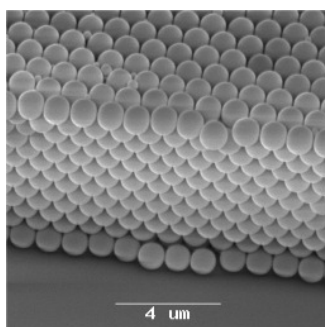




Figure 1: SEM picture of a polystyrene opal with 1 μm sphere diameter

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One of the key objectives was the selective modification of the templates to define the location of the defects with highest accuracy and resolution. This was achieved by the polymerisation of an infiltrated photoresist within the voids of the opal template. After inversion with silicon the modified regions turned into air voids. Three dimensionality of the defects inscribed in the template volume was achieved by application of the two-photon polymerization (2PP) technique realized at the LZH. To date, this is the only real 3D structuring technique that has been experimentally demonstrated and which had been developed shortly before the beginning of the NewTon project.

Two critical issues have been resolved by LZH in order to realise the 3D defect inscribing process. First of all, the resist employed in the inscribing process had to satisfy several crucial requirements. The resist had to be suitable for 2PP structuring and at the same time it had to be chemically compatible with polystyrene. Also chemical and physical properties of the resist had to allow its infiltration into the tiny air voids of the opal template the removal of the unprocessed resist by chemical development after the inscribing process. At all stages chemical or mechanical damage of the polystyrene opal had to be excluded. Commercially available ORMOCER (*micro resist technology* GmbH, Berlin) and newly developed ORMOSIL were identified to satisfy all requirements.

Another crucial point was the required accuracy for defect inscribing. A defect inscribing accuracy better than 50 nm was needed. In order to achieve this, a new 2PP setup was built at the LZH. The setup implemented high precision air bearing translation stages (Aerotech, Inc.). In addition to high accuracy, the structuring speed up to 50 mm/s with maximal structuring area of 100 mm x 100 mm was demonstrated with the new setup. These characteristics allowed process optimisation towards higher yields. As an example, the Y-splitter inscribed in the opal template is shown in Fig. 2.

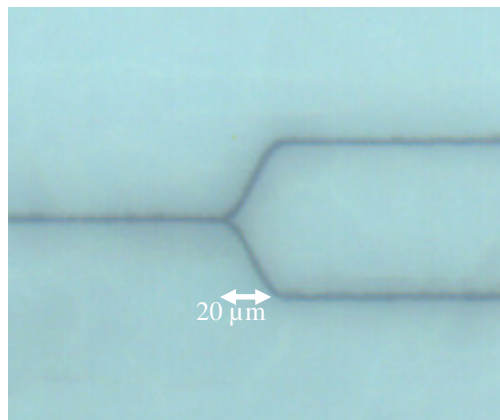




Figure 2: Microscope image of a polystyrene crystal with Ormosil defect waveguides forming a splitter with 20 μm splitter length

The major drawback of the existing 2PP technique is the fact that it is a serial inscribing technique and unlikely to be suitable for mass production. Combining the parallel-write techniques developed at the ENST Bretagne and the two photon polymerisation (2PP) techniques developed at LZH opens the route to industrial production of 3D PBG devices.

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The feasibility of 2PP parallel-write structuring was investigated. We demonstrated for the first time successful 2PP parallel-write over a large area.

The inscribed opal template was inverted with silicon. An inversion process for a polystyrene based template was developed by LZH in cooperation with the group of Cefe Lopez in Madrid (Instituto de Ciencia de Materiales de Madrid). For inversion a CVD-process using disilane (Si_2H_6) was applied, but the template material had to be developed to withstand the temperature of several 100 °C and the process specific pressure conditions. For this purpose the opal template was processed in an atomic layer deposition setup at room temperature. As a result polystyrene spheres and inscribed defects were covered with a thin layer of material which is stable at high temperature. We used SiO_2 , Al_2O_3 or ZnO . After that the polymer template was removed by high temperature treatment. Resulting structures were then covered with a layer of silicon in the CVD-process to achieve the high index contrast (Fig. 3).

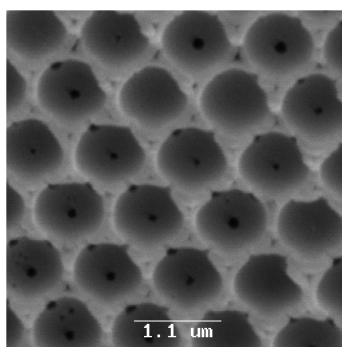




Figure 3: SEM picture of a ZnO and Si inverted opal (compare to Figure 1)

The 3D photonic crystals based on Si inverted-opals were explored as hosts for effective air-channel waveguides serving as parts of photonic circuits. Three basic shapes of straight waveguides were considered: cylindrical and square cross-sections and a chain of spheres. Modelling showed that the transmission is strongly dependent on the lattice position of the waveguide and its direction. The influence of imperfections on the existence of photonic band gaps as the principle mechanism for waveguiding in such channels was studied. Double-layer Si inverted opals were proven to have no complete photonic band gap. Different components of the passive photonic contours were analysed numerically: straight waveguides, waveguides with bends, splitters, frequency selective elements (Mach-Zender interferometers) and couplers. Optimal parameters were identified. As an overall conclusion waveguides with the square cross section showed the best performance in terms of losses and possible functionality as parts of integrated circuits.

The characterisation of PhCs was carried out along the research lines. Geometric characterisation during all stages of the manufacturing process was analysed by confocal microscopy, SEM (LZH, BASF), AFM (BASF) and interferometric microscopy (ENST). The functional / optical characterisation was carried out at the GET/ENSTB where new test benches were developed to investigate spectral filter performance for DWDM, waveguide losses, bandwidth, polarisation dependence (PDL), Bit Error Rate (BER) Penalties and further optical parameterisation with regard to environmental tests: thermal stability, pressure and humidity for harsh environments. One major outcome of this project was the combination of characterisation with the modelling in order to determine the tolerances for production.

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Spectroscopic characterisation of the different samples was performed both at ENSTB and TAS, for wavelengths in the range of 1100 to 1700nm at ENSTB and 400 to 3300nm at TAS. At TAS, a new test bench was developed to investigate the 3D-PBG functions behaviour in the analogue domain.



Apart from planned work, efforts were directed to resolve unforeseen issues. Specifically, the problem of light in/out coupling with waveguides fabricated in the volume of the opal template was not addressed sufficiently in the original work plan. In order to achieve efficient light coupling the 3D PBG waveguides should end with a flat and relatively large surface of the PhC. However, the waveguides were buried in the volume of the PhC. Several techniques were tested for processing opal templates and inverted opals to generate crystal end faces of the required quality. The growing of opals on prescribed glass substrates was investigated (LZH, BASF). Prescribed grooves aid defined breaking of substrate and crystal after crystal growth on the opposite side of the cover glass. Polymer walls created on the substrate surface force the crystal to grow parallel to the grooves. At the end of the project, TAS proposed to use several technological facilities to realise some devices. This activity was not initially in the Description of Work and aimed to realise structures with complex defects using mainly Focused Ion Beam and micro-machining tools to realise waveguides and optical filters with inverted structures provided by LZH and BASF.

1.5 Results achieved – fulfillment of objectives

A large number of results were achieved during the course of the project. Many of the results achieved are beyond the state of the art. Here we give a summary of new technologies developed in the frame of NewTon:

- Production technology for the realization of precision controlled polystyrene spheres developed by BASF
- Self-organization process of polystyrene spheres successfully developed for production of large area opal templates (BASF)
- Process for 3D defect inscription into opal templates by 2PP was developed (LZH)
- High throughput parallel writing using 2PP demonstrated for the first time by LZH/ENSTB
- Heterogeneous functional realization of 2.5D advanced devices using accurate FIB nanomachining demonstrated by TAS
- Software for simulation of 3D PBG devices developed on a multi-platform basis to drastically improve computing time and graphic user interface (PD/DTU)

New technologies developed in the framework of the NewTon project will find applications in the area of 3D PBG photonics and also in many other areas. For example, homogeneous opals have high potential for application in consumer markets, low cost passive sensing, sub-wavelength imaging and lighting. Parallel writing using 2PP could be a very versatile high throughput nanostructuring technology applicable in many areas. The developed simulation software will find applications in simulation of electromagnetic wave propagation in complex 3D structures.

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Initially the markets addressable by NewTon technologies were identified to be in the Telecom / Radiocom domain, Aerospace, Automotive, Computing, Sensors and Lighting, taking advantage of the possibilities offered by the inhomogeneous structures that can be created. It will probably take several years to use some devices using the technologies developed in NewTon.

Following the last achievements of the project, we have identified new possible fields of applications more prone to be successful on a shorter time scale with mass-market applications. These opportunities were neither foreseen in the previous exploitation reports nor in the Description of Work. They include textile, luxury, consumer electronics, food; in the area of sensing, sub-wavelength imaging and lighting.

The end result of the project was the demonstration of the feasibility of the development of 3D PBG photonic devices. Furthermore, the approaches for industrial production of 3D PBG components have been investigated. It has been demonstrated that the combination of 3D PhC template and 3D defect inscribing is a viable technology for future industrial production.

The realization of the functioning 3D PBG photonic component was challenged in this project. New technological approaches were developed in order to achieve the project objectives. Most of the objectives were completed successfully. These include the development of materials and production technology for PhCs and 3D PBGs with defined defects, the design, simulation, and characterization of PhCs and 3D PBG optical components. Still some challenging technological issues will have to be resolved in order to demonstrate 3D PBG functionality of photonic device.

1.6 Project information



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2. Dissemination and use

2.1 *Exploitable knowledge and its Use*

The NewTon consortium integrated partners from academia, SMEs, as well as industrial partners working at all levels of the value chain. This vertical integration of the consortium was most useful in defining applications and possible exploitation paths for products in all identified market segments within the consortium. The market analysis done by TAS in the context of the NewTon project allowed the identification of potential applications for NewTon solutions.

In a general way, the specific skills of each type of partner were used as following:



- The academic partners (LZH, DTU, ENSTB) sought the exploitation of their intellectual property by licensing agreements with SME and industrial partners. The progress made in NewTon also opened new areas of research in the 3-D PBG material domain and thus necessitated the development of new competencies, through PhD theses for instance.
- SME (PD) was most active in supplying fine modeling of 3-D PBG components to the industrial partners of the consortium but also to external potential costumers who could be interested in the new capabilities developed thanks to NewTon.
- The industrial partners (BASF, TAS) used NewTon results to explore new market segments with their systems, or to deliver systems with improved functionality, thanks to the gain brought by NewTon in terms of size, cost and easiness of production.

The exploitation strategy for LZH in the NewTon project involved developing techniques and equipment required for the inscription of defects in PBG template that could be the basis for a spin-off company as well as the development of new competences that could be implemented in new projects.

In the framework of the exploitation strategy, steps toward commercialization of the technology and equipment developed for the NewTon project have been undertaken. For the project realization the laser tool for defect inscription has been built. Based on this laser tool, modifications of the commercial setups for 2PP nano- and micro-fabrication were designed. Modifications of the setup are intended for different applications and different needs of the customers. Several setups have been sold to customers. Currently, a sustainable business strategy for a spin-off company is under development.

The scientific results from the NewTon project were used for diploma and doctoral theses, as well as publications in leading peer reviewed journals. The results were presented at international conferences that raised the awareness of LZH and its capabilities, attracting new partners for future projects and companies needing material processing service. The non-confidential results were included in different courses and teaching modules, and utilized by the LZH Laser Academy.

The NewTon project serves LZH as a basis for future projects. This includes projects related to photonic crystals, as well as those in different areas, where laser material processing is needed. Specifically, FP7-ICT-2007-2 STREP “micro-Fabrication of polymeric Lab-on-a-chip by Ultrafast lasers with Integrated optical Detection” has been submitted to the EC and started at 01.06.2008 after approval by the EC (Contract No. 224205). This project in many aspects relies on the 2PP technique development achieved in the frames of Newton.

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The new competences directly acquired by DTU thanks to NewTon project can be summarized as:



- The certain advance in numerical methods for complex 3D designs. Now we have 2 MSci projects (with a perspective of PhD projects) working on the extension of the FDTD method on nano-structured materials with dispersion, losses and gains.
- Cooperation with BASF, LZH, ENST and an external partner, Cork University, Ireland in characterization and modelling of opal films and opal-based components. Some attempts to organize a close collaborative network by making a proposal for the EU project, unfortunately rejected in the recent call.
- The possible extension of the project outcomes - investigation of the new properties of a single-layer opal film covered by metal – has direct connection to the Plasmonic & Metamaterials, a new Group organized at DTU Fotonik (the new name of our Department). The NewTon project has directly influenced the new group appearance due to the numerical expertise acquired during the modelling of complex 3D structures.
- Illustrative material for the lecture courses “Nanophotonics”, “Numerical methods in photonics”, which are taught at DTU Fotonik.
- Close collaboration with PD by providing a testing platform for their new modeling packages.

The DTU exploitation strategy included patenting or license agreements with SME and industrial partners which might follow from modeling and design of 3D-PBG based components of integrated circuits.

The greatest impact from the fulfilling of the projects goals DTU expects is in the development of new research subjects, partially together with academic partners (LZH, ENSTB). Heavy simulation tasks will be pursued to find out more efficient numerical schemes and algorithms, including accurate 3D modeling of vast areas incorporating comparatively small objects and dispersive materials. The traditional partnership with PD served as a platform for advances in computational photonics. We anticipate that the unique technology of fabricating 3D structures (BASF, LZH) exhibiting complete photonic band gaps will provide samples for further investigations in this area.

Altogether NewTon related activities will give a basis for attracting more students in research at both MSc (or others undergraduate university projects) and PhD levels accompanied with adequate dissemination of knowledge via publications on fundamental and applied subjects in physics and photonics technology.

The exploitation strategy of the ENST Bretagne followed two main routes linked to the two principle roles of the ENST Bretagne in the NewTon project: advanced characterization of PhC type structures and the development and application of parallel-write techniques for the fabrication of structures with PC compatible critical dimensions. The characterization test benches developed and the experience gained in setting them up and using them will continue to be developed in future projects, both national (French) and international by adapting the benches and techniques learnt to the characterization of similar sized structures fabricated using other techniques such as multibeam interference in polymer dispersed liquid crystal structures. Publications based on this knowledge with the other partners have already been submitted, other presentations are also planned and the work will form part of a PhD thesis. In this way the ENST Bretagne is becoming recognized as being one of the leading international

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laboratories in the characterization of PhC structures for optical telecommunications applications, opening routes to new partnerships and projects in this field.

The second aspect, parallel-write techniques of submicron structures, is already leading to spin-off exploitation, partly based on the experience gained during the NewTon project. A national conference presentation of these aspects has already been given, a PhD thesis was completed early 2008 and a follow up PhD is planned. A small spin-off company for the design and rapid fabrication (using parallel-write techniques similar to those developed in NewTon) of 2D diffractive optics is currently being formed. Closer links have been established with LZH on parallel-write techniques during the NewTon project to investigate the use of parallel write techniques with 2-photon polymerization techniques – particularly intoOrmocer type materials for the direct-write of both PhC and conventional waveguide structures. It is hoped that these investigations will lead to further joint publications, research projects and industrial partnerships.



Photon Design has a natural route to exploitation of NewTon work via its photonic crystal simulation product CrystalWave. Most of the tools provided to the NewTon project are now on offer commercially in the CrystalWave product; contributing to the company's business and international exports to Asia, N. America as well as around Europe.

The work done within the NewTon framework has provided significant improvements to the CrystalWave's ability to model 3D photonic crystal structures, including the ability to define more arbitrary 3D structures easily, a much improved 3D band solver, and the availability of a cluster version of CrystalWave's FDTD engine. These improvements will strengthen the company's market position for photonic crystal design tools in the coming months and years.

The NewTon project fitted very well to the strategic BASF "Growth Cluster" Nanotechnology which BASF has defined as one of the key topics for BASF research. The long-term character of BASF Growth Cluster research implies that the result of the NewTon project is regarded as the first step on a long path, BASF will pursue.

This project was a typical collaboration project for BASF and therefore BASF has agreed upon the numerous publications and presentations already made during the running of the NewTon project and which will further be necessary in order to attract leading project partners. In this context the results of the NewTon project were presented in a BASF Press Release and in scientific meetings with universities and institutions. In the NewTon project acquired knowledge relates especially to the production of the monodisperse dispersion particles, to the crystallization of the dispersion into the polymer opal, and to the characterization both of the dispersion and of the produced polymer opal.

For the development of the dispersion it was necessary to expand the existing BASF know-how from the production of particles with a diameter of about 300 nm to dispersion particle sizes of 1000 nm diameter. This diameter was necessary for infrared telecommunication. We were able to produce such large particles for the first time with a very narrow size distribution of Sigma-values with less than 2%. Such small distributions were necessary for the crystallization of large defect free single crystals. The dispersion development also implied the production of dispersion particles with reactive surfaces in order to stabilize the produced polymer opal before it was infiltrated with photoactive materials. The emulsion polymerization as developed could easily be up scaled within BASF production lines. This up scaling possibility was a key challenge during the development as it will be necessary for further evaluating the results economically in the more or less near future. The crystal growth

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technology was in addition developed and adapted to the demands of the large particles with 1000 nm diameter. It was able to produce large volume 3-dimensional polymer opals and we were also able to apply for a patent for that new process. Thus the NewTon project results will also be protected for economical evaluation.

BASF is now highly interested in continuing the development of three-dimensional structured photonic crystals and is currently exploring the most feasible ways.

Two European patent applications have been filed during the project lifetime:



1. EP06123516.4 from 06.11.2006 with European Patent Office (AE 20060769/KSc, PF 58527), Large Area Photonic Crystal with Uncharged Polymer Particles, Reinhold J. Leyrer, Wendel Wohlleben
2. EP07114965.2 from 18.09.2007 with European Patent Office (AE 20070537, PF 60088 Functional Surface), Colloid crystal as template for photonic crystal used in infrared telecommunication devices-Part 2: Crystallizable, dispersion particles with a diameter till 1µm having a functional surface, Reinhold J. Leyrer, Wendel Wohlleben

The exploitation strategy of TAS was based on the development of new market segments thanks to the gain brought by NewTon in term of size, cost and easiness of production and of new capabilities for optical data processing.

TAS identified two main markets: aeronautics and Telecom/Radiocom. For these domains, the technology developed in NewTon is of interest because of its very high level of integration. Such a very high level of integration is mandatory for Microwave Photonic Modules to be used in future phased array antennas. Among the other interesting applications of this technology one can mention the use of 3D PBG to implement complex signal or data processing functions to be used in opto-electronic integrated circuits/processors for future onboard all-optical communication networks. These optical functions are based on a complex combination of basic functions, that includes: straight or bent waveguides, splitters, mirrors, optical isolators, optical circulators, optical filters, optical multiplexers and demultiplexers, optical resonators and optical tapers to control the light injection and more complex functions based on non-linear interactions: all optical switch, all optical amplifier, all optical modulator and all optical wavelength converters.

The first use of PBG based devices, in a medium term approach, could be for sensor applications. The interest in the 3D-PBG technology is associated with its high level of integration useful to realize highly integrated multifunction sensors.

In a longer term approach the technology developed in NewTon could replace optical functions made nowadays by a set of passive optical devices. For such use, PBG based integrated functions will have the benefit of large level of integration that is very interesting for on-board applications that have strong constraints in volume, weight and power consumption. Thanks to the preliminary development in NewTon, this technology could be compatible with rapid prototyping and therefore for mass production, allowing an efficient transfer from design to system application.

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2.2 Dissemination of knowledge

Overview table for the years 2006 to 2008:

Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
Project website	All	All	Unknown	LZH
12 Peer-reviewed articles	Research	All	Unknown	All
30 Conference Proceedings	Research	All	Unknown	All
4 Press Releases	All	All	Unknown	LZH, BASF
3 Theses	Research	All	Unknown	LZH, ENST
1 Book chapter	Research	All	Unknown	DTU
7 Conferences	Research	All	Unknown	All



The detailed list of conferences where NewTon project was presented is below.

NewTon related participation in Conferences:

1. 10th ICTON 2008, 7th Europ. Symposium on Photonics Crystals, June 22-26, 2008, Athens, Greece (invited);
2. DFG Annual Meeting, Berlin, 2008 (invited).
3. 3rd Pacific International Conference on Application of Lasers and Optics 2008, PICALO-2008.
4. Photonics West 2008 Conference, Advances in Slow and Fast Light (SPIE, San Jose, California, USA, 2008) (invited).
5. Kick-off Workshop of the COST MP0702, April 28-29, 2008, Warsaw, Poland
6. CLEO/QELS 2008, 4-9 May 2008, San Jose, Ca, USA, 2008.
7. XVII International Workshop OWTNM 2008, Eindhoven, the Netherlands 13-14 June 2008.

2.3 Publishable results

The dissemination of NewTon results among the international research communities and towards industries is successful since, during the project duration:



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- 12 papers have been published or accepted for publication in international peer-reviewed journals;
- 30 proceedings on 3D PBG have been presented in conferences by the partners;
- 4 press releases targeting a more general audience have been published;
- 3 theses have been defended on NEWTON related subjects for masters and PhD degrees;
- 1 partner has written a chapter on 3D PBG in a book dedicated to PhC and metamaterials

The detailed list of these numerous publications is reported here:

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