Computer data at the speed of light

Newsletter 3 – January 2015

Introduction

In the information and communication industry the performance of microprocessors continues to increase. Consequently, the data flow to and from the processors has to increase accordingly. However, communication becomes a more and more dominant bottleneck for the overall system performance. This has led to the introduction of optical data transmission (e.g. glass fiber) for the replacement of electronic data transmission (e.g. copper wire) in most transmission applications longer than 10 meters. With further development of the information society, there will be a need for even faster data transfer and correspondingly a higher state of integration of electrical and optical components, as is stated in the European Roadmap for Photonics (Mona). To enable such a tight integration between electrical logic and optical communication, new optical materials and structures are required that possess excellent characteristics and can be integrated in a cost effective way.

In October 2011 the project “FIREFLY” started in the EC FP7 program. The aim of this project was to develop new optical components, which would make it possible to transmit data in optical domain on the board, along with novel assembly strategies and technologies. The full name of the project is “Multilayer Photonic Circuits made by Nano-Imprinting of Waveguides and Photonic Crystals”.
The FIREFLY consortium consists of partners from the industry, *IBM Research*, *TE Connectivity*, *VERTILAS GmbH* and *Momentive Performance Materials GmbH* as well as research groups from *TNO*, *imec*, *VTT*, *Tyndall* and *Utrecht University*.
The final results of the project, that ended November 2014, are presented in this newsletter.

The FIREFLY concept

The FIREFLY concept that has been defined at the beginning of the project is shown in figure 1. This schematic representation of the intended outcome, has been used throughout the project as our guideline for all research and development activities.

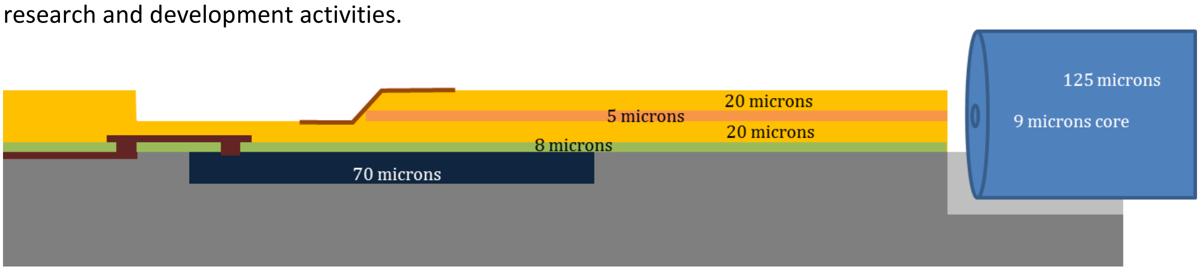


Figure 1. Layout of the final photonic integrated circuit (PIC) demonstrator.

On a wafer substrate (grey) a Vertical Cavity Surface Emitting Laser (VCSEL) (black) is embedded in a pocket and covered with a polyimide (PI) planarization layer (green). Vias are laser ablated and filled with copper (brown) for electrical connections. This is covered with a polymer under cladding (yellow), the polymer waveguide (orange) and the polymer top cladding (yellow). A fibre alignment part (light grey) couples the fibre (blue) with the waveguide stack. A 45° mirror (brown) is manufactured in the top cladding and optionally covered with gold. This mirror replaces the originally planned photonic crystal structure that has been investigated for the in-plane and out-of-plane bending of light.

Technological achievements

The key building blocks for the polymer based photonic integrated circuit (PIC) developed are:

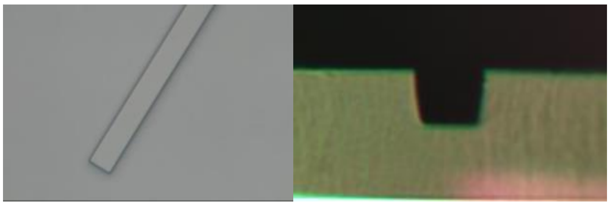
- Transparent polymers for waveguiding at around 1550 and 1300 nm wavelengths;
- Nano-imprinting as a fabrication technology for waveguide stacks aimed at making smaller optical components on a large scale, with more design flexibility and to reduce production costs;
- Integration of waveguides with VCSELs using 45 degree mirror technology;
- Waveguide - fiber coupling method;
- Nanostructured photonic crystals for bending of light;
- Technology demonstrators have been made to show the feasibility of the new technologies.

FIREFLY is sponsored by the FP7 ICT program of the European Commission

Low loss silicone materials

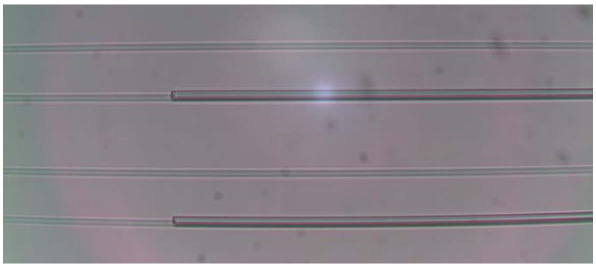
There are numerous publications describing polymeric waveguide material systems, including acrylates, polyimides and cyclic olefins. The organic-inorganic hybrid Ormocer® is often used for polymer waveguides and is being used as bench mark in this project. For the materials assessed in FIREFLY, we focussed on a range of parameters, like the costs, processability and optical loss at 1550 and 1300 nm for large-area interconnection applications.

Momentive has developed material compositions containing molecular groups which have an intrinsically low loss. Although the low loss originally envisioned has not been fully obtained, these materials can be processed into waveguides with the versatile UV-based nano-imprinting technology. In addition, the refractive index between core and cladding can be accurately tuned.



Waveguide preparation

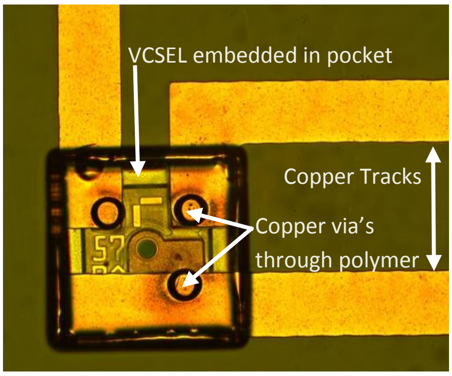
Three technologies are compared for the large scale production of waveguiding structures. Single-mode waveguides were successfully processed from Ormocer® materials with nano-imprinting and standard lithographic processes (mask litho and laser direct imaging (LDI)). Ormocer materials were also used to prove the possibilities of multilayer imprinting with 1 µm accuracy. As an example a part of a 2-level waveguide component is shown below.



Promising results have also been obtained with the new silicone materials of Momentive by IBM with Laser direct imaging (LDI) patterning and nano-imprinting by VTT and TNO; see the picture below of two imprinted silicone waveguides illuminated from behind.

VCSEL embedding

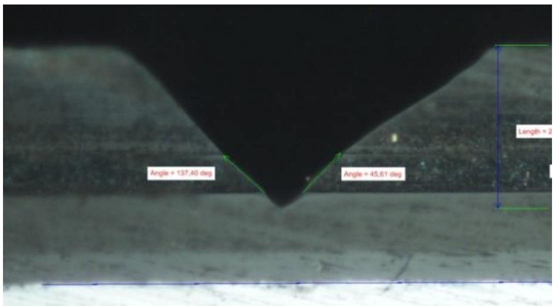
The light source in the FIREFLY project was chosen to be a long wavelength VCSEL based on the Indium Phosphide material system with direct modulation bitrates greater than 20 Gb/s. The single mode output is polarisation stable which is important for controlled waveguiding using bends, mirrors and other PIC elements. Vertilas developed and modified the 1310 nm and 1550 nm VCSELs to retain performance after the embedding and connection processes. These lasers are mounted in a pocket that is etched in the silicon substrate using DRIE. The depth and width of the pocket is very critical in view of the required planarization by the polymers layers that are applied later in the process. Electrical connections were made using copper tracks and through polymer via's.



The picture shows a long wavelength VCSEL overcoated with polyimide with via holes which were opened by laser ablation. Copper was then deposited to form the tracks on top of the polyimide and to make the electrical connections with the VCSEL's coplanar contact pads through the via's.

45 degree mirror in polymer waveguide

In order to achieve the coupling of light from the embedded VCSEL into the waveguide stack above, a mirror was needed. This mirror had to be exactly 45° and had to be very accurately placed above the VCSEL and aligned with the waveguide. Imec succeeded doing this with laser ablation for making the mirror in polymer and a laser vision system for alignment with the VCSEL.



VTT developed a local imprinting process in which a mirror is imprinted in a cavity above the VCSEL using a micro prism. By maximizing the VCSEL output from the waveguide, the exact position of the imprint can be found, followed by UV curing of the polymer and metallization.

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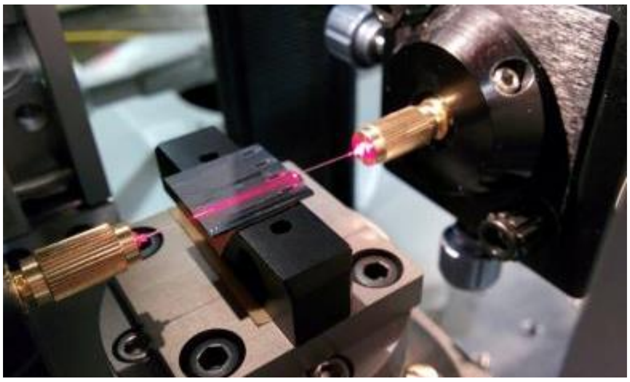
Fibre-waveguide coupling

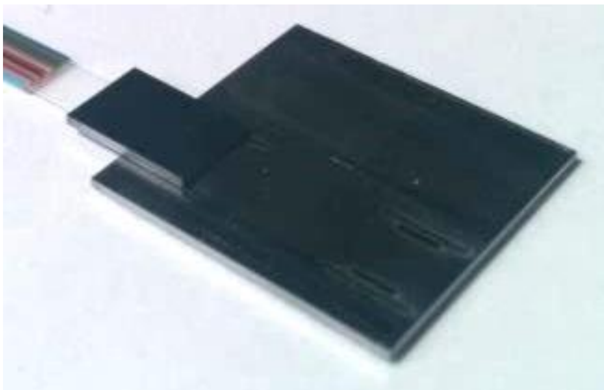
For the development of methods for the fibre-to-waveguide coupling, industrialization and accuracy to prevent losses were the main objectives for TE Connectivity.

Waveguide end facets and bond areas were cleaned by imec using laser ablation. A specific alignment block was realized making it possible to flip chip bond and actively align and fixate fibres with waveguides. Waveguide end facets and bond areas were cleaned by imec using laser ablation.

The picture underneath shows the experimental setup for fiber-chip coupling measurements. The chip is positioned on the short pole in the middle of the setup, the single fiber is on the left of the chip and the ribbon is on the right of the chip. Experiments revealed that a fiber-chip coupling loss of 1.3 dB could be achieved using passive flip chip technology. Mode mismatch already consumes 0.7 dB thus the alignment error and end facet manufacturing technique is consuming 0.6 dB



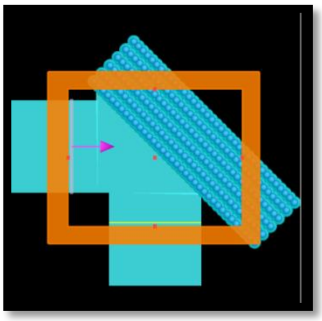
Picture of passive aligned fiber alignment block with terminated fiber ribbon mounted on a waveguide chip:

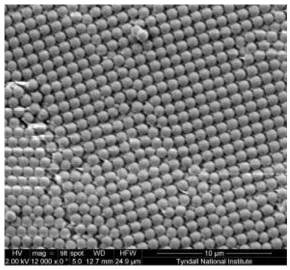


3D Photonic crystal structures for light bending

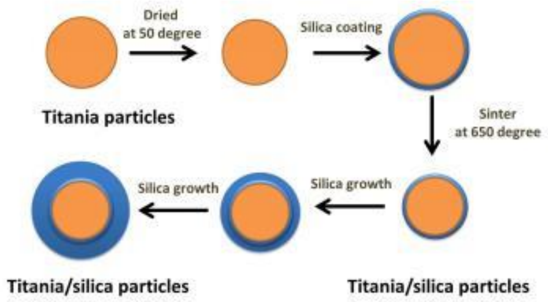
One of the most uncertain parts of the project was the development of photonic crystal (PhC) structures for the bending of light. If this would succeed, it would give great opportunities to reduce the chip size due to the smaller bending radius of the waveguides. In addition, it would make other photonic components possible, such as splitters and polarization filters.

Using modelling studies, Tyndall showed that the light can be bended efficiently in 3D photonic crystal structures and calculated the optimal stacking and dimensions for 90° bending of light.





Utrecht University succeeded in making monodisperse particles consisting of a crystalline titania core (for high RI) and silica shell (for spacing in between the cores), which have been used as base material by TNO for the PhC structures.



For the assessment of the vertical bending by an integrated photonic crystal, a waveguide stack with seed layer was designed by TNO, TYN and VTT, and fabricated using a multilayer imprint and mask lithography process. The waveguides guide the light to and from the seed area. In this area the nanoparticles are deposited locally using a method developed by TNO, to form the photonic crystal.

It was shown that stacks of oriented particles can reflect light in the right direction (both vertical and horizontal). However, the integration with waveguides is complex, and the fabrication process has been slow so far.

Technology demonstrators

In order to actually show the results of the project and proof their functioning, a number of technology demonstrators have been made throughout the project. By starting thinking about integration of components right at the start of the project, a lot of issues became clear early enough to solve them in time. The result is presented on the next page.

Conclusion

A great step forward has been made in the realisation of polymer photonic integrated systems. Several new components as well as integration technologies have been developed.

More information on: www.fp7-firefly.eu

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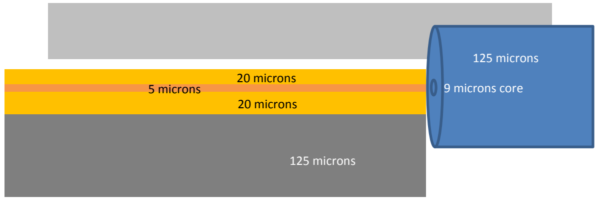
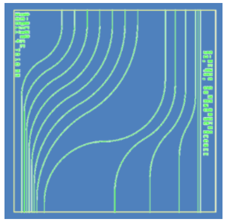
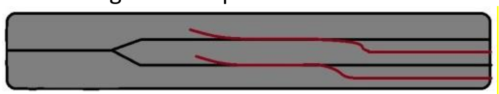
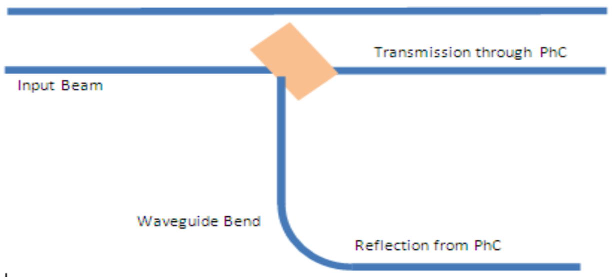
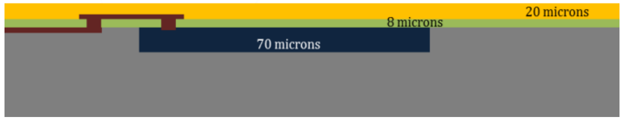
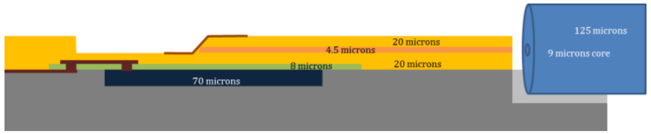
Overview of the final technology demonstrators

Demo nr	Description and schematic drawing	Partners involved
Demo 6.2.3	Integration of waveguide and glass fibers – Glass fibre assisted alignment 	TE
Demo 6.3.1 & 6.3.2	Horizontal bend in waveguide stack of silicone and Ormocer materials. 	VTT & TNO
Demo 3.3B	Multi-level waveguide components. 	VTT & TYN
Demo 6.3.3	Horizontal and vertical bending with PhC structures 	TNO & TYN

Demo nr	Description and schematic drawing	Partners involved
Demo 6.4.3	VCSEL embedding 	Imec & TE & VERT
Demo 6.5.1	Integration of vertical bend and waveguide by using a 45° mirror as an insert in the imprinting mould. 	VTT & TNO
Demo 6.5.4	3nd generation - mirror fabrication with VCSEL-to-waveguide mirror coupling 	Imec & VTT
Demo 6.6	Photonic Integrated Circuit 	TYN & TNO & Imec & TE & VTT

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