Photonic modelling and packaging of chip-level interconnects

Optical interconnects have been a topic of discussion for a number of decades now. In the roughly fifty years following the invention of the laser, photons have replaced galvanic wires as information carriers in high-speed telecommunication and data communication applications. Novel devices and technologies paved photon's way down the interconnect hierarchy. At the lowest level, we find the intra-chip level interconnects. We believe that the scale of miniaturisation and accuracy of the micro-opto-mechanical components constituting the intra-chip level optical interconnect are a main challenge for the fabrication technologies of micro-opto-mechanical systems. Moreover: techniques developed at this level can be considered as generic for other levels of the optical interconnect hierarchy.

With this work we specifically aimed at evaluating and enhancing a rapid prototyping technology for micro-optical and micromechanical components, Deep Proton Writing, to fabricate devices for parallel free-space optical interconnects at chip-level. Deep Proton Writing uses accelerated protons to locally modify the chemical and physical properties of a material. These modifications allow a selective chemical processing, yielding flat surfaces and hemispherical lenses on a polymer substrate, typically Polymethyl Metacrylate. Deep Proton Writing underwent a considerable evolution during the last five years. We have contributed to the further extension of the Computer Aided Design and Manufacturing capabilities of Deep Proton Writing by integrating design and characterisation software enabling design iteration. We also tested a method to accurately position a preprocessed sample in the Deep Proton Writing setup using particle current monitoring or beam monitoring. The method allows for the premilling of non-critical surfaces, reducing costly irradiation time. Our research on the technology, in collaboration with the colleagues of the Applied Physics and Photonics department, has lead to a first inventory of the Deep Proton Writing specifications. This specification list is an important piece of information for our work on the tolerancing of an optical interconnect module.

The optical interconnect system we propose consist of a prism to deflect an optical beam emitted by an array of Vertical Cavity Surface Emitting Lasers over 180° to an array of detectors. Microlenses at the sending side and the detection side of the interconnect repectively collimate and focus the diverging laser beam. We have designed and demonstrated a full assembly solution for this interconnect, using Deep Proton Writing prototyped components.

A main contribution of our work is on the implementation of a coupled opto-mechanical tolerancing tool. The simulation software uses a vectorial description of the building blocks of an opto-mechanical system and encompasses an algorithm to update fabrication and assembly errors. We hereby specifically implemented a method to resolve object collisions in a realistic manner enabling us to simulate an assembly process as in real life, including dimensional and geometrical errors of the individual components. We have used this framework to analyse the tolerance behaviour of the intra-chip level micro-opto-mechanical interconnect system in terms of manufacturability. We explicitely aimed at setting the dimensional and geometrical tolerances of the assembly to enable low-cost fabrication by minimising the rejection rate of the complete fabrication and assembly process allowing an acceptable performance degradation with respect to the nominal optical interconnect performance.

We determined that Deep Proton Writing is able to provide the required accuracy for a prototype optical interconnect system. The complete assembly stack we have designed can be prototyped with a fabrication and assembly yield of 90%. However, the adhesive bonding of the optical interconnect and the chip in the main package remains a challenge for current commercial bonding devices.

We also investigated the usage of a special, aspherical, microlens shape. This special shape is designed to reduce spherical aberration of the lens, which is the prime cause for the light loss in the optical interconnect module. The aspherical microlens shape is indeed able to increase the optical transmission efficiency through the optical interconnect module but we determined that at the current state-of-the-art commercial adhesive bonding accuracy these special lenses are not providing a gain from a tolerancing point of view.

Michael Vervaeke was born in Asse, Belgium, in 1975. He graduated as Industrial Electromechanical Engineer from the Katholieke Hogeschool Sint-Lieven (Gent, Belgium) in 1997. He enrolled subsequently for the Masters in Engineering at the Vrije Universiteit Brussel (Brussels, Belgium) where he obtained his degree in Electrotechnical Engineer with majors in Photonics in July 2000. That same year he joined the Applied Physics and Photonics department of the VUB where he pursued research on the packaging and integration of micro-optical and electrical devices. He developed a three-dimensional mechanical model of an intra-chip optical interconnect module and builds demonstrator platforms using in-house rapid prototyping technology (Deep Proton Writing). He authored more than 49 publications in international conference proceedings in his research field as well as in education, and 7 journal publications.