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Optical Coupling and Optoelectronics Integration Studied on Demonstrator for Optical Interconnects on Board

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Abstract

We have studied methods to design and fabricate coupling structures for short distance optical interconnects on printed wiring boards (PWBs). In order to demonstrate the developed technologies, a parallel optical interconnect was integrated on a standard FR4-based PWB by using surface-mounted component packages and board-embedded optical waveguides. The aspect of particular interest in this study was the in-coupling efficiency and alignment tolerances of the transmitter module, since they will determine the overall performance of the system to a large extent. The transmitter was built on multilayer ceramic (LTCC – low-temperature co-fired ceramics) substrate, which was then surface mounted onto the O/E-PWB using ball grid arrays (BGA). A 4-channel VCSEL array was used as source. In order to reduce the farfield divergence, the VCSEL had integrated microlenses UV-moulded directly on top of the VCSEL emitting area made in a wafer-scale process. Optical waveguides were made of optical polymer material and patterned by laser ablation. A discrete optical out-of-plane coupler component was realized by deep proton writing (DPW) technology and inserted into a laser ablated cavity to bend the light beam by 90° and to couple it to the waveguide. The results of the alignment tolerance and coupling efficiency measurements of the coupling structure are presented.

Key words: optical interconnect, micro-optics, LTCC, polymer optical waveguide

Introduction

With ever-increasing processor clock frequencies and telecom data rates the electrical interconnects inside equipment are becoming a bottleneck. The performance of electrical interconnects has many physical limitations, for instance, due to dispersion, electromagnetic emission, and susceptibility against electromagnetic radiation. Optical transmission with high bandwidth, low loss and cross-talk, insensitivity to EMC/EMI and low heat dissipation could offer several advantages in off-chip I/O connections of fine-pitch packages and chip-to-chip interconnects.

In recent years, a number of optical chip-to-chip interconnections has been demonstrated, e.g. [1,2]. At the board-level, embedded multimode waveguides with similar physical topography and dimensions to electrical strip-lines can be regarded as the most promising approach. Polymeric waveguides as additional optical layer in PCBs have the potential of fulfilling integration and compatibility requirements.

Background – Evolution of Optical Interconnection Demonstrators at VTT

Since 2002, VTT has been running research projects in which we have studied technologies to design and fabricate high-bit-rate optical interconnects on PWBs using board-embedded polymer waveguides and surface-mounted component packages. The work has been carried out with several collaborators, including Helsinki University of Technology to name one. The aim has been that the developed technologies should be compatible with existing PWB technology. One key element in this research has been VTT's in-house LTCC pilot production line. LTCC substrate technology was selected for high-speed optoelectronic module platform thanks to the possibility to implement precision structures for optical alignment directly onto the electronics packaging substrate. LTTC also enables high packaging density due to its multilayer structure and possibility for passive-component integration and bare-chip encapsulation. In addition, good high frequency and thermal properties as well as stability, reliability, and compatibility with hermetic sealing are advantageous for high-speed optoelectronics modules. A review of the LTCC photonics integration at VTT can be found in Ref. [3].

Our first optical interconnection demonstrator, shown in Figure 1, utilized modular structure [4]. The system consists of three separate units: transmitter, receiver, and optical waveguide board. The optical front-ends of the transmitters and the receivers are based on LTCC modules, which were assembled using BGA connection on transmitter and receiver PWBs. The modular approach allows testing and characterization of alignment tolerances with different waveguides and optical coupling structures. Three different coupling concepts were compared.

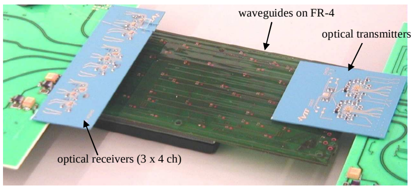

Figure 1: Modular demonstration platform.

Our second demonstrator was 4x10 Gb/s optical interconnect completely integrated on a standard FR4 PWB [5]. The optical link demonstrator consists of 4-channel BGA-mounted transmitter and receiver modules built on LTCC substrates as well as of four parallel multimode optical waveguides fabricated on the PWB. A photo of the demonstrator is shown in Figure 2.

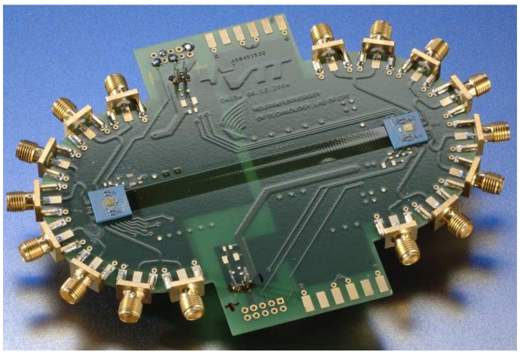

Figure 2: Photo of the 2nd optical interconnect demonstrator on FR4 PWB. Optical waveguide layer is on the PCB between the (blue) transmitter and receiver modules.

The schematic structure of the transmitter and receiver modules and the optical coupling are illustrated in Figure 3. Coupling between the VCSEL/PD array and the waveguide array is based on two microlens arrays and a micromirror. One lens array is mounted into a cavity on the BGA side of the LTCC substrate, whereas the other one and the mirror are mounted on the PCB. With this design, an expanded and collimated beam is obtained between the two microlens arrays, i.e. between the module and the board; thus, relieving the sensitivity to the potential misalignments due to the BGA board assembly. The characterized transversal tolerances with 1 dB loss margin were ±40…60 µm and total loss of the link estimated to be around 19 dB.

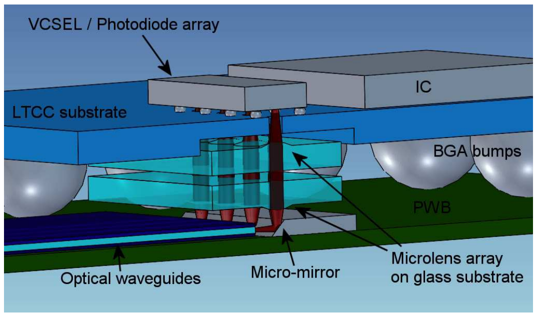

Figure 3: Schematics of the optical coupling and module structures of the 2nd demonstrator. Expanded beam concept between O/E-module and PWB loosens alignment requirements.

Design and fabrication of the modified optical in-coupling structures

Within the framework of the Network of Excellence in Micro-Optics (NEMO) supported by the European Commission through the FP6 program, project partners can access various micro-optical technologies not yet available on commercial markets. To enhance the performance and to reduce the amount of optical components in the 2nd VTT demonstrator described in the previous chapter, altogether three novel technologies were introduced to this demonstrator platform.

Assembly of the discrete microlens array that collimates the VCSEL beam requires high accuracy and is thus costly. The Centre Suisse d'Electronique et de Microtechnique (CSEM) has developed a wafer-scale replication process, which combines UV-casting and lithography, to realise microlenses directly on top of the VCSEL wafer [6]. These i-VCSELs can reduce the farfield FWHM–divergence to around 6º with 7 mA driving current and 1 mW of emitted optical power, according to our measurements. Figure 4 shows 4-channel i-VCSEL array chip with 250-µm pitch wire-bonded onto the bottom of a cavity on an LTCC substrate.

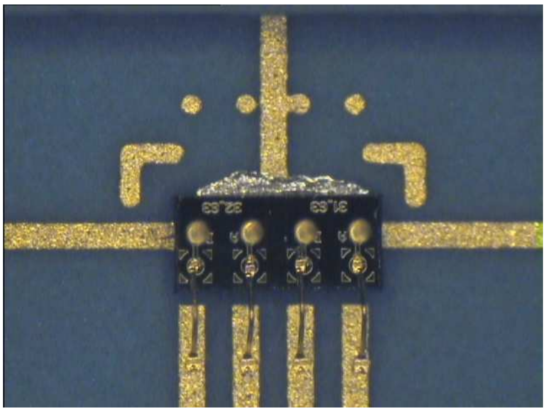

Figure 4: i-VCSEL array chip in the bottom of the cavity on LTCC substrate.

Multimode optical waveguides were fabricated on top of 2nd VTT demonstrator PWB at the Ghent University, Belgium. The optical material, Truemode Backplane™ Polymer, was spin-coated on the PWB. It is a commercially available acrylate based polymer (Exxelis Ltd.) which shows excellent optical and thermal properties and is fully compatible with standard FR4 processing, according to the supplier. Waveguides were patterned by excimer laser ablation and had a cross-section of 50 µm x 50 µm and NA of 0.3. After spin-coating of the top cladding, a micro-cavity was ablated (shown in Figure 5). A detailed description of the laser ablation process in optical waveguide fabrication is given in [7].

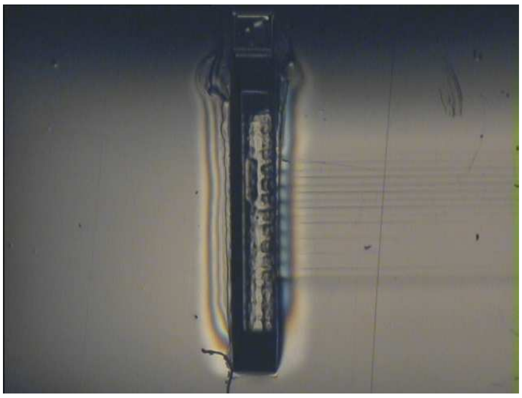

Figure 5: Laser ablated cavity on PWB.

In order to couple the light to the optical waveguides, the light beam has to be bent by 90º. In this study, we used a pluggable micro-optical component incorporating a 45º micromirror fabricated with DPW technology at the Vrije Universiteit Brussel, Belgium. Photo of the realised component is shown in Figure 6. The fabricated coupling components are potentially suitable for low-cost mass production since the DPW technology enables fabrication of moulds for standard replication techniques, such as hot embossing and injection molding [8]. In addition, the component should be made of another material than the currently used PMMA in order to enable standard surface-mount assembly of the module with reflow soldering process.

Figure 6: Micro-optical out-of-plane coupler.

The principle of the optical coupling and the structure of the transmitter module are schematically illustrated in Figure 7. The module is built on an LTCC substrate with a cavity for the i-VCSEL array. The cavity enables to adjust the separation between the VCSEL and the PWB so that the optical components can fit in between them. The array chip is mounted with conductive adhesive and wire-bonded to contact pads. The DPW coupling component has a mechanical alignment structure with laser ablated cavity edge and can be assembled either by a die bonder or by a pneumatic gripper on a precision active-alignment station. The component is fixed with UV-cured adhesive. The transmitter module can be mounted to PWB with BGAs by using flip-chip bonder, or alternatively, it might be assembled with a high-precision SMT pick-and-place-machine.

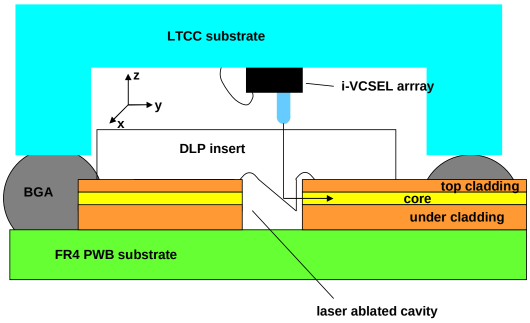

Figure 7: Schematic of the optical coupling and module structures.

Characterization of the optical performance

Optical loss measurements were made according to Figure 7, where the ends of the 3.5 cm long waveguides were polished and the output light was butt-coupled to a 200/220-um MM fiber with 0.22 NA. Preliminary results of this measurement gave average insertion loss of 10.4 dB. This includes in-coupling, waveguide propagation and out-coupling losses. The propagation loss of the ablated waveguides is 0.12dB/cm [7].

Alignment tolerance measurements were done (before the BGA assembly) by attaching the transmitter module into a moving stage of Newport AutoAlignment Station 8100 and by measuring the out-coupled optical power as a function of misalignments in the lateral directions (x- and y-axes). Axis nomination is shown in Figure 7. Figure 8 shows the obtained alignment tolerance curves.

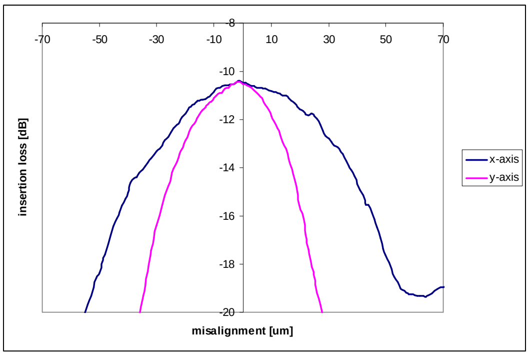

Figure 8: Alignment tolerances of the transmitter module.

-3dB alignment tolerance is ±33 µm along x-axis and ±20 µm along y-axis. -1 dB alignment tolerances are ±16 µm and ±10 µm along x- and y-axes, respectively.

When compared to VTT's 2nd demonstrator, this coupling structure demands higher alignment accuracy, because it does not provide expanded beam concept. However, the structure includes less components. Thus, the assembly process is simpler and potentially more cost-effective. Optical coupling efficiency performance between VTT's 2nd demonstrator and this study can be considered quite similar, although measurement results are not entirely comparable.

Conclusions and future perspectives

A novel optical coupling scheme was presented, consisting of transmitter module built on an LTCC substrate and equipped with a VCSEL array with integrated microlenses; a pluggable micro-optical out-of-plane coupling component made with the DPW technology; and laser ablated polymer waveguides and cavities. Promising results were obtained from the characterization of the optical performance, indicating that the technology could be feasible for optical interconnects on PWBs.

Further study is planned to include the making of waveguide facets with 45° micromirrors by laser ablation. In the future, we will also investigate in more detail the mounting process of the DPW coupling component and the transmitter module in order to optimize the optical coupling efficiency.

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