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24-Channel Optical Transceiver Module for Waveguide-on-card Interconnects

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Abstract: 24-channel 850nm optical transceiver modules based on silicon carriers with through-silicon electrical and optical vias have been assembled and tested at 12.5Gb/s/channel. Packaged on an organic carrier, the modules enable waveguide-connected multichip modules.

OCIS Codes: (200.4650) Optical interconnects; (060.2330) Fiber optics communications

1. Introduction

In the IBM-DARPA Terabus program, we have previously demonstrated a highly-integrated parallel optical transceiver module utilizing separate arrays of sixteen 985nm VCSELs and sixteen 985nm photodiodes (PDs) flip-chip attached to a single-chip CMOS IC driver/receiver chip [1]. These "Optochips" were coupled to multimode polymer waveguides integrated on a printed circuit board [2]. A full 160 Gb/s bidirectional link was demonstrated. However, the substrate emitting 985nm optoelectronic arrays rely on custom optoelectronic components that are not commercially available. In addition, at 985nm we measured typical losses in the waveguides of about 0.11dB/cm, limiting practical link lengths to ~35cm. Commercial communications VCSELs operate at 850nm, where we have measured waveguide losses as low as 0.04dB/cm. This lower loss would permit ~1m waveguide links. Both because of the commercial availability of 850nm components and the lower waveguide loss, we have developed new packaging and integration technologies to migrate these waveguide optical interconnects to the industry-standard 850nm wavelength. Here we describe the complete 850nm transceiver modules that have been fabricated and tested and discuss how they may ultimately be used for multichip modules (MCMs) that communicate with other MCMs in a server system over optical waveguides and fibers.

2. **Optics in today's supercomputers and servers**

The 850-nm optical transceivers are based on an Optochip comprised of a Si carrier with flip-chip attached 0.13-µm CMOS ICs and optoelectronic arrays, as pictured in Figure 1, where they are contrasted with the earlier 985nm Optochips. The Si carrier is the foundation of the 850nm optical transceiver assembly. It performs the key functions of mechanically supporting the OE and CMOS chips and lens array, while also providing all of the on- and off-carrier dc and high-speed electrical connections at C4 electrical interconnect densities. The Si carrier has three copper wiring levels for interconnection between the CMOS IC s and the OE arrays. It also includes a dense array of electrical through-Si-vias (TSVs) for the off-carrier dc and high-speed electrical connections as shown in Figure 2. In addition, to allow optical transmission through the silicon carrier, 150-µm diameter "optical vias" (holes) are etched through the carrier at the locations of each VCSEL and PD array element. Previously, we have demonstrated a probe-able 24 TX + 24 RX 850nm Optochip using a simplified version of the Si carrier that did not include the TSVs, but did include top-surface wiring to interconnect the CMOS ICs and OE arrays [3].

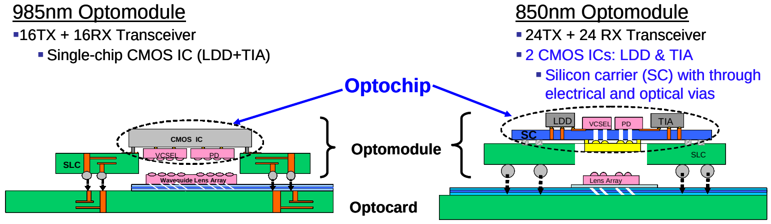
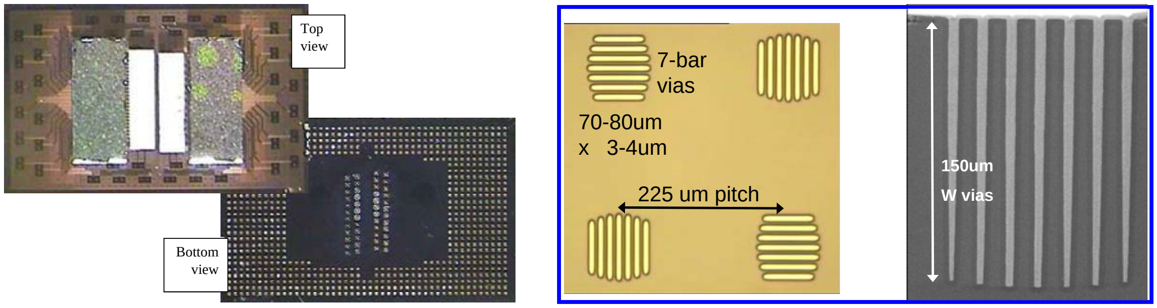


Figure 1. Schematic comparison of 985nm and 850nm Optomodules. Note that the 850nm Optomodule includes a silicon carrier which is not present for the 985nm version.



Assembled 850-nm Optochip | Through-silicon vias

Figure 2. At left, assembled 850-nm TSV Optochip. The top view shows the 4 components bonded to the Si carrier, and the bottom view shows the optical vias in the center surrounded by bond pads which are each connected to a through electrical via fabricated using tungsten as shown at right. The Si carriers are thinned to 150µm after fabrication to reveal the bottoms of the electrical vias.

The TSV Si carrier measures 6.4mm x 10.4mm, which is 2.5X smaller than the earlier probe-able carrier. The center of the TSV carrier contains the 48 optical vias where the 24-channel 0.9mm x 3.5mm VCSEL and PD arrays are flip-chip attached using AuSn solder. The 24-channel laser driver and receiver ICs, each measuring 1.6mm x 3.9mm, are also attached using AuSn solder. Optochips based on electrical thru-via Si carriers with flip-chip bonded ICs and OEs have been assembled and DC electrical characterization verified electrical continuity and demonstrated electrically and optically functional Optochips with 24 VCSELs and 24 PDs.

These 850nm Optochips have been attached to a high-speed, high-density organic carrier to form the full 850nm Terabus Optomodule shown schematically in Figure 1, with the assembled Optomodule shown in Figure 3. The organic carrier is a thin-core build-up flip-chip package with dimensions of 35mm x 35mm. High density C4 pads (100µm diameter on 225µm pitch) on the top surface are used to attach the Optochip while typical BGA pads on 1mm pitch are provided on the bottom surface for subsequent surface mounting of the Optomodule to a printed circuit board which also has multimode polymer waveguides on the surface. Within the C4 Optochip attachment area, a 4.0 mm x 3.6 mm cavity is milled out in the center of the organic carrier to allow optical coupling to/from the Optomodule. In designing the organic carrier, all wiring was excluded from the area of the cavity for all layers. An Injection Molded Solder (IMS) transfer process was optimized to provide 100% solder coverage on the organic carriers. After solder transfer, a flip-chip bonding process was developed to attach the Optochip to the organic carrier to form the Terabus 850-nm Optomodule. Over 800 solder joins between 100µm diameter bond pads on 225µm pitch on both the organic carrier top surface and the Si carrier bottom surface are simultaneously achieved. This dense array of C4 bonds provides all the electrical I/O to/from the Optochip. Initial high-speed electrical characterization of the complete module showed receiver channels operating at 12.5Gb/s and transmitter channels operating at 15Gb/s. This is the first demonstration of the Terabus Optomodule with a dense 24TX + 24RX transceiver Optochip constructed with a TSV Si carrier.

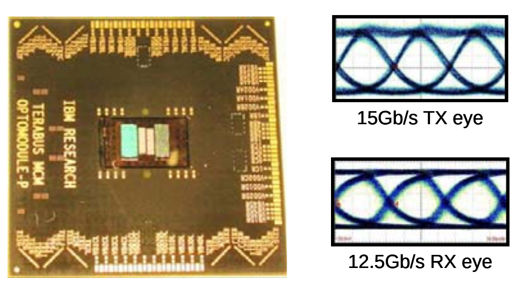


Figure 3. At left, assembled 850-nm Optomodule, with the Optochip attached in the center. At right are typical eye diagrams. The TX eye is the measured VCSEL output, when the Optomodule is driven by test equipment and high speed electrical probes contacting probe pads on the top surface of the organic carrier. The RX eye is obtained by driving a receiver with the output of an 850nm Optochip, and sending the electrical signal to an oscilloscope via high speed electrical probes contacting probe pads on the top surface of the organic carrier.

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3. Optically Enabled MCM Concept

One goal of Terabus is to extend a standalone optical transceiver towards the concept of an optoelectronically-enabled multichip module (OE-MCM). The density of electrical connections that are available to connect from today's first level chip packages (MCMs or single chip modules, SCMs) to a printed circuit card is limited by printed circuit card technology to a pitch of about 0.8mm. Multiple contacts are needed for each high speed electrical signal. The density of optical interconnects is much higher, approximately the 250µm pitch of typical VCSEL arrays. As a result, an OE-MCM, as pictured in the concept of Figure 4, could allow ~10x more interconnect bandwidth to an MCM or SCM [4]. With the advent of multicore processors, ever increasing bandwidth is required and it is likely that optical interconnects will be ultimately be required to support that bandwidth. With good design and manufacturing techniques, waveguide interconnects between OE-MCMs should consume less power than on-board electrical links and also should be low cost.

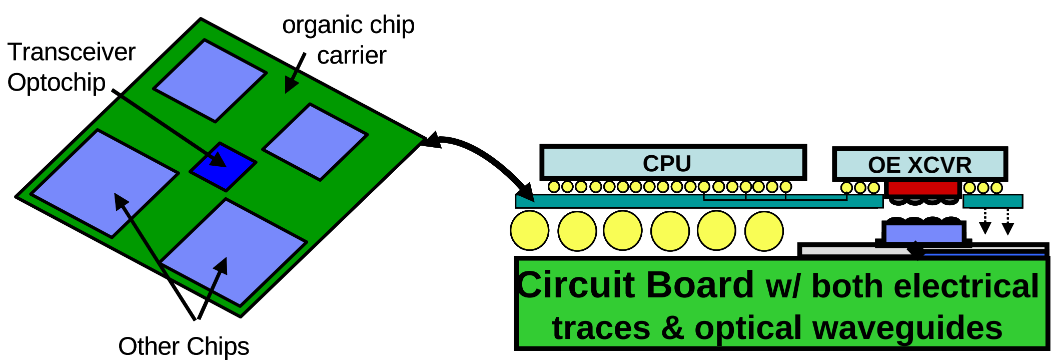

Figure 4. Optoelectronically-enabled multichip module (OE-MCM) concept.

Acknowledgement

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