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An Optoelectronic Crosspoint Switch: The Devices and a Polymer-based Integration Platform

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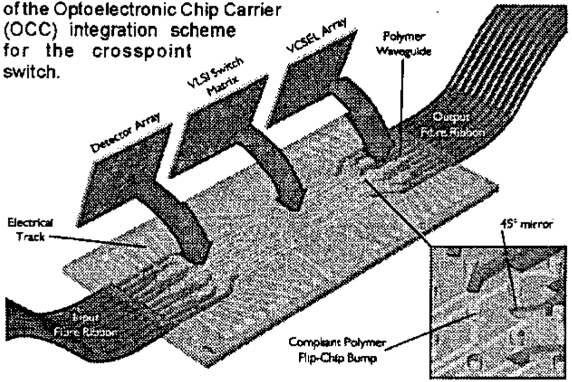
Introduction: The use of optics in modern avionic systems is increasing. In the emerging integrated modular avionics (IMA) architectures it is envisaged that most of the intra-cabinet and cabinet-subsystem interconnections for the "System Area Network" on-board an aircraft, will be made using optical links. It is also envisaged that large numbers of relatively modest-scale, compact crosspoint switches will be at the core of this implementation, to provide the required dynamic reconfiguration.

The work reported here describes the construction of a 4 x 4 optoelectronic crosspoint switch demonstrator. At the heart of this demonstrator is a custom high-speed electronic crosspoint chip with integrated receiver and laser driver circuitry. The Optical Chip Carrier (OCC) approach, shown in figure 1, has been developed as an integration and packaging platform to enable the compact assembly of the optoelectronic interface devices (detectors and VCSELs) with the high-performance crosspoint chip and the optical input/output connections. The footprint of the OCC is dominated by the size of the fibre ribbon connectors.

Figure 1: Computer generated image of the Optoelectronic Chip Carrier (OCC) integration scheme for the crosspoint switch.



In this scheme the detector, VCSEL and crosspoint chips are flip-chip bonded onto the OCC using a variation of the compliant-bump-bonding technique[1]. Gold-coated polymer bumps linked with gold tracking provide the electrical connections between the two optoelectronic chips and the electronic chip. This is in contrast to using wire bonds for connecting the chips and reduces the possibility of interference at high frequencies due to the "antenna" effect of wire bonds. Polymer waveguides with 45° mirror ends are used to carry the optical signals between the arrays and the butt-coupled 250 μm pitch, fibre ribbon channels. This is shown in more detail in figure 2. The compliant flip-chip bonding technique is attractive as it allows easy reworking of pieces, no special preparation of die is required (as long as they have gold coated bond pads), and the temperatures used are compatible with the polymer waveguides.

Devices: The operating wavelength is 850 nm and commercially available emitters and detector arrays are being used with the custom designed crosspoint switch - A 125 μm pitch, 2 x 2 VCSEL array and a 250 μm pitch, 1 x 4 GaAs metal-semiconductor-metal (MSM) detector array. The detectors are approximately 80 μm in diameter. Both arrays are compatible with the desired 2.5 Gb/s data rate and suitable for compliant bump flip-chip assembly.

The 4 x 4 optoelectronic crosspoint chip was designed by Imperial College and fabricated using 0.8 μm SiGe HBT BiCMOS technology. The chip incorporates transimpedance amplifier receiver circuitry for the four photodetector inputs, the switch core and four laser drivers. It is a non-blocking architecture with broadcasting capability and the data paths are asynchronous. The switch uses fully differential ECL programming circuitry. The laser drivers are optimised to drive VCSEL arrays with shared ground cathodes and provide an externally controllable modulation current of between 0 and 10 mA. The main parameters of the crosspoint chip are listed in table 1.

Technology	0.8μm SiGe HBT BiCMOS
Chip Area	1.6 x 2.3 mm
Chip Size	4 X 4
Data Rate	0 - 2.5 Gb/s
Chip Delay	422 ps
Programming Time per Channel	< 1 ns
Current Sensitivity	25 μA
Control Signal logic	ECL
Power supplies	-5, -1 V
Power Consumption including laser drivers	820 mW

Table 1: Main parameters of the crosspoint chip.

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A data rate of 4 Gb/s per channel was simulated giving an aggregate data rate of 16 Gb/s. The predicted static power dissipation of the laser driver sections is ~80 mW each. The electrical testing of the chip proved successfully with clear output eye diagrams obtained for 1 Gb/s operation. Testing at higher speeds was limited by available test equipment.

Polymer: A novel multifunctional acyrlate-based photo-polymer was developed as part of this work. Details of the polymer are reported in [2]. The direct laser writing of the polymer features allows for rapid prototyping of the platform as well as flexibility with its layout. A focussed Helium-Cadmium laser beam is used to facilitate the direct writing of the ~50 x 50 µm multimode waveguide cores and 50 µm diameter, 100 µm tall bumps, on a glass substrate. Examples of these are shown in figure 3. Cladded waveguide losses of less than 0.17 dB/cm have been measured at 850 nm. Figure 4 is a schematic showing the mirror structures that have been fabricated and tested. These are being characterised, as well as waveguide bend losses.

Substrate metallisation: The patterned metallisation of the carrier is achieved using an additive pattern plating process. The underlying principle of this additive technique is to deposit a thin blanket layer of gold over the entire sample followed by patterning with photoresist so as to cover the areas where metal deposition is not required. The exposed area of the gold layer is then plated to the required thickness (~1 µm). When the plating is complete, the resist is removed. Finally, an etching step is required to remove a sufficient thickness of gold in order to isolate the individual bumps and tracks.

Summary: The devices and the integration platform for the assembly of a 4 x 4 optoelectronic crosspoint switch have been described. We will report on the performance of the mirror structures and bumps, and on the progress made in the assembly and testing of the switch.

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References:

[1] M. Breen, D. Duane, R. German, K. Keswick, and R. Nolan. "Compliant Bumps for Adhesive Flip Chip Assembly." In J. H. Lau, editor, *Flip Chip Technologies,* chapter 7, McGraw-Hill, pp. 269-287, 1996.

[2] N. Suyal, F. Tooley, A. McCarthy, F. Bresson, A. Fritze, and A. Walker. "An optical polymer for photonic integration." *Proceedings of SPIE - the International Society for Optical Engineering,* Vol. 4417, pp. 214-221, 2001.

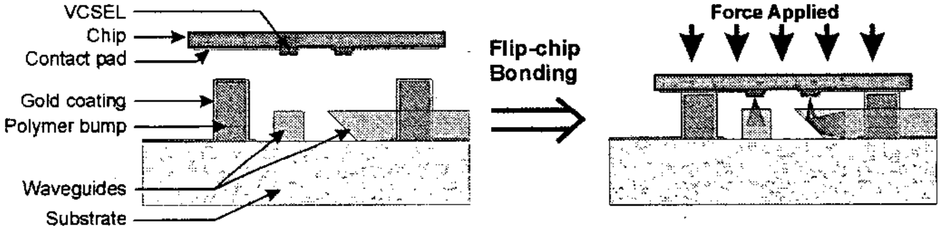

Figure 2: Cross sectional schematic diagrams of a VCSEL array device, being flip-chip bonded onto a substrate using compliant polymer bumps. The VCSEL outputs are coupled into the polymer waveguides using metallised or total-internal-reflection mirror structures.

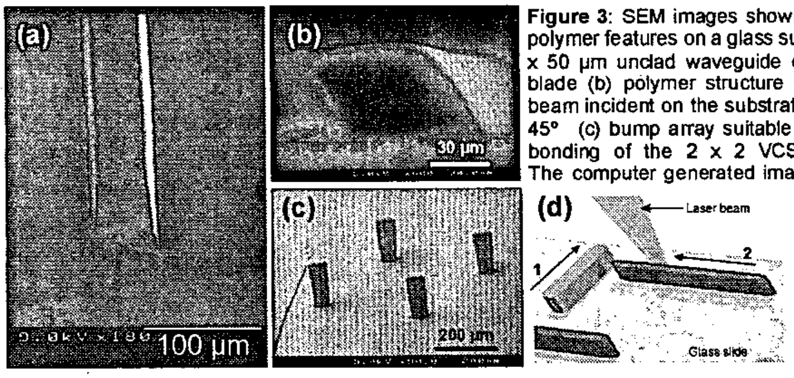

Figure 3: SEM images showing laser written polymer features on a glass substrate (a) ~50 x 50 µm unclad waveguide cut with a razor blade (b) polymer structure written with the beam incident on the substrate at an angle of 45° (c) bump array suitable for the flip-chip bonding of the 2 x 2 VCSEL array chip. The computer generated image in (d) shows the possible direct-write structures with the laser beam at 45° to the substrate.

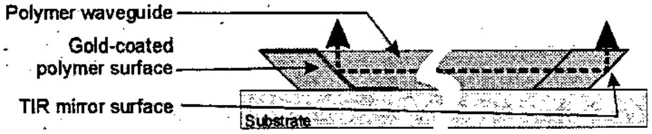

Figure 4: Schematic showing the principle of the 45° mirror structures for coupling into, & out of, waveguides.