Integrated Optical and Electronic Interconnect Printed Circuit Board Manufacturing

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1. Introduction

At high bit rates copper tracks in printed circuit boards (PCBs) suffer severe loss and pulse distortion due to radiation of electromagnetic waves, dispersion and bandwidth limitations. The loss can be overcome to some extent by transmitting higher power pulses and by changing the dielectric constant and loss tangent of the PCB substrate material. However, high power pulses consume power and can cause electro-migration which reduces the board lifetime, although the copper tracks can be surrounded by another metal to prevent this at the expense of further processing steps. The use of special board materials can be costly and some materials containing high dielectric constant crystallites can cause poor adhesion. The pulse distortion, dispersion and bandwidth limitations can be overcome to some extent by the use of pulse pre-emphasis and adaptive equalisation at further cost. Electromagnetic waves are radiated efficiently at high bit rates removing power from the track so causing loss, but more importantly they are also received efficiently by other nearby and distant copper tracks on the same PCB, or on adjacent PCBs, or PCBs and other electrical conductors outside of the system enclosure. This EMI crosstalk causes increased noise and so degrades the signal to noise ratio and the bit error rate of the copper track interconnections. Therefore, the main forces driving the development of alternative interconnect technologies are the EMI crosstalk, which becomes increasingly more serious as bit rates increase for longer and denser interconnects, and secondly the cost of overcoming the other problems that occur in copper interconnects at high bit rates.

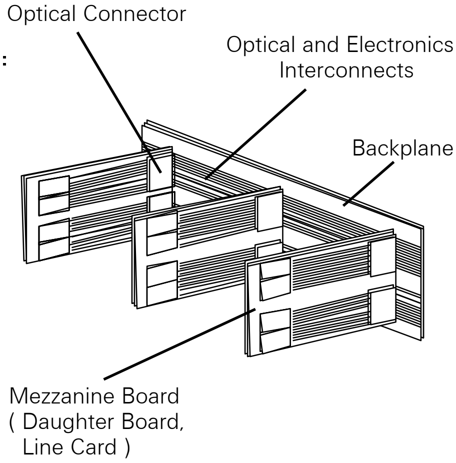


Fig.1: Schematic view of backplane Architecture.

Optical fibres have replaced copper cables for long distance, backbone and submarine applications where they offer wide bandwidths for low loss, produce and receive no electromagnetic interference, and are relatively low cost. Optical interconnects are beginning to penetrate the markets at shorter distances, such as in local area networks, and as their cost is reduced, will be used within the system enclosure.

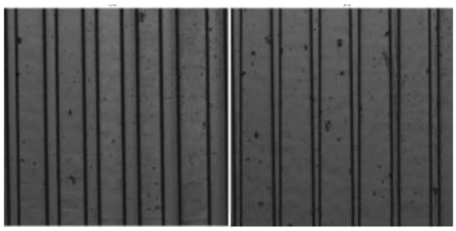


Fig.2: Photolithographically fabricated straight and tapered waveguides of a range of widths and taper ratios

The use of optics is expected to occur first where the problems for copper are most significant which is for high bit rate, dense interconnections in large area backplanes within non-conducting enclosures. Optical fibres are not the most convenient for interconnections within a system as they can only bend through a large radius of about 10 cm, otherwise light escapes from the fibre core into the cladding resulting in loss and signal corruption. Fibre connectors form a major part of the cost of the optical interconnect and a system with many fibres has many costly connectors. The fibres must be individually routed and errors in routing are time consuming to debug and correct. The fibres can be laid flat on the PCB plane and even bonded together within an epoxy layer, but this is not suited to low cost mass production. An alternative technology suitable for low cost mass production is that of multimode polymer buried channel optical waveguide interconnections within layers in the multilayer PCB formed by the same, or slightly modified, processes already available within PCB manufacturing facilities. Copper tracks are still required in such substrates to transmit power through the backplane (or motherboard), Figure 1, in order to power mezzanine (or line, or drive, or daughter) boards and copper is still a practical and low cost option at low data rates.

Hence, there is a need to develop a new type of multilayer hybrid PCB in which optical waveguide interconnects are used for the highest data rates, with copper tracks for lower data rates and for power lines and earth planes. These issues have been anticipated by system design companies such as Xyratex Technology, IBM Zurich and Siemens C-Labs, microprocessor designers such as Intel and materials development companies such as Dow Corning, NTT, Rohm and Haas and Exxelis, who have instituted research in their own laboratories and in associated universities into optical waveguide interconnect technology.

Leading Universities and Research Institutions such as Cambridge (CAPE), University College London (UCL), Heriot Watt University, Loughborough University, National Physical Laboratory (NPL), IMEC - Ghent University, TFCG Microsystems, Belgium, Paderborn University, Germany, Helsinki University of Technology, Espoo, Finland and ETRI, South Korea are developing novel polymer materials, developing fabrication techniques, discovering design rules for waveguide layout and carrying out precision characterisation.

Optical buried channel waveguides usually have a core with an approximately square or rectangular cross section made from a high refractive index (slow speed of light) material and a cladding surrounding the core of a lower refractive index (higher speed of light). They operate by total internal reflection (TIR) in a similar way to optical fibres. The cost of waveguide connectors is minimised by choosing to use multimode waveguides which typically have cores of 40 - 70micron width which can tolerate more misalignment than single mode waveguides. The optical buried channel waveguides are formed on a plane by a variety of fabrication techniques which can be implemented, after slight adaptation, in PCB manufacturers. Arrays of low-cost vertical cavity surface emitting lasers (VCSELs) emitting 850 nm wavelength and arrays of photodiodes operating at 10 Gb/s are readily available at low-cost for use in optical transmitters and receivers. At this wavelength, polymer is a convenient low-loss material for use as the core and cladding. Polymers can be chosen or designed which can be easily processed to form waveguides at low temperatures, have low cost, and can withstand subsequent high temperature reflow soldering processes.

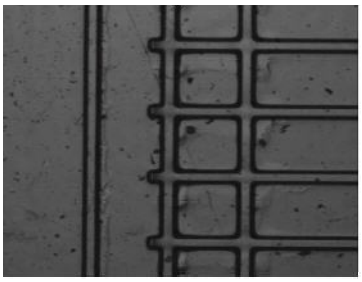


Fig 3: Photolithographically fabricated 90º waveguide crossings

For optical printed circuit boards to be brought into widespread use, layout tools must be made readily available which design both the copper tracks and the optical waveguides [1]. In 2006 David R. Selviah of UCL, formed a large consortium of complementary universities and companies and led a successful bid to carry out a Flagship project entitled "Integrated Optical and Electronic Interconnect PCB Manufacturing (OPCB)" in the Innovative Electronics Manufacturing Research Centre (IeMRC). The consortium companies represented a complete supply and manufacturing chain and route to market for the polymer waveguide technology including companies manufacturing PCB layout tools, computer programs for modelling the behaviour of multimode waveguides, developing and supplying low loss polymer formulations, manufacturing multilayer PCBs, supplying printer fabrication equipment together with end user system companies who require optical printed circuit boards. The following sections describe the project's objectives, the approaches being taken and some examples of what has been achieved so far in the project with an indication of future directions.

2. The OPCB Project's Objectives

This three-year research project is exploring novel methods, compatible with traditional multilayer PCB manufacturing processes, for the manufacture of optical waveguides capable of operating at very high data rates within an optical layer in the PCB. Several process routes are under investigation, each with different levels of risk and cost. In addition, modifications are being researched for commercial computer aided design software for PCBs to allow them to also layout optical waveguide patterns. The detailed objectives are:

(a To establish waveguide design rules for several different manufacturing techniques and to incorporate them into commercial design rule checker and constraint manager layout software for printed circuit boards so that PCB designers can easily incorporate optical connection layers without detailed knowledge of the optics involved. To investigate and understand the effect of waveguide wall roughness and cross sectional shape on the behaviour of light and the effect on waveguide loss.

(b) To develop low cost manufacturing techniques for integrated Optical and Electronic interconnected Printed Circuit Boards, OPCBs. To develop and to compare the commercial and technological benefits of several optical printed circuit board manufacturing technologies – photolithography, direct laser-writing, laser ablation, embossing, extrusion and ink-jet printing – for high data rate, small and large (19"), rigid and flexible, printed circuit boards so that it will be clear which technology is best for each type of PCB. To characterise the behaviour of optical waveguide backplane systems in real world conditions, including temperature cycling, high humidity and vibration.

(c) To design a commercial, low cost, optical connector (dismountable, passive, self-aligning, mid-board) as the next stage from the prototype demonstrated in an earlier project (Storlite Project). To develop novel connector designs suited for interfacing flip chip lasers and photodiodes to OPCBs, and OPCBs to OPCBs through a right angle connector.

3. The Consortium

The consortium consists of 3 universities and 10 companies. Dave Milward of Xyratex Technology acts as Industrial Project Manager, while David R. Selviah of UCL is the project Technical Leader.

The funding for the project is provided by EPSRC through the IeMRC and by the consortium industrial partners amounting to a total of £1.3 million over 3 years. The EPSRC funding is divided between the 3 universities who carry out the bulk of the research described in subsequent sections.

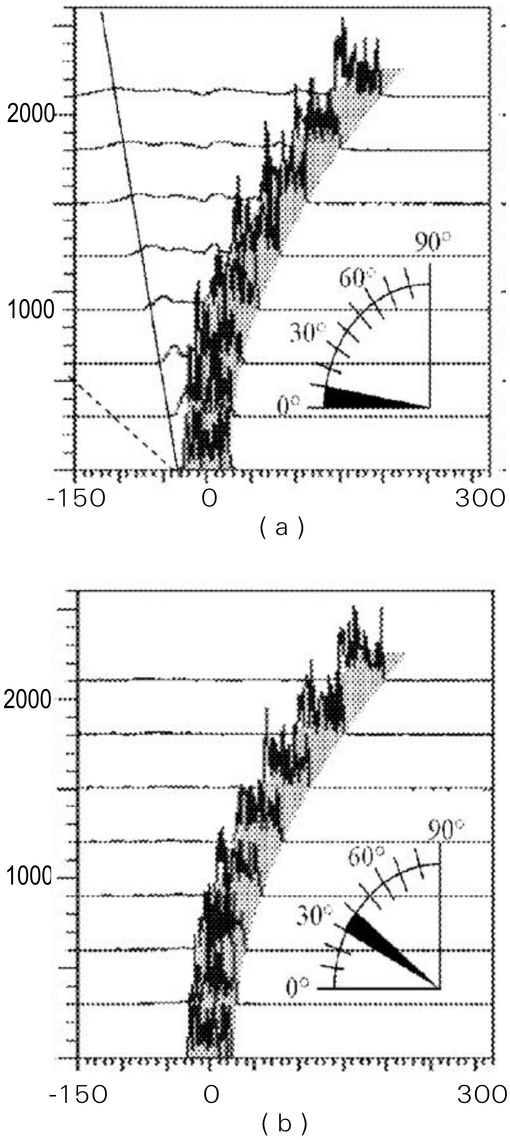


Fig 4: Computer simulations of the optical field in a 90º waveguide bend
(a) at the start of the bend after a straight input waveguide showing radiated light beyond the outside of the bend,
(b) a third of the distance along the bend

4. Waveguide Layout, Modelling and Characterisation

University College London (UCL) lay out waveguide test patterns and system demonstrator waveguide interconnection patterns using modifications they have made to Cadence software layout tools. Their experimental measurements of these waveguide components after fabrication, Figures 2 and 3, in various polymers using a range of fabrication techniques are compared to their computer modelled results in order to gain a detailed understanding of the physical behaviour of coherent light in multi-mode waveguides and so to establish design rules [2-10]. Figure 4 shows an example of the modelled field in a multi-mode waveguide bend. A novel theory is being developed for analysing the effects of waveguide side-wall roughness. Low-cost, self-alignment techniques are being developed for use in optical connectors for aligning lasers and photodiodes to waveguide end facets and the misalignment tolerances are being assessed. UCL, as lead university, forges international links with other waveguide researchers such as in their recent mutually beneficial visit to IMEC - Ghent University, TFCG Microsystems, Belgium and promotes and disseminates their own [2-10] and the consortium's results [13-14] via a range of international conferences and journal articles.

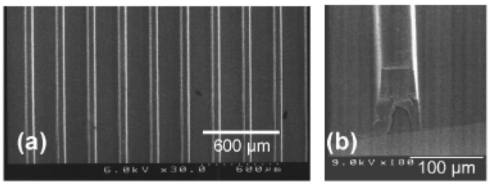
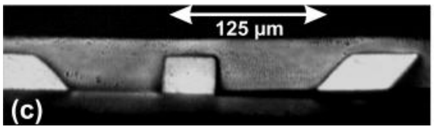
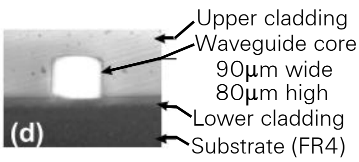


Fig 5: The SEM images in (a) show Directly written, unclad polymer waveguides (~50 x 50µm) on a glass substrate. The guides are on a 250µm pitch and the cross-section of one of the guides is shown in (b) - It was cut using a scalpel blade. The optical microscope images in (c) & (d) show end-on views of back-illuminated cladded structures fabricated on FR4 substrates - those in (c) were fabricated using a normal and ±45 angled beams having a flat-top intensity profile. The core shown in (d) was written at 30 mm/s using a focussed Gaussian beam.





5. Laser Direct Writing of Waveguides

Heriot-Watt University [11,12] has previously developed a direct UV-laser-writing technique so as to form multimode polymer waveguides. In the OPCB project, the key aim is to explore how these techniques can be extended to suit optical backplane applications – both in the context of scale and manufacturability. Fabricating waveguides over metre-scale boards requires not just the ability to write over large areas but also, if production time is to be minimised, faster writing speeds e.g. >50 mm/s. The HWU group has set up a laser-writing facility capable, in principle, of operating over an area 300 mm x 600 mm at up to 1 m/s. Using this system, they have been working on the challenge of writing well-defined, low-loss waveguides very much faster than the 100 ì m/s write speeds typically used in previous work, Figure 5. Using laser spots with tailored intensity profiles and an optimised photopolymer formulation, recent results have demonstrated speeds of around 50 mm/s, for writing 50ì m multimode acrylate waveguides. Both straight and curved guides can be fabricated. The HWU group is also exploring fabrication techniques by which their proven techniques for creating embedded 45º out-of-plane mirrors, Figure 5, can be made compatible with large board processing.

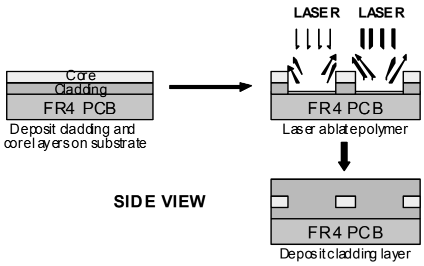


Fig 6: Schematic diagram of laser ablation for the formation of waveguide structures.

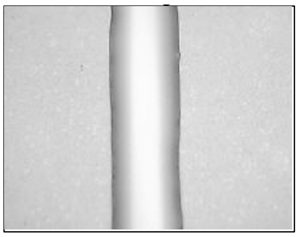


Fig 7: Plan view of ink jet deposited optical waveguide material on a modified glass surface (track is approximately 75micron wide).

6. Laser Ablation and Inkjet Printing of Waveguides

Loughborough University is investigating the laser ablation of polymer materials to form waveguides (fig. 6). Two routes are being investigated: the first involves the use of a commercial Nd:YAG system, based at an industrial partner, to machine waveguide structures. This method is attractive as it is utilising equipment already established in PCB manufacturing facilities for the drilling of microvias and therefore would not require additional capital investment. The effect of machining parameters on the depth and speed of ablation is being investigated, together with wall roughness. The second approach considers the use of an excimer laser to form waveguides. However, as this type of laser can use a mask projection technique to shape the beam spot, the fabrication of more complex 3D terminations, such as curved mirrors at the end of the waveguides, is also being investigated.

A significant aspect of the research at Loughborough covers the use of ink-jet printing to deposit polymer waveguide materials. This has the potential to enable fast printing over large areas. For ink-jet fabrication, a potential process route is expected to consist of the initial deposition of a cladding material layer, onto which the core material is jetted to create the appropriate waveguide structure. This will then be enclosed in a further layer of cladding. In order to create core structures with appropriate dimensions and cross-section, the viscosity and surface tension of the jettable core material is crucial in achieving optimum results. Furthermore, the interaction of the ink-jetted material with the substrate is key in determining the wetting behaviour and the stability of the liquid as-deposited structure.Fig 7 shows a line of UV curing optical waveguide material ink-jet deposited onto a glass substrate for which surface modification was carried out to control the wetting, enabling a feature approximately 75microns wide and15 microns high to be formed.

7. Conclusions

The research being carried out within the IeMRC OPCB project by the 13 member consortium addresses a wide range of problems that need to be solved before multimode polymer waveguide technology becomes widely available. The research ranges from formulation of novel polymers to development of new processes and methods for deposition and patterning of the materials suitable for large area substrates and applicable to PCB manufacturing environments. The characterisation and modelling of these structures will lead to the establishment of design rules for optical waveguide components such as bends and tapers which can be implemented within design and layout software tools, further aiding the uptake of this technology. Further details of the research can be found in [13-16].

8. Acknowledgments

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9. References

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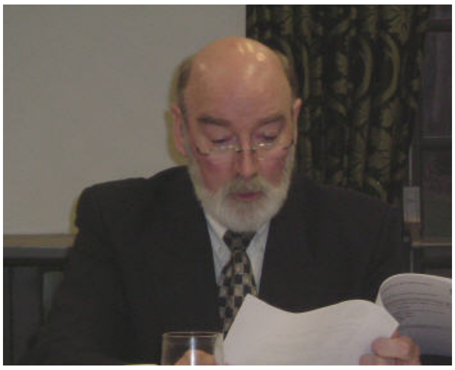
The Membership Secretary's notes May 2008



The Institute now has in excess of 225 Members, drawn from all parts of our Industry; an Industry which is stabilizing across Europe, and increasingly seeing the benefits of belonging to an organization which exists solely for its members.

We are providing six evening Seminars, two Symposia and a one-week foundation course as well as our quarterly journal this year and I would like to thank everyone who is supporting us at these events.

We would like to send our congratulations to **Rex Rosario**, who has been elected to the board of the **IPC.** Rex is one of our longest serving members and is also the Chairman of the EIPC, a platform which will enable him to champion the cause of the European PCB Industry.

Soldertec Global/Tin Technology has announced their Annual Lead-Free Solder Awards and **Bob Willis** proudly receives the 'Process Development Award', in recognition of his many achievements and enthusiasm in assisting industry in the preparation for the implementation of lead-free legislation. Bob coordinates the SMART Group activity for the EU project LEADOUT, currently Europe's largest funded research project. Bob has been a Council Member of the ICT for many years.

Walt Custer is also in the news again. Prior to his Keynote speech to the Wallstreet Journal, Walt was introduced, not as plain old Walt Custer, or even the famous Walt Custer. Apparently, he is now the **very** famous Walt Custer!

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