PCB-Integrated Polymer Photonic Devices

N. Bamiedakis, A. Hashim, J. Beals IV,
R. V. Penty, I. H. White
Electrical Engineering Division, Department of Engineering
University of Cambridge, 9 JJ Thomson Av.
Cambridge, CB3 0FA, UK
nb301@cam.ac.uk

T. Hutter, S. R. Elliott
Department of Chemistry
University of Cambridge, Lensfield Road
Cambridge, CB2 1EW, UK

Abstract— **This paper describes recent achievements in the integration of polymer waveguides onto low-cost PCBs and their further functionalisation with active materials for the formation of hybrid photonic devices suitable for use in various application areas.**

Keywords- optical interconnects; opto-electronic printed circuit boards; polymer waveguides;

I. INTRODUCTION

The deployment of optics in board-level communications has received particular interest in recent years due to the increasing demand for interconnection bandwidth in servers, data centres and supercomputers [1, 2]. The limited bandwidth of electrical interconnects as well as their inherent disadvantages, such as susceptibility to electromagnetic interference, size and density issues and increased requirements in terms of power consumption and thermal management when operating at high data rates (> 5 Gb/s), have led to the consideration of the use of optics for short-reach on-board and on-chip communication links. While for on-chip communications silicon photonics is the leading candidate, owing to its compatibility with CMOS technologies, for board-level communications (card-to-card and module-to-module, i.e. link lengths in the range 0.1-1 m), polymer-based waveguide technologies appear to be the most promising solution owing to their potential to be cost-effectively integrated onto conventional printed circuit boards (PCBs). Firstly, a new range of polymer materials has been recently developed possessing the essential mechanical and optical properties to be directly integrated with electronics onto PCBs and the environmental stability to withstand the operating conditions of standard electronic systems [3, 4]. Secondly, multimode waveguides are developed for use as they offer relaxed alignment tolerances and therefore, reduced assembly and packaging costs in the formation of optoelectronic (OE) PCBs. Numerous different integration approaches have been proposed for the formation of such hybrid systems and various demonstrators have been reported in recent years differing in system design, fabrication and assembly methods. Significant work has been carried out in this area by our research group, resulting in novel PCB-integrated polymeric photonic components and the demonstration of complex board-level polymeric architectures.

The potential to cost-effectively form optical waveguides on PCBs can be further enhanced by providing additional functionality in the optical layer, thus enabling the use of OE PCBs in other applications areas than optical interconnects, such as sensing and display. Towards this goal, collaborative research has been carried out looking into the functionalisation of the polymer waveguides with different materials such as liquid crystals, active glasses and chemical dyes and has resulted in the demonstration of novel photonic structures. In this paper therefore, we review our recent work on the integration of polymer multimode waveguides on PCBs and present various demonstrated hybrid polymeric photonic devices. Specifically, we present optoelectronic units and functionalised polymeric devices formed on low-cost PCBs such as (i) a 10 Gb/s optical transceiver, (ii) a PCB-integrated liquid-crystal optical gate, and (iii) a PCB-integrated ammonia optical sensor. The work reported here highlights the versatility of such hybrid polymeric photonic devices and demonstrates their suitability for use in a wide range of applications areas.

II. POLYMER MATERIALS AND OE PCBS

The work reported here is based on the use of siloxane polymer materials developed by Dow Corning Corp. (OE-4140 and OE-4141). These polymer materials have been appropriately engineered to possess the essential properties for integration onto PCBs: they can withstand the high temperature environments (in excess of 250°C) required for solder reflow and PCB lamination processes, exhibit low optical losses below 0.05 dB/cm at 850 nm, and the essential environmental stability for a long-life operation [5]. While the materials also allow patterning with processes suitable for large-scale manufacturing such as stamping and embossing, the waveguide components presented here are fabricated with standard photolithographic techniques.

The basic design of the OE PCBs is based on low-cost FR4 substrates and assumes that the electronic and photonic components reside on different sides of the board. The top side of the board accommodates all electronic components and signal tracks, whilst the optical waveguides are formed on the board underside (Fig. 1a). The interface between the optical and electrical layers of the board is achieved with simple electro-optic connectors that accommodate the active optoelectronic devices (laser and photodiode) and which can be mounted onto the board with conventional pick-and-place assembly tools. The use of such connectors eliminates the need to form any beam-turning elements in the optical layer thereby simplifying the fabrication of the OE PCBs. To allow integration with the different active materials, selected waveguide regions are left exposed to the air. Details of this board-level integration method can be found in [6].

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III. HYBRID POLYMERIC PHOTONIC DEVICES

A. 10 Gb/s PCB-integrated optical transceiver

As a proof-of-principle of the proposed on-board integration method, a 10 Gb/s optical transceiver is formed on low-cost FR4 substrates with conventional methods of PCB manufacturing (Fig. 1). This optoelectronic unit integrates the electronic driving circuits of the transmitter and receiver modules with a polymer 1×2 Y-splitter enabling bidirectional 10 Gb/s optical communication [6]. The unit can be deployed as a front-end optical unit interfacing with standard MMF.

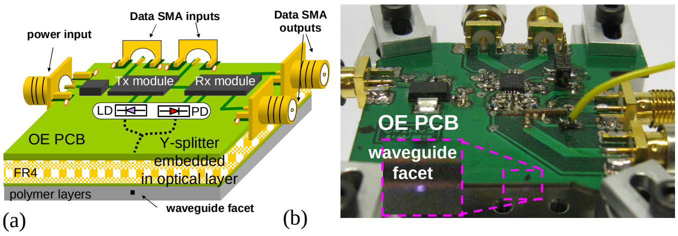

Figure 1. (a) Schematic of realised optical transceiver and (b) photograph of the actual unit with inset picture of illuminated output waveguide facet.

B. PCB-integrated liquid-crystal optical gate

Polymer multimode waveguides are integrated with liquid-crystal (LC) materials on standard FR4 substrates forming an active optical cladding switch (Fig. 2). The copper layer of the PCB is used to apply an electrical field across the LC-waveguide interaction region and control the orientation of the LC molecules and therefore, the optical absorption along the waveguide structure. Low ON-state losses of 0.5 dB are demonstrated while a 15 dB extinction ratio between the ON and OFF state is achieved over a wide wavelength range [7].

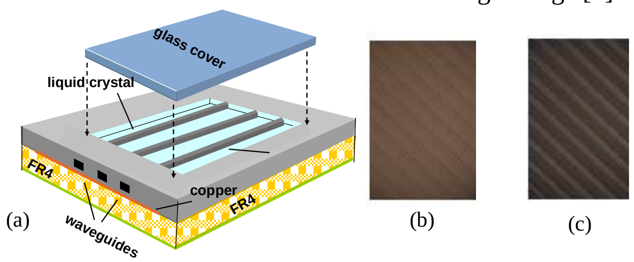

Figure 2. (a) Schematic of the liquid-crystal optical switch and images of the optical waveguides in the (b) ON and (c) OFF state.

C. PCB-integrated ammonia gas sensor

A platform for the formation of low-cost PCB-integrated optical gas sensors has been developed. Regions of polymer waveguides integrated onto PCBs are left exposed to the air and are coated with chemical dyes that are sensitive to the presence of specific analytes (Fig. 3a). The sensor operation relies on the change in optical absorption of the dye-coated waveguide region as a function of the concentration of the analyte's molecules in the air. The use of waveguide arrays coated with different dyes can further enable detection of multiple gases from a single chip and the generation of a "behaviour fingerprint" for each analyte of interest. As a proof-of-principle, polymer multimode waveguides are fabricated on FR4 substrates and functionalised with chemical dyes that are sensitive to the presence of ammonia (NH_3) (Fig. 3) [8]. Linear sensor operation is achieved with both good reversibility and repeatability and with sensitivities of approximately 30 ppm. The potential to detect multiple analytes from a single device is also demonstrated using principal components analysis (PCA).

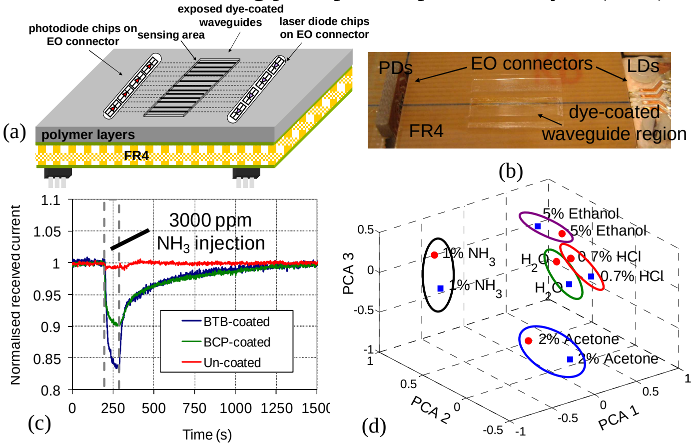

Figure 3. (a) Schematic of PCB-integrated optical sensor, (b) image of realised proof-of-principle demonstrator, (c) typical response to NH_3 presence and (d) results of PCA analysis on the sensor response to different analytes .

IV. CONCLUSION

Multimode polymer waveguides constitute a promising candidate for use in board-level optical interconnections as they can be cost-effectively integrated onto standard PCBs. The further functionalisation of the optical waveguides with active materials can result in hybrid polymeric photonic devices suitable for use in other application areas. Recent achievements in this field demonstrate the potential of the technology and provide promising incentive for further development.

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