Hybrid Integration of Optical Polymer Waveguides and 25 GHz Photo Detector Arrays

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***Abstract*— We demonstrate hybrid integration of very high-speed (25 GHz) photodetector arrays vertically coupled with polymer waveguides via a 45° mirror. The fiber-waveguide-detector insertion loss is less than 2dB, the detector responsivity is larger than 0.4mA/mW, and the crosstalk level is around -30dB.**

I. Introduction

Recent progress in optical communication networks has led to the growing need for highly functional, small footprint, low power consumption and low-cost optical modules. Integrating multiple optical functions into a single device is a key step for achieving these goals. With hybrid integration technology, discrete elements can be made each on the best suited material system and can be tested and selected prior to assembly. Hybrid integration can offer the benefits of micro-optical packaging and allow for further miniaturization, higher degree of machine-assisted assembly, less fiber connections and potentially higher performance and reliability.

Polymer planar light wave circuit (P2LC) technology is attractive because it offers the potential of fairly simple and low cost fabrication based on low-temperature processes and low-cost packaging involving passive alignment [1-2]. The optical loss of optical polymers has been reduced to less than 0.1dB/cm recently [3]. Polymer waveguides can be patterned into different geometries, allowing different optical signal processing functions such as wavelength routing, multiplexing and switching to be performed. Passive optical functions can also be implemented in the form of thin film elements featuring very small size, high optical performance and virtually temperature independence. Furthermore, optoelectronic devices such as photodetectors (PDs) and laser diodes (LDs) can be incorporated into the polymer board, perspectively in a (semi)automatic manner by means of a pick-and-place machine.

In this paper, we address the hybrid integration of single PDs and photo detector arrays (PDAs) into the P2LC platform using a vertical coupling scheme via 45° turning mirrors. Particularly, we focus on very-high speed PDs with cut-off frequencies in the 25 GHz range which play a crucial role in the current development of 100GHz transmission systems (e.g. DQPSK; 4x 25 Gb/s wavelength multiplexing). Figures for insertion loss, detector responsivity, crosstalk level and high frequency response will be presented.

II. Fabrication Technology

Fig. 1 depicts the vertical coupling scheme for a bottom illuminated PD coupled to the P2LC waveguide via an integrated 45° mirror. Inserted are the side view of the 45° mirror and the top view of a mounted PD. The polymer material is commercially available and utilized in qualified devices. Buried waveguides are formed using conventional spin-on and reactive ion etching techniques. Silicon is used as substrate. The refractive index contrast (Δn) can be readily adjusted between 0.06 and 0.20 by varying the composition of the waveguide core material. Using e.g. Δn =0.06 the cross-section of the single-mode waveguide core measures about 6x6 μm^2. The typical waveguide loss is around 0.5dB/cm at 1550nm and 0.4dB/cm at 1310nm.

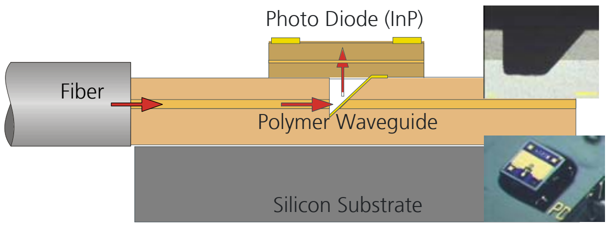

Fig. 1 Coupling of a planar photo diode to the polymer optical motherboard via an integrated 45° mirror

The 45° mirror can be created either by using an angled dicing saw or by locally etching the polymer material with the aid of grey-tone mask lithography and subsequent reactive ion etching. It should be emphasized that the sawing process leaves optically smooth waveguide and mirror facets, thanks to an inherent polishing effect. This behavior is believed to be unique to polymer materials, as contrasted to inorganic substances. After trench formation a thin reflecting Au metal layer is deposited on the mirror facet by oblique thermal evaporation ensuring the waveguide output facet to be left uncoated. The PD is placed on top of the polymer chip in a purely passive way, by a state-of-the-art bonder with positioning precision of ~1um. The PD is fixed by UV glue with adequate index matching to suppress back reflection. Shear force tests showed critical bonding values of up to 20 N/mm^2. The backside of the PD is AR coated against this glue which completely fills the mirror trench. The mirror loss measured with a multi-mode fiber is around 1 dB. The actual PD coupling loss of course also depends on the diameter of the

PD active area, its alignment position, and how it matches the actual beam spot. Using a 25 Gb/s capable PD with a typical active diameter of some 20 µm an insertion loss of only 1.8 dB was obtained at best so far, including fiber/chip coupling loss and the propagation loss of a 3 mm long polymer waveguide.

The bottom illuminated PD is designed with a full p-metal contact on its top side which facilitates uniform current flow and serves as optical reflector for the laser light to double-pass the absorbing layer. This is beneficial regarding achievable responsivity particularly with very high-frequency PDs, the absorption layer thickness of which is limited by the transit time to the order of 1 µm. On the other hand, the back illuminated PD is more sensitive to beam divergence because of the longer optical path of the beam between waveguide output and the active PD region. By thinning the PD substrate and applying a tapered waveguide output, especially when using waveguides of higher index contrast, the effective beam diameter at the active PD region can be kept as small as ~10µm ($1/e^2$). This value is fairly well below the active diameter of PDs suitable for 25 Gb/s reception, a bit rate which is in the focus now for 100 Gb/s transmission applications (4x25 Gb/s wavelength multiplexed or DQPSK schemes).

III. PhotoDetector Array coupling

Fig. 2 schematically illustrates a 4-channel fiber-waveguide-detector array (PDA) which was fabricated and characterized. The photograph at the bottom shows a completed device comprised of the surface-mounted detector array chip with four individual PDs (20 µm diam.), the P2LC waveguide board and four input fibers attached to the polymer waveguides using on-chip alignment grooves. The center spacing between the waveguides is 250 µm, which allows the use of standard fiber ribbons. The total chip measures 5 mm (length) by 1.3 mm (width).

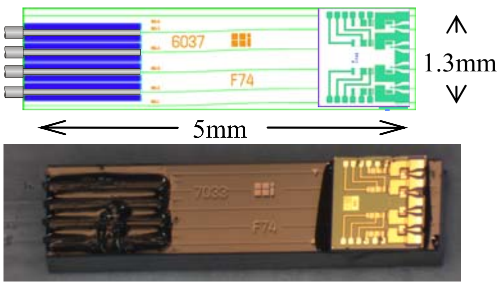

Fig. 2 4-channel fiber-waveguide-detector array.

The optimal coupling position was carefully defined in terms of waveguide position, cladding/core layer thickness and width of the mirror trench. The PDA is then mounted on top of the 45° mirror at the proper location and fixed with UV glue. Finally the fiber array is plugged in and glued for the measurements. The measured responsivity mostly varied between 0.3 mA/mW to 0.4 mA/mW, with the highest value being 0.43 mA/mW. The results have to be compared to the reference value of 0.65 mA/mW of the sole PD obtained from direct fiber illumination. The static crosstalk level was found to be on a similar level, -28 dB to -30 dB, for any of the individual PD elements within the array, suggesting stray light to be a limiting factor. The polarization dependent loss is around 0.6 dB and the optical return loss into the launching fiber (back-reflection) was determined to be lower than -35 dB.

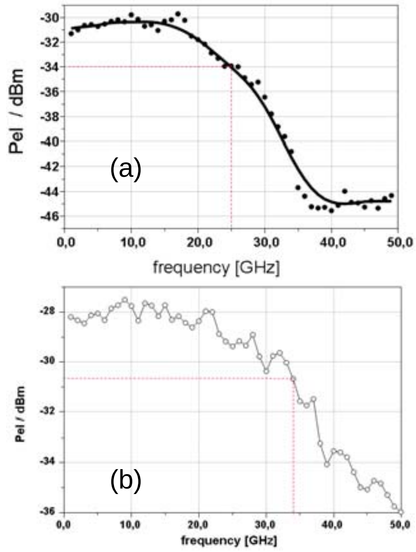

Fig. 3 PD frequency response, (a) without impedance matching and (b) with impedance matching.

Fig. 3 shows the small-signal frequency response of a mounted PD chip. The measurement was performed directly on the chip using a suitable RF probe head. Without dedicated electronics for 50 Ω impedance matching, the 3 dB bandwidth is at 25 GHz, and by applying impedance matching the bandwidth increases to 34 GHz (Fig. 3(b)), however at the expense of responsivity.

IV. Conclusion

To summarize, we have demonstrated hybrid integration of polymer waveguides and photodetectors using a vertical coupling scheme. The easy-to-fabricate, yet efficient 45° mirror is one of the key features of the polymer platform. Integrated 4-channel arrays with 25 Gb/s capability showed low insertion loss, good responsivity, fairly low crosstalk and back-reflection, which will allow their application to advanced receiver architectures for 100 Gb/s optical transmission systems.

V. Acknowledgements

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