Board-Level Single-mode Polymer Optical Waveguides

Ahmed Elmogi[1,2,3], Erwin Bosman[1], Sandeep Kalathimekkad[1], Nuria Teigell Beneitez[1], Rafik Guindi[3], Jeroen Missinne[1], Geert Van Steenberge[1]

[1]Centre for Microsystems Technology (CMST), imec and Ghent University, Gent, Belgium
[2]KACST-Intel Consortium Center of Excellence in Nano-manufacturing Applications (CENA), Riyadh, Saudi Arabia
[3]Nano-electronics Integrated Systems Center (NISC), Nile University, Cairo, Egypt

In optical interconnects, there is an increasing discrepancy between current proposals for optical backplanes, which strongly focus on multimodal waveguides, and those for very high capacity transmitter and receiver modules being realized in silicon photonics, which focus on single mode transmission systems. In this paper we present a board-level single mode polymer optical waveguide technology which may merge these two worlds. First, the refractive indices of selected commercially available polymers have been measured, and used as an input for the design of the single-mode waveguides. Simulations are performed using an FDTD (finite-difference time domain) method (Lumerical). Depending on the core/cladding material combination, point-to-point square waveguide structures, with typical dimensions between 1x1 μm^2 and 5x5 μm^2, have been fabricated by laser direct imaging (LDI).

Introduction

Optical interconnects are being used for shorter and shorter distances, and the first (near) commercial demonstrations of optical transmission over the back plane of computing systems are starting to appear. However, there is an increasing discrepancy between current proposals for optical backplanes, which strongly focus on multimodal waveguides [1-2], and those for very high capacity transmitter and receiver modules being realized in silicon photonics, which focus on single mode transmission systems. Fabrication of single mode polymer waveguides on standard printed circuit boards (PCBs) is extremely challenging, as the waveguide patterning technology has to be compatible with large panels, being mechanically instable. Amongst all reported single mode waveguide technologies, laser direct imaging was selected as the most promising approach. This technique is mask-less which allows faster prototyping in contrast to conventional mask-based photolithographic approaches in which a mask first has to be designed and fabricated before waveguides can be produced. Hence, the waveguide core can be directly patterned according to the desired pattern. Moreover, this technique is capable of patterning high resolution features with long and linear dimensions over comparatively large planar areas.

The waveguide models were simulated based on a finite difference time domain (FDTD) method (Lumerical) to ensure the single mode operation at the telecom wavelengths. The graph in Figure 1 gives the relation between the maximum core size and the relative index difference between the core and cladding materials for single mode operation at a 1550 nm wavelength. For this simulation, the index of the cladding material was assumed to be 1.553, in agreement with the typical polymer cladding materials being used. It is clear that for a certain index contrast there is a corresponding maximum core size for single mode operation and the higher this index contrast, the smaller the single-mode core size. In this work, LightLink™ (core) and DWL-Epo were used as the waveguide core materials, in combination with respectively LightLink™ (cladding) and ormocer as cladding materials. The refractive indices of the LightLink core and cladding at 1550 nm are 1.506 and 1.481 respectively. But, the refractive index of the DWL-Epo material is estimated to be 1.556 at 1550 nm and the refractive index of ormocore material is 1.5375 at the same wavelength. Therefore, the maximum single-mode core sizes for the DWL-Epo and LightLink waveguides are about 4 µm and 3.8 µm respectively. The LDI design is developed based on the simulations results.

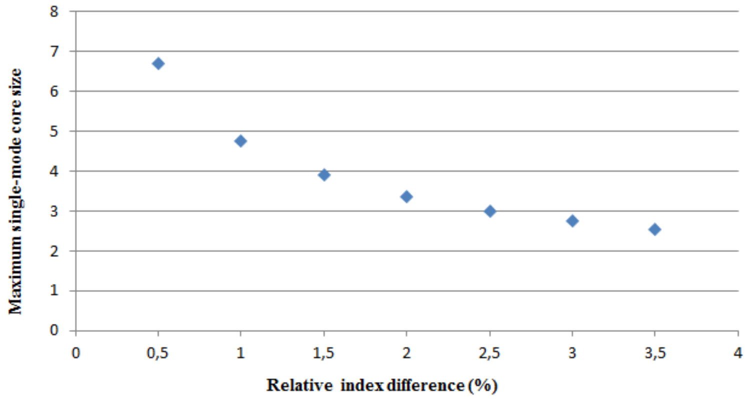


Figure 1: The maximum single-mode core size vs. the relative index difference

Waveguide Fabrication

The waveguide process flow is illustrated in Figure 2. Before depositing the waveguide layers, the FR4 substrate is cleaned by rinsing in acetone, then in a mix of acetone & IPA and then in DI water (2 minutes in each bath) and dried for 20 minutes on a hotplate at 120 °C. The optical materials are then deposited by means of spin coating and subsequently soft baked on a hotplate. Table 1 gives a detailed overview of the waveguide processing parameters for the two different core materials.

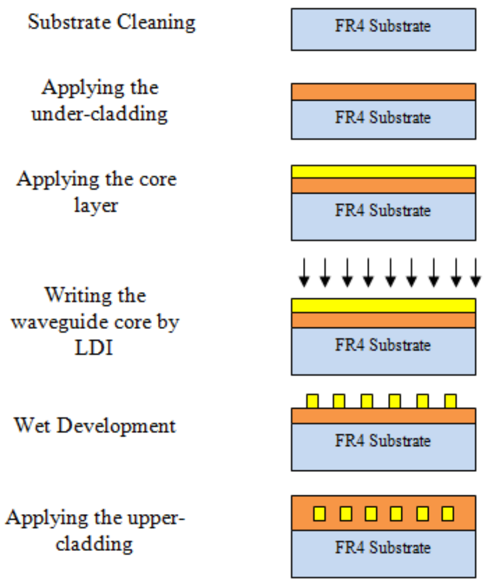


Figure 2: The process flow of the waveguide fabrication using Laser direct Imaging (LDI)

Table 1: The waveguide processing parameters

Process Step	LightLink cladding	LightLink core	DWL-Epo core	Ormocer (ormocore)
Soft bake	15 minutes @ 90 °C	30 minutes @ 90 °C	2 minutes @ 50 °C then 4 minutes @ 90 °C	4 minutes @ 80 °C
UV exposure	2 minutes (flood exposure) at 10 mwatt/cm^2 lamp intensity	LDI processing	LDI processing	2 minutes (flood exposure)) at 10 mwatt/cm^2 lamp intensity
Post exposure bake (PEB)	10 minutes @ 90 °C	10 minutes @ 90 °C	3 minutes @ 50 °C then 5 minutes @ 90 °C	2 minutes @ 80 °C
Development		20 seconds in LightLink XP-3636 developer then DI rinse	1 minute in mr-Dev 600 then 1 minute in IPA	
Hard bake	90 minutes @ 150 °C	90 minutes @ 150 °C	15 minutes @ 120 °C	90 minutes @ 150 °C

The laser imaging process was optimized by writing waveguides at different intensities and defocusing values so that the parameters, at which the waveguide width matches the design itself, can be determined. Figure 3 shows the effect of the laser intensity on the waveguide width for the two different materials. When the nominally 5µm-wide waveguide in the design was taken as a reference and the laser power equals 150 mW, it was found that the points, at which the intensity equals 239 mJ/cm^2 and 537 mJ/cm^2 are the optimum doses that match the 5 µm width for the LightLink and the DWL-Epo materials respectively.

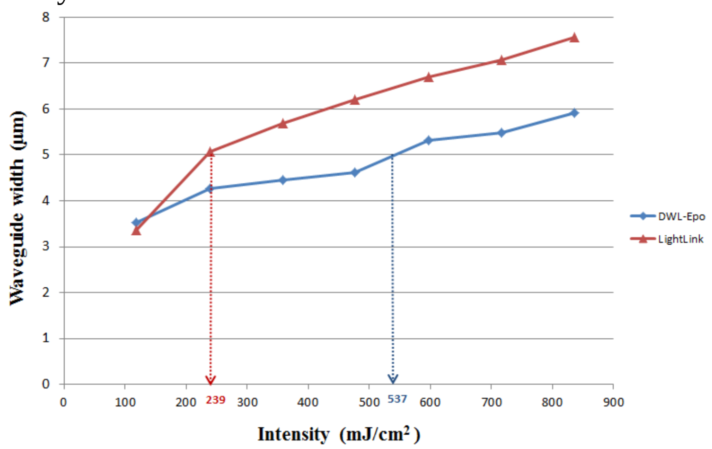


Figure 3: The relation between the laser intensity and the waveguide width

Scanning electron microscope (SEM) images of DWL-Epo patterned core of 3 µm thickness and width ranging from 1 to 5 µm are shown in Figure 4. Furthermore, cross section views of other waveguides arrays of the LightLink and the DWL-Epo on an FR4 substrate are shown in Figure 5. These waveguides are written using the laser parameters determined in Figure 3 in order to precisely match the waveguide dimensions. Optical profiler measurements (using Wyko NT3300) show the surface corrugation of the fabricated waveguides as introduced in Figure 6. Cut-back measurements are currently on-going in order to determine the propagation losses.

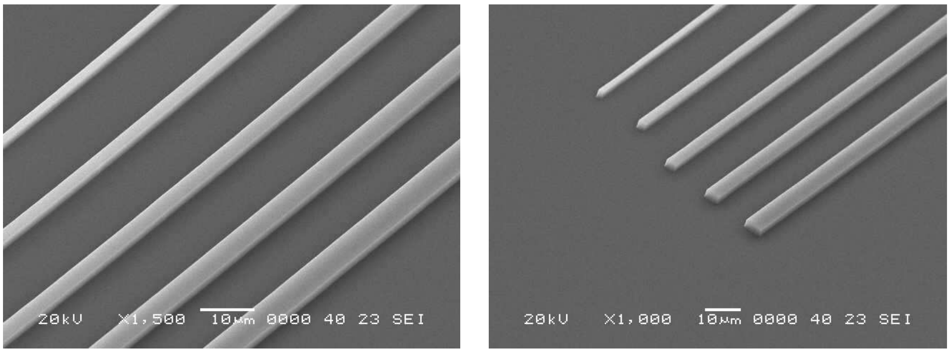


Figure 4: SEM images of the patterned DWL-Epo core layer

(a)

(b)

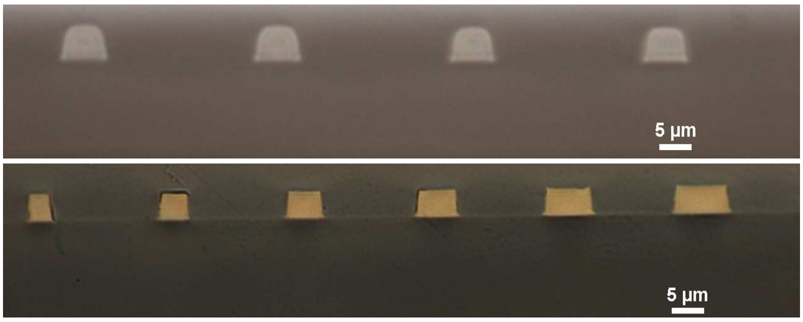
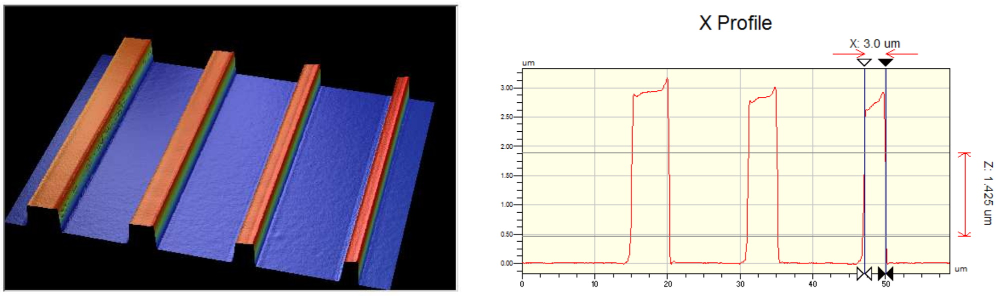


Figure 5: Cross section view of waveguides array (a) LightLink waveguides (b) DWL-Epo waveguides



(a) (b)

Figure 6: Surface corrugation of waveguides array (a) 3D view of the fabricated waveguides (b) the 2D view of waveguides array of 3 µm thickness and width ranging from 3 to 5 µm

Conclusion

In this paper, we have presented board level single-mode polymer waveguides fabricated by the laser direct imaging (LDI) technique. This technique is cost-effective and provides faster prototyping and fabrication of high resolution structures. The waveguides have been first simulated using an FDTD method. Then, square waveguides with dimensions of about 1 to 5 µm have been fabricated using LDI.

References

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