Integration of Printed Optical Waveguides in Printed Circuit Boards

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The integration of mass producible printed optical waveguides in conventional printed circuit boards (PCB) is the next step to establish optical data communication. We introduce a concept on how to manufacture flexographic printed optical waveguides according to the requirements of the integration in PCB production.

1 Introduction

To achieve higher data transmission rates in integrated systems optical data transmission plays a major role due to better electromagnetic compatibility. To utilize the advantages of optical data transmission highly integrated and mass producible optical waveguides on circuit board level are required [1].

The high volume production process addressed in this paper is flexographic printing, which allows the production of circle segment shaped optical waveguides on a planar substrate [2]. The approach to integrate printed optical waveguides in printed circuit boards (PCB) requires the waveguides to withstand production loads. Due to the PCB production being performed under heat influences up to 200°C, heat resistant substrates like polyimide (PI) are already widely used for flexible PCBs. This paper addresses the challenges in printing functional optical waveguides on this substrate.

2 Cladding concept

To implement optical data transmission, the core of the waveguide system is required to have a higher refractive index compared to its surrounding materials [3]. Due to the refractive index of the PI (Taiflex THKS200520ME) exceeding the refractive index of the used core varnish (J+S 390119) by about 0.15, a cladding layer is introduced [4]. This cladding is supposed to ensure the optical wave guidance while also protecting the waveguide against the upcoming PCB-integration process.

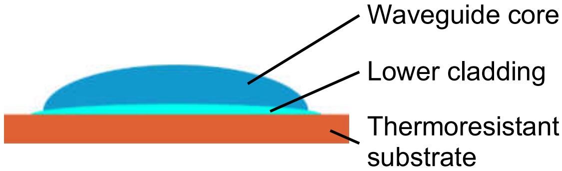

Fig. 1 *Concept for a printed optical waveguide on a printed lower cladding to detach the waveguide from the substrate*

In Fig. 1 the cladding concept is shown. To achieve a sufficient cladding surface quality the approach is to produce the cladding with flexographic printing as well. The waveguide core varnish is adapted, to allow for a slightly reduced refractive index and thus comply with the cladding material requirements. This is investigated by diluting the established core varnish with two monomers (M1 and M2), which are an integral component of according J+S 390119. Fig. 2 shows, that the dilution with component M2 results in a significant reduction of the refractive index by 0.004. Thus, the adapted material is sufficient to detach the waveguide core from the PI substrate.

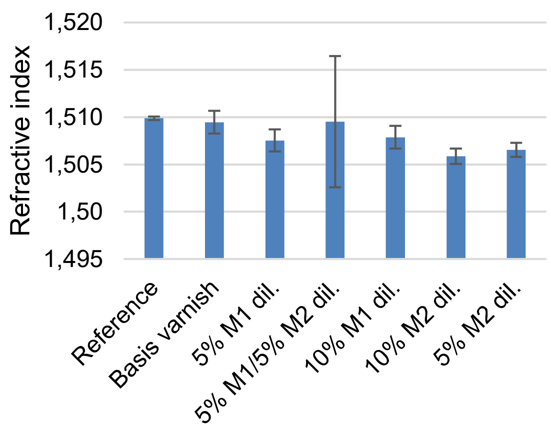

Fig. 2 *Refractive index measurements on core varnish and diluted core varnish, which can be used as a lower cladding material*

3 Printing accuracy

When printing a cladding below a waveguide, both structures have to be positioned on each other with high accuracy. This leads to the issue of flexographic printing systems, which are originally used for high volume graphical printing applications. An investigation is performed, comparing the printing results from two different printing forms with respective cladding and waveguide core structures. In these layouts, calibration crosses are placed in each corner of the substrate, to identify the positional offset.

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In Fig. 3 the positional difference in two planar dimensions is evaluated. Therefore, two neighbouring lines were measured under a confocal microscope to be evaluated with image processing methods. The standard deviation illustrated is the according accuracy of each measurements line detection algorithm. It can be seen, that with sufficient adjustment before the printing process over the whole printed substrate a printing accuracy of less than 50 µm is achieved. Although deviations from the reference (coordinate origins) are not similar oriented, as measurements of the top-right calibration cross shows.

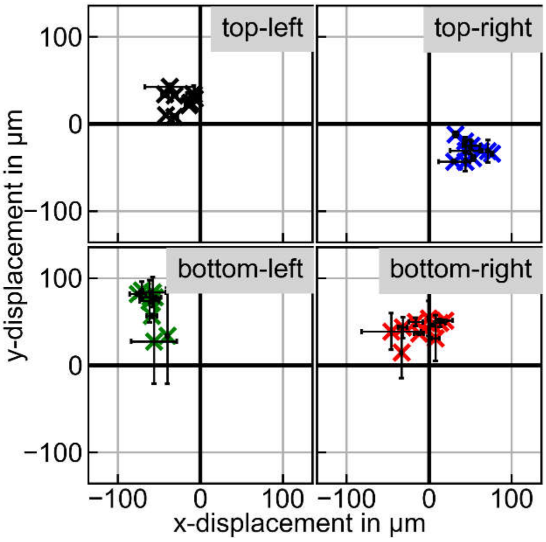

Fig. 3 *Displacement of the calibration crosses of the printed waveguide (measured points) compared to the previously printed cladding (coordinate origins)*

4 Optical Characterization

A waveguide with cladding is printed on PI and measured concerning its light guiding ability. Therefore, the light intensity distribution is compared between waveguides with a lower cladding printed on PI and waveguides without lower cladding printed on PMMA. Both waveguide systems are produced with 20 layers of core varnish and a printing stamp width of 200 µm. In Fig. 4.1 the input source of the experimental setup can be seen as it couples into the centre of a waveguide. It was observed that compared to waveguides on PMMA (Fig. 4.2) no light intensity can be measured at the output side of the PI waveguide at a length of 100 mm. When back cutting the waveguide on PI to a length of 25 mm (Fig. 4.3) a far lower intensity than the 100 mm waveguide on PMMA can be measured. It is assumed that either the refractive index of the cladding was not spatial equally lowered or due to printing defects the waveguide core touched the substrate. In both cases the light couples out of the waveguide core, which results in a high damping of the waveguide system and neglects the ability of this system to guide a sufficient amount of light.

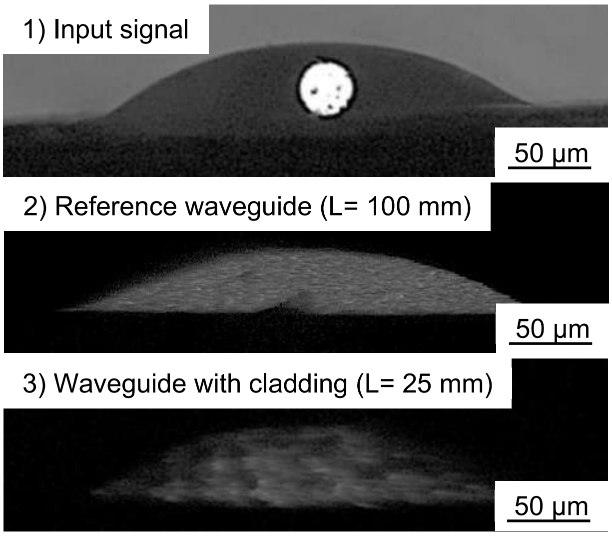

Fig. 4 *Example measurement of relative optical intensity distribution*

5 Summary

The cladding concept to print optical waveguides on various substrates is essential when it comes to industrial integration of high volume producible waveguides. To implement this concept, the established core varnish is diluted to reduce its refractive index by 0.004. By one layer of diluted cladding varnish and multiple layers of core varnish a waveguide system on PI is printed and tested. The result is a significant lower light guiding ability compared to a waveguide on PMMA with the same length due to local inhomogeneities in the cladding. In future work, the cladding layer has to be examined in more detail. Therefore, an even lower refractive index is targeted and printing tests, to evaluate homogeneity of the lower cladding will be conducted. The possibility of using a wider cladding compared to the waveguide and multiple cladding layers will also be considered.

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