Flexographic printing of multimode waveguides and optodic bonding of laser diodes for integrated polymer optical sensor systems

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We present flexographic printing as a manufacturing process for step index waveguides with typical widths of 150–400 µm and circular segment cross sections. Bare silicon laser diodes are subsequently butt coupled and mounted by optodic bonding. We describe the optical characteristics of the assembled system and specify the performance as a basis for future utilization.

1 Introduction

Several current technological trends account for a high demand for highly integrated, low-cost and mechanically flexible sensors in the future. Components made of lightweight composite materials are equipped with structural health monitoring systems [1]. The electrification of the car requires a comprehensive condition monitoring in the field of battery technology [2] and ubiquitous data collection of human biological signals in health applications leads to an increasing utilization of sensors [3]. Various conventional sensor systems are available for such applications, which are based on the conversion of the measured quantity into electrical quantities such as voltage and current. In comparison to such solutions planar optronic systems can be advantageous which are based on a direct conversion of the measured variable in properties of light. Such optical systems can be constituted entirely of polymers, offer simple multiplexing, inherent protection against surges and electromagnetic interactions, explosion protection and a relatively low mass.

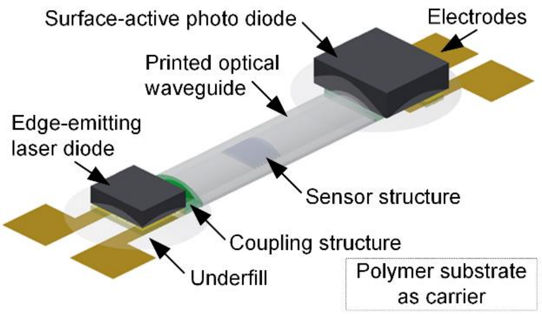

Fig. 1 *Planar optronic sensor system consisting of printed waveguide with integrated sensor structure, laser diode and photo diode.*

Planar optronic systems can be realized out of thin and large-area polymer films, on which optical waveguides carry out the distribution of light. For an efficient production in terms of costs and use of resources, the optical waveguides can be produced by printing technology. We present flexographic printing as a possible solution for this task. Due to the high specific power, reliability, small size and relatively low cost, we use unpackaged silicon laser diodes as light sources and bond them directly to polymer films. Alternatively, other groups work on highly integrated and fully organic light sources and detectors [4]. Figure 1 shows a planar optronic system consisting of a printed waveguide with integrated sensor structure, a laser diode as light source and a photodiode as detector.

2 Flexographic printing of multimode waveguides

Printing processes can be utilized for several different manufacturing purposes, combining a high throughput and a large processing area.

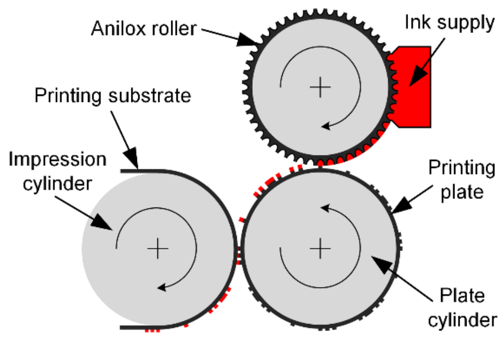

Fig. 2 *Flexographic printing unit.*

Flexographic printing is a letter press process in which three cylinders roll off of each other. An anilox roller with an engraved cell structure on the perimeter first collects liquid polymer from a chambered doctor blade. On the perimeter of a second cylinder, a printing plate with elevated structures on the surface is mounted. During contact of the printing form with the anilox roller, the elevated structures of the printing plate are wetted. The plate cylinder then

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rolls off the impression cylinder and generates a mirror-inverted image of the printing plate on the substrate by a deposition of fluid polymer, followed by UV curing. Figure 2 shows the working principle of a flexographic printing unit.

Waveguides are formed by a multi-layer approach in which single layers of polymer (Jaenecke + Schneemann Druckfarben, UV Glanzlack praegefaehig) with a refractive index of 1.516 (@ 635 nm) and widths of 100–500 µm are printed and cured subsequently on top of each other. The underlying substrate is made of polymethyl methacrylate (PMMA, Plexiglas XT 99524, thyssenkrupp Plastics) with a refractive index of 1.490 (@ 635 nm). Up to 45 printing cycles have been performed with a resulting height of 110 µm. Measurements of the optical attenuation currently result in the range of 0.5 dB/cm (@ 638 nm) with a material contribution of 0.1 dB/cm. The following figure shows a confocal microscopy of a printed waveguide section produced by 10 layers of acrylate.

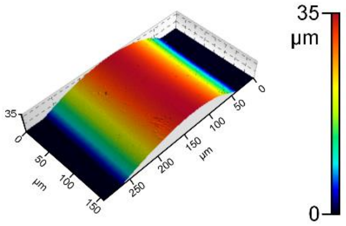

Fig. 3 *Confocal microscopy of printed waveguide; 10 layers of acrylate.*

3 Optodic bonding of laser diodes

To realize fully integrated, large area optronic systems we developed a bonding process to integrate and couple micro optoelectronic components as light sources or detectors onto the flexible polymer substrate. We chose a laser diode as light source in form of a bare chip with dimension of 300 x 250 x 100 µm emitting at 650 nm. Such small-sized dimension facilitates its miniature integration as well as alignment with the waveguide. The technique, called optodic bonding, is based on a flip-chip die bonding process [5]. Compared to conventional techniques, we apply UV-curing adhesives as bonding material to ensure both mechanical and electrical connections. The adhesives are accordingly cured by UV-irradiation from the sides or from the bottom (Fig. 4). In order to achieve a sufficient coupling efficiency of light propagation, we conducted geometry-based simulative investigations on the influences of the positioning accuracy on the coupling efficiency with the waveguide. With the help of the assembly system, we can achieve a lateral positioning accuracy of ±5 µm in the x- and y-direction. In addition to this, a large portion of the positioning deviation derives from the tilt of the laser diode during the bonding process. The simulation results indicate that little influence is caused for the optical coupling by the deviations of the lateral positioning within 5 µm. The basic rule for a little loss caused by the rotational deviations is the restriction of the tilt from -3° to 0° about x-axis, from -2.5° to 2.5° about y-axis and from 0° and 5° about z-axis.

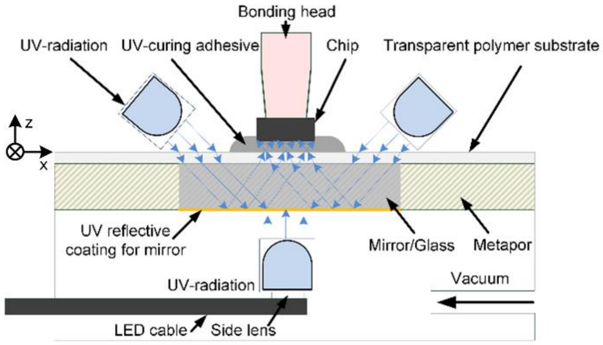

Fig. 4 *Schematic of optodic bonding.*

4 Conclusion

Planar optronic systems on the basis of printed polymer waveguides and bonded laser diodes offer a promising solution for future sensor system applications. The main focus of our further research lies in the preparation of sensor networks, comprising of several light sources, sensors and detectors. This enables us to realize large-area systems for the spatially resolved detection of various measurement parameters.

Acknowledgements

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