Additive Manufacturing of polymer based waveguides using Hybrid µ-Stereolithography

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An additive manufacturing process based on conventional stereolithography and an aerosol jet system has been developed for the manufacturing of polymer based waveguides. An elliptical core shape with a surface roughness (R_a) of 39.0 nm is able to guide light, which is shown qualitatively. A cladding part with smaller refractive index serves as a substrate and protection part.

1 Introduction

Integrated sensor networks are commonly used for detection of different parameters such as temperature, humidity, stress or pH-value. In comparison to electric circuits optical based communication systems have the benefits of a large bandwidth, integration density and independence of electromagnetic interferences in terms of the demand for more and more sensing devices on small space [1]. Figure 1 shows a schematic illustration of the example in an optic integrated system. The packaged laser diode module requires free-form optical interconnection to transport the emitted light efficiently, which is not possible with conventional additive manufacturing (AM) technologies.

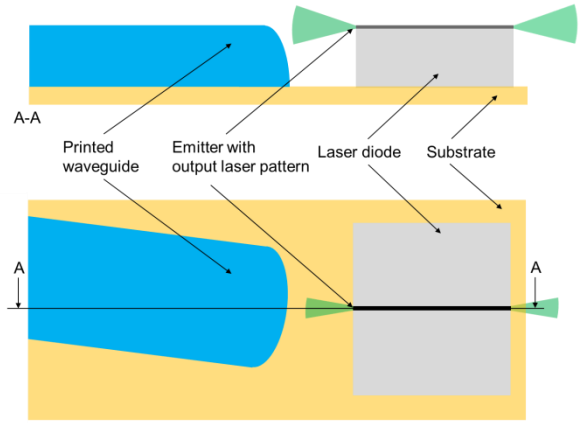

***Fig. 1**: Two optical devices showing lateral, angular and height offsets due to manufacturing tolerances*

Recently, fabrication of optical waveguides by two-photon polymerization (2PP) process has been reported [2]. However, 2PP does not have a suitable throughput for industrial applications. To overcome this problem we have developed a hybrid µ-stereolithography (hybrid MSL) using aerosol jet printing system [3,4] as new additive manufacturing technology. This hybrid MSL can realize conventional stereolithography based 3D printing on any free-form surface. In this study the fabrication of polymer based waveguide structures is demonstrated by hybrid MSL.

2 Experimental Setup

The hybrid MSL system realizes a layer-by-layer AM process, which combines conventional µ-stereolithography and an aerosol jet printing system to generate polymer optical waveguides on a free-form surface in 3D. The experimental procedure for a thin film layer prepared by hybrid MSL can be found in [4]. Before fabrication of the core structure a polymer sheet layer, which works as clad part, was prepared on a glass slide. The clad part was made of Penthaerythritol triacrylate (PETA, Sigma Aldrich) containing 0.2 wt.% of photo-initiator (Irgacure369, Ciba) by a UV mold process. Then, the aerosol jet printing system (Optomec Inc.) deposited a uniform thin film on the PETA layer [5]. Ormocer® (Micro resist technology GmbH) was used for fabrication of the core part of the waveguide structure. After the coating of Ormocer® a 2D patterned photo-polymerization was carried out using a combination of UV CW laser (Zouk, λ=355nm, Cobolt AB) and an x-y galvanometric mirror scanner (Hurry SCAN 14, SCANLAB AG). Motion of scanner was controlled by CAD data. The laser beam was focused on the Ormocer® layer with an F-θ lens. During laser irradiation, the process area was surrounded with nitrogen (N_2) inert gas in order to avoid inhibition of the polymerization by oxygen. Afterwards non-exposed PETA was removed by washing in a mixture of iso-propanol and 4-methyl-2-pentanone with laser-exposed PETA structures remaining on the glass plate. Finally, the fabricated core structure made of Ormocer® was covered with an additional PETA coating during a 2nd UV mold process. Namely, an Ormocer® core structure is embedded in a PETA clad layers.

3 Results

The combination of Ormocer® and PETA are well matched in their properties such as transparency, refractive indices and adhesion at the interface of Ormocer® to PETA. Table 1 shows the refractive index and surface roughness of the material pair

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evaluated by a confocal microscope. The evaluated area was completely polymerized by UV exposure. The difference of refractive index between Ormocer® and PETA is 2.97 %. This is enough for reflection of propagated light inside Ormocer® as a core part and PETA as cladding such as in a step index fiber. The surface roughness R_a (ISO 4287) for an Ormocer® core and PETA cladding part are measured to be 39.0 nm and 2.1 nm, respectively.

Material	Refractive index	Surface roughness
Ormocer	1.533 [7]	39.0 nm
PETA	1.483 [8]	2.1 nm

Tab. 1 *Materials used for optical interconnects*

Figure 2 shows the cross sectional image of the embedded Ormocer® core in the PETA clad part as observed by an optical microscope. A uniform PETA clad part is formed without defects such as bubbles, cracks or changed color. The Ormocer® core part was fabricated by three-layer structuring. The elliptically shaped Ormocer® core parts show a line width of 35.1 µm and a height of 16.6 µm. However, the cross sectional image with an elliptical shape is not corresponding to the original CAD design which is rectangle shape. This is attributed to the surface tension of the Ormocer® material and N_2 inert gas flow from the side to the surface during the polymerization process, resulting in deformation to the elliptical shape.

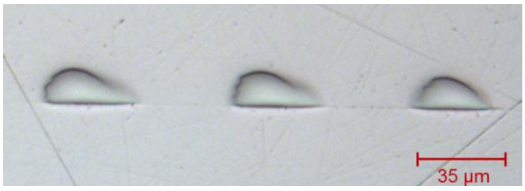

Fig. 2**:** *Cross section view of the waveguide*

To measure the profile of guided light beam a 632.8 nm wavelength He-Ne laser beam was coupled to one facet of the written waveguide by high-magnification microscope objective lens. Figure 3 shows an optical microscope image of the facet (left) and guided pattern of He-Ne laser beam transmitted by the waveguide (right), respectively. The optical loss could not be quantified since the length of the propagation along the waveguide was too short for a back cutting dampening measurement. The intensity profile of propagated laser beam at the end facet pattern indicated multi-mode.

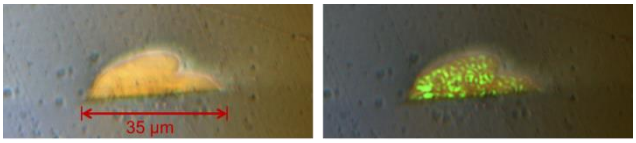

Fig. 3*: Light guiding test, not illuminated end facet (left), intensity pattern with encoupled light beam (right)*

4 Conclusion

Fabrication of polymer based optical waveguides has been demonstrated by hybrid MSL using an aerosol jet printing system for new approach in AM. The liquid photosensitive material pair Ormocer® (core) and PETA (cladding) for a waveguide structure was transferred to aerosol to generate a thin coating, which cannot be realized by conventional stereolithography technique. The cross section view of an elliptical shape was produced reproducibly but needs optimization in process control. In addition, the fabricated waveguide has smooth surface (roughness R_a: 39 nm). A light guiding test was successful with He-Ne laser, the intensity pattern changes during the propagation from single mode to multi mode. Thus, the fabrication of waveguide structure by hybrid MSL can be expected as new process technique for optical interconnection.

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