Flexography Printing of Polymer Optical Waveguides

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Summary: In this article flexography printing of polymer optical waveguides is discussed. For this purpose a Heidelberger Speedmaster printing machine is used. At first, a general introduction to the field of polymer optical waveguides is given followed by the current state of the art of dispensing methods. In the third part of this article, the flexography printing method is presented with its challenges for an application to produce polymer optical waveguides. The results of first printing tests with modified flexography printing parameters are shown exemplarily.

Keywords: Optical, Printing Of Light Guiding Structures, Optical Polymer, Optical Fibre, Integrated Optical Communication.

1. Motivation

The importance of optical waveguides for data communication tasks in the industrial field is constantly increasing. Polymer optical fibers (POF) are more flexible, economical and easier to handle in comparison to conventional glass fibers. Furthermore, POF ensure a good data transfer rate and offer adaptivity to different conditions of application. With the development of conductive polymer the aspect of electric energy transport through POF is possible. The motivation of this paper is to introduce a new innovative production process for an efficient and adaptive mounting of polymer optical waveguides onto fine surface structures, which can be adapted to 3D product geometry. The relocation of sensors, optoelectronic, signal transmission and polytronic functions can be directly possible into product surfaces including metal surfaces. This will enhance the integration of measurement engineering like expansion or temperature sensors into systems and increase their integrated intelligence. Generally, POF's are composed of two dielectric materials. These materials build the *cladding* and the *core* layers with respective refractive indices n_k and n_m while $n_k > n_m$. The cladding layer is usually protected with a jacket material for the mechanical protection of the POF (Fig. 1) [1].

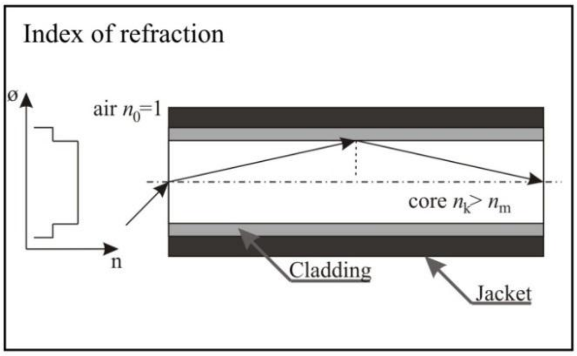


Figure 1. Schematic drawing of a step-index fiber [1].

2. Dispensing of polymer optical waveguides

The actual research works and projects treat the adaptation of printing technologies to realise function structures and they are limited to the printing of electronic components [2, 3], especially the print of RFID-Labels and passive electronic for example diodes [4, 5]. In the way to new production alternatives for polymer waveguides a process of direct writing of light guiding structures is described in [6] and its required material characteristics were identified. The most important characteristic of the used polymer is the refraction index with about 1.5 for n_k. The cladding refractive index n_m has to be smaller. The numerical aperture N_A is another important parameter and depends on the relative refractive-index difference between n_k and n_m [1]:

$$N_A = \sin\alpha_{\max} = n_k \cdot \sqrt{2\cdot(n_k - n_m)} \qquad (1)$$

where α_{max} is the maximal acceptance angle of the optical waveguide which increases with an increasing relative-index difference. N_A influences different properties of polymer optical waveguides such as the bending sensivity or the bandwith, which decrease with an increasing N_A.
The used polymer must have an appropriate resistance against the estimated stresses and variations in temperature in their conditions of application. Another parameter is an optimal combination of the surface tension between the cladding and core materials to avoid possible hydrophobic attitude in the boundary surface. Furthermore, the materials must have an epoxy resin, which cures under UV-light [6]. The technical realisation of the light guided structure requires a production process of four main steps, which are represented in figure 2 [6].

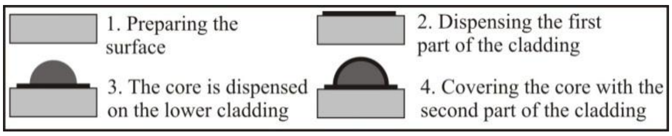


Figure 2. Creation of surface integrated light guiding structures [6].

At the beginning, the surface is prepared by cleaning it and removing possible marks. Then the first cladding part is dispensed on the surface and cured with UV-light. The third step consists on dispensing the core on the cladding.
To avoid irregularity and imperfection in the core structure a constant dispensing speed and amount have to be maintained. In

the fourth step the core will be covered with the second cladding part [6]. The direct integration of the polymer optical waveguide in system components allows the combination of mechanical and data transfer parts of a system. This combination allows new concepts and strategies for sensor technology and system-integrated intelligence.

3. Flexography printing of polymer optical waveguides

3.1. Flexography

Printing technologies are classified according to the method of ink die and ink transferring to the printing material. Examples of those technologies are the letterpress printing like the flexography, the intaglio printing, the planographic printing like offset printing and the porous printing like screen printing. Flexographic printing is favoured as a process to produce polymer optical waveguides. It is a cost-effective and widely used process in the serial production. Moreover, it allows the realisation of a high ink layer thickness. The principle of flexographic printing is illustrated in figure 3.

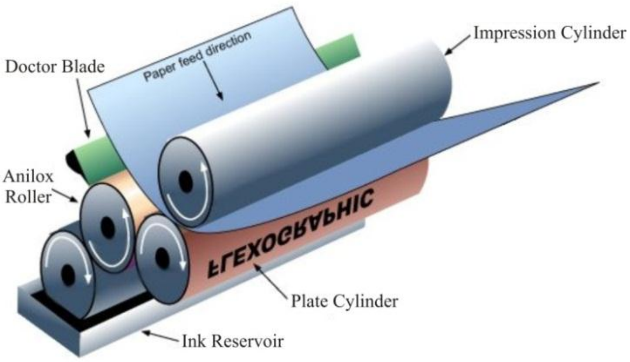


Figure 3. Flexography deck [7].

A flexible relief plate made of molded rubber or photopolymer materials is fixed on a plate cylinder. The ink is transported from the reservoir to the relief plate through an anilox roll. With a doctor blade the volume of the transferred ink from the reservoir and therefore the coat thickness of the printing can be set up. The impression cylinder presses the print substrate against the plate cylinder and in this way the printing process is realised. This process has the ability of printing on non-porous substrates and it is useful for printing on plastic foil as well.

3.2. Challenges and procedural method

The challenge for the printing of light guiding structures via flexography is to achieve a sufficient layer thickness, a high degree on dimensional accuracy within the waveguides lengths and a surface roughness of less than λ/10. Furthermore, an optimal combination of surface tension between the core and cladding material has to be defined to avoid a hydrophobic behaviour on the boundary surface. The optical waveguides will be direct printed on flexible surfaces and mounted in 2D or rather 3D geometry. For this reason a sufficient mechanical stability and protection has to be achieved. Different lacquers were used to realise first tests. The surface tension is measured with a contact angel goniometer. The contact angle is measured as the angel formed between a lacquered foil and a liquid drop. Examples of the measurements are shown in figure 4.

The contact angel can be described in the equilibrium with the Young equation:

$$\cos\theta = \frac{\sigma_S - \sigma_{LS}}{\sigma_L} \tag{2}$$

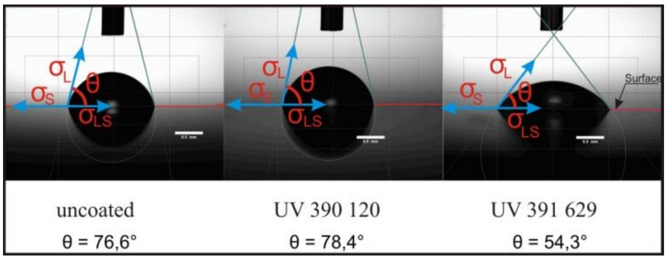


Figure 4. First contact angle measurements.

With σ_{LS} as the solid (foil) surface tension, σ_L as the liquid surface tension and σ_S as the surface free energy between solid and liquid. The procedure to determine the surface tension is described in DIN 55660-2 and has to be realised with an absolute dispersing and an absolute polar liquid drop [8]. With a bigger contact angle θ up to 90° the form approaches to a hemisphere. The intended purpose of the measurement is to define the surface tension of different lacquers and find a relation between this parameter and the resulted contact angle. The surface tension can also determine the behaviour of the boundary surface between two printed layers of different lacquers. An optimal linear and parallel boundary surface is approached. Figure 5 shows exemplary imperfection, air pockets and repulsion in the boundary surface due to bad surface tension combination.

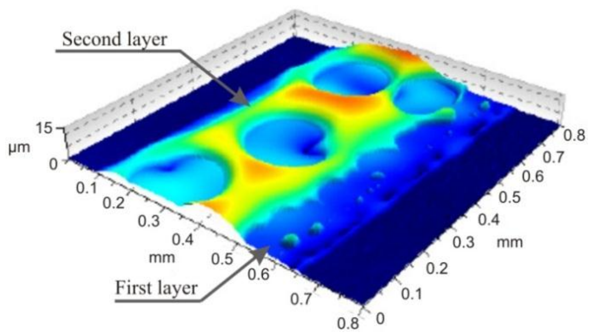


Figure 5. Two printed lacquers layers.

Another challenge is to achieve a sufficient layer thickness with flexography printing. For this purpose 5 different adjustments of the doctor blade for 5 different ink volume zones were analysed. Furthermore, single and double layer printing were investigated. For the evaluation of the layer thickness a confocal microscope was used. The results are shown in figure 6.

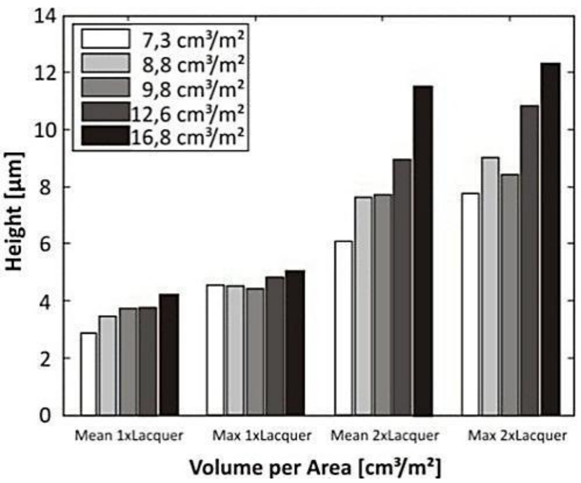


Figure 6. Total layer thickness for single and double layer printing.

The results indicate that a higher layer thickness is possible with multiple printing layers. The achieved thickness is in general sufficient for the production of optical waveguides. According to [1] a cross-section area of at least 5 µm x 5 µm is necessary to ensure light propagation within the waveguide.

Another important point is the dimensional accuracy of the printed wave guides. It can be characterised by investigating the cross-section along the waveguide's length. The confocal microscope delivers a 3 dimensional data-matrix of the considered sample. An example is shown in figure 7. The squeezing boarders limit the structure width to a defined value, which should not be exceeded.

The pressure between the plate cylinder and the impression cylinder has an influence on the dimensional accuracy, especially for small volumes. A possible quality index for the dimensional accuracy of the cross-section is the standard deviation. The less this deviation, the better the dimensional accuracy of the probe.

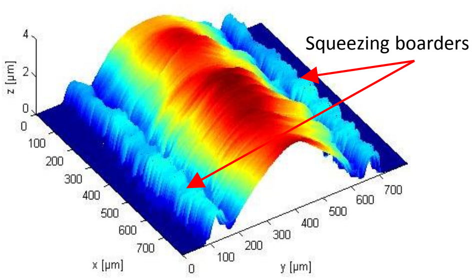
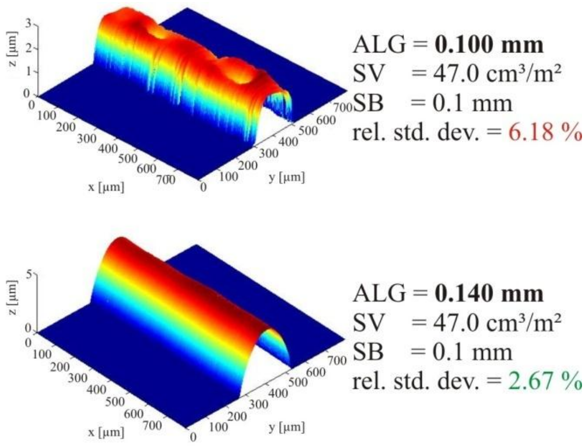


Figure 7. Example of a 3D structure of a printed waveguide.

Figure 8 shows the results for different pressures between the plate cylinder and the impression cylinder for a constant structure width and a constant volume in the screen roller.

The dimensional accuracy has direct influence on the attenuation of the optical waveguide. The attenuation is classified into two groups: intrinsic and extrinsic.



ALG: Contact pressure plate cylinder-impression cylinder
SB : Structure width
SV : Volume of screen roller

Figure 8. Experimental results for different pressure values between printing cylinders.

The intrinsic attenuation is caused by the absorption and Rayleigh-dispersion in the used material. On the other hand the extrinsic attenuation is caused by absorption, dispersion and radiation due to the imperfection of the produced optical waveguide. Figure 9 shows an example of radiation loss due to microbends.

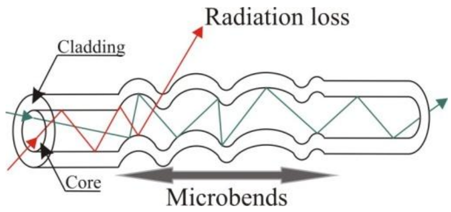


Figure 9. POF radiation losses induced by microbends [1].

With good dimensional accuracy less extrinsic attenuation occurs. The measurement of the attenuation value depends on the launching condition and the waveguides length. For short distances the attenuation value is small and affects barely the light propagation. However, for development purposes it is important to determine the attenuation value for the polymer optical waveguides produced by flexographic printing process.

4. Conclusions and Outlook

With the flexographic printing process a sufficient dimension of at least 5 µm x 5 µm for the realisation of polymer optical waveguides is possible. Layer thickness of more than 10 µm with 16,8 cm³/m² volume per area in the screen roller and double printing were achieved. For the structure width of the polymer optical waveguide a maximum value should not be exceeded to avoid squeezing boarders between plate cylinder and impression cylinder, which affects the dimensional accuracy and consequently the attenuation of the realised light guiding structure. The different parameters for the flexography printing process such as pressure between plate cylinder and impression cylinder as well as the volume of the screen roller have to be optimised to realise structures with a constant cross section. The relative standard deviation which serves as a quality index should tend to a minimum for optimized dimensional accuracy.

The relation between the surface tension and viscosity of the used materials and the resulted form of the structure and consequently the dimensional accuracy has to be developed on basis of the realised measurements. This would help to define basic conditions and formulas of an optical waveguides printing procedure. Future tests will investigate the adaptation of the dispensing method to the flexographic printing process and then experimental attenuation measurements will be possible.

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