Advanced production of direct applied wave guides

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Abstract

The application of optical structures in data transfer and measurement steadily increases. Polymer optical fibres (POFs) are superior to electrical conductors, due to their light weight, their resistance to damage and electromagnetic interference. Just like their glass equivalents they provide a high data transfer rate. By using direct dispensing 3D-light guiding structures on surfaces and the integration of light guiding structures into metallic components can be accomplished. The first part of the article describes the main properties of POFs and there influences of processing with dispensing technology. In the course of this article the technical implementation and structural properties are described. A short overview on printing of wave guides is given.

Keywords: optical polymer, direct writing of wave guides, dispensing technology

1. Introduction

A new production process for light guiding structures has been developed. Within this method it is possible to create light guiding structures made of polymer optical fibres on metallic surfaces. An application on 3D-shaped bodies is possible. By using direct dispensing, stepped index fibres can be produced. Therefore, the cladding material will be dispensed in the first step, afterwards the core material will be applied on top and finally the second cladding will cover the structure. In every step between the polymer is cured by UV-light. The integration of electro-optical components within directly dispensed structures is much easier. The preparation of end cross section surfaces is not necessary. Cutting down the production steps of cutting and polishing, the whole process can be economized [1]. Further investigations are related to a different production process. Within the knowledge of direct dispensing the topic on future investigations is the development of processes for printing polymer optical fibres. At this stage the potential of printing wave guides within gravure printing is shown.

2. Motivation

A main motivation for this project is the integration of light guiding structures directly in and on a 3D-shaped metallic surface. These structures should provide a high and secure data transfer, resistance to electromagnetic radiation and potential separation. The direct integration of electro-optical components is one of the goals of this project. Because of liquid processing the integration in direct dispensed structures is much easier, because there is no further preparation like cutting and polishing the end cross section necessary. In the next step alternative production processes should be carried out for low cost applications. Therefore, the idea of printing optical wave guides is the topic of future investigations. The knowledge of processing direct dispensed POFs will be used.

3. Required material characteristics

For direct dispensing of POFs the material characteristics can be divided in three different parts. Regarding light guiding characteristics the main optical aspect the refraction index has to be considered. With a refraction index difference of 4 %, for example a refraction index of 1.44 for cladding material and 1.50 for core material, the numerical aperture is 0.42. Different fibre parameters are dependent on the numerical aperture, for example injected light power and sensitivity for bended structures [2]. The transmittance should be 100 % for the guided wavelength. To secure resistance against estimated stress mechanical characteristics like temperature resistance have to be in a range of -40°C to 120°C. Different properties of POFs are important for their dispensing behaviour. Particularly the viscosity [3] and cure behaviour belonging to the most important facts [4]. These one component resins needs a low viscosity for the cladding and for core materials applied in 2D-trench structures. To apply core material on the surface it is necessary to use highly viscous polymers.

4. Technical implementation

High quality requirements regarding the dispensed structures of optical polymers refer to high demands in processing. Unevenness of the surface occurs in the range of up to 50 µm. As a result of a variation of dispensing distance during processing different effects can be seen. Long distances will cause separations of structures, which look like a row of pearls. If the distance is to short the dispensed structure will be destroyed by the needle. Differences of about 50 µm will produce structures with bad qualities. Both effects can be seen in **figure 1.**

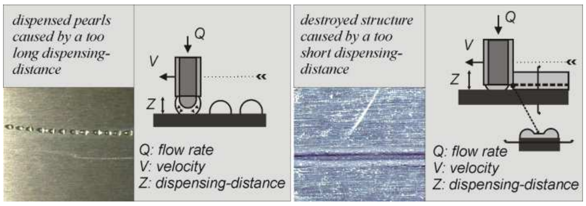

Figure 1: Effects of wrong dispensing distance

The implementation of a Z-resolution of 5 µm enables a control of the dispensing distance. For processing a surface scan is needed. The measured Z-profile is combined with the original CNC-file for producing light guiding structures. Within a cost-efficient-solution a XYZ-dispensing robot interprets these CNC-commands and corrects them with the measured Z-profile from the surface scan. **figure 2** shows the dispensing robot.

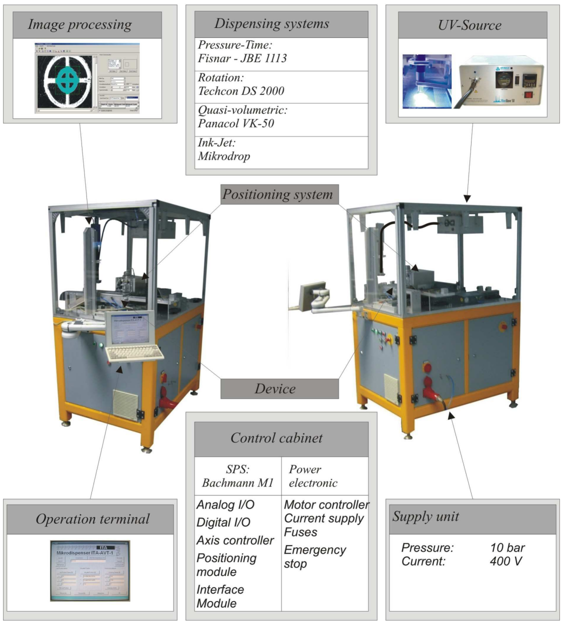

Figure 2: Dispensing robot

If the dispensing needle for 3D-applications has an orthogonal position to the surface, two additional rotation axes for the robot will be needed, which means an increase in production costs and handling efforts. Instead of using the orthogonal positioned needle the surface tension and contact angle (angle at which a liquid/vapor interface meets the solid surface) is used to allow self alignment. This contact angle is unique for every material combination which depends on the used polymer and the device material. Therefore, the acceptable pitch of the device surface has to be determined. For a flexible production process it is definitely a disadvantage that every material combination has another contact angle. In order to avoid different core-geometries by using different material combinations the cladding can be applied by a coating process. In this case the material combination is reproducible and the contact angle is independent of the device material.

With direct dispensing light guiding structures can be produced in different ways. They can be integrated in a device, can be applied on a device surface, or can be produced as dam structures. Integrated wave guides and their production steps are shown schematically in **figure 3**.

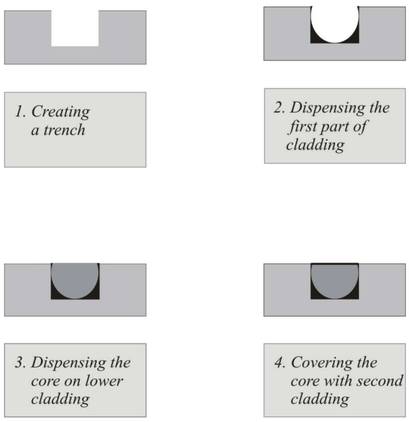

Figure 3: Production steps for surface integrated light guiding structures

After creating the trench structure in step one the first cladding will be dispensed. Due to low material viscosity and surface tension the adhesive is allocated regularly in the trench. In a third step, the core material is filled in the cured lower cladding. By covering the core with the second part of the cladding the structure is closed. After each step the applied polymers have to be cured with UV-radiation. **Figure 4** shows the four necessary production steps to create a surface applied light guiding structure.

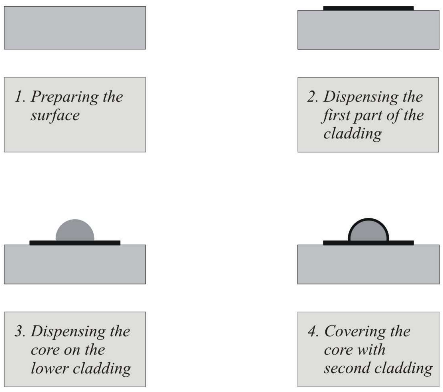

Figure 4: Production steps for surface applied light guiding structures

After preparing the device surface in step one, the cladding is dispensed directly on the surface area. Small irregularities can be compensated by surface tension of the lower cladding material. Before adding the core material on top the lower cladding has to be cured. Because of high requirements regarding the stability of profile shape a high viscous material has to be used. Processing parameters like dispensing speed and flow rate must be constant. After the core is cured by UV-light the second cladding to cover the core will be dispensed, finished by a final curing step. A different method to apply light guiding structures on surfaces is the dam structure, shown schematically in **figure 5**.

Parallel structures, to separate transmitter and receiver channel can be produced as dam structures. After cleaning the surface from different dust and grease deposits the cladding (high viscosity of material necessary) is created on the surface in shape of two side by side lying polymeric crawlers. As a result of surface tension there will be a curved shape created between these parallel structures. With this procedure it is possible to compensate scratches in the surface. The space between both structures will carry the core material. Requirements regarding the viscosity of core materials are not high. It is possible to use high and low viscous materials. After applying the core, the structure is covered by another cladding layer. The advantage of dam structures is the comparatively lower demand of position accuracy. Of course the distance of these parallel dam structures has to be constant.

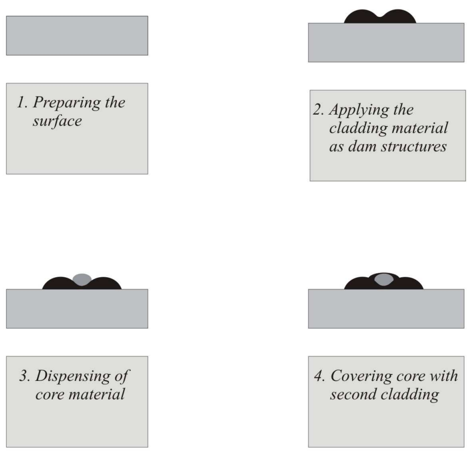

Figure 5: Production steps for surface applied dam structures

For surface applied light guiding structures dimensions of approximately 400 µm widths and 250 µm heights can be produced. This method is limited to a maximum radius for bended structures. To fulfil the requirements of total reflexion the maximum radius is described by the critical angle alpha total [5]. In case of exceeding alpha total an optical leak will be the result.

5. Structural properties

To ensure that the light is led through the fibre due to total reflection, the influence of the cladding material in two different straight structures is examined. One structure is produced without and the other structure with a cladding. The test shows that the radiation output for uncoated wave guides, measured in mV, has a much lower value and only a small peak area which can be seen in **figure 6**. The measured output of uncoated light guiding structures has a voltage of 350 mV. The compared structure with cladding has a higher output in generally from 800 mV and a bigger peak area. Furthermore there was carried out an investigation about curved structures with a radius up to 35 mm.

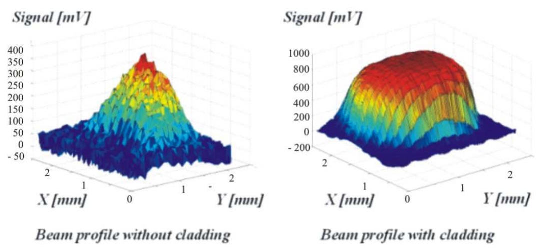

Figure 6: Radiation output of light guiding structures with and without cladding

The cross section reached dimensions from 2.00 mm to 0.70 mm. Over a distance from 150 mm the optical signal can be guided inside the structure. Compared to straight light guiding structures there is a loss of 40 % in transmission by using curved structures with a radius of 35 mm. Attenuation is measured by the cut-back-method, which means cutting the pattern in slices and comparing the outcome of every slice [6]. The investigated values are between 0.06 db/cm and 0.16 db/cm [7].

6. Printing technology

Differentiation between the main four printing processes is shown schematically in **figure 7.** The transfer of the printed media (black highlighted) depends on the difference of printing parts and nonprinting parts within the printing plate.

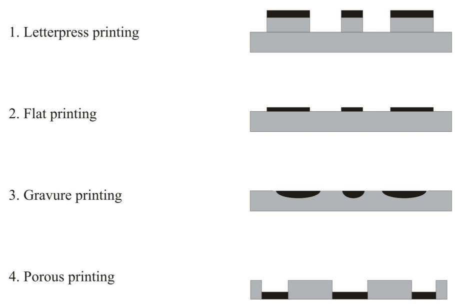

Figure 7: Main printing processes

These construction items result in the medial film thickness that can be transferred. The biggest film thickness can be achieved by using gravure printing and porous printing. By using stencil printing, which belongs to the group of porous printing processes wave guides were produced. The processing steps are quite similar to the processing of dispensed structures on surfaces. In the first step the lower cladding is applied to an even surface by a spray coating process. Afterwards the core material can be applied by stencil printing on the lower cladding. Therefore the printing plate is adjusted on the device and the optical polymer is applied. To guarantee the needs of a stable shape a high viscous polymer is used. Finally, the second cladding applied by spray coating covers the core material. Between every step the materials have to be cured by UV-light. An advantage of this technology is the application for low cost production. The printed wave guides are reproducible in the same shape and quality.

7. Summary

The presented technology shows the feasibility to create light guiding structures directly on and in a 3D-surface by using dispensing systems. Also it is possible to integrate this technology in a fully automated process. Also the feasibility of printing wave guides by using stencil printing was shown. For future applications, the light guiding structures can be integrated in automotive application. It is possible to create optical sensors by using the described technology.

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