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Ablation and functionalization of flexographic printing forms using femtosecond lasers for additively manufactured polymer-optical waveguides

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Abstract

An efficient and low-cost approach to manufacture Opto-Mechatronic Interconnect Devices will be obligatory to handle the strongly increasing amount of data. The presented approach is based on a flexographic printing process. To adjust the transferred material the printing form is functionalized by means of laser-induced structures using an ultrashort-pulsed laser. The long-term goal is to adjust the printing result through microstructures in the printing form in order to create spatially resolved material transfer.
In this work, first the ablation parameters are investigated at different repetition rates using a femtosecond laser. Further, a line structure is inserted in the material transferring areas of the printing form, which is consequently widened. Its influence on the printing result is presented.

Keywords: Ablation; Functionalization; Femtosecond Laser; Adjustable Material Transfer; Flexographic Printing

1. Introduction

While data grows drastically each year [1], its manageability drags behind. For short range (chip level) and long range (glass fiber) data transmission solutions are already well developed [2]. For mid-range data transmission though, there is no well-developed solution yet. Optical components offer several advantages over electrical, in particular a fast transmission speed and higher bandwidths [3,4]. Therefore, the DFG-funded research group OPTAVER faces this challenge by developing an efficient and low-cost approach to manufacture Opto-Mechatronic Interconnect Devices, shown in figure 1. Initially, a flexible carrier substrate is preconditioned by means of flexographic printing (i) and subsequently the polymer optical waveguide (POW) is applied additively by Aerosol Jet (ii). The application of the conditioning lines are crucial to the whole manufacturing process due to two main reasons. On the one hand, the low surface energy causes a self-centering effect of the waveguide material, preventing the waveguide material to flow apart [5]. On the other hand, the geometry of the POW correlates directly with the shape of the conditioning line edges and therefore with its quality. Additionally a space resolved material distribution is required to allow for transforming complex structures on the substrate into a 3D-Shape. One approach to influence the printing result is to functionalize the printing form by means of laser-induced microstructures [6].

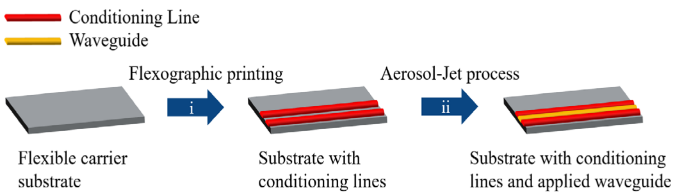

Fig. 1. Optaver process chain for Opto-Mechatronic Interconnect Devices.

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Nevertheless, the functionalization of flexographic printing forms is not yet state of the art. Because several parameters in the printing process affect the printing result, this work aims to create further basic knowledge on how precisely ablated areas on the printing form affects the printing result. First, in this work ablation studies of the printing form material are performed using a femtosecond laser. Subsequently a line groove is inserted in the stamp structure of the printing form. The groove is consequently widened and its influence on the printing result is studied.
In figure 2 an exemplarily cross-section of the printing form is shown. It consists of two stamp structures (S1, S2). Each stamp transfers material forming a conditioning line. The middle of the two stamps features a gap (B), leaving space on the substrate to apply the waveguide.

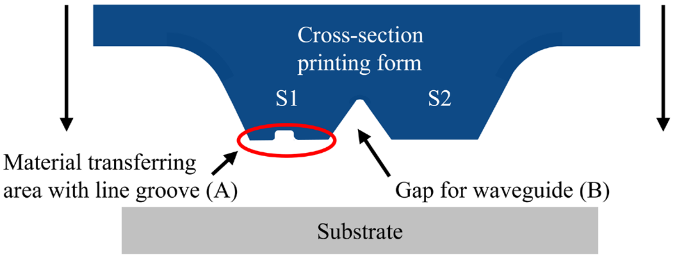

Fig. 2. Shape of stamp structures on flexographic printing forms.

2. Experimental

2.1. General

Laser source

All trials have been performed with a Monaco ultrashort pulse laser from Coherent Inc. The operating wavelength is 1035 nm. The maximum average optical power is 60 W. The M^2 factor is 1.16. The repetition rate is ranging from single shot up to 50 MHz. The pulse duration can be tuned from 252 fs up to 10 ps, but was set to the shortest pulse duration for all experiments. A Gentec Maestro power meter and UP19-W detector has been used to measure the average power.

Material and Printing

The ablation trails were performed on the actual printing form material - a black elastomer (ethylene propylene diene rubber (EPDM)), which absorbs most wavelengths close to 100%. ContiTech Elastomer-Beschichtungen GmbH provided the material (Model: Conti Laserline CSX).

The printing was performed on a Speedmaster 52 from Heidelberger Druckmaschinen AG. The printing speed was kept constant at 3,000 sheets per hour. The infeed was kept constant as well, after preprinting and adjusting.

A poly methyl methacrylate (PMMA) foil with 175 µm thickness was used as substrate. The printing material was a UV reactive varnish from Actega GmbH (Model: Actega G8-372 L NVK-S).

Experimental set-up

To ensure a leveled surface the printing form material was positioned on a vacuum plate. Further, a camera system was used for positioning and process monitoring. A cross-jet and a suction system was used to minimize interaction with ablated particles.

After the beam expander the raw beam had a diameter of 10 mm. A combination of Scanlab's galvanometer scanner (Model: intelliSCAN 10) and a telecentric F-Theta objective with focal length of 59.7 mm resulted in a focal diameter of 16.5 µm @ e^{-2}.

2.2. Ablation trials

The ablation was investigated at 100 kHz and 250 kHz, while the peak beam fluence was varied from 0.5 up to 50 J/cm². Percussion drilling was used to ablate the material using 10, 25 and 50 pulses. After measuring the depth using a Laser-Scanning-Microscope (Model: VX-1000 from Keyence), the ablation depth per pulse is calculated by dividing the measured depths dp by the number of pulses np (1).

$$d_p = \frac{d_m}{n_p} \tag{1}$$

The fluence (F) for a Gaussian beam can be calculated by (2) with E_p as pulse-energy and ω as the beam radius (@ e^{-2}).

$$F = \frac{2*E_p}{\pi*\omega^2} \tag{2}$$

2.3. Printing form trials

As previously mentioned, grooves with different widths were inserted in the stamp structure (S1). The analyzed stamp structure has a width of 450 µm. In figure 3 an example of a stamp structure with its ablated line is shown.

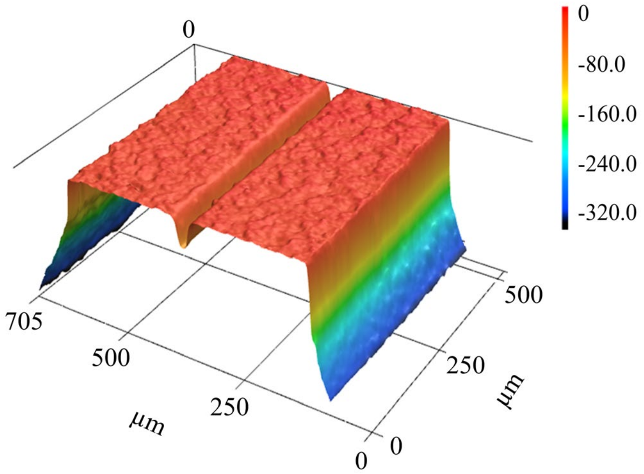

Fig. 3. Laser scanning image of the stamp structure (S1) with inserted groove.

The width of the ablated groove is continuously widened. All parameters are summarized in the following table 1. The different ablation parameters were achieved using the previously described setup. The scanning speed was kept constant at 1,000 mm/s. The average power was 6.7 W at a repetition rate of 250 kHz (27 µJ pulse energy) with five passes. To widen the grooves, several small grooves were inserted close to each other. The number of small grooves determined the width of the wider groove.

Table 1. Ablated groove dimensions.

Groove No.	Ablated width in µm	Ablated depth (max.) in µm
1	30.7	43.1
2	98.9	57.1
3	184.5	55.2
4	278.2	58.4
5	364.1	55.9

3. Results and Discussion

3.1. Ablation Trials

100 kHz

The results of the ablation trials using 100 kHz are shown in Figure 4 with a logarithmic x-axis. In general, the ablation depth increases with increasing fluence. Furthermore, the ablation depth per pulse is higher when fewer pulses are applied.

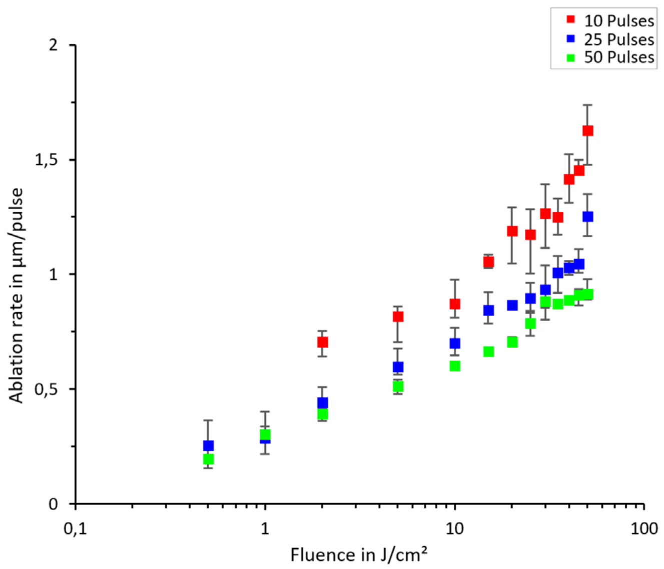

Fig. 4. Ablation rate (µm/pulse) as a function of fluence (J/cm²) at 100 kHz.

Unlike metals, the printing form material (EDPM) has no clear boundary between sublimation and thermal ablation. The ablation depth increases exponential with rising fluence. The fit in the logarithmic display is linear for the measurement series with 25 pulses and 50 pulses, while the fit for 10 pulses is slightly exponentially. The ablation rate (50 Pulses) seems to converge towards 0.9 µm / pulse. The highest ablation per pulse is 1.6 µm / pulse and occurs at the maximum fluence in the measurement series with the lowest number of pulses. The fact that the ablation per pulse decreases with an increasing number of pulses can be explained by several facts. On the one hand, as the number of pulses increases, the groove is deepened and an edge angle is formed. This reduces the intensity, because the area on which the laser beam impacts increases. On the other hand there might be a chemical modification during the first ablation, which can impact the absorption behavior for the following pulses. Factors like melt dynamics, plasma shielding, imperfections of the material and others might be relevant to the ablation process as well.

The ablation threshold is between 0.2 and 0.25 J/cm² for the measurement series with 25 and 50 pulses. For the measurement series with 10 pulses it is below 0.5 J/cm². Below this fluence no noticeable ablation could be detected.

250 kHz

The results of the ablation trials with 250 kHz are shown in Figure 5. This also shows that the ablation depth increases with increasing fluence and that the ablation depth per pulse is higher when fewer pulses are applied. The ablation behavior is similar. All measurements show an almost exponential increase of the ablation rate, with slightly different gradients.

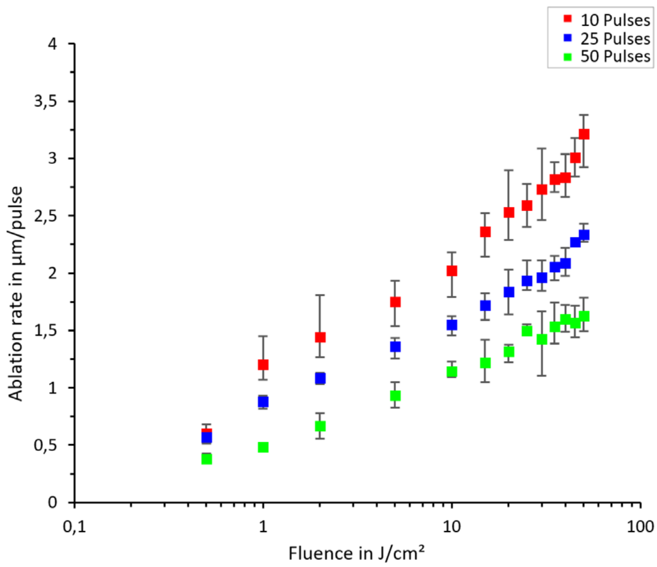

Fig. 5. Ablation rate (µm/pulse) as a function of fluence (J/cm²) at 250 kHz.

The highest ablation depth per pulse is 3.2 µm and occurs at the maximum fluence in the measurement series with the lowest number of pulses. The ablation threshold is below 0.5 J/cm² for the measurement series with 10 and 25 pulses and below 0.25 J/cm² for the measurement series with 50 pulses. The previous considerations from the 100 kHz ablation trails also apply here.

In general, the ablation shows a similar behavior while increasing the repetition rate from 100 kHz to 250 kHz. At 250 kHz more heat is brought into the process and the ablation rate per pulse is increasing.

With the results of the ablation parameters, further experiments can be carried out. Especially for upscaling the functionalization to larger areas, further investigations concerning repetition rate and pulse length are necessary. Nevertheless, the accuracy of the printing form plays a crucial role in the flexographic printing process, since already deviations of several µm can lead to total different printing results, as described in the next chapter.

3.2. The results of the ablation

After inserting the grooves into the stamp (S1) very different printing results occur, depending on the width of the grooves. Figure 6 shows the printing results that correlate with the different widths of the grooves in Table 1 (Section 2.3).

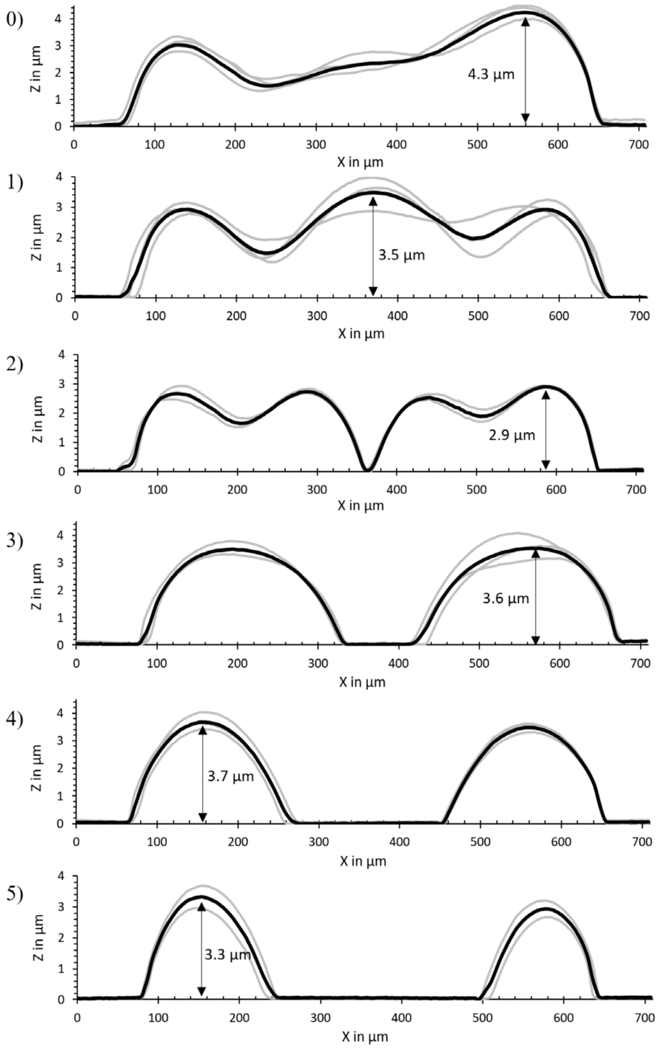

Fig. 6. Influence of the groove parameters on the printing result. The black line represents the mean value of representative cross sections of three different printed conditioning lines.

As a reference no. 0 shows the printing result for an untreated stamp (S1) with a width of 450 µm. No. 1 – 5 show the printing results, where the grooves were consecutively widened. While the grooves in no. 2-5 prevent a material transfer - leaving a gap at the corresponding position, in no. 1 the groove lead to a material accumulation at the point where the groove is inserted. This can be explained by the fact that during the printing process the stamp is pressed onto the substrate. This squeezes the material from the material-transferring surfaces into the fine groove. Therefore, material accumulates in the groove. The grooves of no 2-5 are too wide, so this effect only occurs when the width of the ablated line is below 98 µm.

The results show that the size of the longitudinal groove strongly influences the material transfer behavior and the printing result. This can be used to adjust the amount of the transferred material on the one hand and the distribution of the material on the other hand. In general functionalizing the printing form is a powerful tool to adjust the required parameters of the conditioning lines, which leads to improved waveguides in the OPTAVER Process.

4. Conclusion

This work presents the ablation parameters of a ContiTech flexographic printing form, which consists of ethylene propylene diene rubber (EPDM) using a femtosecond laser system with a center wavelength of 1035 nm. The ablation behavior does not change significantly by increasing the repetition rates from 100 to 250 kHz. At the repetition rate of 250 kHz a higher ablation per pulse is observed.

The long-term goal is to manipulate the printing result through microstructures in the printing form in order to create spatially resolved material transfer. Therefore, the effects of ablated grooves in the printing form were shown. While in small grooves (< 98µm) material accumulation occurs, the opposite effect occurs in wider grooves. With wider grooves, no material is transferred and gaps occur.

The laser functionalization of flexographic printing forms is still at its beginning. Further experiments have to be carried out to achieve e.g. a perfect spatially resolved material transfer.

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