Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 56 (2014) 983 – 990

Physics Procedia

8th International Conference on Photonic Technologies LANE 2014

Laser processing of thin glass printed circuit boards with a picosecond laser at 515 nm wavelength

K. Plat[a,*], P. v. Witzendorff[a], O. Suttmann[a], L. Overmeyer[a]

[a]Laser Zentrum Hannover e. V., Hollerithallee 8, D-30419 Hannover, Germnany

Abstract

High temperature applications of printed circuit boards (PCB) require materials with specifically adapted properties. Hence, conventional electrically isolating glass fiber and epoxy-resin materials have to be replaced by thin borosilicate glass. Therefore, an industrially suitable process to remove the metal coatings from the brittle thin glass has to be developed. Laser processing has the advantage of individualization for the production of customer-specific PCBs. Thus, laser ablation of metal coatings for electrical isolation is investigated with different material composites based on thin glass. The study aims to identify a laser process for a picosecond laser source with 515 nm wavelength to perform the process without damaging the glass substrate with a high throughput.

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH

Keywords: thin glass printed circuit board; ablation

1. Introduction

Polymers are often used as an electrically isolating base material for printed circuit boards. However, miniaturization and high temperature applications restrict the use of printed circuit boards (PCB) made of epoxy-resin, glass-fiber fabrics (FR 4) and polyamides. High temperatures often cause deformation or decomposition of the plastic materials. There is subsequently a risk of cracks or breakage in the dielectrical layer due to the thermal

* Corresponding author. Tel.: +49-511-2788-284 ; fax: +49-511-2788-100 .
E-mail address: k.plat@lzh.de

Peer-review under responsibility of the Bayerisches Laserzentrum GmbH
doi:10.1016/j.phpro.2014.08.009

expansion characteristics of the materials. This can, for example, lead to pad cratering, i.e. the formation of craters on the surface of the PCB [1]. For high temperature applications above 250 °C, thin glass could be a suitable substitute for the conventional polymers used as a basis material for the circuit boards. Glass has also a high chemical stability and a low thermal expansion coefficient of $7.2 \cdot 10^{-6}$ K^{-1}. The field of aerospace technology has interesting applications for these new, thin glass circuit boards. Within this paper the structuring process was investigated for metal coatings on thin glass from 145 µm to 500 µm thicknesses. To avoid thermal induced damage of the thin glass substrate, laser beam sources with pulse durations of several picoseconds are used to perform the structuring. Ablation with these pulse durations has been proved to enable precise ablation on thermal sensitive materials [2-5]. In reference [6] the laser ablation of different metals is described with different picosecond laser. In this publication, the copper ablation depth per pulse is in the range from 30 nm (0.765 J/cm² fluence per pulse) to 280 nm (15.3 J/cm² fluence per pulse).

The aim of this investigation is to find appropriate laser parameters to remove the copper and chrome coating from the thin glass to produce the electrical circuit without damaging the substrate material. A completely removed area is electrically isolated and optical transparent.

2. Experimental setup

2.1. Setup for the laser processing

The picosecond laser (Trumpf, TruMicro 5050) with a maximal average output power of 22 W at the wavelength of 515 nm using an external frequency conversion was used for the experiments. In Table 1 an overview of the experimental laser parameters is presented. The laser beam focus diameter has a Gaussian shaped profile in TEM_{00} mode.

Table 1. Overview laser parameter.

Laser source	TruMicro 5050 (Trumpf)			
wavelength	(nm)	515	fluence (J/cm²)	7 - 27
pulse duration	(ps)	7	pulse overlap (%)	25, 35, 45, 50
focal length	(mm)	100, 255	repetition rate (kHz)	10, 50, 100
beam focus diameter	(µm)	10, 20	scan cycle	1 - 55

The pulse overlap describes the spatial overlap along the scan vector of two temporally successive laser pulses. In Table 2 the scan velocities for different repetition rates and pulse overlaps is presented for a spot diameter of 20 µm. Compared to a repetition rate of 10 kHz, the scan velocity is increased by the factor five at 50 kHz and by the factor 10 at 100 kHz.

Table 2. Overview scan velocities d_{spot} = 20 µm.

Laser parameters	f_{RR} = 10 kHz	f_{RR} = 50 kHz	f_{RR} = 100 kHz
Pulse overlap (%)	v (mm/s)	v (mm/s)	v (mm/s)
25	150	750	1500
35	130	650	1300
45	110	550	1100
50	100	500	1000

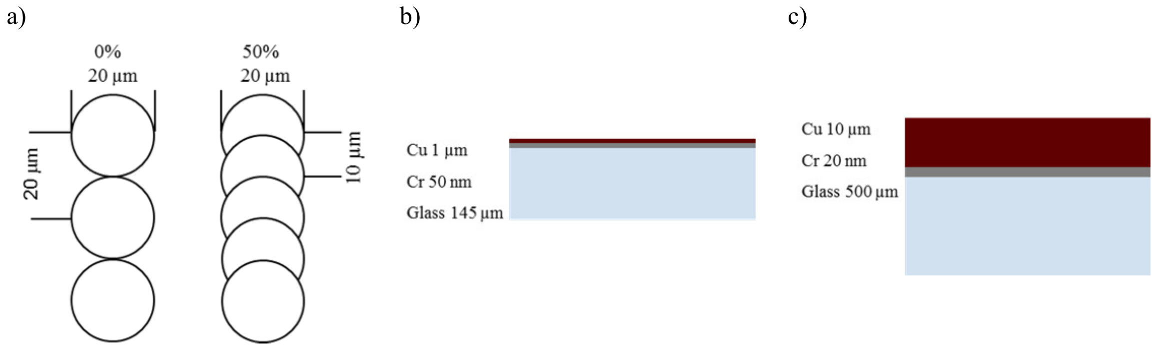


Fig. 1. a) Laser pulse overlaps b) Sputtered material c) Galvanized material.

The ablation process was performed on metal coated thin glass substrates. For the deposition of chrome and the copper-layer on the thin glass a de-sputtering process in vacuum chamber was used. A higher thickness of the electrically conducting material is necessary for a higher current flow of a printed circuit board. The growth of the film is usually realized by galvanization.

The first investigate material (Fig. 1 b) is thin glass (145 µm) sputtered with a chrome intermediate layer (50 nm) and a copper layer (approximately 1 µm) on top, is then laser processed and finally galvanized to increase the thickness which is necessary to achieve adequate electrical conductivity. The second material (Fig. 1 c) is a thin glass substrate (500 µm) coated with chrome layer (20 nm) by sputtering and then coated with a copper layer (10 µm) by a galvanizing process.

The average roughness R_a of non-irradiated metal sputtered substrate materials is 0.017 µm and the average roughness of galvanized material is 0.396 µm. The coating processes lead to different average surface roughness. The sputtered coatings have a smother surface than the galvanized coatings.

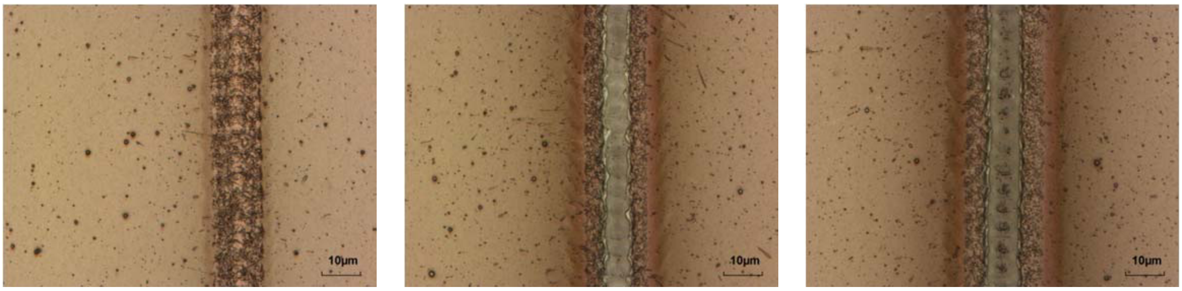
The coated thin glass has been mounted on a frame during the laser process, to avoid absorption from the sample holder when the metal coating is removed. The laser beam was focused by a f-theta optics onto the copper surface. Within the experiments the pulse overlap, the repetition rate and the fluence was varied as stated in Table 1.

3. Results and discussion

To implement the laser ablation processes of metal coatings from thin glass for the production of printed circuit boards, the following criteria have to be considered. The thickness of the metal coating depends on the different coating processes, like sputtering or galvanization. The ablation depth (a_d in µm) describes the removal of the coating. A complete removal of the coating without damaging the substrate material is equivalent to the thickness of the coating. The average roughness (R_a in µm) is a criterion for the quality of the ablation. A low value of the roughness implies a homogenous removal of the coating. The average roughness has been measured by the laser confocal microscope. The laser irradiation influences also the remaining material at the edges. For a precise ablation this heat affected zone (haz in µm) should be at a low value.

Fig. 2 shows the results of the laser ablation process of sputtered material. The coated thin glass was laser irradiated by a single line scan. The focal spot diameter was 10 µm throughout the experiments on sputtered samples. With increasing laser fluence the copper and the chrome layer were removed. A complete ablation of this sputtered material is achieved at a laser fluence of 17.2 J/cm² with a single line scan. Complete removal has been verified by measuring the ablation depth with a confocal laser scanning microscope, Fig. 3. The ablation depth of the irradiated line is 1.205 ± 0.026 µm with an average roughness of 0.049 µm within the irradiated area. The low average roughness indicates that the glass substrate remained in undamaged condition after laser processing. Damage of the glass substrate at higher fluencies can be seen in Fig. 2 c) at the dark spots on the irradiated line. For these parameter-set, the ablation depth is 1.482 ± 0.020 µm with an average roughness of 0.106 µm. But this higher average roughness of the ablated area indicates a prior damage of the glass substrate. The material reliability decreases and can lead to a break of printed circuits board.

a) b) c)



a)
$H = 6.7$ J/cm²
$a_d = 0.847 \pm 0.024$ µm
$w = 11.984 \pm 0.319$ µm

$R_a = 0.048$ µm
Incomplete removal

b)
$H = 17.2$ J/cm²
$a_d = 1.205 \pm 0.026$ µm
$w = 7.455 \pm 0.164$ µm
$haz = 24.440 \pm 0.106$ µm
$R_a = 0.049$ µm
Complete removal

c)
$H = 26.9$ J/cm²
$a_d = 1.482 \pm 0.020$ µm
$w = 10.914 \pm 0.140$ µm
$haz = 30.056 \pm 0.189$ µm
$R_a = 0.106$ µm
Complete removal with substrate damage

Fig. 2. Confocal microscope images of laser ablation of sputtered material, $v_{scan} = 500$ mm/s, $f_{RR} = 100$ kHz, Ov = 50 %, $d_{spot} = 10$ µm, different fluencies.

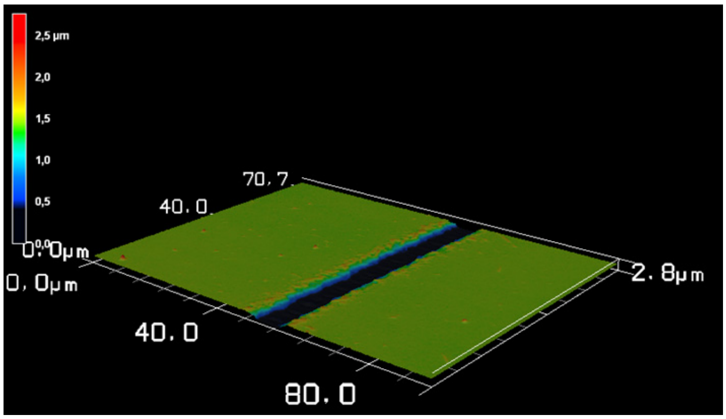


Fig. 3. Laser ablation of sputtered material, 3D-figures of laser confocal microscope of Fig. 2 b) $v_{scan} = 500$ mm/s, $f_{RR} = 100$ kHz, Ov = 50 %, $d_{spot} = 10$ µm, H = 17.2 J/cm², $a_d = 1.205 \pm 0.026$ µm.

For the process study with galvanized material, the laser beam was scanned by a galvanometric system over the copper area of 3 mm x 3 mm. The focal spot diameter was 20 µm. The area was irradiated by parallel line scans where the line overlap is equal to the pulse overlap. 10 J/cm² has been chosen as laser fluence. The ablation depth of the copper and chrome coating have been studied as a function of the repetition rate (f_{RR} in kHz) and the pulse overlap (Ov in %) and show the ablation depth of the copper and chrome layer on the thin glass with a thickness of 500 µm. The surface is modified by ablation depending on the laser parameters. With an increasing number of scan cycles, the depth of material removal increases. The result of the ablation process with the picosecond laser can be devided into the same three regimes as for the removal of the sputtered films:

- 1: Incomplete removal
- 2: Complete removal
- 3: Complete removal with substrate damage

Fig. 4 depicts the images captured by the confocal microscope. The laser fluence was constant at 10 J/cm² and the repetition rate was 50 kHz. To demonstrate the incomplete, the complete, and the complete removal with damage, the pulse overlap from 25 % to 50 % versus the number of laser scan cycles is presented. For each ablated area, with different laser process parameters the ablation depth (a_d) as the difference between the laser-irradiated area and the non-irradiated area has been measured. For the removal of metal coatings with a thickness of 10 µm a higher number of laser scan cycles is necessary in contrast to the thin coating of 1 µm. The first laser scan induces an ablation depth a_d of copper and chrome in a range of 0.2 and 0.5 µm, depending on the pulse overlap. With the increase of 10 laser scan cycles the ablation depth is between 4.1 and 7.7 µm, Fig. 4 a) –c). This removal is also incomplete. A complete removal of the coatings is reached with at least 25 laser scan cycles, Fig. 4 d).

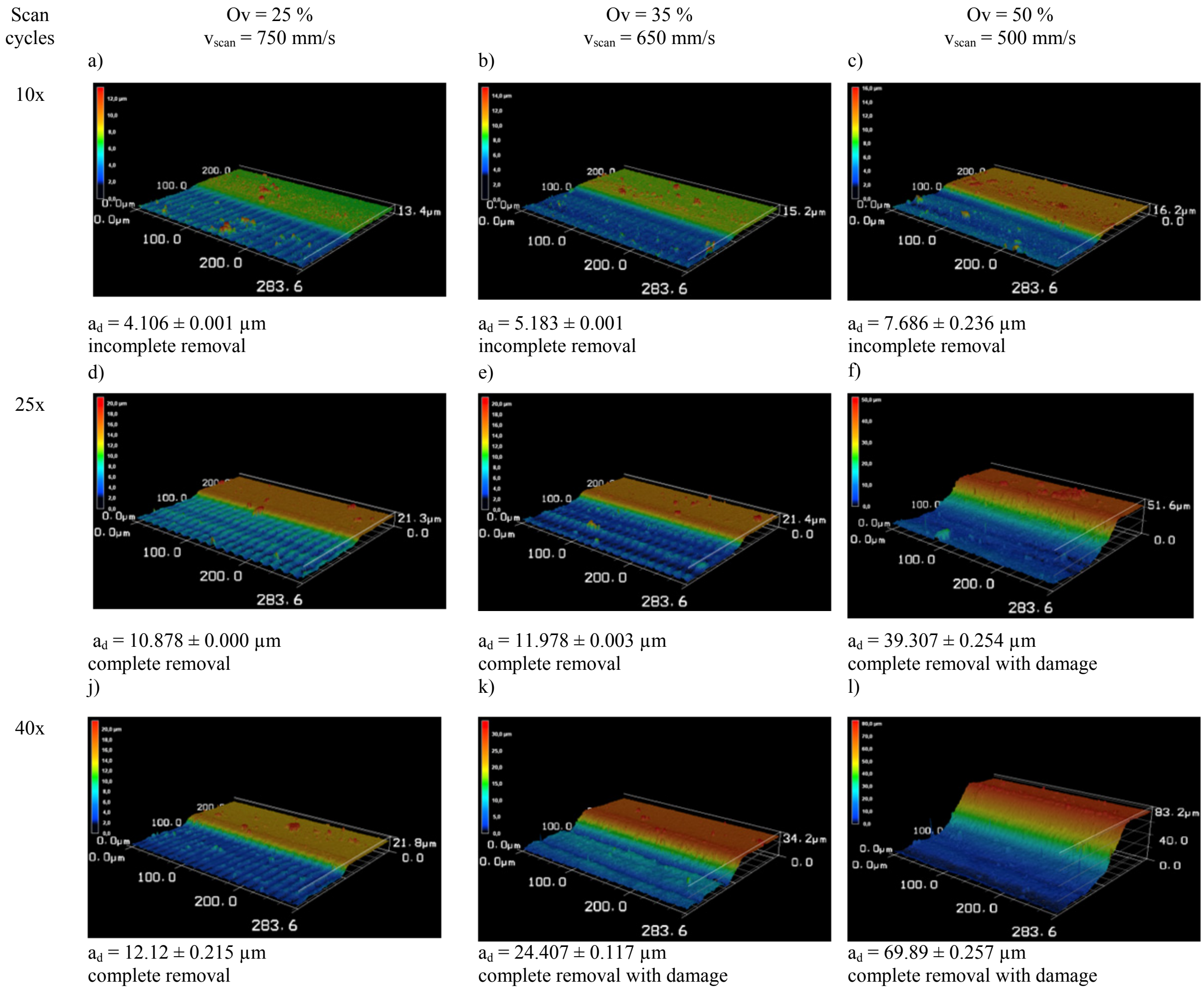


Fig. 4. Laser ablation of galvanized material, 3D-figures of laser confocal microscope, H = 10 J/cm², f_{RR} = 50 kHz, number of scan cycles versus pulse overlap, d_{spot} = 20 µm.

In accordance to the additional chrome layer of 20 nm, the single pulse ablation depth is approximately 288 nm at fluence per pulse of 10 J/cm² which is in agreement with reference 6. The pulse overlap influences the quality of the removal; generally, with an overlap of 25 % the ablated area appears inhomogeneous.

Fig. 4 f), k), l) and m) show results where the removal is complete but the thin glass substrate is damaged.

The red copper front side of galvanized material after laser processing is presented in Fig. 5. Areas of 3 mm x 3 mm have been laser irradiated with different laser scan cycles and pulse overlaps at a constant laser fluence of 10 J/cm². With a single laser scan cycle the two layers chrome (20 nm) and copper (10 µm) can not be completely removed. From 25 laser scan cycles, the coating can be removed and the transparent glass is visible. At least 25 scan irradiation cycles are necessary for the complete removal.

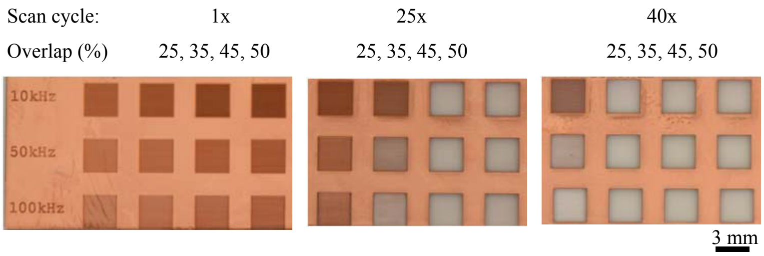


Fig. 5. Images after laser process from the front side of galvanized material, H = 10 J/cm², f_{RR} = 50 kHz, different scan cycles and pulse overlaps.

Fig. 6 summarizes the results. Ablation depth (a_d in µm) versus overlap (Ov in %) is plotted in the diagram for the four different overlaps (25 %, 35 %, 45 %, 50 %). The dotted line marks the thickness of the coatings on the thin glass substrate. To achieve the desired ablation depth of 10 µm, a pulse overlap of 25 – 35 % with 25 scan cycles should be used.

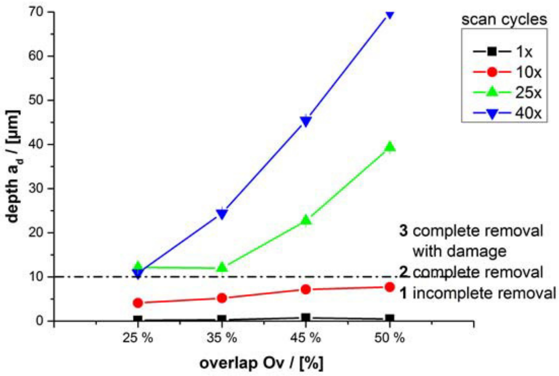


Fig. 6. Laser ablation of galvanized material, H = 10 J/cm², f_{RR} = 50 kHz, different scan cycles and pulse overlaps.

With the ablation study of metallic layers from thin glass, a printed circuit board layout was created as demonstrator, Fig. 7.

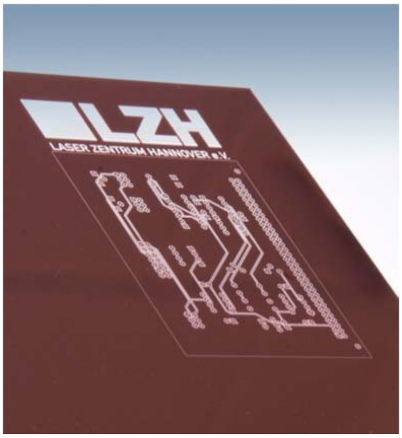


Fig. 7. Laser structured metal coated thin glass.

4. Conclusion and Outlook

New materials for printed circuit boards (PCB) based on thin glass with chrome and copper layers have been successfully processed with a picosecond laser for the patterning of electrical circuits. A complete removal of metallic layers from the thin glass is necessary to create costumer-specific printed circuit boards. Therefore, the ablation behavior of different metal film thickness has been analyzed by laser confocal microscope. The quality and the depth depend of the laser ablation fluence and the number of repeated laser scan cycles. The laser fluence and the pulse overlap have to be adjusted to achieve an adequate material removal without damaging the glass substrate.

Both investigated materials, sputtered and galvanized, show three different regimes of incomplete removal, complete removal and complete removal with substrate damage. Sputtered materials with thin metal coatings (1 µm) can be electrically isolated with a single laser scan cycle however galvanized materials with thicker metal coatings (10 µm) require multiple laser scan cycles.

The lower coating thickness of the sputtered material results in a decrease of the laser processing time for the removal. This includes an increase of the throughput with a factor of approximately 25 for printed circuit boards. Therefore, sputtered thin glass substrate should be laser structured, so that isolated areas have been generated and then finally galvanized in order to apply laser patterning in a cost efficient way. Future examinations will focus on the generation of multilayer thin glass boards, so that the effect could be scaled for this production.

Acknowledgements

The project “Glass PCB – Development of a Multilayer Circuit Board Based on Thin Glass” has been funded by the Central Innovation Program SME (ZIM) of the Federal Ministry of Economics and Technology (BMWi).

References

[1] Zhang, J., Li, T., Wang, H., Liu, Y., Yu, Y., 2014. Monitoring extent of curing and thermal-mechanical property study of printed circuit board substrates. Microelectronics Reliability, Volume 54, Issue 3, 619-628
[2] Momma, C., Nolte, S., Chichkov, B. N., v. Alvensleben, F., Tünnermann, A., 1997. Precise laser ablation with ultrashort pulses. Journal of Applied Surface Science 109/110, 15-19.

[3] Von der Linde, D., Sokolowski-Tinten, K., 2000. The physical mechanism of short-pulse laser ablation. Journal of Applied Surface Science 154-155, 1-10.

[4] Domke, M., Rapp, S., Huber, H., 2012. Ultra-fast movies resolve ultra-short pulse laser ablation and bump formation on thin molybdenum films. Journal of Physics Procedia 39, 717-725.

[5] Voisiat, B., Gedvilas, M., Indrišiūnas, S., Račiukaitis, G., 2011. Picosecond-laser -beam-interference ablation as a flexible tool for thin film microstructuring. Journal of Physics Procedia 12, 116-124.

[6] Siegel, F. 2011. Abtragen metallischer Werkstoffe mit Pikosekunden –Laserpulsen für Anwendungen in der Strömungsmechanik. Berichte aus dem LZH Band 02/2011

[7] Kmetec, B., Kovačič, D., Možina, J., Podobnik, B., 2009. High-speed energy efficient selective removal of large area copper layer by laser induced delamination, Journal of Applied Surface Science 255, 8598-8602.

[8] Düsing, J. F., Temme, T., Kling, R., 2007. Micro patterning of metal thin films on polyimide foils using high-repetition picosecond laser, Laser Assisted Net Shape Engineering 5, 1157-1166