

New connecting and micro material processing techniques with ultra-short pulse lasers and high speed optical manufacturing tools

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Abstract

We present new micro processing and connecting processes with state-of-the-art ultra-short pulse laser systems with pulse durations in the femtosecond to picosecond time-scale. Laser processes like shock-wave induced thin-film delamination (SWIFD), laser patterning of conductive thin films, fabrication of interconnection lines and laser-induced forward transfer (LIFT) of functional materials for the fabrication of microelectronic elements such as interconnects and embedded circuits are discussed in detail.

These laser-induced processes and fabrication methods offer new possibilities for the packaging of semiconductor, surface mounted and/or hybrid systems and subsystems.

Additionally, processing methods with these laser systems for innovative applications in the microelectronics field like the laser-lift-off for flexible displays and printed circuits, welding of brittle glass materials like sapphire and gorilla glass used in the communication area and micro machining of ceramic substrates with compact workstations equipped with high speed manufacturing tools are also presented.

1. Introduction

Ultra-short pulse laser systems with pulse durations in the range of a few hundred femtoseconds to a few tens picoseconds are gaining increased acceptance in the field of industrial nano- and micro-processing as they provide a nearly athermal interaction of the laser radiation with targets like metal, glass, plastic or semiconductor material. Additionally, in most of the processing methods using these ultra-short pulse laser systems no further post-processing of the parts is necessary [1 - 6].

Compared to commonly used Q-switched diode-pumped solid-state lasers or pulsed fiber lasers used in industrial laser processing applications, state-of-the-art ultra-short pulse lasers today have a high availability in a 24/7 manufacturing environment, an excellent processing quality in combination with a reasonable material throughput and a very good process efficiency compared to the aforementioned laser sources [7].

Ultra short laser pulses can perform a nearly cold ablation of virtually any material from diamond to dynamite and can machine brittle materials like gorilla glass without cracking. This unique radiation can also weld these brittle materials in a special manner or can induce color changes on the surface or inside them. Nevertheless it is very important to learn the basic laser-matter interaction principles by investigation and to find out the appropriate processing regimes.

Fig. 1 shows the basic differences between the melt-dominated and the vapor-dominated laser processing with pulsed and/or Q-switched laser systems compared to ultra short pulse laser.

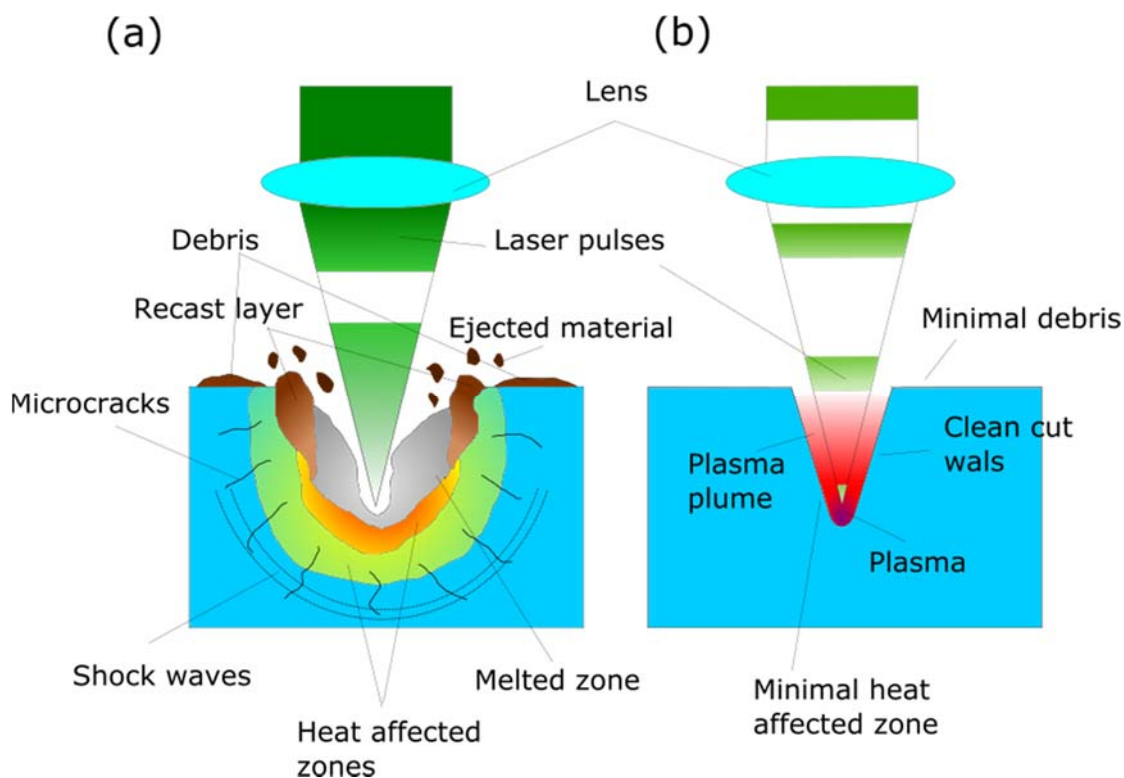


Fig. 1: Laser/material interaction with short (a) and ultra short (b) laser pulses

The reduced size but higher complexity of parts and systems especially in the electronic device industry demand new high precision micro-machining concepts that can only be performed with ultra-short pulse lasers that produce only minimal heat affected zones (HAZ) in the machined parts [8, 9].

The use of ultra-short pulse laser systems in drilling applications produce high quality micro holes [10] or the cutting of stainless steel, plastic foils or GRP components material show excellent results without thermal damage even at high processing speeds [11] to name only two new applications with ultra-short pulse laser.

Although the solar cell and panel market for Si cells is still facing a significant drop special renewable energy projects with thin-film flexible solar cells are gaining

new ground. The texturing and laser structuring of such thin-film or even organic flexible solar cells presupposes the use of ultra-short pulse laser systems to achieve high overall efficiencies [12, 13].

Additionally, the worldwide medical device market can profit from new and innovative products and processes only feasible with ultra-fast lasers, e.g. the laser-micro cutting of polymer-based life-science devices [14, 15].

Other new and innovative processes, especially for the connection of subsystems in the microelectronic field, like the fabrication of interconnection lines using the laser-induced forward transfer (LIFT) of functional materials with ultra-short pulse laser radiation, will be shown in the following sections.

2. Material and Methods

For all experiments we used the ultra-short pulse laser *PHAROS* from company *Light Conversion* of Lithuania with single pulse energies up to 1.5 mJ and a mean power up to 20 W at the fundamental wavelength of 1030 nm. The compact setup contains a seed oscillator, a regenerative amplifier, a stretcher/compressor unit and an optical module for frequency conversion to 515 nm, 343 nm and 257 nm, respectively, directly attached to the output of the amplifier module. Nevertheless, all processes described later, were performed at the fundamental wavelength of 1030 nm.

The laser is also tunable in pulse duration from 190 fs up to 10 ps with pulse repetition rates up to 1 MHz. This makes the *PHAROS* system an ideal candidate for the optimal tuning of the laser parameters to achieve lowest thermal damage to the substrate.

For the laser beam steering we either used a galvo scanner from company *Cambridge Technology* (*Lightning LPX-10 Digital Scan Head*) with a telecentric f-Theta lens from company *Sill Optics GmbH* (*S4LFT0082/328*) or a fixed fine cutting head from company *Precitec GmbH* (*FineCutter*) together with a high dynamic and high precision XY-positioning table system with a resolution of 50 nm and a precision of +/- 1 µm used in the laser micromachining concept *microcut2000 UKP* of company *LLT Applikation GmbH* or the laser machine concept *CompactMark* from company *LASIT S.r.l./Italy*.

3. Laser processes

3.1. Laser-induced forward transfer (LIFT)

Laser-induced forward transfer (LIFT) is a direct-writing technique that allows the deposition of tiny amounts of material from a thin film (deposited onto a transparent holder) to a receptor substrate using a laser pulse. The principle of LIFT is shown in Fig. 2 together with some possible structures.

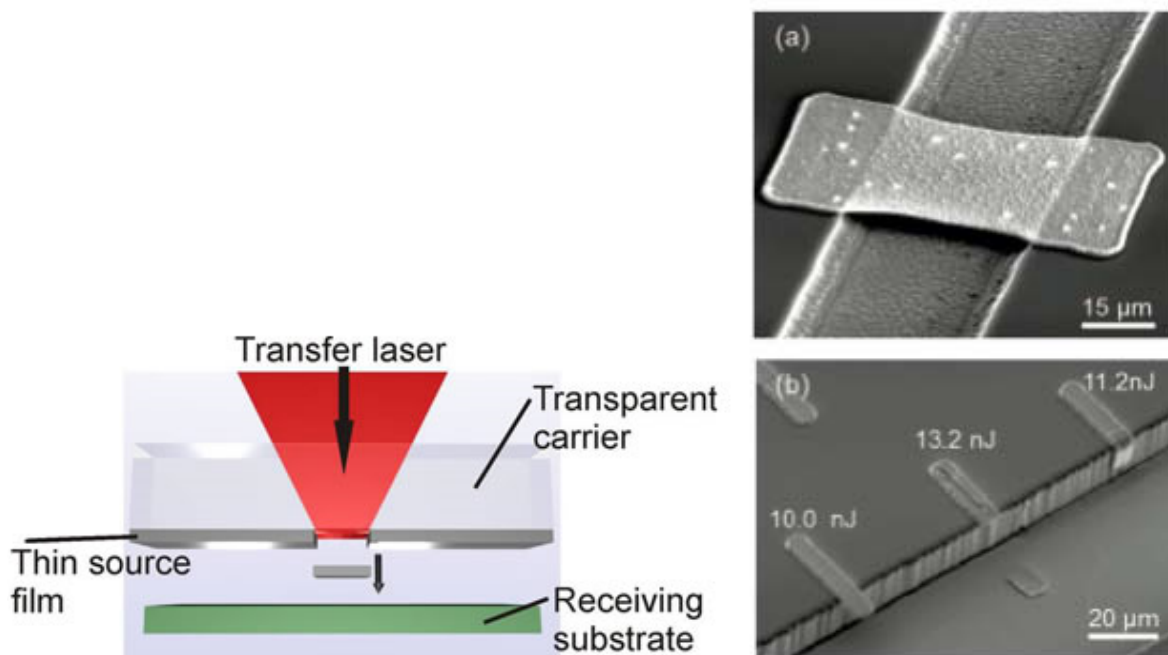


Fig. 2: Principle of LIFT and examples of possible LIFT structures

This transfer laser vaporizes a small portion of the thin film on the donor substrate that recondenses onto the receptor substrate in form of a solid dot. Instead of using solid thin films it is also possible to use pastes and liquids or even organic material as donor material. With a high-speed 2D or 3D galvo system and/or a polygon scanner we were able to produce dots, rectangles, lines and bridges or any other free-form structure in the μm range that can be applied in innovative SMT or semiconductor devices.

3.2. Shock-wave induced thin film delamination (SWIFD)

Another nearly non-thermal structuring method for functional layers is the shock wave induced thin film delamination (SWIFD) process that is in some aspects related to the LIFT process. It can be used in the micro structuring of thin films especially in the structuring of flexible thin film solar cells with $\text{Cl}(\text{G})\text{S}$ or CdTe as photosensitive material. Fig. 3 shows the principle of the SWIFD process in comparison to the direct structuring of functional layers [16].

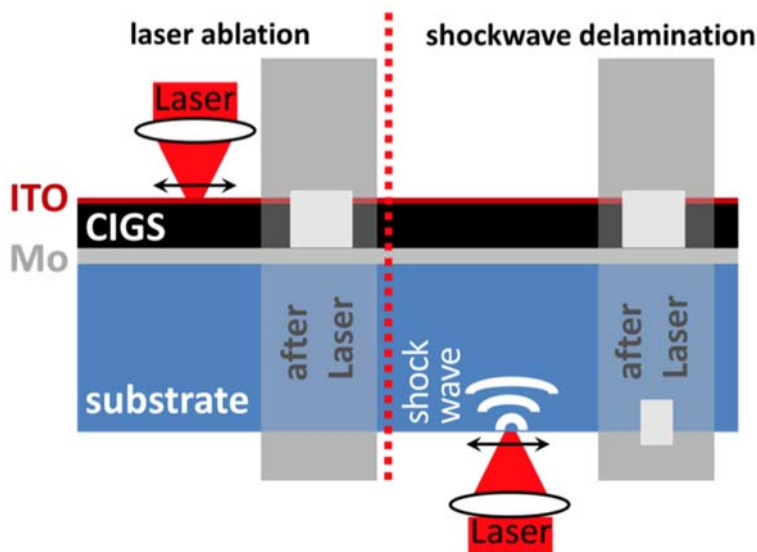


Fig. 3: SWIFT process (right) compared to direct laser ablation (left) (Source: [16])

The main differences between the two nearly athermal methods to selectively remove thin films (ITO, CI(G)S, CdTe or Mo) are the direction of the laser light and the lateral precision of the structuring which is much better in the case of direct laser ablation using high precision scanner and XY-positioning systems.

Fig. 4 shows the result of the direct P3-structuring of a CI(G)S thin film on a flexible solar cell with polyimide as substrate material with the PHAROS-system (290 fs, 300 kHz, 5 W, 80 % pulse overlap)). No heat-affected zones (HAZ) can be seen either on the Mo surface or at the CI(G)S sidewalls.

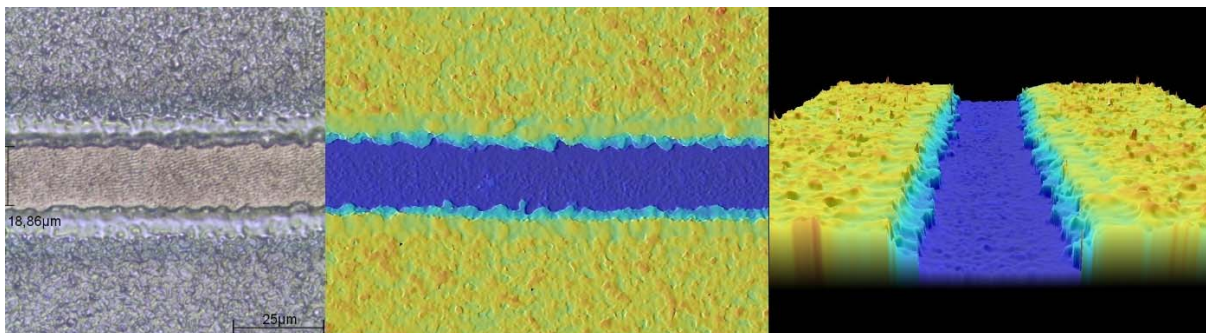


Fig. 4: P3-structuring of ITO/CI(G)S on a thin-film solar cell

The disadvantages of the laser-induced shock wave delamination of the thin film structures (Fig. 3 right) are that the substrate material is damaged by the laser pulse and the thin films are ablated in an explosive non-predictable way (see Fig. 5). Nevertheless this procedure has less or no thermal influence on the remaining CI(G)S structure.

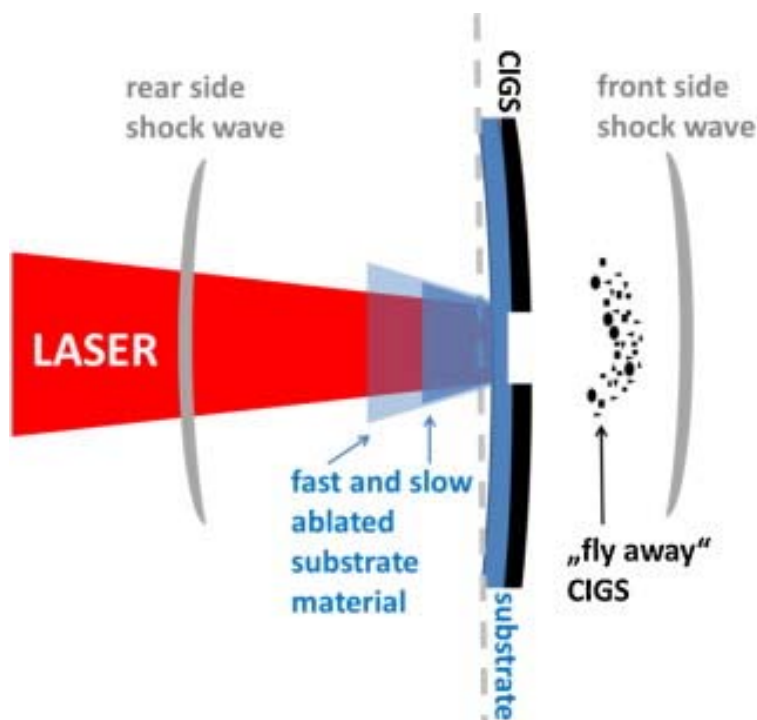


Fig. 5: SWIFT of CIGS film on substrate (Source: [16])

On a larger scale this procedure is used in the production of flexible displays, e.g. OLED displays for mobile use. The laser-lift-off-process for these displays is schematically shown in Fig. 6. A polyimide film is deposited on a glass substrate together with RGB-OLEDs and a multilayer of organic/inorganic protection films. Afterwards the carrier glass is irradiated with a broad laser beam to separate the polyimide film completely from the glass substrate.

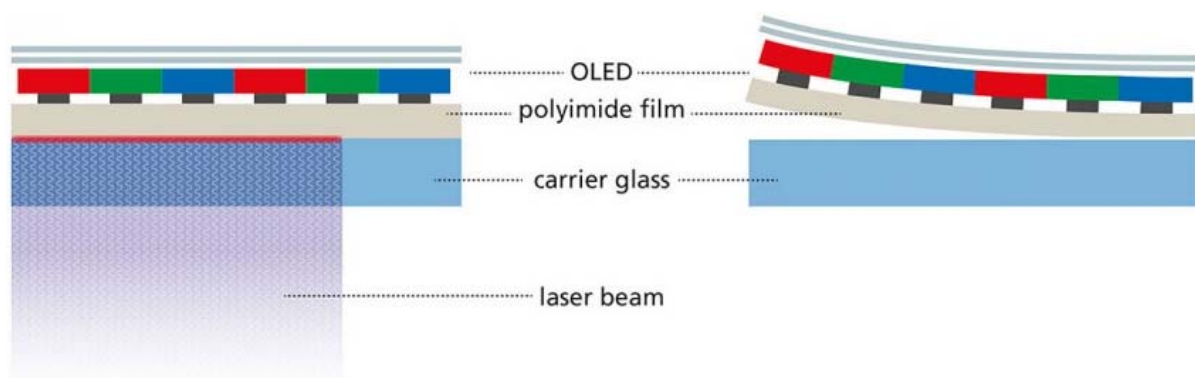


Fig. 6: Laser-lift-off-process of an OLED display

3.3. Welding of brittle glass materials

As ultra short pulse laser systems produce power densities in the range of GW/cm^2 to TW/cm^2 it might be astonishing that it is possible to weld brittle glass materials like gorilla glass or sapphire. Using specific pulse durations, pulse energies and repetition

rates that are possible with the *PHAROS* laser system mentioned above we performed durable glass welds between two transparent glass samples according to Fig. 7.

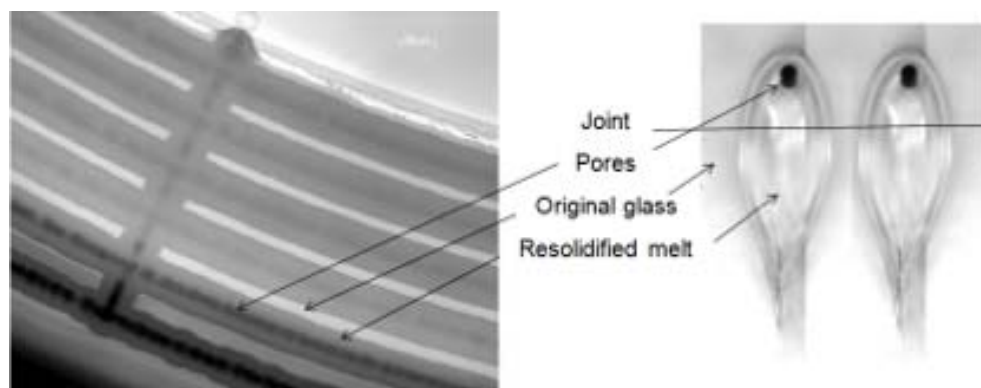


Fig. 7: Glass welding with ultra short pulse laser

The welds have a droplet-like appearance within the original untreated glass consisting of resolidified melt. At the top of the weld a small dark region (pore) is clearly visible where the laser radiation reaches a power density of about 1.5 TW/cm^2 .

3.4. Laser micro-machining of ceramic substrates

Ceramic material like Al_2O_3 or ZrO_2 used in microelectronic circuits are normally cut with pulsed CO_2 -lasers and are broken along the perforated lines. Normally the size tolerance of the single circuit is of minor importance. In high performance applications, however, where size tolerances matters the ceramic substrate can only be cut with ultra short pulse lasers to reach size tolerances of only 10 to 20 μm . ZrO_2 that has a very low thermal conductivity can only be cut with ps to fs laser pulses to avoid breakage of the substrate during laser-micromachining. Fig. 8 a/b shows the results after laser scribing both sides of the ZrO_2 substrate with different laser parameters and after breakage.

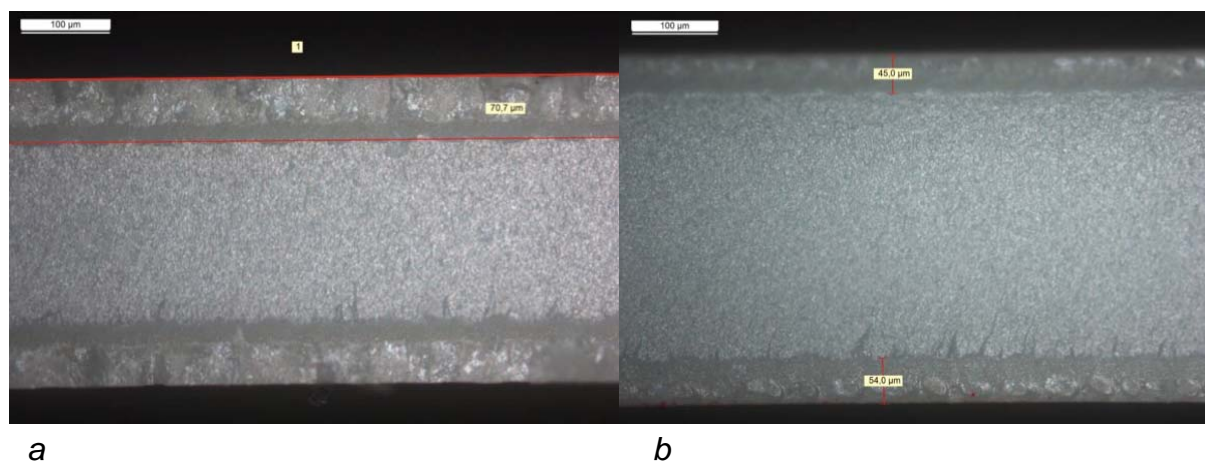


Fig. 8: Two sides scribing of ZrO_2 with different ultra short pulse laser parameters

Using high pulse energy and high repetition rate for the scribing of the above mentioned ceramic substrate could lead to micro cracks within the laser treated areas (Fig. 9a). After optimization of the laser parameters to lower pulse energy and lower repetition rates the micro cracks completely disappeared (Fig. 9b). This shows that laser-machining of a special material always needs an optimization of the laser parameters together with the scanning speed of the beam deflector, especially for the ultra short pulse lasers with fs to ps pulse duration.

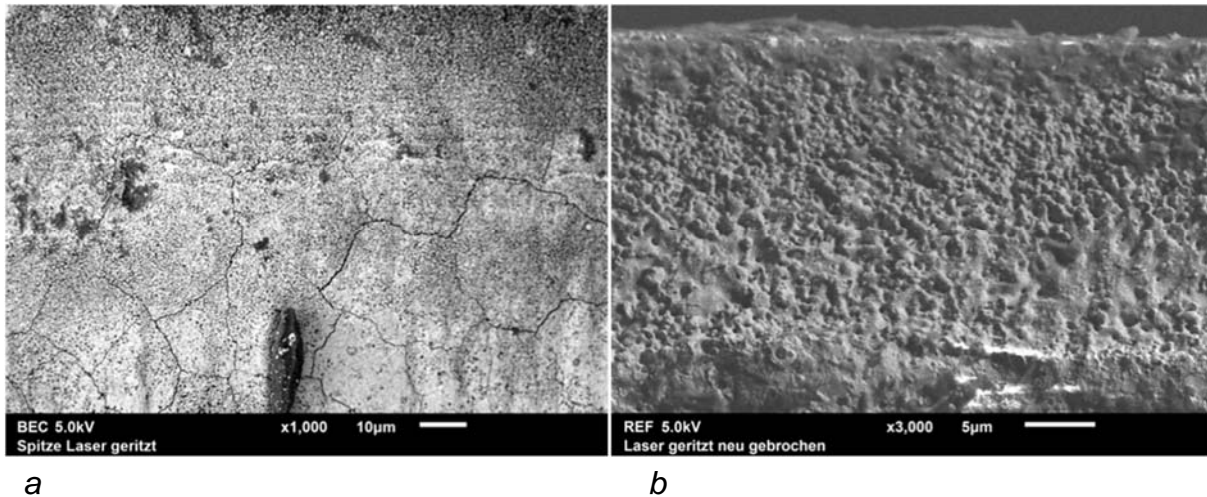


Fig. 9: Details of the laser-scribed areas with different laser parameters

4. Summary

We have presented a survey of several new micro-processing and connecting processes using an industrial-proven ultra short pulse laser with pulse durations from about 190 fs to 10 ps time scale together with state-of-the-art high speed scanner tools with deflection speeds of more than 10 m/s. New laser processes like the SWIFD or LIFT techniques can be used in the precise fabrication and processing of microelectronic parts within the μm -range or smaller.

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