LANE 2016

9th International Conference on
Photonic Technologies LANE 2016

Industrial Paper

New micro and macro laser machining applications using fiber laser and ultra short pulse laser systems in compact laser machines

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Abstract

We report on new industrial process developments and applications using state-of-the-art fiber laser and ultra short pulse laser systems within compact laser machines with up to 5 moving axis. The ultra short pulse laser source provides a mean power of 18W with the ability to produce picosecond to femtosecond laser pulses with high single pulse energy and repetition rates up to 1 MHz at 1030 nm, 515 nm, 343 nm and 247 nm in an extremely compact unit. The fiber laser system provides mean powers up to 100W at 1064 nm and up to 50W at 532 nm wavelengths with pulse repetition rates up to 200 kHz and 600 kHz, respectively. Precise structuring of thin-film solar cells on plastic and glass substrates, scratching and isolating of ceramic substrates covered with a thin silicone film for LED manufacturing, micro-machining of metals, thin glass, ceramics and (bio) polymers for medical applications as well as marking and cutting of plastic, glass and metal samples are discussed in detail. Additionally, diffractive and refractive beam shaping optics were used for parallel beam processing and precise drilling, cutting and structuring of thin electronic films and materials. The results were analyzed with different optical methods regarding thermal influence zones and machining quality.

Keywords: Micro and macro laser machining; ultra short pulse laser; fiber laser; beam shaping optics; thermal influence zone

1. Introduction

In the fast growing field of laser macro and micro machining with complex and compact laser machines two laser sources are competing as the perfect laser tool: the pulsed nanosecond fiber laser and the ultra short pulse laser with pulse durations reaching from hundreds of femtoseconds to a few picosecond. Both laser systems produce more or less pronounced thermal influence zones during laser processing of solids as already described in detail by Chichkov et al. (1996). Another important feature to successfully integrate such laser devices into multi-axes laser machines is its required reliability in a 24/7 industrial environment, its modularity and compactness, its easy integration within the laser machine and last but not least its stable performance over a long production period as described for an industrial-proven ultra short pulse laser system by Steiger (2013). Additionally there is an ongoing development process to improve the performance of these interesting laser sources for new micro laser machining applications as shown by Ryll and Schmitz (2015). The newest development for further improving the reliability and ease of integration in production laser machines is the combination of both laser sources: a high power fiber laser with pulse durations in the femtosecond to picosecond time scale as reported by Lin and Yang (2010).

We report on new industrial applications using a state-of-the-art fiber laser and an ultra short pulse laser that can be used in laser processes for consumer electronics (Mottay (2015)), in laser micro processing of semiconductors and dielectrics (Weiler (2008)), in the laser structuring process of CIGS thin-film solar cells (Steiger et al. (2009)), the laser processing of thin glass printed circuit boards (Plat et al. (2014)), laser

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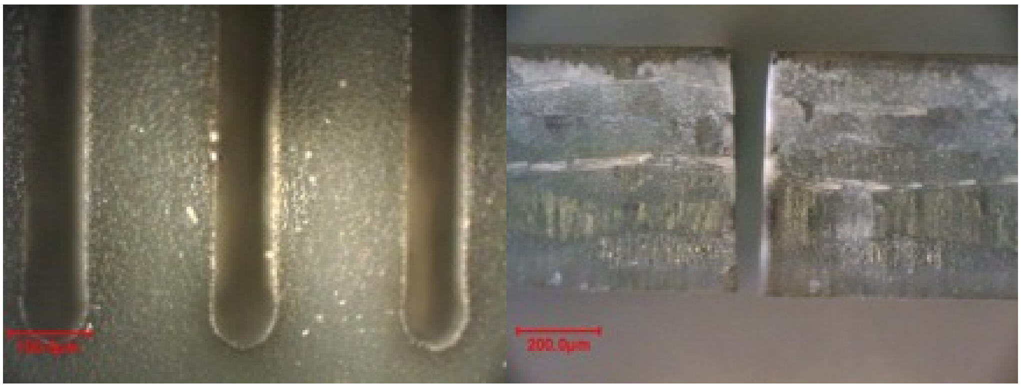
surface texturing (Hoult and Amidon (2015)), the laser welding of glass substrates (Gabzydyl and Capostagno (2016)), as well as applications for the medical industry (Patschger et al. (2016)).

2. Materials and methods

For all the experiments we used the ultra short pulse laser *Pharos* from company *Light Conversion* with single pulse energies up to 1.5 mJ, pulse repetition rates up to 1MHz and a mean power up to 18W at 1030 nm or a fiber laser system from company *IPG Photonics* with pulse repetition rates up to 200 kHz and a mean power up to 100W at 1064 nm. The different laser systems were integrated either in the machine concept *microcut2000 UKP* of company *LLT Applikation GmbH* or the machine concept *CompactMark* from company *LASIT S.r.l.* depending on the necessary precision for the application. For the beam steering we either used a galvo scanner *Lightning LPX-10 Digital Scan Head* from company *Cambridge Technology* with a telecentric f-Theta lens *S4LFT0082/328* from company *Sill Optics GmbH* or a fixed fine cutting head *FineCutter* from company *Precitec GmbH* together with a high dynamic and high precision XY positioning system with a resolution of 50 nm and a precision of +/- 1µm if necessary.

3. Results

Figure 1 shows the results of cutting experiments with the scanner arrangement on FR4, a fiberglass reinforced laminate. Figure 1a displays the entrance side of the laser beam, figure 1b the side view of the cut through a 600 µm thick FR4 sample that shows nearly no signs of smoke or carbonization for thicknesses ranging from 200 – 600 µm using the ultra short pulse laser system with 290 fs pulse duration and 500 mm/s scanning speed. The fiber laser in contrast shows a more or less pronounced thermal influence zone at the cutting area depending on the pulse repetition rate and the wavelength.



a b

Fig. 1. FR4 fiberglass reinforced resin (a) top view (b) side view.

a b

Fig. 2. Silicone film on ceramic substrate (a) top view laser cut in silicone (b) cut and broken ceramic sidewall.

We also machined ceramic samples with a thickness of 500 µm covered by a 120 µm thick silicone film used in LED manufacturing (Fig. 2 a). After cutting the ceramic samples were broken as in the normal manufacturing process. Neither the silicone film nor the ceramic substrate showed any sign of thermal influence zone or debris formation on the surface or the sidewalls of the substrate when the fs laser system was used for the procedure (Fig. 2 b). Again only the fiber laser produced significant damage zones in the silicone and the sidewalls of the ceramic.

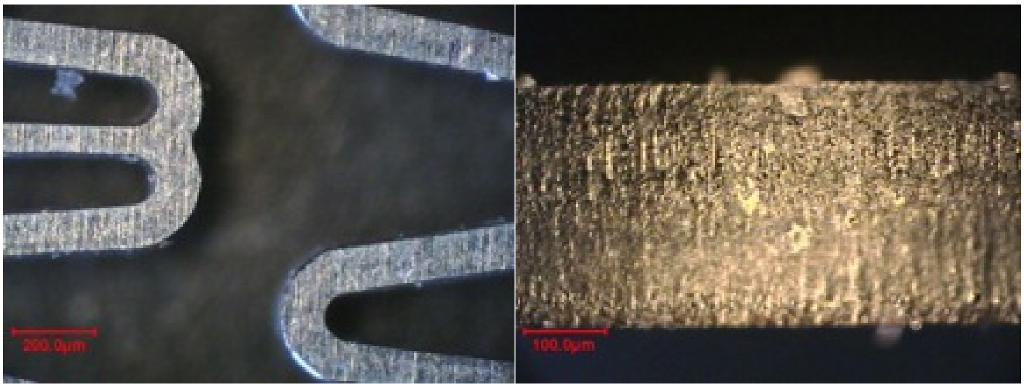


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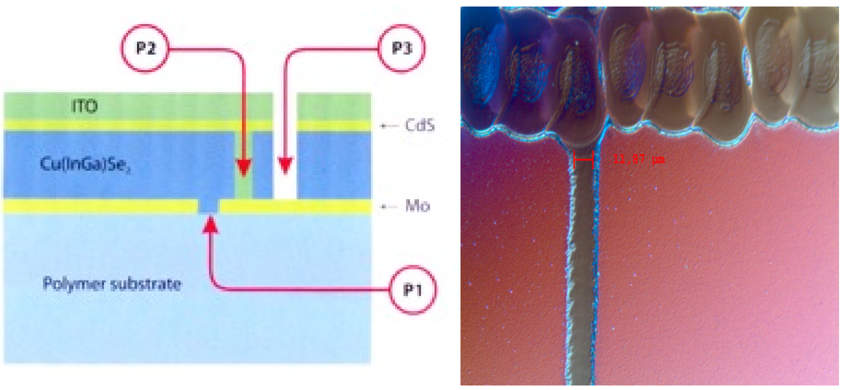
Fig. 3. Stainless steel sheet cut sample (a) top view (b) side view.

Figure 3a shows the cutting result in 150 µm thick stainless steel with the fixed optic and the high dynamic XY table arrangement to create stent-like structures. A cutting speed of 600 mm/s was used. Figure 3b displays the side view of the stainless steel sheet cut with 300 µm thickness. Although this material thickness is quite large for the machining with an ultra fast laser like the *Pharos* no thermal influence zone is visible. The cutting speed was 300 mm/s. Besides stainless steel we also machined metals like titanium and very brittle Wo alloy with both laser systems with nearly the same results regarding quality and thermal damage.

The most pronounced differences in the machining with the fiber laser and the ultra short pulse laser could be seen in the structuring of thin films of only a few micrometer thickness, e.g. in the P1, P2 and P3 structuring process of thin-film solar cell with an active layer of copper indium (gallium) diselenide (CI(G)S) 1-2 µm thick.



a b

Fig. 4. P1, P2 and P3 structuring process (a) process steps (b) P1 structuring with fiber laser and ultra short pulse laser.

Figure 4a displays the general P1, P2 and P3 structuring processes. As carrier substrates different materials like metals, polymers or glass can be used depending on the final use of the solar cell. Figure 4b shows the result of the P1 structuring process of Mo with either a fiber laser (horizontal line) or an ultra short pulse laser (vertical line). It is clearly visible that the fiber laser produces significant thermal damage to the glass substrate (local cracks) whereas the ablation of the Mo layer with the ultra short pulse laser is performed with no signs of heat effected zones or debris. The best results were obtained with a flattop laser beam profile and fs laser pulses of the ultra short pulse laser together with the high dynamic and high precision XY positioning system integrated in the *microcut2000 UKP* laser machine. Figure 5 shows the P3 structuring result in the optical and confocal microscopic appearance with no visible damage or debris to the Mo layer (dark blue).

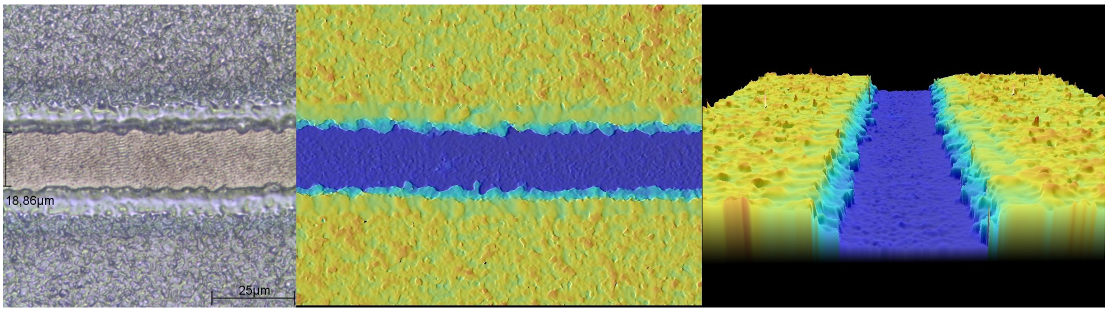


Fig. 5. Optical and confocal microscopic appearance of the P3 structuring result with fs laser pulses and flattop beam profile.

4. Summary

With fiber laser and ultra short pulse laser systems we performed cutting and structuring processes on plastic, metal, ceramic and thin film samples in compact laser machines with high processing speeds and excellent machining results. By choosing the right process parameters like pulse energy, pulse repetition rate, process speed, pulse duration and beam profile we demonstrated machining with no or only minimal thermal influence zones and debris formation on the surface or the sidewalls of the samples. In many of the processes the fiber laser produced much larger heat effected zones and surface debris by recrystallization of molten material than the ultra short pulse laser. This behavior was especially observed in thin film structuring like the P1, P2 and P3 structuring of solar cells. In combination with special beam shaping optics the ultra short pulse laser is the ideal candidate for new laser micro machining applications like the cutting of bio absorbable stents for coronary arteries.

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