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Compact laser and trepanning system solutions for versatile micro-machining

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Abstract

In a joint project between a manufacturer of high-class laser systems and a non-profit company that operates technology transfer, new laser and trepanning systems were developed and validated for industrial micro-machining tasks. The new compact high-power q-switch laser systems, the *conqueror* series, generate 7 ns laser pulses at maximum single pulse energies of 500 µJ at 532 nm and nearly 400 µJ at 355 nm. The new trepanning systems were developed rotate two strongly focused laser beams onto the work-piece for precise drilling and cutting applications. New implementation strategies were addressed to make full advantage of the compact size and low weight of the new devices. Processing examples on micro-machining of copper layers, polyamide foils, thin glass, quartz, and sapphire substrates will be discussed.

Keywords: UV q-switch laser; trepanning; micromachining; sapphire; polyamide; glass

1. Introduction

There is an increasing need for processing techniques, that obey continuously miniaturizing components and structure sizes, e.g. for the fabrication of consumer products, for automobile engines, and space craft devices. State of the art mechanical tooling is progressively dealing with impractical-to-break boundaries in micromachining, due to the new constraints in material selection, structure sizes and tolerances. Laser induced material removal is increasingly accepted in the industry as an important complementary method for an overwhelming variety of fabrication tasks, for example marking, drilling, cutting, welding, structuring of metals and prototyping.

The advances in laser technology are underlining the rapid development of reliable laser sources with large variety parameter settings to choose from. For the laser material machining, e.g. micro-drilling of metals or glass, several parameter settings that have to be taken into account, such as the combination of wavelength and pulse width (providing for the appropriate optical and thermal penetration depths), laser beam quality, repetition rate and single pulse energy, average and peak power, pulse to pulse control and technical aspects like reliability and stability outside a laboratory environment.

The company *Compact Laser Solutions GmbH* (CLS) in Berlin, Germany, represents a highly innovative inventor of laser technology, having more than 25 years of experience in the development of state-of-the-art pulsed DPSS lasers. Traditionally, CLS has manufactured laser systems generally for marking solutions, providing the first entirely air-cooled DPSS marking laser for this application. In 2014, CLS has joined a research project together with the *Laser- und Medizin-Technologie GmbH Berlin* (LMTB), to develop compact and efficient high-power laser systems generating short pulses at wavelengths of 532, 355 and 266 nm and pulse widths between 7 and 12 ns. The implementation and validation of the new laser CLS laser sources for micromachining was conducted at the laser application lab of the LMTB, which further emphasized the innovation of the project by providing newly developed trepanning systems for laser cutting and drilling.

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2. Laser and Trepanning Systems

The main focus in the development of the new CLS laser sources during the joint project was placed on the pumping geometry and resonator design, consisting of 4 mirrors for IR, a q-switch component and the Nd-doped crystal, which is pumped by a single diode-laser only. The laser resonator studies, conducted at CLS demonstrated early, following the original concept of internal frequency conversion, i.e. the SHG-crystal is inside the resonator, was not advantageous. Although the achievable degree in the conversion efficiency for 532 nm was almost 100%, the temporal pulse profile showed a strong asymmetry in time-resolved measurements. Over 30% of laser intensity is located in the aftermath of the pulse pedestal, which decreases the potential for an efficient conversion into the UV (355 and 266 nm). In addition, a strong asymmetry in the temporal profile characterizes a significant disadvantage for many laser micromachining applications. This problem is evident for laser drilling and cutting of glass substrates, where the laser energy in the pulse tail induces additional stress into the material. Hence, the new CLS IR-resonator was optimized for external frequency conversion from IR to green and UV, capable of generating more than 30 W (q-switch) at 1064 with a “real” FWHM pulse width of ca. 10 ns, pumped by one diode-laser.

For the projected micromachining studies of glass and polymer substrates, a customized 2-wavelength laser system was configured, yielding over 14 W average power at 50 kHz for 532 nm and over 13 W average power at 50 kHz for 355 nm. The pulse width for both wavelengths is below 10 ns and the maximum single pulse energies available reaches levels of 500 µJ at 532 nm and nearly 400 µJ at 355 nm. Two examples of CLS industrial laser products, based on the customized 2-wavelength system, are depicted in Fig. 1. The entirely air-cooled Conqueror Series depicted in Fig. 1a is characterized by an extremely compact and light-weight laser head for versatile integration, yielding 25 W (50 kHz) at 532 nm or 10 W (50 kHz) at 355 nm. The Conqueror *All in One* depicted in Fig. 1b offers similar specifications as in the Conqueror *Series*, boosting the UV average power to 12 W. However in the *All in One* case, all components and connectors are integrated in one housing to ensure maximum stability and safety. In addition, CLS provides a 3-wavelength system, Conqueror *3Lamda*, where the wavelengths 355, 532 and 1064 nm can be chosen separately and combined via software, representing an optimal tool for laboratory studies.[†]

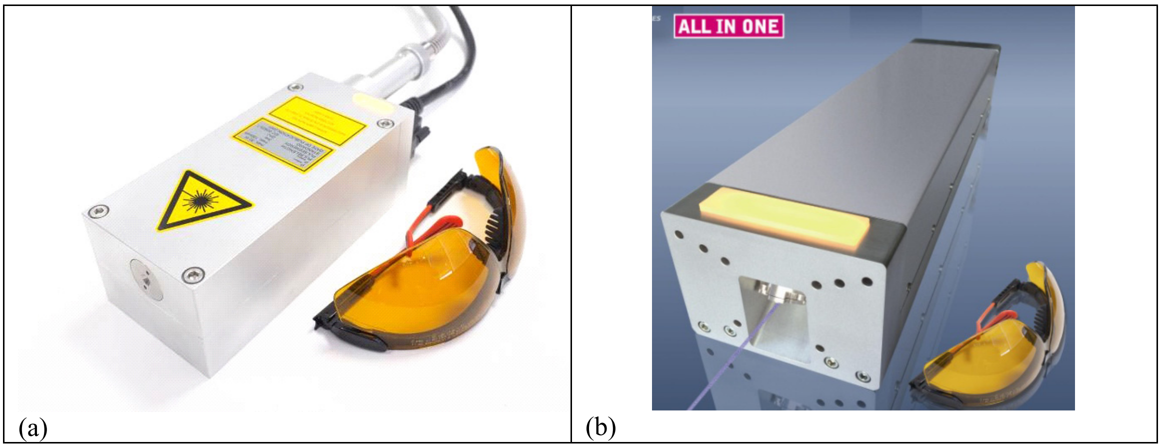

Fig. 1. (a) Conqueror *Series* with a very compact laser head; (b) Conqueror *All in One* system, where laser head, controller, and power device is integrated in one unit. Optional, controller and software for scanner applications are implemented in any Conqueror system.

To exploit the advantages of laser technology for micromachining, several versatile trepanning systems optics have been designed and implemented by LMTB, based on either a single element or an arrangement of rotating, Ashkenasi et al. (2010, 2011, 2015) and Jahns et al. (2013). The goal of these new trepanning systems is to offer a versatile alternative to scanner systems, which inhibit some disadvantages in micromachining due to problems in the long time performance stability. In addition, the trepanning system based on rotating refractive optical elements allows a great deal of freedom in choice in focal length, gas nozzle design, rotating speed and wall taper. In the frame of this project, the LMTB has developed specialized, low-cost trepanning systems for cutting (Type1.f18) and core-drilling (Type1.2P), as depicted in Fig. 2a and 2c.

The Type1.f18 is designed to ensure tight focusing of the laser beam with a focal length of f = 18 mm (or any value above 18 mm, if appropriate for the application). A special beam splitter device in the trepanning system yields two narrowing laser beams passing parallel the rotating element which yields the circular laser energy distribution on the work piece. In this special case, two focused laser beams are now rotating on the work-piece.

[†] For more details and data sheets: http://www.compactlaser.de/en/products/

For cutting applications, the work-piece is moved relative to the trepanning system. The example of a cutting application of glass using the dual-beam Type1.f18 is shown in Fig. 2b, where the rotation speed was set between 20.000 and 40.000 rpm to minimize stress related effects on the brittle dielectric material at laser repetition rates above 30 kHz. The pattern on the glass surface was induced by single pulse ablation using the pilot CLS 2-wavelength laser system at 355 nm. The larger cutting width was set to ca. 350 µm, while the second, internal cutting width is around 180 µm. The displacement of the two laser beams is adjustable, i.e. the cutting widths can be customized to optimize the processing performance.

For core-drilling applications, the LMTB designed the Type1.2P trepanning system, where two different optical elements are rotated at different speed. The core-drilling cutting width is realized by the high-speed rotating element (similar as in the case of Type1.f18), which can be adjusted individually. In the example presented in the right image of Fig. 2d, the core-drilling cutting width is ca. 350 µm. The fast orbital laser pulse distribution is superimposed by a large diameter orbital (slower) motion, caused by the second rotating element. The left image of Fig. 2d demonstrates the ablation pattern on steel after using the pilot CLS 2-wavelength laser system at 532 nm. The processing was stopped after completing only a single 2 mm orbital cycle.

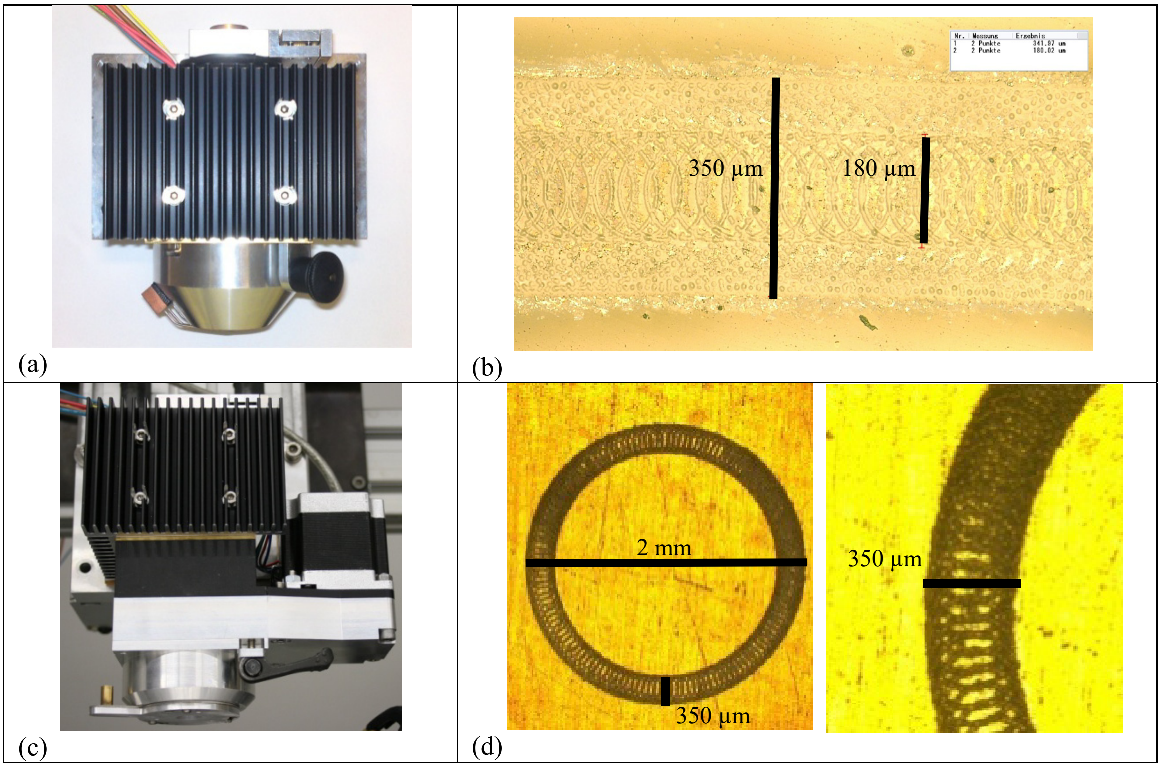

Fig. 2. (a) Trepanning system **Type1.f18** in the dual laser beam configuration; (b) microscope image of fused silica after laser machining with the dual beam **Type1.f18** (single pass for cutting); (c) Trepanning system **Type1.2P**; (d) microscope image of steel after laser machining with the **Type1.2P** (single 2 mm diameter orbit completed for core-drilling at a width of ca. 350µm).

3. Application studies

In the joint project of CLS and LMTB, the laser and trepanning systems were implemented to conduct micromachining studies at 532 and 355 nm on several different materials, whereas the focus was on copper, glass, fused silica, sapphire and polymer foils. Fig. 3 depicts two examples processed with the LMTB trepanning systems at a laser wavelength of 355 nm and a pulse width of ca. 7 ns. The high quality of the through hole in sapphire after core-drilling, as depicted in Fig. 3a, demonstrates only few local sites of chipping in sizes < 20 µm. The 100 µm polyamide foil, as shown in Fig. 3b, was fixed on white cardboard to ensure flatness. The cutting was conducted at reduced UV-laser power, 1 W at 60 kHz. The cut edges are free from black signatures, related to carbonization (picture was taken directly after machining, no post-cleaning was performed). Using green and UV laser light, a series of investigations were performed in rear-side ablation of glass substrates, such as D263T and soda-lime. Here, we observe a slight improvement in the reduction of chipping on the through-hole edges using UV-laser pulses. For fused-silica, the improvement using 7 ns laser pulses in the UV instead of 532 nm was even more evident. Using nanosecond laser pulses at 532 nm, the laser machining results depend strongly on the type (manufacturer and OH-concentration) of fused silica. In addition, the laser machining using the 7 ns UV laser pulses provided better high-aspect through-hole drilling capabilities for fused silica. We were able to complete 0.2 mm diameter holes in 10 mm thick fused-silica samples, yielding an impressive aspect-ratio of 1:50.

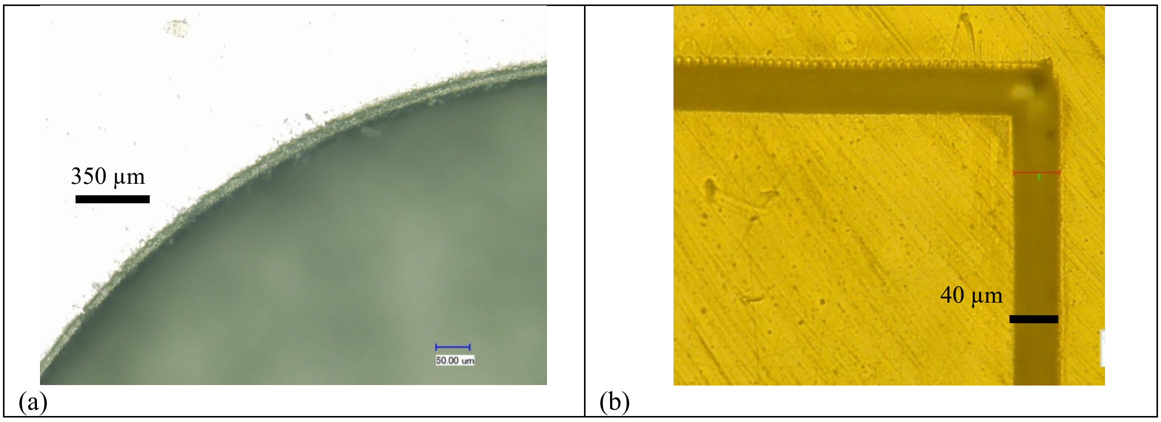

Fig. 3. (a) enlargement of a 2 mm diameter hole in 0,4 mm thick sapphire after laser core-drilling with a cutting width of 350 µm; Located chipping on the edge remains below 20 µm (b) microscope image of a 100 µm thick polyamide foil after laser machining with a cutting width of 40 µm. The polyamide sample was not cleaned after laser machining, showing no signs of carbonization directly after UV-laser micromachining.

4. Summary

In a joint project, the laser manufacturer CLS and the non-profit research & application company LMTB have combined their effort and successfully developed and validated new laser and optical systems for short nanosecond laser pulse micromachining of dielectrics and metals at 532 and 355 nm. Several innovations gained during the project have been registered as patent. CLS has managed to expand their industrial laser products for high-quality laser marking **and** micromachining application, i.e. the Conquerer *Series*, the Conquerer *All in One* and the Conquerer *3Lambda*. The trepanning systems Type1.f18 and Typ1.2P represent two latest examples of a series of different rotating optics, developed at the LMTB and available for licensed industrial out-sourcing.

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