9th International Conference on
Photonic Technologies LANE 2016

Industrial Paper

High precision machining applications with short and ultrashort pulse thin disk lasers

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Abstract

Pulsed thin disk lasers with high peak power, pulse energy and beam quality are predestinated for a range of micro processing applications. We present an overview of recent micro cutting and drilling applications for medical device, automotive, electronics and tool manufacturing, including damage-free micro-processing of Polylactide and leather, processing of polycrystalline diamond tools, and others, using femtosecond disk lasers up to 16 W and nanosecond disk lasers with independently tunable repetition rate and pulse width at pulse energies up to 6.5 mJ. The examples illustrate solutions for the increasing need for economic micro machining processes.
Femtosecond disk lasers enable new possibilities by combining smallest heat affected zones and highest machining quality, while being able to maintain the special properties of high-tech materials in the machined area. Besides, nanosecond disk lasers allow high ablation rates by an optimized thermal micro processing, particularly for hard and brittle materials like SiC, PCD or highly heat conducting metals like Al, Ti or Cu alloys.

Keywords: laser micro machining; medical device; automotive & electronics; femtosecond disk laser; nanosecond disk laser

1. Introduction

Workpieces with µm precision or features are more and more frequently required in different industries, either driven by the development of new products, e.g. medical micro stents, or by the need for higher energy efficiency, e.g. automotive fuel injection nozzles. Compared to conventional micro machining methods like mechanical tools, EDM or etching, laser micro machining offers advantages like non-contact working without tool-wear or wet chemistry or cost-intensive vacuum processes, 2D and 3D processing with multi-axis laser machines, feature sizes down to a few µm, and high machining speeds.

Diode pumped femtosecond and nanosecond thin disk lasers are particularly well suited beam sources for industrial micro machining due to their high peak powers, pulse energies, beam quality and optical stability, which result basically from the very effective thermal management of the disk laser medium compared to other geometries like rod or slab. This beneficial thermal management of thin disks enables a superior beam quality at high energy, because it reduces thermal lensing and in consequence avoids phase front distortions. Since beam quality is one of the crucial factors for the machining quality in micro applications, thin disk lasers offer a clear competitive advantage in this respect. The industrial reliability of Jenoptik disk lasers is based on two decades technological experience and over 20.000 units (cw and pulsed) in the field.

Femtosecond disk lasers enable new possibilities by means of non-thermal ablation that maintains the special properties of high-tech materials in the machined area. Due to the very short pulse duration, material ablation takes place with a minimum of thermal energy diffusion into the bulk material. Femtosecond pulses offer unmatched sharp and clean cut edges without bur, a minimized width of the Heat Affected Zone (HAZ), machining of nearly all materials without thermal damage, including metals, glass, diamond, ceramics, thermally sensitive polymers and other organics, as well as selective material removal in thin film systems.

Nanosecond disk lasers allow high ablation rates by an optimized thermal micro processing, particularly for hard and brittle materials like SiC, PCD or highly heat conducting metals like Al, Ti or Cu alloys.

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Cost efficiency of laser micro machining applications requires optimization of the process strategy in order to match the individual goals for machining speed (productivity) and machining quality (size of HAZ, cut edge sharpness, wall taper angle, wall surface quality). The strategy includes the choice of beam delivery optics (scanners, fixed optics) as well as means to control heat accumulation (pulse energy, repetition rate, single pass with high pulse overlap, multi pass with low or no pulse overlap, process gas, and others). Cost efficiency is supported by the obtainable high machining quality that can save post-processing steps.

2. Experimental Setup

Several applications with industrial background were demonstrated on realistic lab setups based on fixed cutting head, galvanometer scanner, and trepanning scanners. The employed laser sources are listed in table 1.

Table 1. Laser sources.

Laser	JenLas® *femto 16*	JenLas® *disk IR70E*
Wavelength	1030 nm, 515 nm (SHG)	1030 nm
Power (IR)	16 W	65 W
Typ. Pulse width	550 +/-150 fs	30 – 300 ns
Repetition rate range	Single shot – 510 kHz	Single shot – 300 kHz
Pulse energy	Up to 100 µJ	Up to 6.5 mJ
Typical M²	< 1.25	< 1.2
Features	Quick change of repetition rate ~ 1…2 sec.	Pulse width and repetition rate is adjustable indpendently
	Programmable pulse picker (including frequency divider 1…10000)	Programmable pulse picker
	Internal SHG - switchable (THG on request)	External pulse synchronization

Fig. 1. (a) JenLas® *femto 16*; (b) JenLas® *disk IR70E.*

3. Results

3.1. Trepanning contour cutting of a CuBe micro clamp with 0° taper angle

Micro clamps (Fig. 2a, 2c) for a microelectronics application were cut with the fs laser from CuBe sheet of 500 µm thickness. The lab setup comprised a Steinmeyer trepanning head type SLH200 that is based on rotating optics (Fig. 2b), and a x-y motion stage. The trepanning head rotates (tumbles) the beam, so that the beam was useable similar to a milling tool. The application requires 0° wall taper angle, which was made possible by the tumbling movement of the beam axis at the focal position, in connection with the x-y movement of the CuBe sheet. The machined workpieces show 0° taper, 70 µm minimum feature size, and an excellent surface and edge quality.

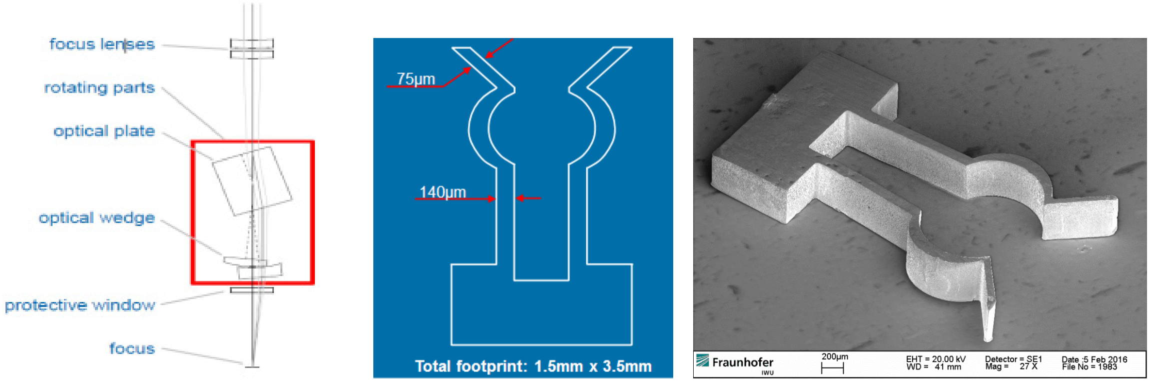

Fig. 2. (a) Optical setup of the trepanning head; (b) Dimensions of the CuBe micro clamp; (c) SEM image of the fs-machined micro clamp made of 500 µm thick CuBe sheet.

3.2. Stainlessss steel micro drilling with defined taper angle

Fuel injection nozzles (Fig. 3) were drilled in stainless steel with the fs laser at 5…10 W average power and an Arges trepanning head type Precession Elephant. The holes with an entrance diameter of ~ 200 µm require < 1µm accuracy, a negative wall taper angle of 4° and surface roughness R_a < 0.1 µm for optimized flow. The realized typical hole drilling time was 1.5 s.

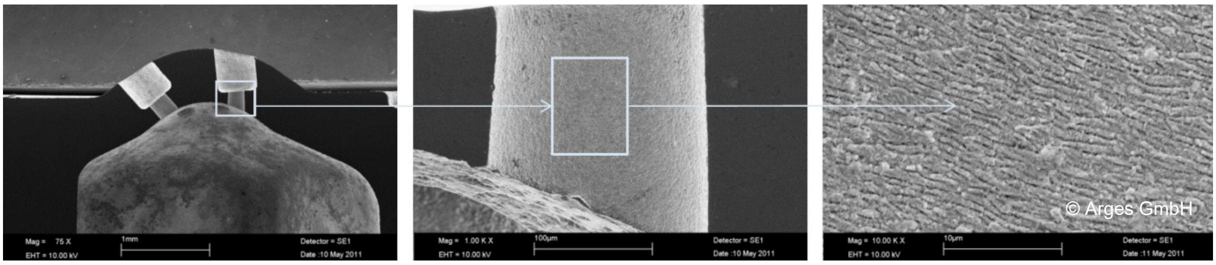

Fig. 3. (a) SEM image of the Cross section of a nozzle head with two injection nozzles; (b) Close-up of the negative tapered, fs-drilled hole; (c) Wall surface structure inside the hole.

3.3. Scribing of predetermined break lines in automotive airbag leather covers

Rear-side break lines of airbag covers in leather lining (Fig. 4) of premium cars have to remain invisible from the viewing (passenger) side over the lifetime of the car. Mechanical cutting of the break lines has deficiencies regarding cycle time and cutting depth accuracy for well-defined break loads. By a multi pass fs laser scribe process with galvo scanner and end point control by means of a transmission sensor array, both parameters were improved so that the fs laser process was approved by automotive customers.

Fig. 4. (a) Genuine leather cut with fs laser at 0.5…1 m/s feed rate without any visible thermal damage; (b) Inevitable swelling of the genuine leather around the cut with longer pulse laser due to a larger heat affected zone.

3.4. Cutting of Polylactide for bio-resorbable stents

Today's fs laser stent cutting machines with rotating axis cut bio-polymer stents (Fig. 5a) in single pass strategy. Cut edge quality and cutting speed can be further optimized by fluence (J/cm²) and pulse overlap. Cutting trials were made with flat Polylactide sheets (PLLA, PDLLA) of 120 µm thickness, from which a triangular sample geometry (Fig. 5b) was cut out using 10 W fs laser power and a galvo scanner without process gas. An excellent edge quality (Fig. 6) and very small HAZ was achieved at an effective cutting speed of 73 mm/s with a multi pass process at a fluence of 28 J/cm². The corresponding ablation rate was approx. 22 mm³/min. In contrary, with a single pass process it was not achievable to cut the 120 µm thick foil with both, sufficiently low HAZ and a reasonably high cutting speed. The reason was high heat accumulation due to the large pulse overlap that is necessary in the case of a single pass process.

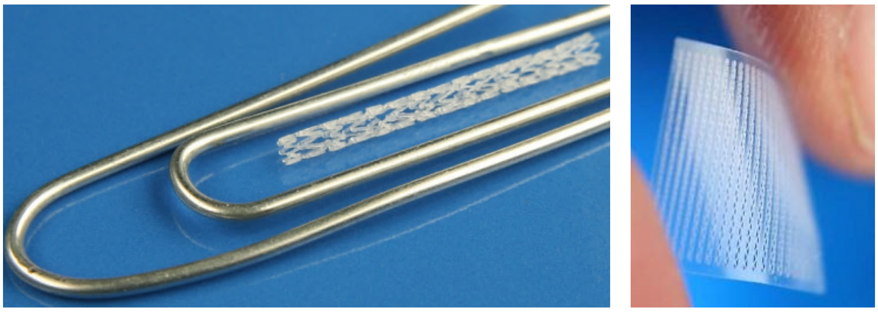

Fig. 5. (a) Stent made of bio-resorbable polymer; (b) Triangular sample geometry in PDLLA sheet for process optimization.

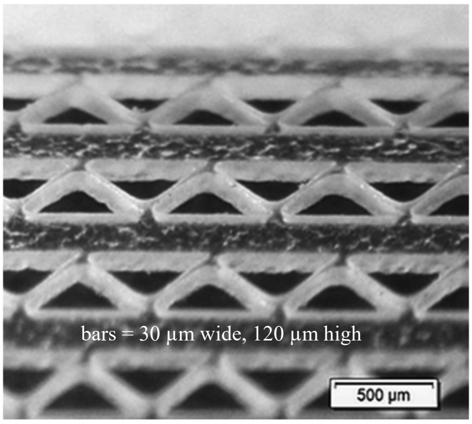

Fig. 6. Microscope image of fs laser cut sample geometry in PDLLA sheet.

3.5. Diamond tool finishing with ns laser

Indexable inserts with polycrystalline diamond (PCD) tips (Fig. 7, 8) require a PCD edge of < 2 µm radius and taper angle < 1°. The nanosecond laser cutting process involves fast rough machining of the PCD and the hard metal, followed by finishing of the PCD. A ns pulsed beam source with independently adjustable pulse width and pulse energy like the JenLas® disk IR70E proofed to be particularly beneficial for this application, since the roughing of hard metal allows higher thermal load for faster machining, realized with 300 ns pulse width and > 5 mJ pulse energy, than the PCD finishing, that required 30 ns pulse width and far lower pulse energy in order to control edge chipping and thermal damage.

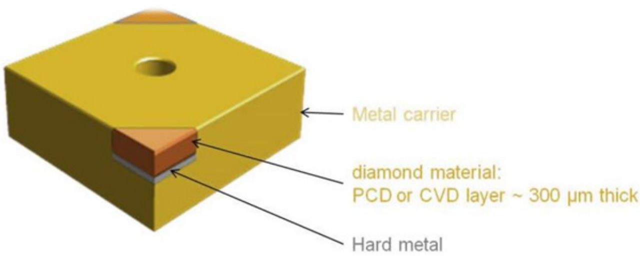

Fig. 7. Indexable insert with 2 diamond material tips.

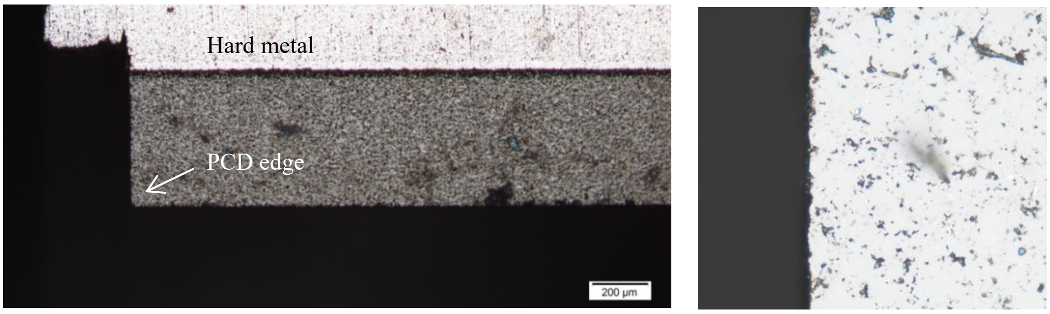

Fig. 8. (a) Microscope image of a cross section of the nanosecond laser machined PCD layer on hard metal; (b) Close-up of the PCD edge.

4. Summary

Several micro machining applications with industrial relevance were demonstrated by using femtosecond and nanosecond thin disk lasers on realistic lab setups. The success of application results regarding machining quality and speed depends as much on properties of the laser beam source, as on the process strategy.

In respect of the laser, a major benefit of the thin disk geometry of the active medium proves to be its superior beam quality, as well as its high peak power, pulse energy, and stability. The process strategy (e.g. beam delivery optics like 3D-scanners or trepanning heads, focus size, fluence, wavelength, pulse overlap, motion speed, number of passes) plays an important role in fs and ns based micromachining, because heat accumulation of successive pulses, which increases the HAZ and impairs machining quality, typically limits the utilizable average power of the beam source. Therefore a proper process strategy is necessary to match productivity requirements and cost efficiency.

The examples show how thin disk lasers enable new products or improved machining methods. Precision applications that require non-contact processing without thermal damage and without the need for post-processing depend particularly on the use femtosecond thin disk lasers.