Femtosecond fibre laser for material processing

Hans-Erik Swoboda, Horiba Jobin Yvon GmbH, Bensheim, Germany

The ultrashort pulses from femtosecond lasers allow precise material processing and thus show great potential in the field of micro- and nano-processing. In the past, however, the rather low average power and low repetition rate of these lasers have hindered many commercial applications. First results from the application laboratory demonstrate that fs-lasers based on fibre technology are promising alternatives.

Femtosecond-amplifier systems (1 fs = 10^{-15} s) based on CPA-technology (Chirped Pulse Amplification) [1] (where laser pulses are first stretched and then recompressed after amplification) have now become widespread following their commercial introduction at the beginning of the 1990s. Particularly in fundamental research, the pulse length is used as a measure for ultrafast processes in all kind of different systems and samples. The resolution of the resulting detection system is only limited by the length of the pulses and as a result is faster than any conventional detector.
That fs-lasers can additionally be used for materials processing was also recognised very early on, as can be seen from the countless literature references [2]. Here, both the very high peak power and the shortness of the pulses play an important role in the process. These two features enable a "cold" machining of any material, as the interaction between laser pulse and material takes place on a time scale much shorter than the typical heat transfer times within the material. **Figure 1** illustrates schematically for hole drilling which advantages fs-pulses have in machining as compared to machining with long pulses. Firstly, the amount of heat introduced is reduced substantially. In the so-called "Heat Affected Zone" (HAZ) the material can be modified in an uncontrolled way, changing the properties even outside the area where the actual machining takes place. Secondly, the amount of unwanted molten material polluting the untreated surface is strongly reduced or even non-existent. And lastly, surface modulations, micro cracks and shock waves into the interior of the material show up in a strongly reduced way when working with fs-pulses.
All of the above lead to much cleaner and more reproducible results when processing materials in the micro and nano regimes. Over the last 10 years many groups in fundamental science and industry worldwide have tested the use of fs-lasers for many different applications [3-5]. Clark-MXR has investigated many diverse materials with various geometries in their own applications laboratory (ceramics, glass, copper,

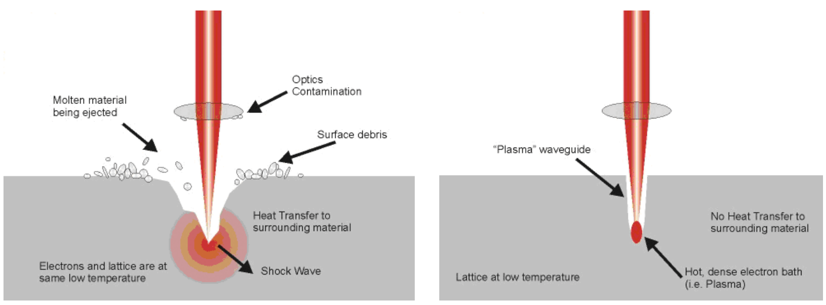

Bild 1: Comparison of laser materials processing with long (left) and fs-laser pulses: reduced heat penetration into adjacent material, no debris build-up due to molten and resolidifying material *(pictures: Clark-MXR)*

Originally published in German in Photonik 1/2008

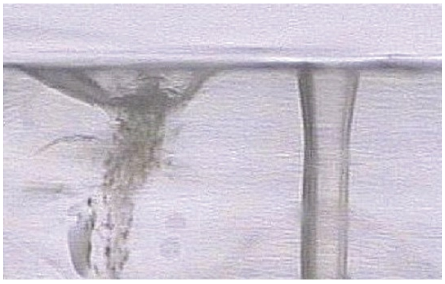

Bild 2:Drilling of 400 µm holes in a glass substrate, left with a ns-pulse system, right with a fs-pulse system

aluminum, diamond, rhenium, to name but a few). As one example **Figure 2** shows 400 µm wide drillings through an approx. 2 mm thick glass substrate.

However, some fs machining tasks were hindered by a lack of sufficient throughput, an aspect largely associated with the laser itself. Ti:Sapphire based solid state amplifier systems, such as the CPA-2000 series from Clark-MXR, typically produce 150 fs pulses with an energy of approximately 1 mJ at around 1 kHz repetition rate. Not only are these repetition rates too slow, the average power of 1 W is simply not adequate for some applications. The high energy of the pulses does mean that the lasers can be used flexibly in a wide variety of applications, and indeed these types of lasers form ideal research tools for establishing process parameters. Nonetheless, for commercial applications the speed of a process is often the most dominant factor. In order to find systems suitable for industrial applications other routes have to be found.

Laser systems based on Ti:Sapphire do not lend themselves well as a solution to this problem, mainly due to the inherent thermal issues within the lasing medium. There are systems on the market exhibiting up to 10 W average power with corresponding repetition rates, but the technology required to achieve this is not insignificant, and usually renders the systems useless for any serious type of commercial application.

In addition, the search for the optimum performance needed for many applications (e.g. when machining transparent materials as shown in figure 2), often leads to the result, that 1 mJ of pulse energy might be too high. This high pulse energy can lead to additional problems if the excessive energy can not be removed or used otherwise.

As a solution for these restrictions the fibre laser seems favourable. Instead of a solid state crystal a fibre several metres in length is used for generation and amplification of the fs pulse, resulting in the following advantages:

- the beam to be amplified can be overlapped with the pump light over a much longer path, with the potential of much higher average power,
- thermal issues become insignificant as the excessive heat can be removed very efficiently via the large surface area of the fibre
- compared to Ti:Sapphire based systems, where a change of repetition rate often means significant changes in parameters of the laser pulse, the better thermal management in fibre based systems means that they are rather more flexible with respect to different repetition rates,
- the fibre laser automatically delivers very high beam quality as the fibre is only used in the fundamental mode,
- and fibre lasers can be diode pumped directly without the need for an intermediate pump laser, thus making the system much more efficient, more robust and less complex in the design, as well as lowering the running costs.

Using all these advantages, a new fs-laser with a much higher average power of 20 W is now available, and capable of much higher repetition rates than 1kHz. In the model Impulse (**figure 3**) femtosecond pulses from a Ytterbium-doped fibre laser are amplified in several amplifier stages. The pulse length is around 250 fs, the repetition rate can be varied in the range between 100 kHz und 25 MHz. This means that fibre lasers can achieve similar pulse lengths to those produced by the Ti:Sapphire based systems being

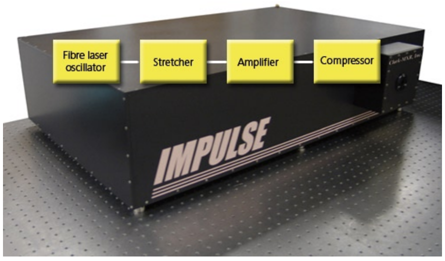

Bild 3: The Impulse fibre laser system

used now for material processing. With more than one order of magnitude more average power and with many orders of magnitude higher repetition rates, the decrease in pulse energy to approx. 10 µJ is acceptable for many materials processing applications.

Initial machining results were achieved in the applications laboratory [6]. **Figure 4** shows typical results in brass, on the left with the new fibre laser at a repetition rate of approx. 500 kHz, on the right with a conventional CPA with a repetition rate of 1 kHz. The cutting edges for the two different samples have similar sizes, roughly 50 µm. Also, the quality of the machining with both lasers is comparable.

The results shown in **figure 5** were also obtained in brass. In this case a more complex structure was machined, consisting of 100 µm wide and approx. 100 µm deep trenches. Again, the quality of machining with the two different laser sources is comparable. However, evaluating the speed of machining (how many trenches can be produced In the same time) the fibre laser is approx. 2000 times faster than the Ti:Sapphire system. This increase in speed is thus even more pronounced than the ratio of the repetition rates (500 kHz vs. 1 kHz) implies, and is probably based on the better focusability of the fibre laser. The slightly longer pulses of the fibre laser (200 fs vs. 150 fs) do not have any influence on the results in this application – a finding well known from earlier results achieved with other lasers.

In summarising these results it should be stressed that Clark-MXR has over 10 years of experience in fs machining with Ti:Sapphire based fs systems working at kHz repetition rates. Over this period many parameters in the machining process could be optimised. However, the results

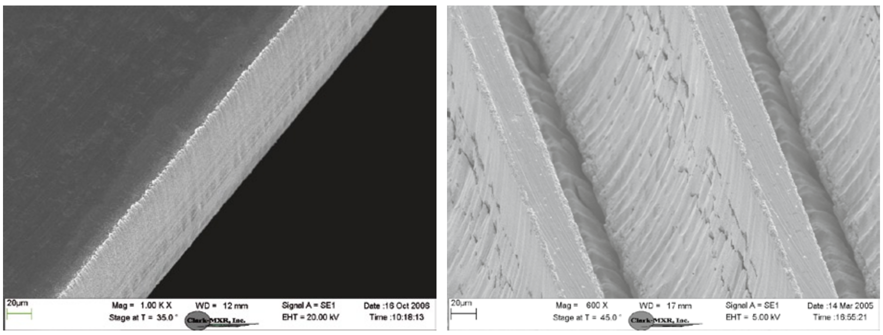

Bild 4: Machining on brass: the quality of the machining with the fibre-laser (left), is comparable with that of the Ti:Sapphire laser (right). In both cases the width of the cuts are approx. 50 µm

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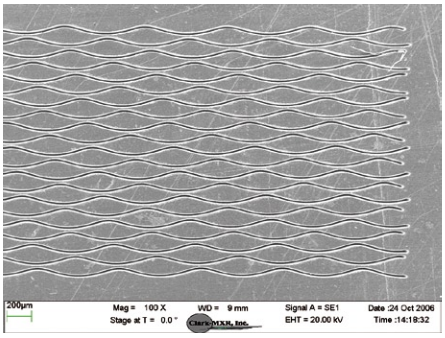

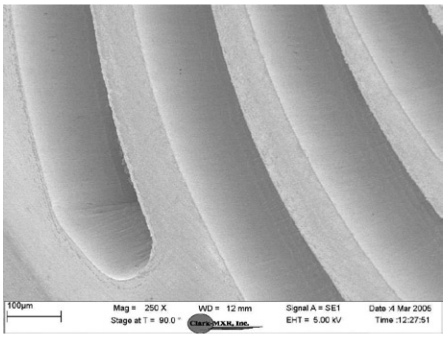

Bild 5: Structure in brass, channel depth and width each 100 µm. The quality of the machining with the fibre (left) and Ti:Sapphire laser is comparable, but the fibre laser is 2000 times faster in the process

with the fibre laser were achieved in first trials, without any optimisation of other process parameters, and without other supporting features such as the use of special process gases, masks etc. With these potential improvements, efficiency and quality of the machining process can certainly be improved even more. These initial promising results lead to the conclusion that a higher repetition rate paired with a higher average power will make femtosecond materials processing even more attractive, and fibre laser technology can make a major contribution in overcoming some of the hurdles currently limiting the application of fs pulses in this field.

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Author contact:

Dr. Hans-Erik Swoboda
Horiba Jobin Yvon GmbH
Clark-MXR Ultrashort-Laser
Neuhofstr. 9
64625 Bensheim
Germany
Tel. +49/6251/8475-15
Fax +49/6251/8475-20
hans-erik.swoboda@jobinyvon.de
www.jobinyvon.de

Originally published in German in Photonik 1/2008