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Industrial femtosecond lasers for micro-machining applications with highest quality and efficiency

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Abstract

High average power, high repetition rate femtosecond lasers with tens of µJ pulse energies are widely used for bio-medical and material processing applications. The unique advantage of material processing with femtosecond lasers is efficient, fast and localized energy deposition, which leads to high ablation efficiency and accuracy in nearly all kinds of solid materials. In this paper, we will give an overview of micro-machining applications enabled by a newly developed, high power and high energy Spirit® HE laser from Spectra-Physics. In particular, the impact of the processing conditions on the efficiency and quality of laser processing of bio-absorbable polymers and glass materials is presented.

Kyewords: Femtosecond laser; industrial micro-machining; implantable medical devices; bio-degradable stents; micromachining of glass; ClearShape

1. Introduction

Femtosecond laser systems have proven their potential in many material processing applications. The unique advantages of the femtosecond lasers such as high ablation efficiency and accuracy of ablated structures on metal as well as on dielectric targets have been demonstrated in many studies. Although the processing quality achieved meets industrial demands, processing speed needs to be improved in order to satisfy an economical industrial use (Dausinger et. al (2004), König et al, (2005)). To process parts quickly and cost-effectively femtosecond laser system with high average power and repetition rate is required. Additionally, laser system has to be robust and stable enough to sustain the demands of the production floor. Robustness and reliability are very important characteristics for industrially-qualified lasers. With the introduction of femtosecond laser system such as the Spirit® platform developed by Spectra-Physics, micro-processing of various materials using femtosecond laser have gained new perspective for industrial applications (Matylitsky et. al (2012), Hendricks et.al (2015), Matylitsky et. al (2015)).

In this paper two industrial applications of femtosecond lasers will be discussed. First, micro-machining of bio-absorbable polymers, which are commonly used for production of bio-degradable stents will be presented. The influence of the processing parameters such as pulse duration, laser repetition rate, laser wavelength and laser pulse energy on the efficiency and quality of laser processing of commonly used bio-absorbable poly-L-lactic acid (PLLA) polymer has been studied.

The second application of a femtosecond laser, described in this paper is machining of transparent materials by non-ablative laser processing. A newly developed, non-ablative femtosecond process, ClearShape™ from Spectra-Physics for machining of transparent, brittle materials with highest quality and speed will be presented.

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2. Laser system

The results presented in this paper have been obtained using a commercially available Spirit® HE 1040-16-SHG laser from Spectra-Physics (shown in Fig.1).

Fig. 1. Spectra-Physics's new Spirit® HE 1040-16-SHG high-energy femtosecond laser.

Compact and engineered to be rugged and reliable for the manufacturing floor, Spirit® HE laser has pulse duration of <400 fs, pulse energies of >120 µJ and average output powers of >16 W. The laser offers process flexibility at the wavelengths of 520 and 1040 nm with programmable pulse energy, repetition rate, and pulse width between 340 fs and 10 ps. A very useful feature of the Spirit® HE laser for the micro-machining applications is the burst mode operation. The femtosecond pulses can be supplied in a burst train which can contain up to 20 pulses. The time spacing between the pulses in one burst is around 13 ns. The number of pulses in one burst and the intensity profile can be controlled.

3. Applications

3.1. Micromachining of implantable stents

Laser cutting using nanosecond lasers was employed in stent fabrication almost from the start. However, thermal interactions of the nanosecond laser pulses with the metal generally result in non-optimal surface finish on metal parts: burring, melting, and recast are standard features of laser fusion cutting. In addition, heat deposition in the material results in a heat affected zone (HAZ) bordering the cut edges. Within the HAZ, material properties or composition are altered. Therefore, cleaning, deburring, etching, and final polishing are routinely employed to bring the stent's surface properties to the level and consistency required for implantable devices. Some of these post-processing steps could be avoided by fabricating stents using femtosecond laser. Figure 1 shows a Nitinol micro-stent machined by the Spirit® laser. Key characteristics include tight machining tolerances, absence of HAZ, no heat-induced distortion of the delicate lattice structure, and very clean cut edges.

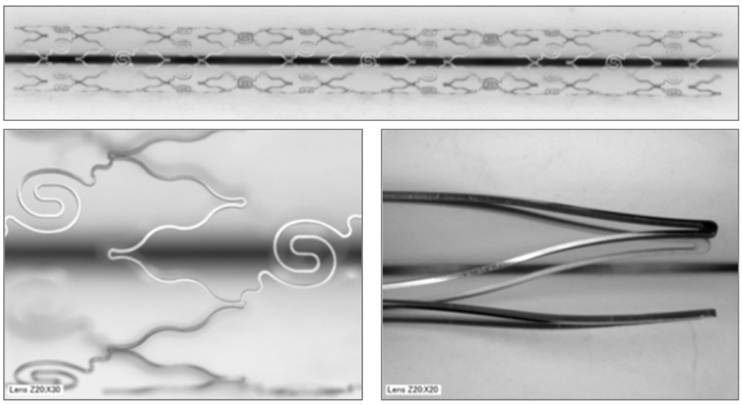

Fig. 2. Ultrafine nitinol stent machined with a Spectra-Physics Spirit industrial femtosecond laser without any post processing. Tube diameter, wall thickness and strut width are 4.25 mm, 45 µm and 35 µm, respectively.

Bio-absorbable materials are a very interesting class of compounds due to their ability to be absorbed by the human body over time (Wang et. al (2012)). The stents made out of bio-absorbable material can help avoid some of the medical complications caused by metal stents. The use of bio-absorbable polymers for production of bio-degradable stents has led to increasing attention to micromachining of bio-absorbable polymer. The choice of laser for production of stents depends on the type of material and cutting details. Because of the low melting temperature (usually below 200 C°) of bio-absorbable polymers any heat load to the surrounding areas during laser processing should be minimized. Therefore, using ultrafast laser pulses for micromachining of bio-absorbable polymers is highly desirable due to the non-thermal nature of laser-material coupling and the possibility of structuring very small micron scale features.

The Spirit® HE 1040-16-SHG laser system has been used to study the feasibility to cut 80 µm thick bio-absorbable material poly-L-lactic acid (PLLA) ribbon by single-scan ablation. Processing quality was investigated using optical microscope. The values of maximum cutting speed in athermal (no HAZ, no melts, no recasts etc.) machining regime as a function of the wavelength and pulse duration used in the experiments are summarized in Figure 3. In order to improve laser cutting performance, helium gas at pressure of 6 bars was applied as an assist gas.

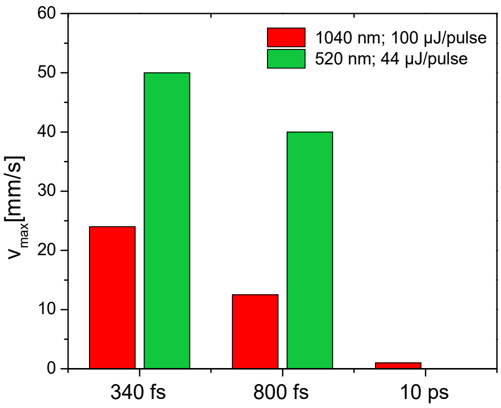

Fig. 3. Maximum athermal cutting speed dependence on pulse width and wavelength. Helium was used as an assist gas.

Results show that the quality of the cut and maximum cutting speed strongly depend on the laser parameters chosen for machining of PLLA material. The maximum cutting speed of 50 mm/s can be achieved for 80 µm thick PLLA ribbon by using 340 fs laser pulses with the pulse energy 44 µJ at 520 nm wavelength. Obtained results emphasize the importance of the high pulse energy available from Spirit® HE for polymer cutting applications. The achieved cutting speed of 50 mm/s is more than a factor 3 higher than that demonstrated using the predecessor Spirit® 1040-8-SHG laser with a maximum pulse energy of 20 µJ at 520 nm (Matylitsky et al (2015)).

3.2. Cutting of transparent, brittle materials

While femtosecond direct ablation method provides already high quality of the laser cut, in the case of glass materials, our results have shown that the cutting speed for thicknesses between 300 µm and 1 mm is below 1 mm/s (Hendricks et al (2014)), which is not very appealing to industrial manufacturers. The newly developed patent-pending ClearShape™ process based on a non-ablative approach allows increasing the speed and further increase in quality compared with direct ablation technique.

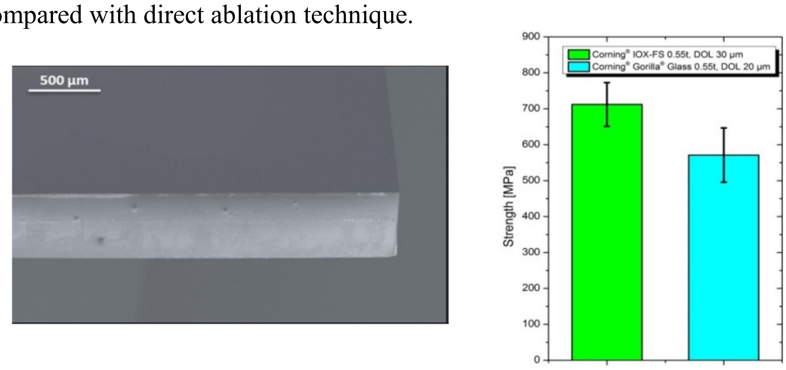

Fig. 4. Example of straight line cut in chemically strengthened Gorilla® glass from Corning® (left), and results of 4-point bending tests for chemically strengthened glasses from Corning® (right) obtained using the ClearShape process in combination with the Spirit laser.

For example, cutting of 0.55 mm thickness chemically strengthened Gorilla® glass from Corning® with 20 µm of depth of layer (DOL) can be demonstrated at speed up to 4 m/s. Besides chipping free edges, the quality of a laser cut (defined by the average roughness of the cross-section) of < 0.1 µm was achieved using ClearShape process (see Figure 4, left). The very high cutting quality leads to extremely high bending strength of up to 700 MPa during four-point bending test of the glass without any post-processing steps (Figure 4, right).

Besides chemically strengthened and unstrengthened glasses, transparent materials such as sapphire and silicon carbide can also be machined. The machining of straight or curvilinear cuts was also demonstrated using ClearShape process in our previous publications (Matylitsky et. al (2015)).

4. Summary

Bio-absorbable materials are becoming increasingly popular for manufacturing of stents. Laser ablation of bio-absorbable PLLA polymer was studied using 340fs, 800fs and 10ps laser pulses. The values of maximum possible speed for athermal cut as function of wavelength and pulse duration of the laser pulses used during laser processing were obtained from the experiments. We have shown that for high quality, athermal results a maximum cutting speed up to 50 mm/s for 80 µm thick PLLA ribbon can be achieved using Spirit® HE 1040-16-SHG laser system from Spectra-Physics. Additionally, our experiments show that the cutting speed for bio-absorbable polymers can be increased upon application of high-energy femtosecond pulses without loss in the quality. Based on results achieved, shorter pulses (ca. 340 fs) at 520 nm with the pulse energy above 40 µJ are very promising for laser micro-machining of bio-absorbable polymers at high machining throughput and quality.

Femtosecond Spirit® HE laser was also used for cutting of transparent, brittle materials such as glass, sapphire and silicon carbide by applying the ClearShape™ process developed at Spectra-Physics. This process allows cutting of glass by using relatively low average power of <4 W at wavelength of 1040 nm, thereby not requiring more difficult to handle high power, higher harmonics laser irradiations such as green or UV laser light. Our results show that Spirit femtosecond laser in combination with the novel ClearShape process results in an optimal solution for the highest quality machining of a wide variety of transparent, brittle materials at highest process speeds demanded by industrial users.

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