Laser micromachining of heat-sensitive polymers using a femtosecond, high power and high energy laser

Laser processing of heat sensitive polymers is finding wide use in various manufacturing sectors such as medical device and organic LED manufacturing. For example, heat sensitive, bio-absorbable polymers are increasingly used for production of bio-degradable stents. Because of the low melting temperature (usually below 200° C) of bio-absorbable polymers, any heat load to the surrounding areas during processing should be minimized. Therefore, using femtosecond (fs) pulsed lasers for micromachining of bio-absorbable polymers is highly promising due to the non-thermal nature of laser-material coupling and the possibility of structuring very small, micron-scale features. Although we have demonstrated a cutting speed of 15 mm/s for 80 µm thick poly-L-lactic acid (PLLA) ribbon using a predecessor femtosecond laser with a maximum pulse energy of <20 µJ at 520 nm, the low pulse energy is a primary limiter to achieving higher cutting speeds [Hendricks, F., et.al, (2015) Proceedings of SPIE 9355, 935502]. Therefore, a newly developed, high-energy femtosecond Spirit® HE laser (Figure 1) from Spectra-Physics has been tested for increasing cutting speed of heat sensitive PLLA polymer.

Compact and engineered to be rugged and reliable for the manufacturing floor, Spirit® HE has an ultrashort pulse width of <400 fs, high pulse energy of >120 µJ and average output power of >16 W. The laser also 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 picoseconds (ps).

SINGLE-SCAN CUTTING OF PLLA POLYMER

The Spirit® HE 1040-16-SHG laser system has been used to cut 80 µm thick bio-absorbable PLLA ribbon with a single-scan. Figure 2 shows microscope images of typical cutting kerfs in PLLA obtained in athermal (left) and thermal (right) laser machining regimes. In a thermal machining regime laser ablation leads to formation of melts and modification of the polymer along the cut. Within the modified area, material properties or composition are altered. Therefore, the production of stents requires expensive post-processing steps. These steps can be avoided by using an athermal laser machining regime that is possible with an ultrafast laser.

Figure 1. Spectra-Physics' new Spirit® HE high energy femtosecond laser.

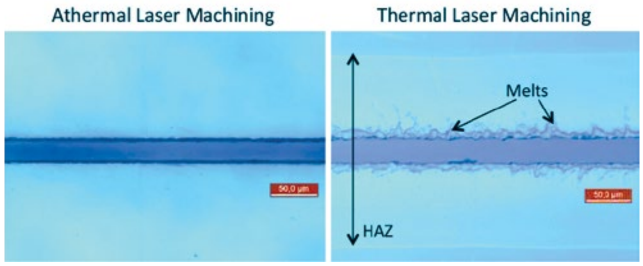

Figure 2. Microscope images of typical cutting kerfs in PLLA obtained in athermal (left) and thermal (right) laser machining regimes.

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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.

From our experimental tests, we observe that melting effects for a single-scan cut are strongly reduced by decreasing the pulse width from 10 ps to 340 fs. Also, we demonstrate that reducing the pulse width from 10 ps to 340 fs results in a more than an order of magnitude increase in cutting speed (from 2 to 25 mm/s) in an athermal laser machining regime in the IR (1040 nm). A similar trend of increasing cutting speed with shorter pulse width is observed at green wavelengths (520 nm). Therefore, the pulse duration is a very important parameter when choosing a proper laser system for athermal laser micromachining of bio-absorbable polymers.

For laser pulses with shorter wavelengths, laser energy can be used more efficiently for ablation of transparent materials. The results as shown in Figure 3 indicate that by applying laser pulses at 520 nm the speed of athermal can be further increased. We demonstrate a maximum single-pass cutting speed of ~70 mm/s for 80 µm thick PLLA ribbon. Our results clearly show the advantages of high pulse energy and short pulse widths in fs laser systems for the cutting of heat-sensitive polymers.

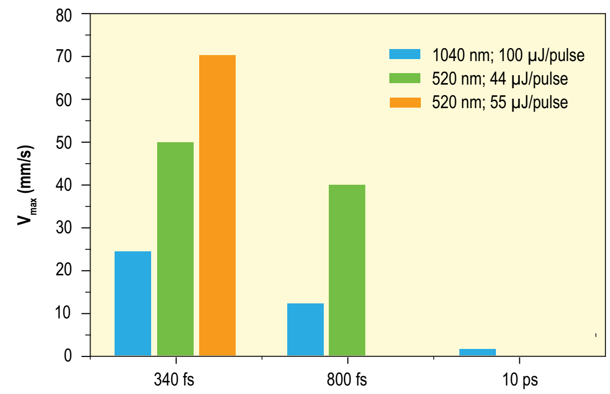

Figure 3. Maximum athermal cutting speed dependence on pulse width and wavelength. Helium was used as an assist gas. The maximum pulse energy of 55 µJ at 520 nm available from a Spirit HE laser results in cutting speeds of 70 mm/s.

PRODUCTS: ***SPIRIT HE 1040-16, SPIRIT HE 1040-16-SHG***

The Spirit® HE femtosecond laser is a flexible, high repetition rate one box ultrafast amplifier. With direct diode pumped technology developed by Spectra-Physics, Spirit HE's innovative and simple architecture offers truly unique performance.

Spirit HE offers impressive versatility to serve the needs of industrial and scientific customers. The laser's high pulse energy (up to 120 µJ) and high average power (>16 W) enable femtosecond micromachining applications with high throughput and the best quality. Pulse energy and repetition rate adjustability (single shot to 1 MHz) make Spirit HE an ideal laser source for medical device manufacturing and high aspect ratio drilling. The laser is optimized for one factory calibrated repetition rate – either at 100 kHz (12 W / 120 µJ) or 1 MHz (16 W / 16 µJ). This basic repetition rate can be chosen by the customer. Additional pre-set repetition rates are optional and can be configured in the factory during assembly upon request. The integrated pulse picker offers the possibility for fast pulse selection and power control by an analog input signal. This simplifies the integration of the laser and offers fast process throughput.

	Spirit HE 1040-16	Spirit HE 1040-16-SHG
Wavelength	1040 ± 5 nm	
Output Power	>16 W @ 200 kHz	
Pulse Energy	>80 µJ @ 200 kHz (16 W) >120 µJ @ 100 kHz (12 W)	
Pulse Duration	<400 fs	
Wavelength (SHG)	NA	520 ± 5 nm

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