



Trends in Ultrafast Laser Micromachining

New lasers and trends in precision micromachining components for semiconductor, automotive and medical industry.

Laser Micromachining is well established in industry. Depending on the application lasers with pulse length from nanoseconds to femtoseconds and wavelengths from 1064nm and its harmonics up to 5μ m or 10.6 μ m are used. Ultrafast laser machining using pulses with pico or femtosecond duration pulses is gaining traction, as it offers very precise processing of materials with low thermal impact.

Ultrafast lasers for precision micromachining can minimize or avoid undesirable thermal effects that limit feature resolution, edge quality and, ultimately, product functionality. Ablation by ultrafast lasers results from a series of complex nonlinear phenomena of absorption and transfer of energy that take place in the surfaces of materials upon irradiation. Provided that a good window of processing parameters is chosen, the resulting thermal effects are in general negligible, making ultrafast lasers excellent micromachining tools applicable to most types of materials. It is thus beneficial to understand how ablation is affected by the laser processing parameters and the material properties, in order to optimize the micromachining processes.

Longer pulse (nanosecond) and continuous-wave (CW) lasers have a photothermal interaction with materials, creating a heat affected zone (HAZ) which limits the minimum size of features that can be cleanly machined. It can also cause functional and structural problems, e.g., damage to underlying semiconductor circuitry, or microcracking that weakens glass touchscreens. And, in external marking of consumer products, the HAZ can appear as charring or discoloration compromising the value of the final device. In addition, photothermal scribing, drilling and cutting often produce an edge burr consisting of recast debris, which may require post-process removal.



In contrast, lasers with shorter pulse widths can significantly reduce these unwanted thermal effects and minimize the HAZ, because these effects are dominated by the relationship between laser pulse duration and the thermal diffusion times of the target material. Moving to the picosecond (ps) regime, the short pulse duration often means that the vaporized material carries away any unwanted heat before it can spread and cause a HAZ, a condition sometimes called thermal confinement. And, the fact that the ejected material consists of very small particles – as small as atoms – means that picosecond laser pulses do not produce recast debris, often eliminating the need for post-processing such as edge grinding, chemical cleaning, etc. In the automotive industry, these qualities enable contoured holes to be drilled in fuel nozzles to support higher fuel efficiency, i.e., greener vehicles.

Large-scale industrial ultrafast laser applications show that the market can be divided into various sub segments. One set of applications demand low power around 10W, compact footprint and are extremely sensitive to the laser price whilst still demanding 10ps or shorter laser pulses. A second set of applications are very power hungry and only become economically feasible for large scale deployments at power levels in the 100+W class. In several industries there is an overarching trend for increased miniaturization together with increased functionality. This fuels a growing interest in using even shorter duration pulses, in the femtosecond (fs) range, where the advantages of shorter pulses are even more pronounced. In materials with high thermal conductivity, particularly many metals and diamond, the thermal diffusion time can be picoseconds, or less. Thus moving from the ps domain to the fs operating regime delivers a measurable reduction in HAZ.

Femtosecond lasers can also process a wider range of materials than any other laser. That's because the high peak power of fs lasers drives non-linear absorption. In this extreme domain, materials absorb the laser light even if they are nominally transparent at the wavelength of the laser! The absorbed photons strip off electrons, instantly breaking the bonds holding the material together, in contrast to the usual photothermal process powered by longer pulse lasers.

Industrial Ultrafast Fiber Lasers

Earlier ultrafast lasers were targeted for scientific applications and had features, cost, and performance characteristics focussed for this market however with progress and evolvement of areas in Industry, ultrafast lasers has taken front seat in manufacturing & production of components for semiconductor, automotive and medical devices. While there are several types of ultrafast lasers, such as titanium-sapphire and diodepumped based, but now, a new generation





of ultrafast lasers for industrial users based on an exciting new material – ytterbium doped fiber laser technology are one of the most common. A fiber laser is a type of laser utilizing optical fibers doped with rare-earth elements as their active gain medium. The fiber gain medium supports simpler internal design and construction, leading to lower costs and significantly increased reliability for the generation of the incredibly short pulses exhibited by ultrafast lasers. Moreover, ytterbium fiber does not yet represent a mature technology, so the performance of these new lasers continues to advance at a steady pace, particularly in average power.

Due to the long, thin nature of gain fibers and high surface area to volume ratio, cooling is much more efficient. Additionally, fiber lasers offer high optical quality provided through wave-guiding properties that reduce thermal distortion of the optical path. Furthermore, fibers can be bent and coiled, allowing for a compact size compared to gas lasers of similar power. They are reliable through high temperatures, have vibration stability, an extended lifetime, and are relatively easy to maintain. With a low cost of ownership, they are becoming more and more accessible to a variety of industries. In addition, they are versatile, as they can operate in the infrared, visible, and shorter ultraviolet range. These lasers are typically characterized by much lower pulse energies than nanosecond lasers, but with very high pulse repetition rates – usually in the MHz range. The high pulse rate delivers overall material removal rates that provide market enabling throughput for many target materials.

These new ultrafast lasers also support burst mode operation which has proved very effective in materials processing with ps lasers. While average power determines throughput, it is the pulse energy that determines whether the laser can cut or not, relative to material strength and thickness. Simply stated, higher pulse energy enables processing thicker materials.

While the developments in fs lasers have been more dramatic, there have also been important recent developments in ps lasers for industrial applications, in two different areas. There is increasing interest in using ps lasers for lower power applications such as drilling small holes and marking in the automotive, semiconductor and medical device industries. This has created a demand for ps lasers at modest power levels, where lower cost of ownership is just as important as other parameters, such as pulse-to-pulse stability.

At the other end of the power spectrum, there is a host of applications where high average power is needed to support high throughput and/or where significant material ablation must be performed.



Applications

Medical Devices:



Laser machining is also crucial in medical device fabrication for manufacturing cardiovascular stents, balloons and catheters. Ultrafast lasers can process metal or plastic with great precision. Thus, they are in high demand for the production of medical devices constructed of such materials. For example, ultrafast lasers are used for machining of medical catheter tips that are able to deliver liquid to cool heart tissue during ablation

procedures to avoid unnecessary burning and scarring. Approved by the FDA in 2001, laser eye surgery for vision correction also utilizes ultrafast lasers. Using this technology, surgeons are now able to create precise flaps in the cornea, providing better patient safety and a quicker recovery time.

Lasers have long been used to texturing (titanium) dental and other implant surfaces to match the dimensions of osteocyte cells and thereby support optimum bone fusion.

Automotive Parts:



With the capability of ultrafast lasers in precise machining of metal parts, they are extensively used in manufacturing of metal parts automotive industry.

For Ex. Ultrafast laser are used for drilling automotive fuel injectors nozzles, where by manipulating hole dimensions, designers are able to create spray patterns that result in more efficient combustion with less fuel to boost engine efficiency.

Luxury Industry:



Ultrafast Lasers are capable of machining minute features with micron-level accuracy and repeatability in a 24/7 manufacturing environment. They are used for cutting small shapes from thin metal substrates. A standout example involves machining intricate watch gears that must be able to interact in order to keep perfect time.

Semiconductor Industry:



Semiconductor circuits are becoming increasingly sophisticated. They integrate more functions, with smaller feature sizes. To this end, wafers are now comprised of many layers of multiple materials, such as low-k materials for faster operation. The thermal effects associated with nanosecond laser processing represent a strong limitation

in the quality of the results. On the other hand, ultrafast lasers have demonstrated their capability to process silicon and multiple materials with a high quality. Several industrial processes have been developed to take advantage of the high precision of



ultrafast laser processing. This includes selective layer ablation, where ablation rates as precise as 30nm per pulse are routinely achieved, and high-precision thin-film transistor electrode cutting, which has a cutting width smaller than 2μ m.

Consumer Market:



The ability of these lasers for high-quality, virtually athermal material processing, they are widely used for manufacturing of Cell phones, microprocessors, display panels, and memory chips are extremely sophisticated components, comprising a large number of different materials, multiple layers of

extremely low thicknesses, and very small features.

Because of the improvement in the resolution of high-definition screens, the pixel size is becoming smaller and thermal effects associated with nanosecond laser processing are limiting the quality of the repair. Moreover, new display technologies, such as organic LEDs (OLEDs) and active-matrix OLEDs (AMOLEDs), make extensive use of organic and polymer materials, which are highly sensitive to heating and incompatible with thermal processing. Because of their very short pulse duration, ultrafast lasers allow for virtually athermal micromachining without any heat generation.