LASER MICROMACHINING

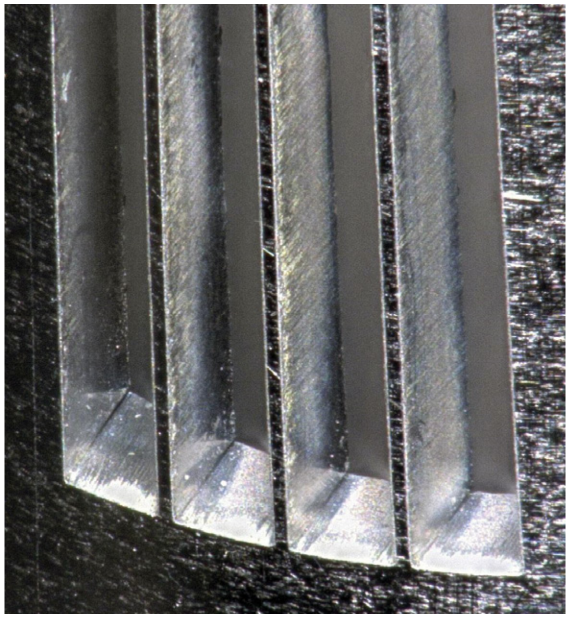
A Flexible, High-Precision Industrial Manufacturing Process with Unmatched Capabilities

INTRODUCTION

Laser technology was developed in the mid-20th century, and in the decades since then it has emerged as a leading processing method for an extremely broad range of applications. From microelectronics and semiconductors, from automotive to e-mobility, and from aerospace to medical devices, nearly every industry has benefited from the laser's ability to cut, join, and texture materials with a high degree of precision. Now, with recent advancements in laser technology, machines capable of high precision laser micromachining are opening new doors in industrial manufacturing.

WHAT IS LASER MICROMACHINING?

Micromachining is a tightly controlled material removal process in which a laser beam is used under highly controlled conditions to reshape a material. For decades, the creation of small drill-holes, narrow pockets and slots, and intricately shaped features in medical device, automotive, aerospace, and microelectronics components has been done with mechanical milling, chemical etching, or electrical discharge machining. However, progressive miniaturization and heightened quality requirements have fueled the need for improved processing techniques that can produce smaller features with fewer defects. Laser micromachining has answered this need and is beginning to replace traditional machining methods across multiple industries. As a remote photonic processing technique that imparts no mechanical force on a material surface, laser micromachining is ideal for creating intricate, tight-tolerance features in small, delicate parts. Processes can be tightly optimized and remain repeatable in high production without the need to sharpen a drill bit, repair a broken blade, or change a worn-out photomask.

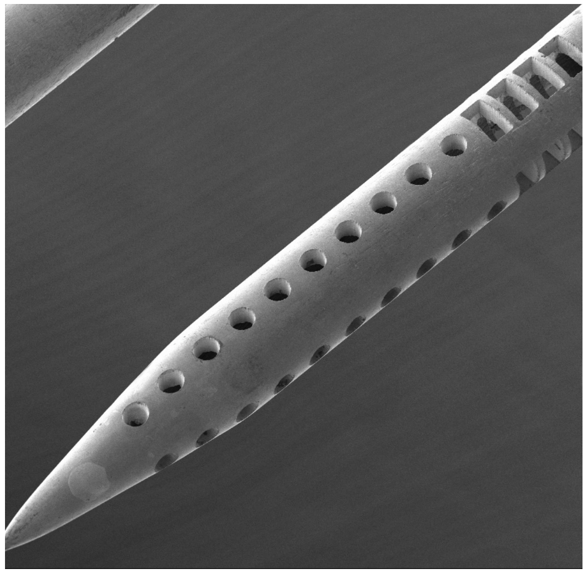


Nickel Titanium Struts
40 μm wide struts machined through nickel titanium hypotube

WHAT INDUSTRIES RELY ON LASER MICROMACHINING?

The medical device industry is one of the fastest growing markets for laser micromachining, with medical device laser processing projected to reach US$3.7 billion by 2025. Advancements in minimally invasive surgical techniques and drug delivery capabilities continually drive the need for smaller and more precise components. One of the most common devices in the medical device field is the catheter, a device with a broad range of applications. Catheters are used for fluid drainage, for drug or nutrient administration, for measurement of blood and intracranial pressures, and to provide access for surgical instruments. Small features, like ports, slots, and grooves, often below 50 μm in size, need to be machined into these devices to facilitate their use. The features must be extremely precise, with tolerances as small as +/- 2.5 μm, and there is very little room for defects or imperfections. Traditional methods like mechanical milling can leave burrs on the parts, and many of these features are simply too small for mechanical tools. Laser beams, on the other hand, can be focused to extremely small diameters, and since they are pure light, there is no chance for broken or worn tools that can cause inconsistent results.

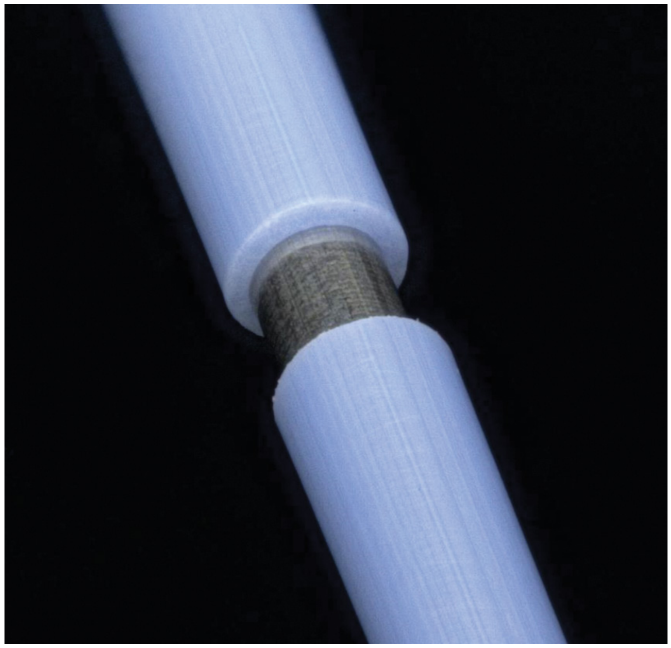
This extreme level of precision transcends the medical device industry and provides unique capabilities in other fields, as well. The semiconductor and display industries use laser micromachining for cutting and drilling ceramic wafers; the energy and renewables industries use it for etching next generation solar cells and for cutting lithium ion battery foils; and the aerospace industry uses it for drilling fine holes into advanced, lightweight space-grade alloys. Every day, new applications for laser micromachining are being created.



Stainless Steel Tube
100 µm diameter fluid delivery holes drilled into stainless steel cannula needle

WHAT TYPE OF LASERS ARE USED FOR LASER MICROMACHINING?

One of the most exciting advancements in laser technology in recent years has been the refinement of the ultrashort pulse, or USP, laser for everyday industrial use. Traditional, older generation cutting lasers emit continuous wave energy, similar to turning on a flashlight, or pulses that last for milliseconds or microseconds. When laser light interacts with a surface for these long time durations, it drives excessive heat conduction and melt expulsion that result in unwanted defects, like burrs, dross, and material embrittlement. These defects compromise the integrity of the finished product and often require expensive and time-consuming secondary cleaning operations. Modern USP lasers, on the other hand, emit extremely short pulses that may be only a few hundred femtoseconds in duration. These pulses are on the timescale of atomic interactions and are short relative to electron relaxation times. This means that each laser pulse's interaction with the material terminates before significant thermal conduction begins to occur, allowing for nearly athermal ablation from the processing surface. The results are highly repeatable features with ablation resolution as small as +/- 1 µm and excellent finish quality – no burrs, no dross, and dramatically reduced heat-affected zones. The multiple wavelength options available with USP lasers mean that there are almost no material limitations – metals, polymers, ceramics, and glasses can all be processed. These results and capabilities cannot be matched with traditional lasers.



Polymer Selective Ablation
200 μm thick polymer coating ablation with no effect on underlying metal tube

WHAT ARE THE CRITICAL COMPONENTS AND DESIGN FEATURES OF A LASER MICROMACHINING SYSTEM?

The laser source is the key component of a micromachining system. As ultrashort pulse laser technology advances, more and more laser OEMs are beginning to offer these lasers. Thus it is critical for a laser integrator to carefully test and vet these lasers to ensure that the best laser is selected for any particular application. This must be done with a sharp focus on the details and requirements on the process itself.

While the laser may be the heart of the micromachining system, a successful process relies on all aspects of the machine working together in harmony. Carefully selected optics and optomechanics are needed to deliver the beam to the work piece; high precision, top-of-the-line motion control systems and stages must work in tandem with machine vision to move the work piece precisely and repeatably; and integrated robotic arms, tube loaders, and conveyors must work autonomously – or collaboratively with an operator – to safely handle parts to support high volume production. Carefully designed user interfaces should enable intuitive machine control, while custom software monitors the system to ensure that everything is functioning properly and collects data and logs errors for rapid, efficient troubleshooting. Machine faults must be handled strategically to prevent damage both to the machine itself and to the work pieces, which are often delicate and expensive. High production can be demanding, so micromachining systems can be equipped with vibration dampeners and temperature control to stabilize and isolate the processing zone, regardless of the dynamics of the production environment. Maintenance requirements must be kept low, but when it comes time to replace a component, easy access to the machine's subsystems can make the work easy and efficient.

Finally, operator safety is paramount. Laser micromachining systems must comply with workplace safety standards to minimize risk to operators. Class I enclosures not only seal in laser light to prevent exposure, but they also create a barrier between operators and fast-moving stages and internal mechanisms. Specially selected fume extraction systems with extremely fine filters remove small particulate from the processing area to prevent operator exposure to hazardous dust. Machines with automated doors or loading mechanisms can be equipped with light curtains and proximity sensors to further enhance safety. A laser system integrator must place just as high of a standard on system safety as they do on system capability.

HOW SHOULD A SYSTEM INTEGRATOR POSITION ITSELF TO PROVIDE HIGH QUALITY INDUSTRIAL MICROMACHINING SOLUTIONS?

A laser system integrator or machine builder should design micromachining systems with the laser process foremost in mind. In many cases, a system integrator may need to draw on decades of experience and hundreds or thousands of successful applications in high precision laser microprocessing in its approach to process development and integrated system design. Applications Engineers should focus on a combination of academic and hands-on knowledge of laser-materials interactions to optimize customers' processes, while R&D and Systems Engineers put the processes to work in systems that satisfy detailed machine specifications and complex requirements. Building strong relationships with customers and maintaining open communication channels will help to ensure that customers' needs are fully understood and fulfilled. To be successful, system integrators that build high quality laser micromachining systems must be as dedicated to their customers' projects and product lines as they are to their own.

CONCLUSION

Laser micromachining promises improvements for modern high-precision processing methods, as well as opportunities for new applications altogether. With the advent of industrially viable ultrashort pulse lasers, laser system integrators and machine builders are now able to offer systems that can provide clean, defect-free parts right after the laser process, often removing the need for secondary post-processing. The medical device, aerospace, semiconductor and displays, and energy and renewables industries already rely on laser micromachining for many of the smallest and most delicate processes. Every day, new applications are developed that further showcase the unique capabilities of laser micromachining.