JPSA Applications Note
advanced laser technology

MEMS Micromachining with UV Excimer Lasers

The emergence of MEMS (Micro Electro Mechanical Systems), promises to revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology, making possible the realization of complete systems-on-a-chip . MEMS is an enabling technology allowing the development of smart products, augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators and expanding the space of possible designs and applications.

MEMS technology is the integration of mechanical elements, sensors, actuators, and electronics on a common substrate through microfabrication technology. While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.

The University of South Florida's Center for Ocean Technology in St. Petersburg, Florida, has been working on the development of MEMS for use in marine sensor applications, among others. Scott Samson, an Optoelectronic MEMS Engineer, was looking for a technology that would enable him to micromachine micron-scale features on MEMS with extremely precise accuracy and controllability. At these dimensions and tolerances, mechanical material processing was no longer feasible, so he looked to UV laser (excimer) micromachining technology as a means of accomplishing it. The product, a MEMS device incorporating tiny movable mirrors that are approximately 100 microns wide, is key to the operation of these optical devices.

The web site www.memsnet.org (see footnote #1) explains the role of MEMS in Samson's (and similar applications) best: "Microelectronic integrated circuits can be thought of as the "brains" of a system and MEMS augments this decision-making capability with "eyes" and "arms", to allow microsystems to sense and control the environment. Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena. The electronics then process the information derived from the sensors and through some decision-making capability direct the actuators to respond by moving, positioning, regulating, pumping, and filtering, thereby controlling the environment for some desired outcome or purpose. Because MEMS devices are manufactured using batch fabrication techniques similar to those used for integrated circuits, unprecedented levels of functionality, reliability, and sophistication can be placed on a small silicon chip at a relatively low cost."

Samson says that his goal, in addition to developing the MEMS devices, is to develop reliable and practical methods for batch fabrication, and it became clear from the beginning that traditional semiconductor processing equipment might not be adequate. They were also looking for a tool that could be applied to new and emerging applications.

"Because we're an R&D lab at the University, and we wanted a broadly applicable tool that we could reconfigure, operate at different wavelengths, and that would meet our strong criteria that we could process different materials." Samson says. He and his colleagues chose an IX-300 excimer laser workstation from J. P. Sercel Associates (JPSA). The JPSA IX-300 ChromAblate™ excimer laser micromachining system is configured to operate at two separate UV wavelengths - 248 or 193 nm (nanometer). It can deliver up to 20 watts of power on target at 248nm, with up to 500 Hz rep rate, and operates with a nitrogen purged beam delivery system (BDS) at 193nm, since shorter UV wavelengths are weakened or absorbed when transmitting through ordinary air; however, shorter wavelength UV is more readily absorbed by a wider range of materials, and thus able to process materials optimally that cannot be processed as well - or at all - using longer wavelengths or other technologies. Samson and his colleagues are using the IX-300 system for several applications including micromachining diamond.

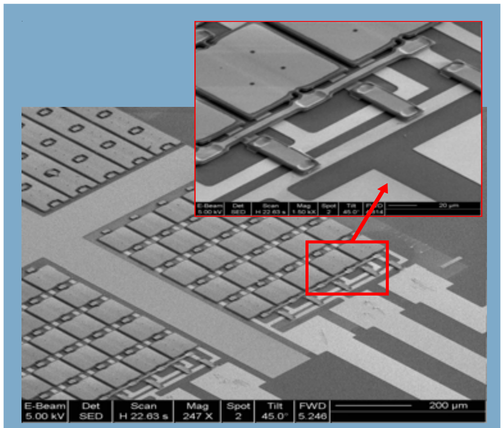

Figure 1. SEM image of moveable MEMS mirrors

Excimer ("Excited Dimer") lasers are gas lasers that generate large-area square or rectangular laser beams, and are used for patterning and large area processing, typically when used to irradiate a photomask which is then demagnified and intensified onto a workpiece. They offer high average power compared to DPSS lasers; the DPSS laser's power might be a few Watts at 266nm; or upwards of 5 - 10W at 355nm. The most common excimer lasers are in the 50-100W range for industrial production use. Effective materials processing with excimer lasers occurs at relatively large areas of focus; i.e., a 500mj UV beam at 1 j/cm2 target fluence theoretically can expose an area of up to 7mm x 7mm. The characteristically large beam of an excimer laser can be projected onto a mask to micromachine specific shapes and patterns; this is known as near field imaging, which involves the use of a mask to project a pattern of laser light onto a part. The features contained in a pattern are then etched into the target material, at a magnification determined by the relative positioning of the optical elements. This technique is the basis for excimer laser micromachining in many materials processing systems.

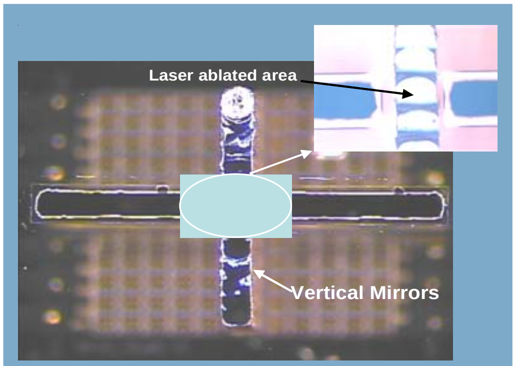

Figure 2. Completed MEMS corner cube retroreflector device created using laser-assisted packaging. Inset image shows the top region of the first vertical mirror, where the laser beam was used to debond it from the Pyrex hold wafer.

Excimer lasers are available in various wavelengths. By adjusting or changing (substituting) the optics, gases, or other parameters, output wavelengths can be changed to 157nm, 193nm, 248nm, or others, making a number of discrete wavelengths achievable, including the same wavelengths usable with DPSS UV systems, e.g., 355nm and 266nm. Each type of laser offers different processing opportunities.

Laser micromachining begins with material removal through the laser photoablation process. Pulses of laser energy are absorbed by thin layers of material. The laser energy breaks the molecular bonds of the material, in effect 'vaporizing' it. The material is ejected as plasma plume. Because the material is ejected as plasma, there is little or no heat-affected zone around the target area; heat is carried away by the plume. The repetition rate of the laser is very rapid, and each pulse removes a controlled, measured, sub-micron thick layer of material. Control of the repetition rate and number of pulses controls depth with sub-micron accuracy.

Samson's MEMS are designed for use in sensors for marine applications, and for other environmental sensing and optical communications, he says. They incorporate very tiny moving optical parts, including the aforementioned mirror structures. The IX-300 laser is used for post-process assembly of several components. The base silicon wafer contains arrays of small movable mirrors, built up using typical MEMS semiconductor process steps . Additional orthogonal vertical mirror surfaces are created using a different MEMS process by graduate student Rahul Agarwal, and bonded to the base wafer, in this case, to create a tiny corner cube retroreflector for data communications. Laser technology is used in conjunction with traditional MEMS fabrication methods which, though not as capable as the laser for more complex applications, are nonetheless cheaper and reliable for batch fabrication. In this case, the passive vertical mirror surfaces can be fabricated using potassium hydroxide etching, a wet etch on silicon process. Once the wet etching is done, the laser can be used to micromachine and fabricate more complex structures or elements. Another difference between etching and laser micromachining is the ability of the laser tool to create or assemble complex 3D structures.

UV laser materials processing provides the ability to micromachine sub-micron features and drill holes in tolerances that simply cannot be achieved with mechanical drilling or machining tools. The lack of a heat-affected zone gives UV laser processing an advantage over other types of laser processing. Holes, channels, and features are clean, sharp, and precise, without cracking, melting, burning, or other problems associated with some types of laser processing.

Conventional chemical or plasma etching techniques provide limited options for the geometries that they can produce . In addition, the use of etching is often not possible or recommended for photonic applications where sensitive optical devices are integrated onto silicon wafers. Short-pulsed UV lasers provide a fast and flexible alternative to micromachine a wide range of features, because excimer lasers excel in three-dimensional micromachining. Adequate beam illumination and projection techniques allow for very sharp-edged and uniform energy density distribution on target. This leads to fine control of the volume of material removed per pulse leading to high machining resolution and high surface finish quality. Typical removal rates are between 0.05- to 1-micron per pulse, for repetition rates up to 400 Hz (for high pulse energy lasers).
When a single pattern must be repeated, the mask itself may contain an array of features, using the large beam cross section for simultaneously machining multiple features. The use of CAD conversion software minimizes set up time for new parts and allows efficient and high quality machining of virtually any geometry. Additionally, by adequately moving the mask and the workpiece in coordinated opposing motion (COMO) larger complex patterns can be created.

Samson continues, "In our application, we do need two mirror surfaces orthogonal to the MEMS mirror arrays. So, we use wet chemical etching to fabricate one of these vertical mirrors onto a separate silicon wafer that's been previously bonded to a Pyrex glass wafer. Then, we perform a metallization process where we sputter-coat a titanium-gold layer, to make it more reflective; the gold that we use also creates a metal-to-metal bonding surface, so we then flip the gold mirror tops and flip them upside-down, and compression bond them onto a gold pad located where we want this vertical mirror to reside. The high temperature thermo-compression bond fuses the gold on our MEMS structures with the gold on this vertical mirror structure. Now that the mirror is bonded to the MEMS, we still have a glass hold component that we want to detach from the mirror. Because these parts are quite fragile, we developed a process whereby we laser micromachine from the glass side of this stack through the Pyrex since the glass is partially transmissive at 248 nm, when the laser energy hits the interface between the glass and the silicon wafer, it de-bonds that interface, so we essentially run along the length of the mirror where it's bonded to the glass, and the glass wafer lifts off. Then we take another similar mirror chip which also includes an integrated package frame, and bond it to the first parts. If we needed additional components, we could continue the process."

Samson rules out using a dicing saw to perform the separation. "We had thought of this approach before we had the laser, but we didn't go through with it. It would have meant taking a dicing saw and cutting through the Pyrex, and essentially cut the very top of the wafer, but those saws are pretty aggressive, spinning at high RPM's. They spray water, you get dicing debris and everything all over the wafer, so the laser is definitely the better way to do it."

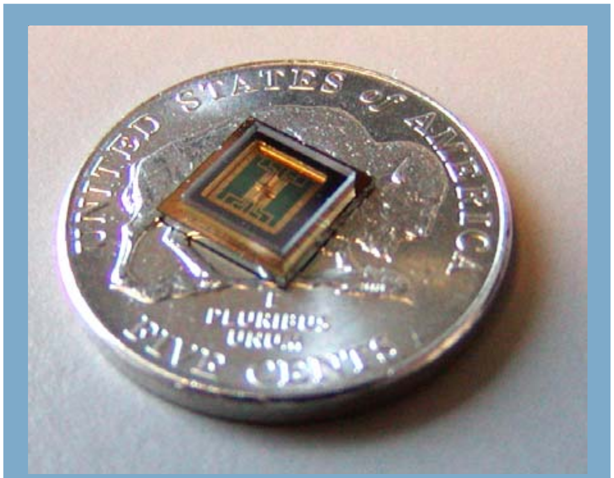

Figure 3. Image of an assembled corner cube retroreflector.

UV laser micromachining has its issues as well; one of the challenges, according to Samson, is the potential for debris redepositing on the tiny MEMS structures from the micromachining process. The use of a water-soluble photoresist, which can be washed off with the debris after micromachining, essentially alleviates this problem. Some MEMS are water tolerant, some are not, and there is the potential, with water washing, for mirrors or parts to 'stick down' following evaporation of the water. But for the time being, it is not a problem, he says.

The ability to create 3D structures with UV lasers such as tapered holes, cones, and other shapes and structures appeals to Samson, and he has a number of future applications in mind that he plans to try. These include making micro-lenses and similar small optical devices. "I also have learned about the technique of hitting your wafer with a high-energy laser, which apparently causes a vibration so that you can, for example, pop stuck parts off the surface so that they're no longer stuck; that's an application that we want to try."

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