HIGH RESOLUTION MICROMACHINING USING SHORT WAVELENGTH AND SHORT PULSE LASERS*

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ABSTRACT

High-resolution micromachining of a range of materials (polymers, fused silica, silicon, diamond) has been investigated using both short wavelength (157nm, F_2) and short (100fsec, $Ti:Al_2O_3$) pulse laser radiation. Results using the two sources will be compared.

SUMMARY

High-resolution ablative pulsed laser micromachining of materials usually requires photons to be absorbed strongly in sub-micron depths on the surface on time scales less than it takes for heat to diffuse away from the irradiated region. This requires photon absorption depths in the material to be $\leq 0.1\mu m$, that in turn requires absorption coefficients (linear and/or nonlinear) to be $\geq 10^5$ cm^{-1}. One method of obtaining such high absorption is to use laser photons at increasingly shorter wavelengths in the deep ultraviolet. In general for photon energies exceeding a material's bandgap, absorption becomes stronger as wavelengths become shorter. Thus nanosecond pulses from excimer and 3rd and 4th harmonic Q-switched Nd lasers in the wavelength range 193-355nm are commonly used for micromachining a wide range of materials having bandgap energies $\leq$ 6.4eV (polymers, ceramics, glasses, crystals, metals, etc). However materials that have higher bandgap energies (e.g. fluorinated polymers, fused silica, fluoride crystals) and/or high thermal conductivities (e.g. diamond, silicon) have remained notoriously difficult to micromachine with high resolution using such laser sources.

At 157nm, the F_2 laser produces the shortest wavelength photons available from any commercial device. The higher 7.9 eV photon energy coupled to the recent availability of reliable high-power devices has widened the range of materials that can be practically micromachined with sub-micron precision. Using a Lambda Physik LPF210i F_2 (20mJ/pulse, 100Hz) laser source with an Exitech MS-157 Microstepper incorporating a x36, 0.5NA Schwarzschild imaging objective, sub-micron structures have been micromachined in polymers (photoresists, PTFE, FEP) and fused silica (see Figure 1).

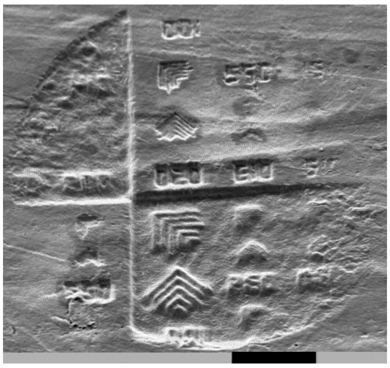


Figure 1. Resolution test mask showing 0.5µm features micromachined in PTFE at 157nm. IJ/cm^2/pulse. 50 pulses etched 10µm deep

As shown in Figure 2 this tool has been used for the selective localized removal of thin films of fused silica (SiO_2) in the repair of integrated circuits.

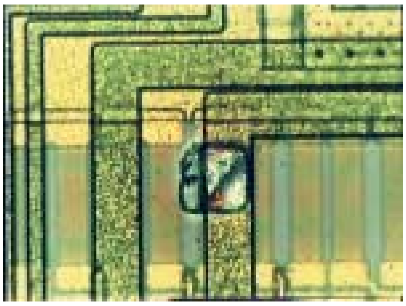
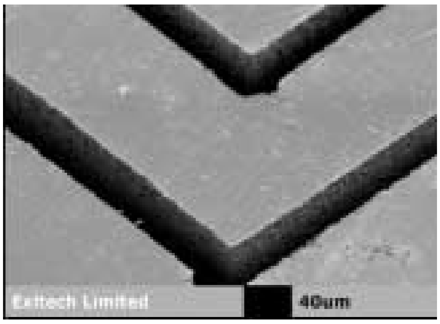
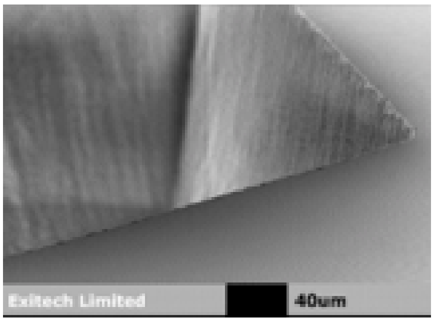


Figure 2. Removal of 17µm square aperture of SiO_2 dielectric layer on an integrated circuit. Using 157nm and MS-157 Microstepper. IJ/cm^2/pulse. 38 pulses

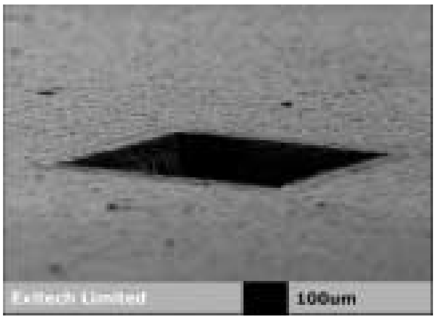
Another method of increasing the absorption of photons in a material is to increase the incident intensity to a level such that a nonlinear polarization is induced that allows multiple absorption of photons across the bandgap. Such high intensities are practically achieved in commercial laser devices using ultrashort ≤ 100fsec duration pulses. Using a Spectra Physics Hurricane mode-locked Ti:Al_2O_3 laser source (800nm wavelength, 0.8mJ/pulse, 1W average power, 1kHz) with an Exitech M2000F micromachining system, results are presented of cleanly micromachined etched structures in FEP, fused silica, silicon and diamond.



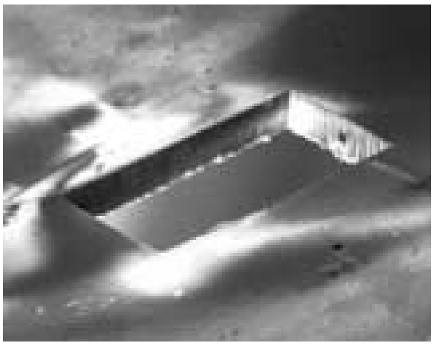
(a) Fluoro-ethylene polymer (FEP)



(b) Fused silica (SiO_2)



(c) Silicon (Si)



(d) CVD deposited diamond film

Figure 3. Femtosecond laser micromachined trenches and apertures in 'difficult to machine' materials

Crucially our results with femtosecond pulses have demonstrated that lasers can be used to micromachine silicon (see Figure 3(c)) with a quality as good as achieved by the photolithography-chemical etching processes used in the manufacture of MEMS and MOEMS devices.

We have demonstrated that both F_2 and femtosecond lasers can micromachine materials with submicron resolution. The F_2 laser at 157nm can cleanly etch materials that, because of their high bandgap energy, are difficult to machine at longer wavelengths – e.g. fluorinated polymers and fused silica. While femtosecond laser radiation can cleanly etch most materials, they are particularly effective at micromachining materials having a high thermal conductivity e.g. diamond, silicon.

As well as quality of result, the laser type chosen to best suit a particular industrial application depends also on other issues like ease of use, reliability, cost of ownership, etc. Both laser sources are more expensive and difficult to use than well established longer wavelength and pulse duration sources. Nevertheless the high quality micromachining achievable with F_2 and femtosecond lasers may well justify their use in certain critical high value added applications.

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[*] We are grateful for partial financial support for this work by the European Commission under Contract Nos G1RD-CT-2000-00198, 'HARP' and BRPR-CT98-0694 'FEMTO'.