Micromachining of packaging materials for MEMS using lasers

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ABSTRACT

New lithographic, deposition, and etching tools for micro fabrication on planar silicon substrates have led to remarkable advances in miniaturization of silicon devices. However silicon is often not the substrate material of choice for applications in which there are requirements for electrically or thermally insulating substrates, low capacitance, resistance to corrosion, or hermetic sealing. Some of the MEMS packaging materials such as ceramics, polymers, and glass are currently being used to fabricate many microdevices. To support the rapid advancements of non-silicon MEMS it is necessary to introduce innovative techniques to process these MEMS packaging materials. In this study we present the application of pulsed laser ablation of ceramics, polymers and glass (MEMS packaging materials) to assist in fabrication of MEMS devices. Microstructuring of Al₂O₃ ceramic, polymers Poly-Vinyl-Alchohol (PVA), polystyrene (PS), and Pyrex glass were performed and studied by pulsed lasers at 193-nm, 266-nm and 308-nm wavelengths.

INTRODUCTION

Non-silicon MEMS devices are rapidly gaining importance and applications. Packaging materials such as ceramics, polymers, and glass are currently used for fabricating many non-silicon MEMS devices. Tools for microfabrication on planar silicon substrates have led to remarkable advances in miniaturization of MEMS silicon devices. Silicon however has a limited functionality in many MEMS applications. The introduction of packaging materials such as ceramics, polymers and glass in MEMS fabrication makes it easy to fabricate 3-D meso or large-scale devices for a wide range of applications at a cheaper cost. The application of these materials helps in constructing multilayer MEMS structures, which is one of the limitations of traditional MEMS devices.

Ceramics are needed in actuators, high temperature components, and harsh environments. Due to their excellent properties ceramics have been a good choice for microelectronics and fabricating MEMS devices. Glass finds application in optics, sensors, and fluid control MEMS devices. Polymers have been micropatterned successfully for application in microelectronics. Applications in the field of microsystems technology require producing structures with micrometer dimensions in various materials. Micropatterns such as microholes, microchannels, and complex 3-D patterns are some of the common structures. Packages on which chips are mounted for connection to other devices have to keep pace with the rapid advances made in ICs, so speed, power, and area should not be compromised. Small distances between chips and shorter interconnection distances are of great important for faster operations. In multilayer sandwiches, blind via holes provide high-speed connections between surface-mounted components on the board and underlying layers. Microchannels and complex 3-D patterns find applications in biomedical and microfluidic devices.

Early fabrication methods in fired ceramic involved machining substrate features with carbide, diamond or ultrasonic tools. These techniques are not cost effective and were limited in the type and size of features they could create. Most of the conventional techniques are not suitable for processing polymers on the micro scale. Techniques such as electron beam etching and photolithography produce too much heat and damage to the polymers. Atomic force microscopy (AFM) utilizes mechanical forces to etch the surface, which is very slow and cannot be used conveniently to etch large surface areas. Some of the techniques used for micromachining glass are ultrasonic machining and photolithography. And as the feature sizes fall in the order of micrometers micromachining approaches to drilling, engraving and shaping these materials must be replaced with photon or particle beam techniques. The requirement for material processing with

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micron or submicron resolution at high speed and low cost is fundamental and special tools are needed for this work, and lasers can play an important role.

Application of pulsed laser ablation to manufacture micro-electro-mechanical systems (MEMS) and micro-opto-electro-mechanical systems (MOEMS) devices have been demonstrated. Glass was micromachined by UV laser for applications in microoptics, microelectronics and microchemicals and ultrashort femtosecond laser pulses were used for creating waveguides. Micromaching of materials such as silicon, PMMA, alumina ceramics, and glass for fabrication of a variety of microdevices using lasers was reported. Advanced CAD/CAM techniques along with excimer laser was reported that produce components for MEMS and MOEMS.

Lasers are currently used in several areas of material processing. The most common applications include welding, drilling, cutting, engraving etc. Lasers are particularly useful, and a variety of highly localized, laser-controlled processes have been developed for material deposition and removal. Laser micromachining offers tremendous advantages over conventional manufacturing technologies such as

- Non-contact clean process
- Single-step processing
- Small heat affected zones (HAZ)
- High precision and repeatability
- Flexible feature size and shape
- Do not requirement of expensive vacuum equipment
- Ability to remove material selectively
- Few processing steps
- Highly flexible CNC programming.
- Capability for serial and batch-mode production.

In this work, we investigate and report laser micromachining of MEMS packaging materials such as ceramics, polymers and glass for non-silicon MEMS device fabrication. The experimental results using UV excimer lasers and a Nd: YAG laser at different wavelengths are reported. This work demonstrate that laser micromachining is a promising technique for MEMS device fabrication and packaging.

**EXPERIMENTAL PROCEDURE**

All the ablation experiments were performed in ambient air. The experimental results were obtained using a 308-nm Xe-Cl Excimer laser, a 193 nm ArF excimer laser (Lamda Physic) and an Nd: YAG laser (Spectra Physics, INDI 30 Series) at output wavelengths of 266-nm and 532-nm. The properties of the lasers used are shown in Table 1. A beam attenuator is used to control the laser intensity. Optics such as a beam polarizer, beam splitter, mirrors and lenses are used and the beam is focused down to the material for ablation.

An energy meter measures the energy of the beam and a He-Ne laser beam is made co-axial to the machining beam for alignment. The materials are mounted on a 3-D stage of a micrometer resolution. Multiple pulses were needed and a repetition rate of 1 Hz for the polymer and a repetition rate of 10 Hz are maintained for the ceramics in the experiments.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Xe-Cl</th>
<th>Nd: YAG crystal</th>
<th>ArF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>308-nm</td>
<td>266-nm</td>
<td>193-nm</td>
</tr>
<tr>
<td>Pulse energy</td>
<td>150 mJ</td>
<td>35 mJ</td>
<td>6 mJ</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>0.1-30 Hz</td>
<td>1-10 Hz</td>
<td>10-100 Hz</td>
</tr>
<tr>
<td>Pulse width</td>
<td>10 ns</td>
<td>6-7 ns</td>
<td>10 ns</td>
</tr>
</tbody>
</table>
A circular aperture is used to shape the beam and a spherical lens of 1-inch focal length is used to focus the beam for the holes and a cylindrical lens of 2-inch focal length is used for microchannels. In laser ablation some of the experimental parameters that determine the feature size are the laser intensity, wavelength, pulse width and the number of pulses.

RESULTS AND DISCUSSION

Drilling of small holes in unfired, fired ceramics, glass and polymers is very important in MEMS applications. The wavelength of the laser beam is an important parameter while processing materials. Since the applications in MEMS are on the order of microns it is necessary to choose the appropriate wavelength for the applications. For processing ceramics the fundamental wavelength of Nd: YAG laser (1064-nm) is not appropriate because most of the ceramics are not good absorbers at this wavelength. At this wavelength, the smallest size of the features is limited and high energies are required. Shorter wavelengths and pulse-widths is the key to attain features on the micro scale. Excimer and frequency multiplied Nd: YAG lasers offer shorter wavelength and pulse widths in the order of 6-10 ns and are suitable for processing materials on the micro scale. Similarly processing glass and polymers at lower wavelengths yields smaller and sharper microstructures.

Excimer laser at 308-nm is used for patterning microholes and microchannels on the ceramics. The repetition rate was 10 Hz. Multiple pulses were targeted on the ceramic samples to produce holes and channels of required dimensions. Dark marks (HAZ) are noticed around the edges of the holes caused by plasma heating of the surface and particle redeposition was noticed. The material ablation was studied at different energies and it was noticed that as the energy is increased the HAZ was more prominent since larger plasma plume was produced around the perimeter of the structures. For all values of energy used, it is observed that there is a drop in etch rate with increasing laser pulses. Figure 1 shows the SEM micrographs of the machined ceramics.

Figure 1: Micropatterned holes and channels in Al₂O₃ ceramics.
The arrays of blind holes drilled were 100μm in diameter. By varying the different experimental conditions the smaller feature size holes can also be obtained. The holes were drilled at the focal plane of the laser beam. The microchannels were patterned using a cylindrical lens of 1 inch and 2 inch focal lengths. As the energy in the experiments was decreased, the HAZ was noticed to reduce. Microcracks and material redeposition can be seen in the SEM pictures. The width of these microchannels was between 10-15 μm wide.

Laser machining of polymers involves ablation, in which the matter is ejected because of the interaction of an intense laser pulse with the polymer material. The two principle types of ablation occurring in polymers are photochemical and photothermal ablation mechanisms. Photochemical mechanism is a mechanism in which the chemical bonds are broken by the photons and the photothermal mechanism is one in which heating is used to remove the polymers. For photochemical ablation to occur, energy of the photons at that wavelength should overcome the intermolecular bond energies of the polymer. The TEM00 beam profile of Nd: YAG allows drilling of sub-micron holes. Polymers PVA and PS are micromachined using 193 ArF excimer and 266-nm wavelengths. It is observed that the thermal damage at 193-nm excimer laser is less than that of the 266-nm wavelength. This is attributed to the shorter wavelengths. Figure 2 shows the SEM micrographs of micromachined PVA at 193-nm and 308-nm wavelengths.

Figure 2: Micropatterned channels in PVA at 308-nm (left) and 193-nm wavelengths (right)

Figure 3: Micropatterned channels in PS at 308-nm (left) and 193-nm wavelengths (right)
It can be seen that there is a distinct difference in the thermal damage between the 193-nm and the 308-nm wavelengths in both the polymers (Figure 3). The 193-nm produced more sharper and distinct edge around the features.

**SUMMARY**

UV pulsed lasers have been used to micropattern features on MEMS packaging materials such as ceramics and polymers. It is noticed that UV lasers with shorter wavelengths produced sharper and distinct micropatterns on these materials. MEMS packaging materials such as Al₂O₃, PVA, and PS have been patterned for applications in producing non-silicon MEMS. Microstructures such as holes and channels that find many applications in the MEMS devices have been patterned.

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**REFERENCES**


