Laser micromachining of thin films for optoelectronic devices and packages

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ABSTRACT

Focused laser micromachining in an optical microscope system is used to prototype packages for optoelectronic devices and to investigate new materials with potential applications in packaging. Micromachined thin films are proposed as mechanical components to locate fibres and other optical and electrical components on opto-assemblies. This paper reports prototype structures which are micromachined in silicon carbide to produce beams 5 μm thick by (i) laser cutting a track in a SiC coated Si wafer, (ii) undercutting by anisotropic silicon etching using KOH in water, and (iii) trimming if necessary with the laser system. This approach has the advantage of fast turn around and proof of concept. Mechanical test data are obtained from the prototype SiC beam package structures by testing with a stylus profilometer. The Youngs modulus obtained for chemical vapour deposited silicon carbide is 360 +/- 50 GPa indicating that it is a promising material for packaging applications.

Keywords: laser micromachining, thin films, MEMS, packaging optoelectronic devices

1. INTRODUCTION

The large and continuing investment in silicon-based integrated circuit technology is leading to rapid advances thin film and related technologies [1]. By-products of these technology developments include materials and fabrication technologies which are readily applied in micro-electro-mechanical systems (MEMS). There are many reports of exciting developments and products in MEMS [2-15]. Recent advances in the chemical vapour deposition (CVD) processes for silicon nitride, for example, have resulted in controlled stress thin films which have favourable mechanical properties for optoelectronic packaging. Using patterned 2.3 μm thick silicon nitride films to form microclips over a silicon V-groove, an optic fibre can be held in place in the V-groove with a clipping force of 10 N per metre of optic fibre length [5]. Other package geometries have been proposed including etched substrates with microclips on both sides to hold optical or electronic components in place [15].

In the development of new MEMS stuctures, laser processing has the advantages of flexibility and fast turn around compared with conventional lithography and etching processes [16-23]. Using a focused laser for direct write avoids the need for photomasks to demonstrate proof of concept, and for a new material it is straightforward to develop a laser etch process compared with developing a reactive ion etch process.

In this study laser micromachining in an optical microscope system using a frequency-doubled or frequency-tripled YAG laser has been applied to prototyping and trimming packages for optoelectronic devices. Prototype structures are made in 5 μm thick CVD silicon carbide beams by first laser cutting a track in the SiC coated Si wafer, then undercutting (and removing the debris) by anisotropic silicon etching using KOH in water, and trimming if necessary with the laser system.

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LASER CUTTING

The laser system used for these experiments delivers 0.6 mJ pulses of either 532 nm or 355 nm radiation at 50 pulses per second and 3-4 ns width. The laser output is delivered through an optical microscope system to uniformly illuminate an area 60 μm x 60 μm on the target to be machined. Through a computer interface the dimensions of the illuminated area are controlled, keeping the energy density per unit area constant, and the target is driven on a precision x-y table. Further details of the system are available in Reference 24. Typical conditions for cutting 10 μm wide tracks in the 5 μm thick silicon carbide films reported here are: illuminated area 10 μm x 10 μm; laser 30 % full power; stage travel 50 μm per second. Long straight tracks can be cut more rapidly using, for example: illuminate 10 μm x 50 μm; laser 30 % full power; stage travel 250 μm per second, with the long axis of the illuminated rectangle oriented in the direction of stage travel. The silicon carbide films are on (100) oriented single crystal silicon substrates and the laser cutting conditions are chosen to overetch through the SiC into the Si which is removed in a later process anyway.

The debris from the laser cutting process are readily dissolved and removed during the alkaline etch process (20 g KOH in 100 ml water at 70 C) used to etch the silicon substrate and undercut the SiC beams for testing. SiC is not etched under these conditions. The debris from the laser cutting process are clearly seen in the optical micrograph in Figure 1(a) where a set of lines have been cut in SiC using the focused laser. Figure 1(b) is a secondary electron micrograph taken at a tilt angle of 45^o in a focused ion beam microscope after a laser cut sample has been wet etched for 15 minutes in KOH and the debris have largely gone.

Prolonged KOH etching of the laser patterned SiC/Si results in the formation of SiC beams due to the well known anisotropic etch properties of silicon [1]. Figure 2(a) is an electron micrograph showing several test SiC beams overhanging a trench etched in the silicon substrate. This is a very convenient configuration for mechanically testing the CVD silicon carbide. Using the computer controlled laser microscope system, more complex shapes for other tests can easily be designed and fabricated as seen in Figure 2(b).

MECHANICAL TESTING

Preliminary mechanical test data on the silicon carbide beams have been obtained by profiling the length of SiC beams with a conventional stylus profilometer (Dektak II). Figure 3(a) is a sketch cross section of the test arrangement, whereby the stylus tip deflects the microbeam with a constant force as it traverses the length of the beam [25,26]. Figure 3(b) shows the height of the tip as a function of distance along a 100 μm wide 5 μm thick beam with an applied force of 0.4 mN. The beam is deflected more than 30 μm at the end. The measurement is repeatable and the beam behaves elastically. This measured profile of the beams corresponds closely with numerical simulations [15]. Simple analytic formulae for small angle beam bend are not applicable in this case of large angle bending. The Youngs modulus deduced from the profilometer data for the CVD silicon carbide is 360 +/- 50 GPa indicating that it is a promising material for packaging applications [15]. Further testing is in progress using various materials and a wide variety of laser cut beam shapes.

POTENTIAL PACKAGING APPLICATIONS

Packaging technologies based upon precise anisotropically etched V-shaped grooves in (100) oriented silicon substrates to position optic fibres are well established [1-3]. One promising variation is shown in Figure 4(a) where a thin film is micromachined into clips which hold the fibre in position [5-6]. In a technology using one photolithographic step to pattern CVD silicon nitride films 2.3 μm thick, microclips have been demonstrated and are capable of holding an optic fibre in place with a clipping force of 10 N per metre of optic fibre length [5]. This approach is well suited for low loss fibre to fibre connectors and

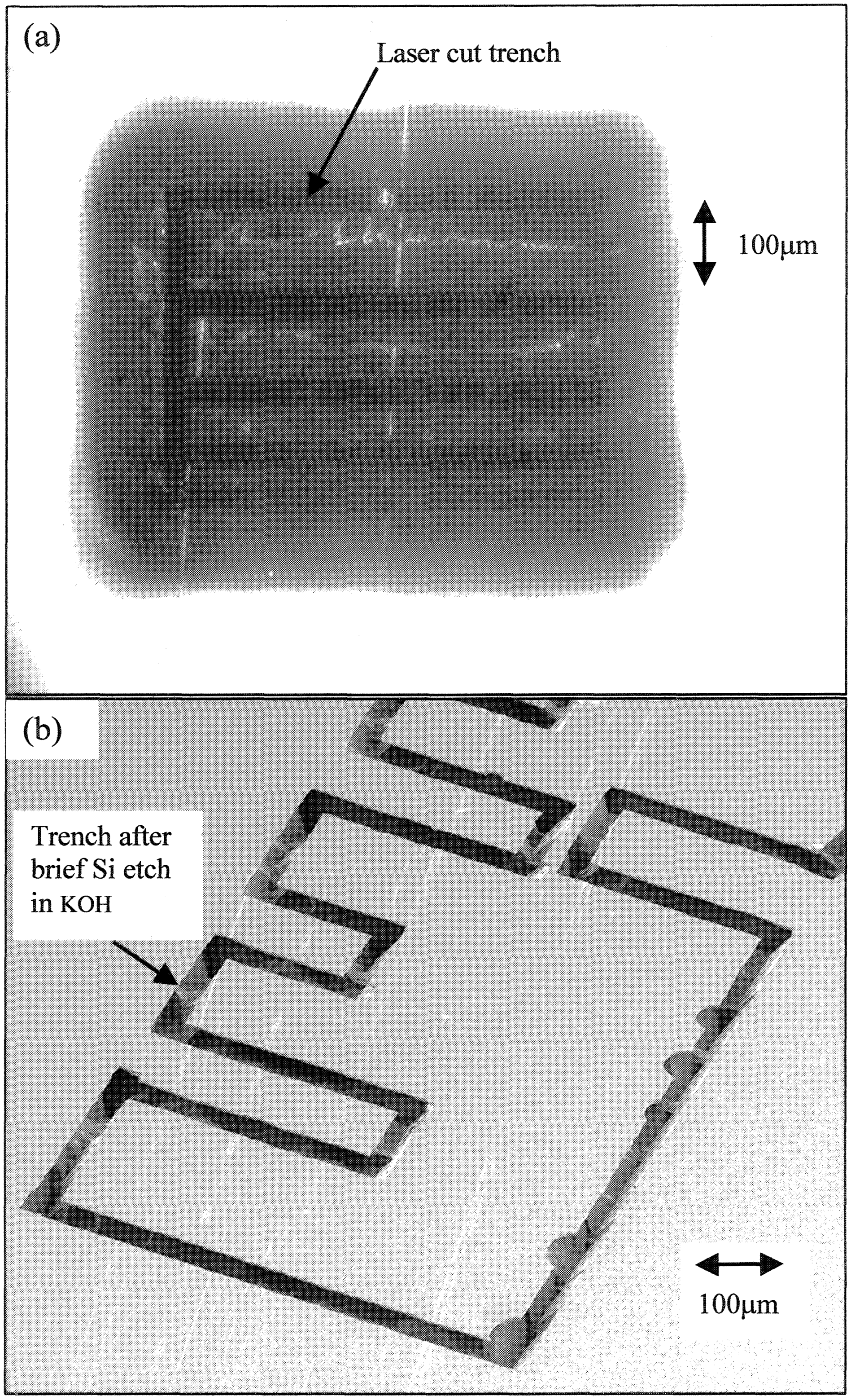

Figure 1. SiC/Si sample (a) optical micrograph after laser cutting showing the debris on the SiC surface, (b) electron micrograph of another sample after a brief Si etch which removes debris.

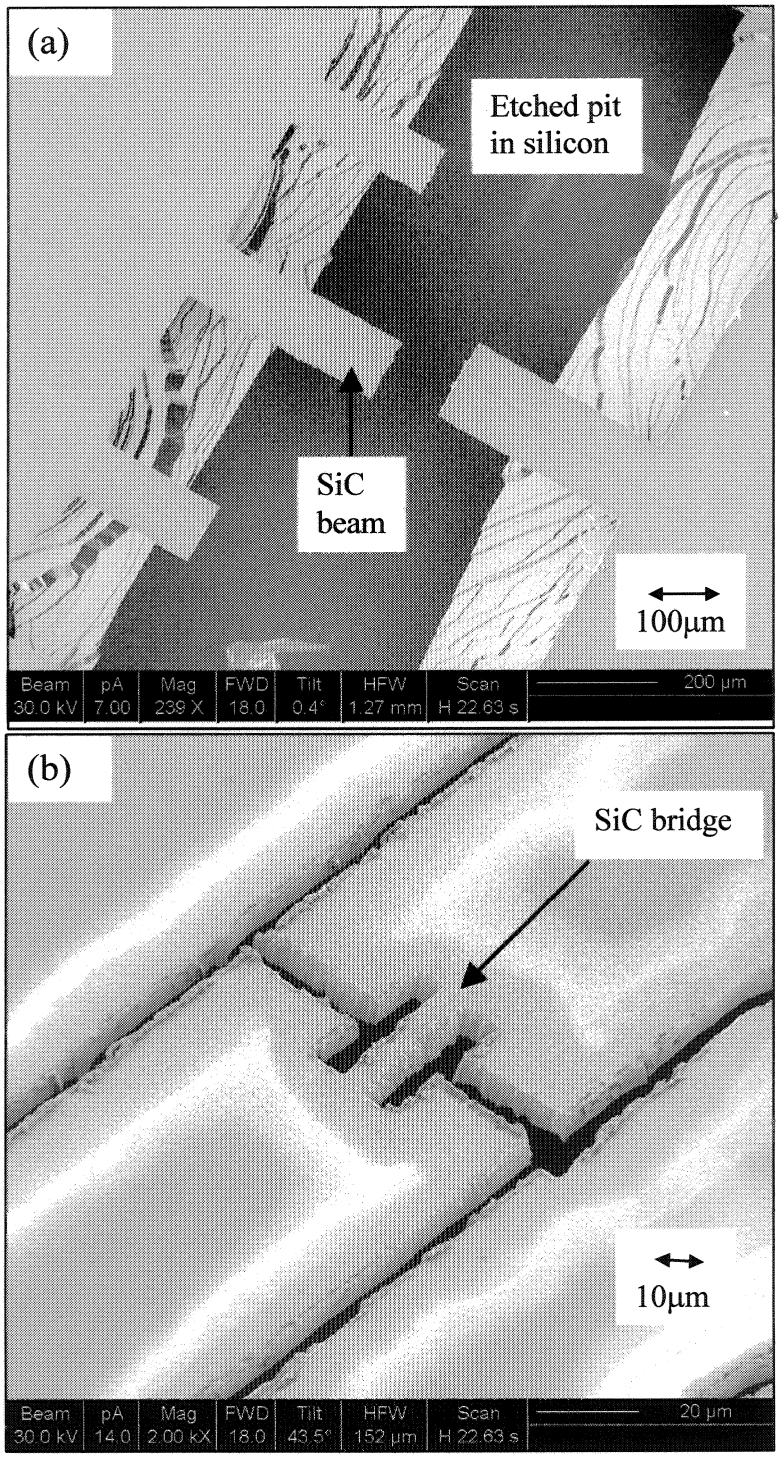

Figure 2. Electron micrographs of micromachined structures in 5 µm thick SiC after laser cutting and under etching the Si substrate with KOH : (a) SiC microbeams for profilometer testing; (b) high magnification secondary image in the focused ion beam system showing evidence that not all the debris from the laser cutting have been removed by the KOH etch process.

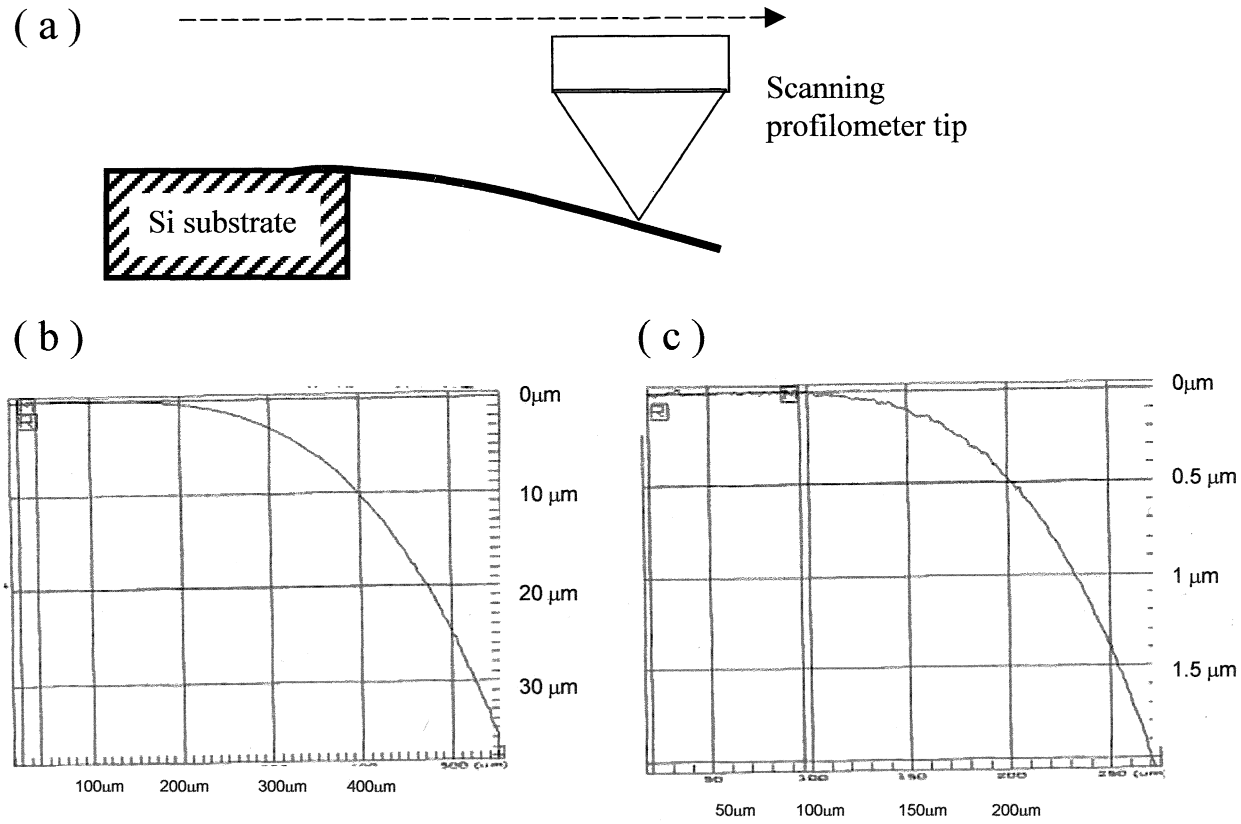

Figure 3. Mechanical testing of microbeams: (a) schematic cross section showing the Dektak profiler tip causing a beam to deflect; (b) Vertical tip position vs scan distance for a 100 μm wide 5 μm thick SiC cantilever with 0.4 mN applied force; (c) detail from (b).

has potential application in variable attenuators since the clips hold the fibres kinematically in place and actuators could possibly be used to control the separation of two fibres in the same V-groove. However, this geometry has the fibre core well below the surface of the silicon and it is unsuitable for interfacing to waveguide or laser devices. Figure 4(b) shows a clip technology capable of holding the fibre core in the plane of the silicon substrate or at a fixed distance from it. It involves two lithographic steps and etch masks of silicon nitride and of silicon oxide [5]. The precision of the fibre location is determined by the lithographic and etch processes to form the V-shaped groove in the silicon.

The above technologies require single crystal substrates and are only suitable for particular applications. Figure 4(c) shows the cross section of a clipping structure with potentially much wider applicability. The inserted component is held by pairs of clips and in this case the precise geometry of the substrate is of secondary importance. For example CVD silicon nitride or silicon carbide could be patterned on the front and back sides of a silicon substrate to form sets of clips, and the substrate removed by a combination of plasma etch and wet etch processes. The simulated clipping force and precision of alignment of the inserted component does not depend strongly on the shape of the silicon trench formed in the deep reactive ion etch (DRIE) process [15]. Of greater importance is the front-side to back-side alignment of the lithographic steps to form the clip patterns.

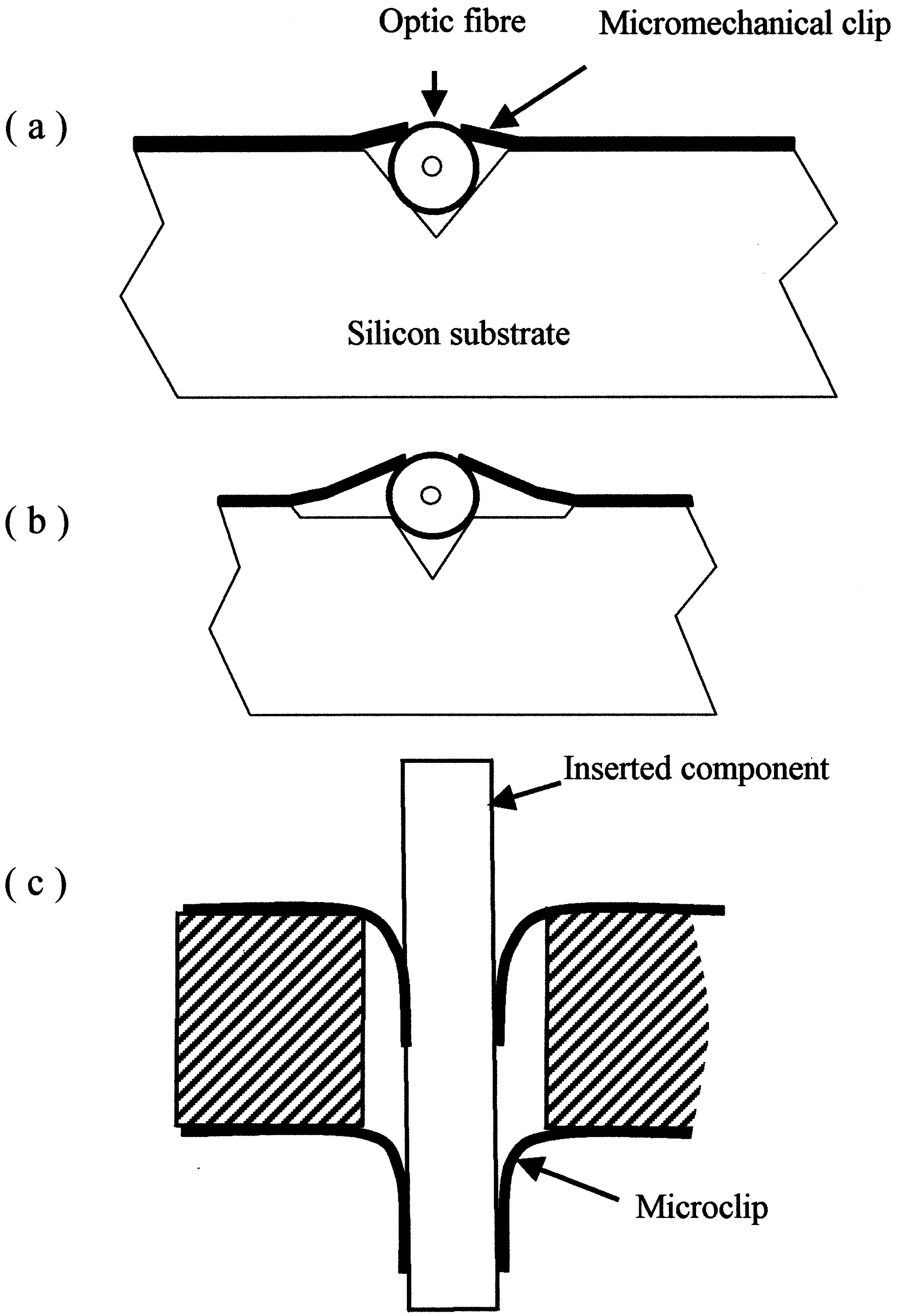

Figure 4. Cross section diagrams of: (a) simple clips to hold a buried optic fibre in a silicon V-groove; (b) clips arranged to hold a fibre with the core near the substrate surface [5]; (c) proposed arrangement with microclips on both sides of the substrate.

The approach outlined in Figure 4(c) could be applied for a wide variety of substrates. Initial experiments are aimed at demonstrating proof of principle in silicon. Other possible materials for the mechanical component including multilayer materials [11] are also under investigation using the laser micromachining approach. These include graded bimorphs of silicon carbide and metals, the objective being to develop actuators on the beams. It would be highly desirable to adjust the position of components while assembling and testing before fixing them in place. The laser micromachining approach is convenient when new materials are to be tested because in contrast to reactive ion etching it is very easy to adapt the process conditions to different materials. It also permits the possibility of trimming assembled components, for example by cutting selected microclips, without the need for lithographic processing of micromachined substrates.

DISCUSSION

This paper has presented a relatively straightforward approach to evaluating the mechanical properties of new materials for MEMS with particular reference to the low cost packaging and assembly of optical and electronic components. Using a personal computer to design new shapes for MEMS components and etch them using a focused laser under computer control is a flexible way to prototype new structures in new materials. The 50 Hz repetition rate of the laser system, the computer control of the geometry of the rectangle to be illuminated, and the choice of output wavelength facilitate rapid prototyping. It is a distinct advantage over reactive plasma based etch processes that the laser etches a wide range of materials at a comparable rate. The test geometry used in this paper is particularly favourable to laser processing because overetching with the laser into the silicon substrate is immaterial since the silicon is later wet etched to form microbeams. In the proposed packaging approach the fabrication tolerances for making an optical system are very demanding, and it would be highly desirable to construct clips incorporating actuators for fine adjustment. Thermal bimorph actuators with silicon carbide and metals are currently being prototyped by laser etching through bilayers. Other possible materials for the mechanical component are also under investigation using the laser micromachining approach.

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