THE LASER-MICROJET® AS AN AGILE MICRO-MACHINING TOOL

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Abstract
The field of laser machining is extremely diverse and virtually all commercially available high power lasers have applications for which they are particularly suited [1]. This paper reports on the application of a Laser-Microjet® (LMJ) as an agile tool for the micro-machining of MEMS substrates, and ferrous/non-ferrous materials. The materials machined during these trials include, gallium arsenide (GaAs) & silicon wafers, steel, tantalum, ceramic packaging (alumina) and kapton. A Nd:YAG laser [2] operating at 1064 nm (infra red) and frequency doubled 532 nm (green) was employed for the machining of the materials.

Key Words
Laser Microjet, MEMS, micro-machining.

I INTRODUCTION

In any systemic process, repeatability is a priority requirement. The ability to precisely control a machining parameter is crucial to the accurate reproduction of a desired structure. This series of trials was designed to give an insight into the potential capabilities of the Laser-Microjet® (LMJ) as an agile machine tool for the following application areas:

1. Patterning of MEMS structures on silicon.
2. Cutting of a variety of other materials useful in the IC or MEMS industries, e.g. polymers, ceramics, ferrous and non-ferrous metals.
3. Dicing of integrated circuits on a variety of substrates.

Particular interest was directed towards speed, cleanliness of cut, and repeatability. The minimum feature size is much greater than that from deep reactive ion etching (DRIE-the major silicon patterning tool), however the LMJ could have advantages in other respects.

II THE LMJ

The technology combines in a unique manner the advantages of a high power pulsed laser with a guiding beam of water to simultaneously cut and cool the work-piece, as shown in Figure 1. The low-pressure water jet has three functions; it is used as a light guide for the laser beam, it allows cooling of the work piece, and finally acts to remove processing debris.

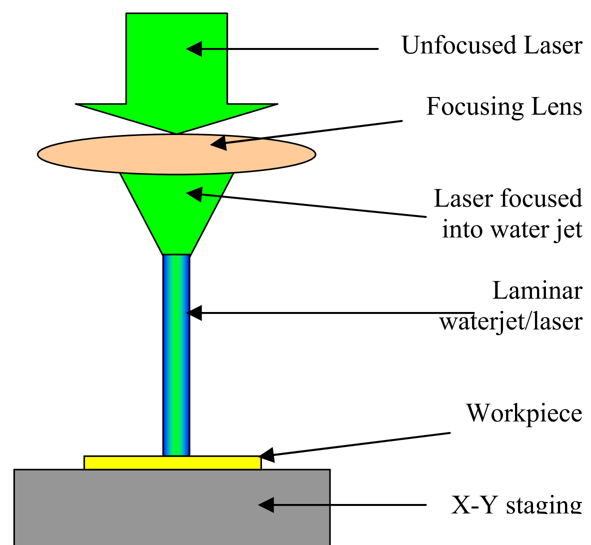

Figure 1. The basic operating principle of the LMJ

The laser beam is focused in a nozzle while passing through a pressurised water chamber [3]. The diameter of the waterjet nozzle, which ranges from 25 µm -75 µm, directly controls the cutting diameter of the laser. Control of the geometry of both chamber and nozzle are crucial for efficient coupling of the laser beam to the water jet. Finally, the water exits the nozzle as a low-pressure jet.

III HOLDING THE WORKPIECE

The trials commenced with the machining of the silicon wafers that were mounted to standard dicing frames and this procedure was used throughout the trials. The frames contained a UV activated LaserTape® [4] that was developed specifically for this process. The dicing frames were then mounted on a vacuum chuck within the LMJ. Table 1 lists the materials used during these trials.

Table 1

Trial number	Deposited material descriptions
1	2 mm Via hole (Silicon)
2	Multiple 1 mm Via holes (Silicon)
3	Spirals (Silicon)
4	Pillars (Silicon)
5	Steel foil
6	Tantalum tube
7	Ceramic chip packaging
8	Gallium Arsenide wafer

IV THE TRIALS

IV.I TRIALS 1 & 2

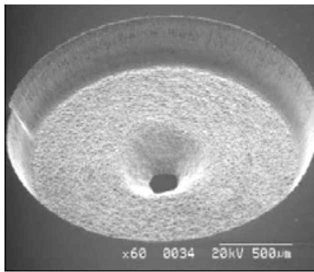

Figure 2. Image of 2mm diameter via hole.

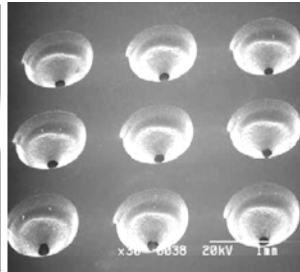

Figure 3. Image of 1mm diameter via hole array.

The machining procedure to create via holes was based on a spiral cutting raster pattern to gradually reduce the wafer thickness. By reducing the diameter slowly to a zero centre diameter a via hole could be created. The machining time was 90s for the 2 mm hole and 33s for the 1 mm hole, shown in Figures 2 and 3 respectively.

The results show an excellent repeatability in that the via holes are virtually identical to each other. They show a consistent round shape, a clean cut and a relatively debris free surface, considering there has been no dedicated cleaning procedure. Because of the way that the LMJ functions, i.e. it uses the water jet as a fluid waveguide, once the water jet is disturbed the laser becomes ineffective as a cutting tool. This is a limiting factor to the achievable depth to diameter ratio and explains the sloping nature of the walls. The machine manufacturers, Synova SA, claim a surface roughness of 3 µm peak to trough and this appears to be the case (Figure 4). Figure 5 shows the back face of the silicon wafer.

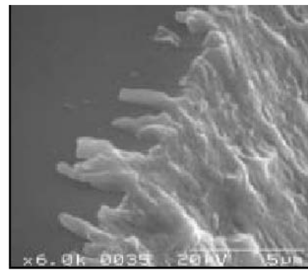

Figure 4. Shows the rim of the 1mm diameter via hole and debris contamination

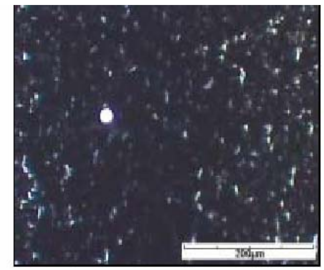

Figure 5. Image of a via hole taken from back face of the wafer

IV.II TRIAL 3

The machining process "Spirals" is based on the same cutting program as the "Via holes" but with a significantly larger pitch. Of special interest was the width of the remaining part of the silicon wafer forming the wall of the spiral to make it as thin as possible with a high aspect ratio. This experiment would examine the LMJ's ability to machine areas while leaving structures untouched.

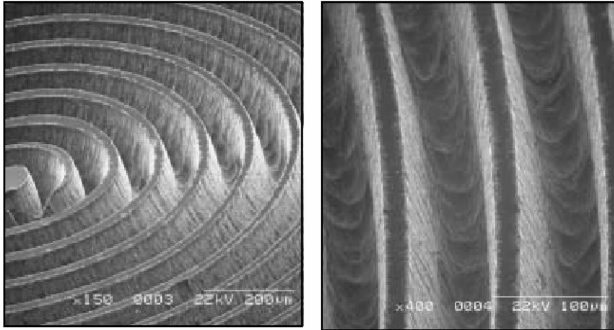

Figure 6-7. SEM images of the spiral showing the sidewalls and the bottom of the cut.

After the cutting process was complete, the laser was switched off and the program rerun using only the water jet. This was done to clean out the channels of any remaining loose debris. The examination showed that the water-jet had effectively cleaned the channel and that the walls of the spiral were smooth and consistent in dimension. This cleaning procedure was repeated on the next set of trials, to create pillars of silicon.

IV.III TRIAL 4

The machining process "Pillars" removed a large area of surface material, leaving pyramid shaped pillars with a top surface area of approximately 10 µm x 10 µm and 120 µm in depth. The consistency and repeatability of the machining process is evident in Figure 8, and Figure 9 shows the cleaning process was again successful as there was no debris apparent during the SEM examination.

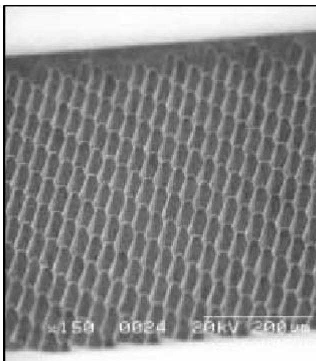

Figure 8. Image of the pillar array

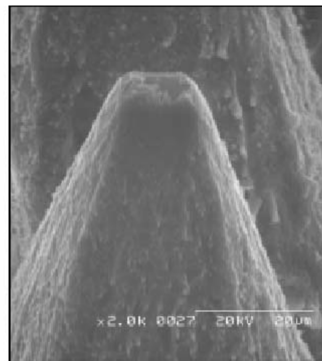

Figure 9. Single pillar

IV.IV TRIAL 5

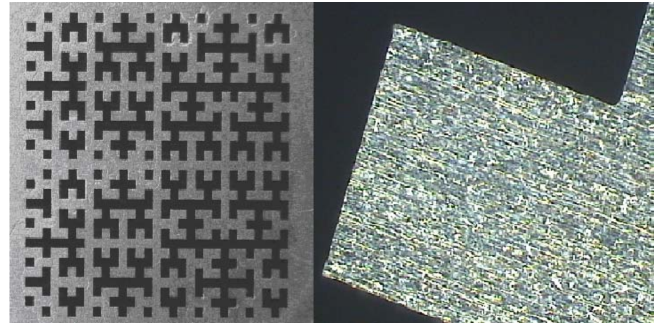

Figure 10. Image of the machined Hilbert pattern

Figure 11. Image of a rectangular section

A sheet of steel foil 100 µm thick was machined with the 532 nm green laser. Figure 10 shows the full pattern; the square holes are 500 µm and cover an area of 16 mm x 16 mm. Figure 11 shows the quality of the cut edge, with no obvious heat damage.

IV.V TRIAL 6

A tantalum tube 12 mm long with a 3 mm outer diameter and a wall thickness of 250 µm was machined as an additional investigation into the LMJs flexibility. It was completed using the 532 nm green laser and 40 µm nozzle, with a water jet pressure of 250 bar. The test comprised of machining two 75 µm diameter holes and a 35 µm slot. The slot is only visible under a microscope and initially appeared to be only partially complete (Figure 12).

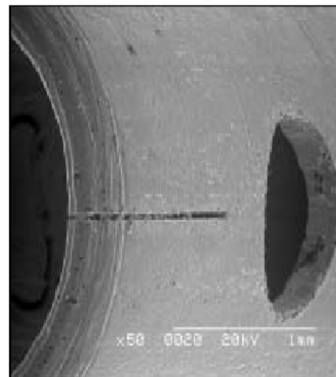

Figure 12 Image of the Tantalum tube showing the slot and a 75 µm Ø hole

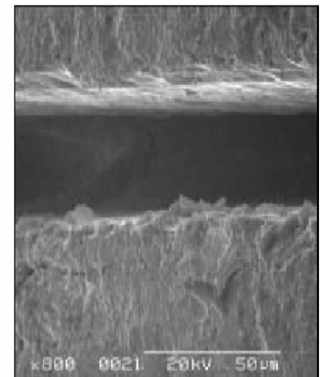

Figure 13. Close-up image of the 35 µm slot

Upon closer examination (Figure 13) it was discovered that this appearance was due to residual debris, and could be eliminated with additional optimisation of the machining parameters.

IV.VI TRIAL 7

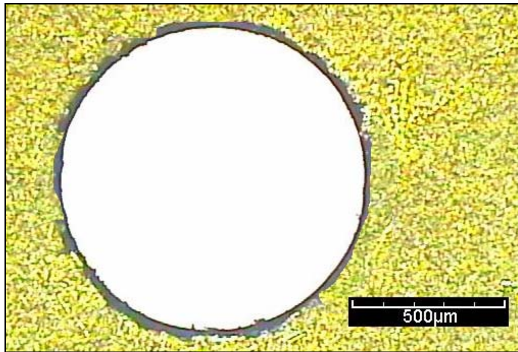

Figure 14. ceramic packaging with 1mm Ø hole

Figure 14 shows a 1mm diameter hole machined through 1mm thick ceramic (Alumina) chip packaging with gold plating. Some of the plating has peeled at the edge of the hole due to lack of adhesion.

IV.VII TRIAL 8

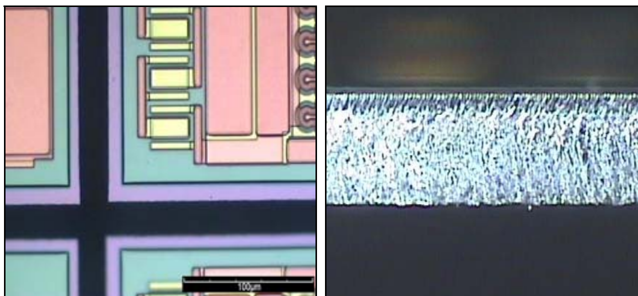

Figure 15 shows a cross street pattern

Figure 16. Image of GaAs cut edge

The machining of GaAs, by diamond saw or by conventional laser, releases arsenic into the atmosphere in the form of dust or as arsine gas. The LMJ, however, contains the Arsenic within the water, which can be filtered out and disposed of in an environmentally controlled manner [5]. The cut quality as shown in Figures 15 & 16 is excellent, being debris free, clean and burr free.

V CONCLUSIONS

As noted at the beginning of this report, this series of trials was designed to give an insight into the potential capabilities of the Laser-Microjet® as an agile machine tool for different applications. The results shown in the images in section IV all show a successful conclusion. The cuts are clean, reliable, accurate, and show negligible heat damage. In particular, the cutting of complicated shapes such as spirals and pillars give excellent results, achieving faithful consistent pattern transfer. The minimum feature size is limited when compared to DRIE, but if this is not an issue then the LMJ looks an attractive tool. It is direct write, fast, flexible and clean in both operation and in waste disposal [6]. The range of materials, which are suitable for the LMJ, is also great. The LMJ has proved to be an agile tool for the MEMS industry, and future trials will lead to additional new applications.

VI ACKNOWLEDGEMENTS

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