MICRO-LASER ASSISTED SINGLE POINT DIAMOND TURNING FEASABILITY TESTS OF SINGLE CRYSTAL SILICON

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ABSTRACT

Semiconductors and ceramics such as silicon, silicon carbide, quartz, etc. are increasingly being used for industrial applications [1]. These materials are hard, inert, light weight and strong. All these properties make them ideal candidates for tribological, semiconductor, MEMS and optoelectronic applications[1, 2]. Manufacturing these material are extremely challenging because of their hardness, poor machinability and brittle characteristics [1, 2]. Due to the low fracture toughness of these materials, severe fracture can be resulted when trying to achieve high material removal rates [1]. In the previous research work, it has been demonstrated that ductile mode machining of semiconductors and ceramics is possible due to the high pressure phase transformation (HPPT) occurring in the material [1]. To study the ductile response of single crystal silicon (Si), a nominally brittle material, single point diamond turning(SPDT) is coupled with the micro-laser assisted machining (µ-LAM) technique.

The patented µ-LAM technology directly heats and thermally softens the workpiece material, in the chip deformation and generation zone, increasing the material's ductility. Improved ductility that results from reduced material hardness allows for easier chip formation, decreased brittleness and ultimately higher material removal rates, i.e. better tool performance and increased productivity, which leads to lower manufacturing costs.

This paper discusses a study done to analyze and compare machining data from SPDT tests on single crystal Si with varying input parameters such as laser power, cross feed, spindle speed and applied load. A total of 7 regions were machined with different µ-LAM parameters. For all machined regions, a constant applied load of 100mN was used. The varying machining parameters experimented include three spindle speeds (10, 20 and 30 rpm(, three heating conditions (0W, 5W and 10W),and three cross-feed rates (10, 20 and 30 µm/rev).

The Universal Micro-Tribometer (UMT) was modified and coupled to the µ-LAM system to perform all of the machining tests (setup shown in Figure 1). This equipment was developed to perform comprehensive micro-mechanical tests of coatings and materials at the micro scale [3]. A single point diamond tool with a 1.3mm nose radius, 45 degree rake angle and 5 degree clearance angle was used for this cutting operation.

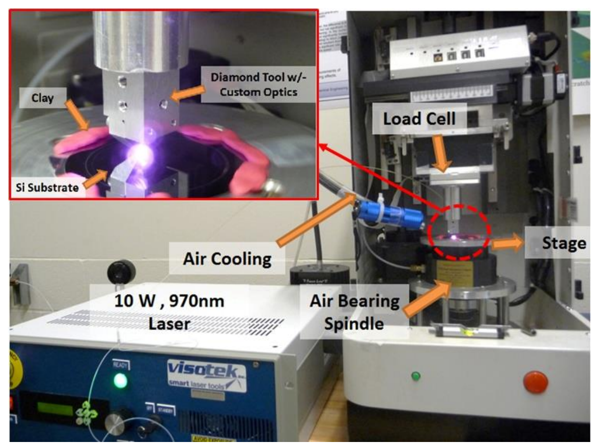

FIGURE 1. Single point µ-LAM setup.

All cuts performed in this study were in the ductile regime. The primary goal was to perform feasibility µ-LAM tests on Si that would be a precursor to scaling up this technique for an actual manufacturing process. The effects of varying µ-LAM parameters were studied by measuring and analyzing the depth of cuts, cutting forces, surface roughness and tool condition. The depth of cuts and surface roughness of the machined regions were measured using a white light interferometer. The tool condition was periodically monitored using high magnification optical microscopy. Figure 1 shows a more reflective Si machined surface (than the polished wafer) obtained using optimized µ-LAM parameters.

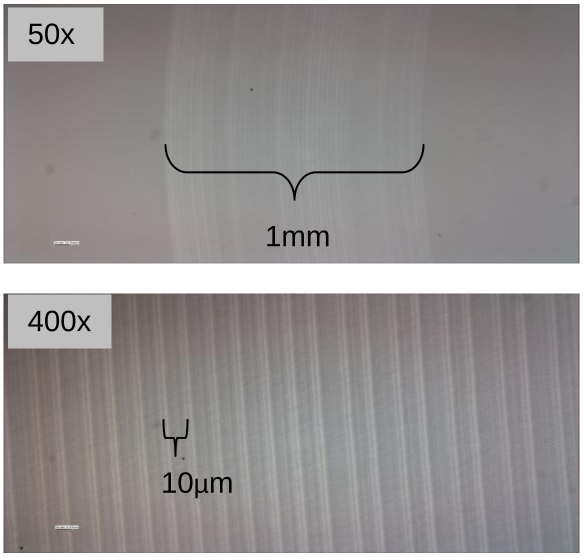

FIGURE 2. Optical microscope images showing the machined region at optimized µ-LAM parameters: 10W, 10rpm & 10 µm/rev feed.

The machined region in Figure 1 indicate no signs of brittle fracture with distinct cross feedmarks, further confirming a purely ductile mode material removal process. It is important to note that the surface finish of the machined regions are either better or comparable to the as received polished wafer surface (Ra < 5 nm).

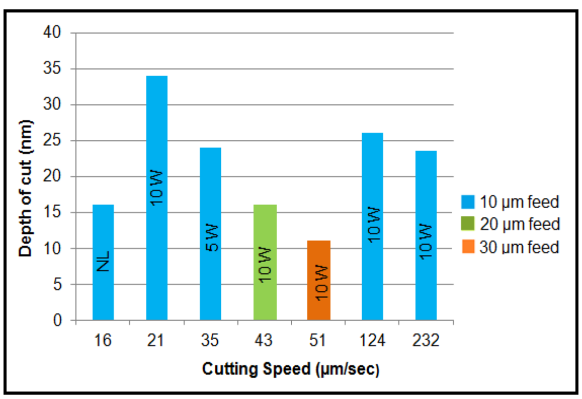

FIGURE 3. Depth of cut and cutting force ratio versus the cutting speed, for varying laser powers and cross feeds.

The results from the analyses suggest that the depths of cuts for all regions with laser are higher than that of no laser power (room temperature). This greater depth directly translate to increased material removal rates and higher productivity while producing a defect free part with no brittle fracture. In addition, the cutting forces for the machined regions with laser are lower suggesting extended tool life for large scale production. And table 1 clearly shows that the cutting speed certainly has an impact on the machined region's depth of cut for an equal applied load (in this case 100 mN) and constant laser power (10W). As the cutting speed increased the ratio of depth and cutting force also increased. When the cross-feed increases, the width of the tool path and contact area in every subsequent cut decreases causing a shallower depth of cut. This is consistent with the current scientific understanding and it is true for both, 'no laser' and 'with laser' machining conditions [2].

Higher depths were obtained at 10 µm feed than other feeds such as 20 µm and 30 µm. Which represents higher material removal rate or productivity at 10 µm feed. But lowest depth and highest cutting force were obtained with 10 µm feed at 0W cut, it is a good indication that the lack of thermal softening effect due to no laser power. Therefore tool wear at no laser power is higher when compare to the other cuts performed in this experiment. These results for the feasibility study show that the micro-laser assisted single point diamond turning tests were successful in demonstrating the benefits of the thermal softening effect from preferential laser heating. This also suggests that the µ-LAM technology would be a suitable candidate for manufacturing Si if higher productivity, improved surface finish and lower tool wear can be demonstrated in larger scales.

REFERENCES

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