Micro Laser Assisted Machining (μ-LAM) of Precision Optics

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Abstract: This paper summarizes the application of the μ-LAM process to the fabrication of precision brittle optical components. Predictive optical modeling, and examples of enhancements to conventional diamond machining by the μ-LAM system are introduced.
OCIS codes: (220.1920) Diamond machining; (220.4610) Optical fabrication.

1. Introduction

Ultra-precision diamond machining and single point diamond turning (SPDT) have gained a considerable amount of attention in recent years. The high level of flexibility of these processes in generating freeform and aspherical optics in a relatively short span of time is one of the primary reasons for this increased interest in SPDT.

While the SPDT processes have shown to produce surface finishes better than 10 nm RMS and form errors better than 200 nm on soft metals [1], the ability to cut hard and brittle materials efficiently is an ongoing research area. The diamond cutting of hard and brittle materials has three main challenges; (1) the existence of brittle fracture zones on the surface of the workpiece (2) much longer process completion times than soft metals, and (3) high degree of tool wear during the cutting. The μ-LAM process provides a solution in addressing these challenges by using the emission of laser light during the machining [2, 3].

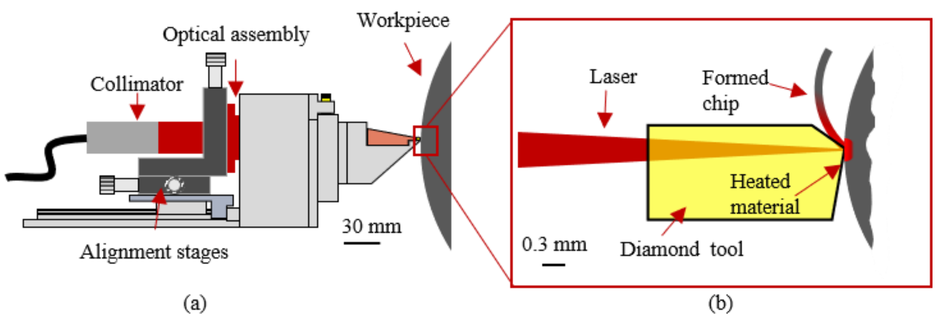

Fig. 1 μ-LAM process; (a) Optimus T_{+1} tool post (b) schematics of the tool-workpiece-laser light interaction

2. Predictive optical model

To deliver the emission of laser power on the tool tip, a custom tool post (Optimus$_{T+1}$) was used. This tool post illustrated in Fig. 1 (a) holds the optics needed to focus laser light with wavelength of 1064 nm at the cutting edge of a single crystal diamond tool, see Fig. 1 (b).

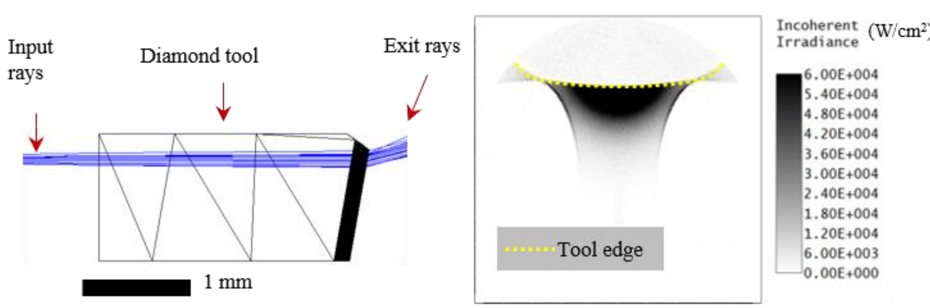

Fig. 2 Optical model of laser through diamond tool

To establish a baseline model of the propagation of the laser through the diamond tool, Zemax OpticsStudio® was used. Fig. 2 depicts the simulation of the laser beam through a diamond tool with a nose radius of 0.3 mm. The uniform laser distribution covers 80% of the tool edge, which is a reasonable coverage for most SPDT applications.

3. Diamond turning single crystal silicon (Si)

SPDT of single crystal Si using μ-LAM process was done. The sample had a radius of curvature (ROC) of 205 mm with crystal orientation of <111> and was machined with a spindle speed of 2000 rpm, feedrate of 1.5 μm/rev, and depth of cut (DOC) of 6 μm. The emitting laser at the cutting edge had a total power of 3 W.

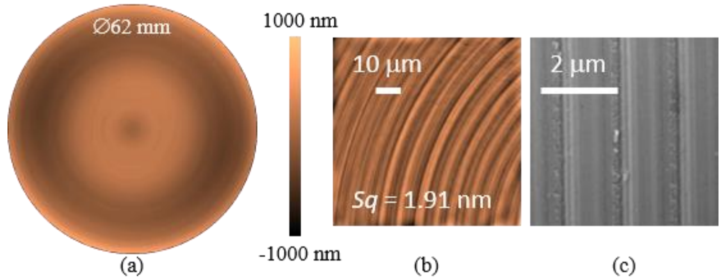

Fig. 3 Machining single crystal Si (a) Fizeau interferogram (b) SWLI interferogram (c) SEM image

Fig. 3 (a) shows the Fizeau interferogram of the surface with form error of 680 nm PV, while Fig. 3 (b) depicts the scanning white light interferogram (SWLI), with RMS of 1.91 nm. In addition, scanning electron microscopic (SEM) images show the brittle fracture zones that are very common in machining Si, had become almost non-existent with the presence of laser emission, see Fig. 3 (c). Thus, suggesting an increase in ductility of the surface of the sample as a consequence of its exposure to high laser power densities.

4. Diamond turning of tungsten carbide (WC)

Precision machining of WC has become very desirable for glass molding applications. Due to rapid tool wear and the very hard surface of WC, commercial SPDT of WC molds is not common. The μ-LAM process was used to machine a concave WC sample with a ∅10 mm and ROC of 10 mm. Spindle speed of 2000 rpm, DOC of 2 μm, and feedrate of 1 μm/rev was used. The laser power at the cutting edge was 7 W.

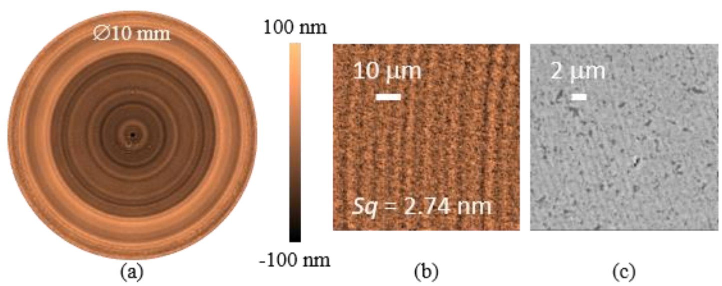

Fig. 4 Machining WC (a) Fizeau interferogram (b) SWLI interferogram (c) SEM image

Fig. 4 (a), (b) show the Fizeau interferogram and SWLI of the surface, with total deviations of 150 nm PV and 2.74 nm RMS respectively. Fig. 4 (c), depicts the SEM image of the same surface. Clear turning marks, as well as very little local defects, confirm the ductile regime machining of WC material. This result is very significant since the μ-LAM process can be an enabling technology in production of WC molds with specifications that are well within the desirable tolerances.

5. References

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3. Ravindra, D., M.K. Ghantasala, and J. Patten, *Ductile mode material removal and high-pressure phase transformation in silicon during micro-laser assisted machining.* Precision engineering, 2012. **36**(2): p. 364-367.