Laser Assisted Plasma Processing: An Overview

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Abstract

In recent years, atmospheric plasma processing such as the Reactive Atom Plasma (RAP) process has come to light as an exciting new prospect in the field of surface figuring of silicon based optical components. It offers material removal rates of more than two orders of magnitude faster than Ion Beam Figuring (IBF) and without the need for expensive vacuum chambers. RAP removal rates are comparable, and in many cases superior, to those of mechanical polishing if not superior. RAP is a dry chemical etching process developed for rapidly figuring substrates at the nanometre level. It is based on atmospheric plasma principles and uses an inductively coupled plasma (ICP) torch fed with argon and fluorine reactive gases. This paper presents a novel improvement of the RAP process called Laser Assisted Plasma (LAP) processing in which in addition to the RAP energy beam a CO_2 laser beam is introduced as an auxiliary heat source. This enables a local increase of the surface temperature to be realised and hence an active tuning of the beam removal function for rapid figuring. This active control depends on an understanding of the fundamental material removal mechanism - an Arrhenius-type chemical reaction that takes place on the substrate surface. The main objective of LAP processing is to address the issue of edge figuring of optical components and this requires a systematic investigation of processing parameters to determine the optimum configuration of the - Cranfield University Precision Engineering fabricated - hybrid laser/plasma system. In the presented research work, surface temperature measurements have been acquired using an 8-14µm wavelength range pyrometer. The experimental results are compared to mathematical models and are further used to determine the thermal response of two important optical materials, ultra low expansion glass (ULE) and silicon carbide. For the purpose of this research work the

processing parameters are laser power, beam size and travel speed. The relation between surface temperature and tool footprint profiles will be shown under varying parameters. Experimental and theoretical results will be compared and discussed.

1 Introduction and Theory

The demand for cost effective optical components is increasing and non-contact surface figuring methods are proving to be an efficient solution. A new technology has emerged in the past ten years; its name is Reactive Atom Plasma (RAP). At Cranfield University Precision Engineering, volumetric removal rates of up to $10mm^3$/min were demonstrated on Corning ULE using the RAP300 machine, which is equipped with a full bore plasma torch. The main benefits of RAP are its deterministic nature, high material removal rates and low processing cost. RAP [1] is based on a radio frequency inductively coupled plasma (ICP) torch and operates by ionising a mix of reactive and argon gases. A temperature-dependent chemical reaction occurs at the substrate. The temperature is primarily determined by the torch heat flux but can be tuned via auxilliary sources, such as a laser energy beam. Typically, when a laser is chosen as the second energy beam, a percentage of the radiation is absorbed by the substrate. Consequently, the tool footprint of the new process is defined by the thermal fluxes from both the laser beam and plasma torch sources. This new hybrid process is called Laser Assisted Plasma (LAP) (see Figure 1). In this work, surface temperature is investigated using mathematical models and experimental data. Preliminary LAP results are presented, and the effect of a laser beam is demonstrated.

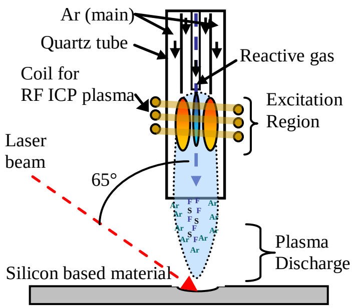

Figure 1: Operating configuration of LAP setup consisting of RAP300 plasma torch coupled with 65° angle of incidence CO_2 laser beam.

2 Preliminary Results

2.1 Laser Heat Transfer to Optical Materials

To investigate local surface temperature changes during typical processing conditions, a model was developed using MATLAB and experimental verification was performed. Both the Cline and Anthony [2], and Nissim et al [3] analytical models were selected to simulate heat transfer from a laser energy beam and were applied to generate surface temperature maps (Figure 2). Two materials were selected for investigation: Corning ULE and Trex SiC, as they are relevant optical materials. A 250W continuous wave (CW) CO_2 (10.6µm) laser beam was modelled, incident at 65° resulting in a 24.3mm major axis ($1/e^2$). Reference [3] was selected specifically

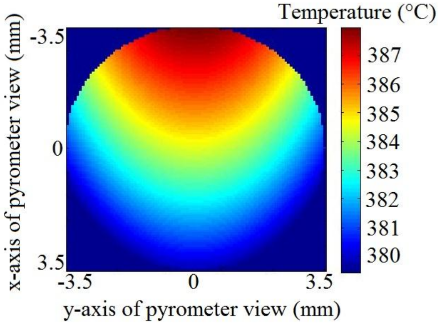

Figure 2: Surface temperature ‘Pyrometer view’. The image is centred on the laser beam spot. Laser scan motion is vertically downwards. This example is SiC, 4m/min.

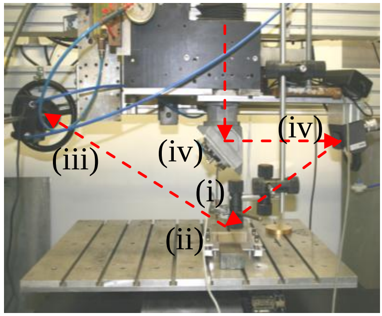

Figure 3: Experimental setup: dashed line indicates laser path; (i) pyrometer; (ii) substrate; (iii) power meter; (iv) folding mirrors.

for its relevance in modelling elliptical laser beam spots, for direct comparison with the equivalent experimental setup, which is shown in Figure 3. Table 1 contains temperatures integrated over the modelled pyrometer field of view and experimental values gathered using an IR-pyrometer. The results show a reasonable correlation between theoretical and experimental data. The most noticeable discrepancy is the case of ULE with feed speed of 3m/min. This may be due to the model’s limitations in accounting for temperature-dependent material properties. Another source of incertitude is temperature variation of emissivity. During future development of the model, these factors will be accounted for by use of a point-by-point temperature feedback to implement this dependence. With the temperature at each point specifying material properties at its neighbours, an improvement in predicted temperatures is expected.

Table 1: Comparison of theoretical and experimental surface temperature.

Material	Power (W)	Feed speed (m/min)	Model result (°C)	Pyrometer reading (°C)
ULE ε=0.848	248	3	404	523±12
	248	4	396	428±10
SiC ε~0.95	244	3	388	365±7
	244	4	383	364±7

2.2 LAP Processing

Additionally, to determine the effect of a laser energy beam during RAP processing, a preliminary investigation was undertaken on polished ULE substrates. A 40W CW CO_2 laser beam was implemented in the RAP300 machine at 65° incidence onto the plasma/matter reaction zone. A ZnSe cylindrical lens with 500mm focal length was used to ensure a round beam spot of 2.5mm width ($1/e^2$). Consequently, an energy density equivalent to that of a normal incidence beam was maintained. The RAP300 torch parameters were: 1200W power, 200sccm SF_6 flow and 15800sccm argon flow. The result was a deterministic alteration of RAP footprint, as seen in Figure 4**.**

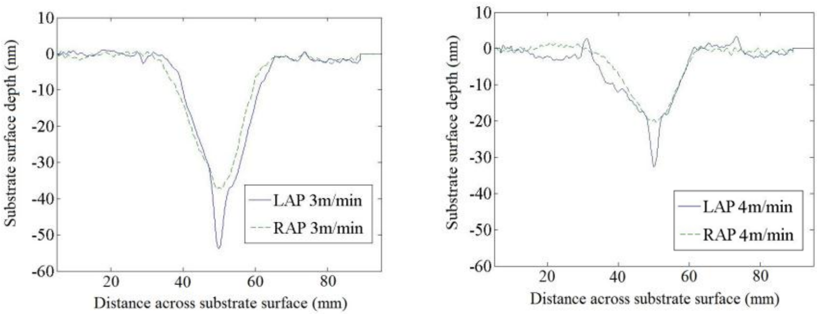

Figure 4: A comparison of LAP and RAP etch profiles on Corning ULE

3 Conclusions

A new hybrid laser/plasma system is being developed for figuring of silicon-based materials. A numerical model predicting temperature rise due to a laser energy beam is applied and reasonable correlation is observed between theoretical and experimental results. In addition, the preliminary etch profile results clearly show the effect of the laser beam. Further work will focus on the implementation of a 200W laser source with a dedicated optical delivery system to enable a detailed investigation of LAP process parameters. The fully refined system is expected to fully address the edge effect issue during surface figuring.

4 References

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