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Novel MW Plasma Jet for Enhancing the Processing Capability of Plasma-Assisted Etching Technology

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1. Introduction

The aim of this PhD project is to increase the processing capability of energy beams that are based on plasma-assisted chemical etching technology. This will be achieved through the creation of a novel microwave generated plasma torch.

This research will enable surface correction at nanometre level of silicon-based components.

The experimental work involved in this project will be carried out using the processing capabilities of the Precision Engineering Institute's RAP300 machine (Figure 1).

FIGURE 1: RAP300 machine in the Precision Engineering Institute (O'Brien, 2011)

2. Plasma-Assisted Figuring Processes

In optical engineering companies the fabrication chain traditionally has three steps but for high end optics an additional stage has been added. The steps of the fabrication chain are as follows: grinding, lapping, polishing and figuring. Figuring is the final step of the optical fabrication chain. It is the step where unwanted features created by the previous processes are removed.

Within industry and academia there are several plasma based figuring techniques of interest:

- Chemical Vaporisation Machining (CVM);
- Plasma Jet Machining (PJM);
- Atmospheric Pressure Plasma Polishing (APPP);
- Reactive Atom Plasma (RAP), (Figure 2).

The RAP figuring process has several advantages over the previously mentioned figuring processes. These advantages include:

- Rapid figuring capability;
- Atmospheric pressure processing;
- Processing of non-conductive material;
- Contamination free plasma .

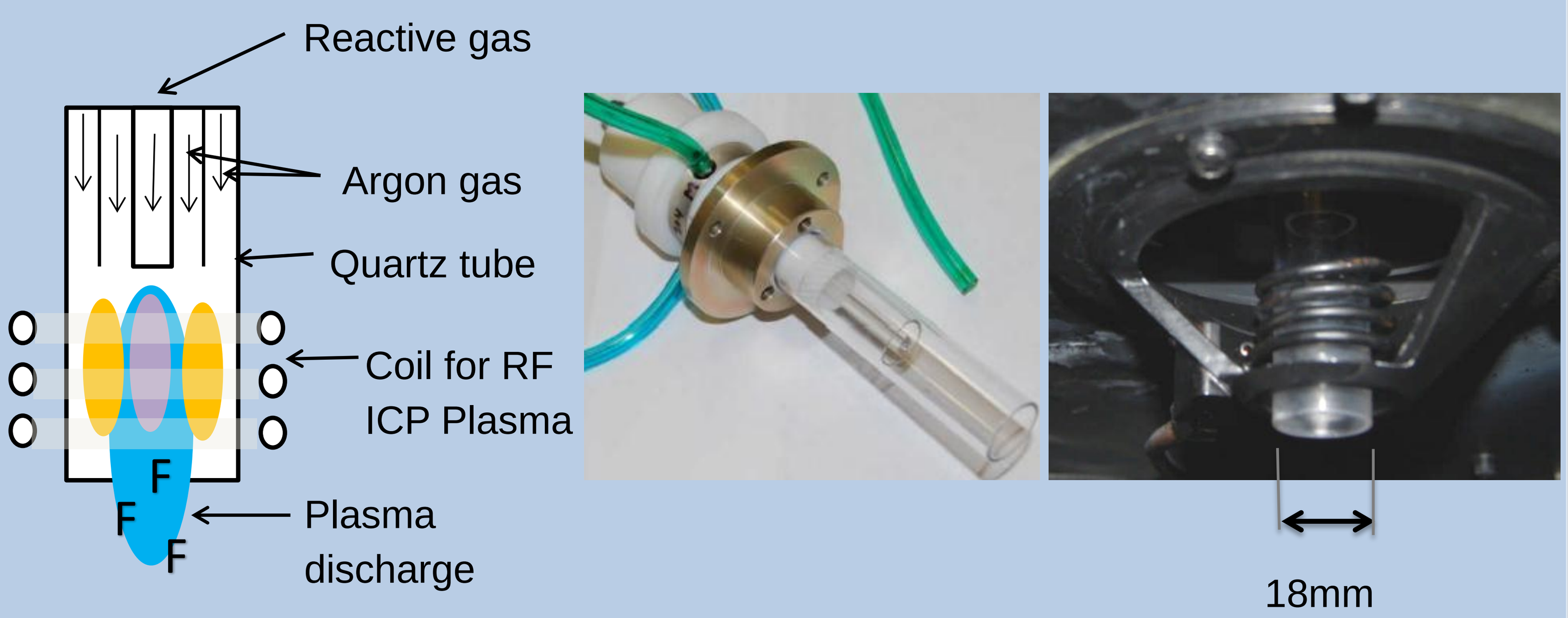

FIGURE 2: Schematic of RAP torch (left), Current RAP300 torch (middle and right). (O'Brien, 2011)

3. Mid- Spatial Frequency Surface Errors

Surface errors are unwanted features that affect the performance of an optical imaging system. The degradation is typically due to the amplitude and the nature of spatial frequencies (Tinker and Xin, 2013). The surface of an optic is typically composed of continuous spectrum of spatial frequencies. However, it is easier to analyse if split into three well defined ranges (Fig. 3): Low Spatial Frequency (LSF), Mid-Spatial Frequency (MSF), High Spatial Frequency (HSF). MSF is often a consequence of using sub-aperture tools during the latter manufacturing stages of optical fabrication: this is now a common need when making complex shape optics such as freeforms.

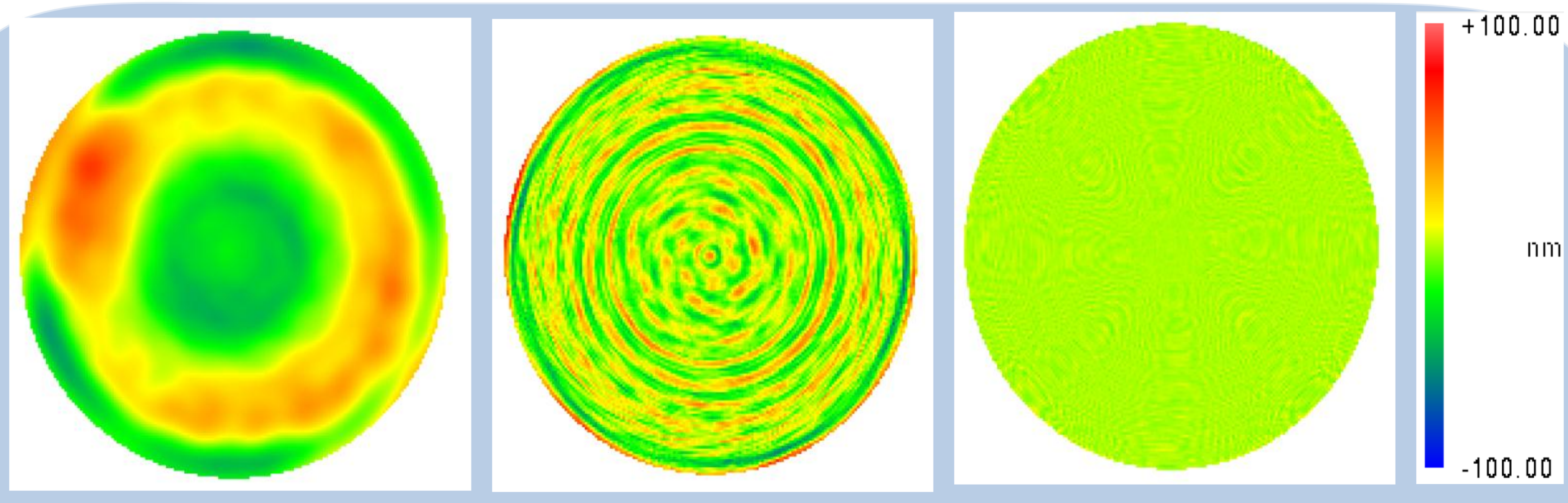

FIGURE 3: Topography of the spatial-frequency surface errors (Youngworth, R). Left: Low-Spatial Frequency, middle: Mid-Spatial Frequency, right: High-Spatial Frequency

4. Microwave Generated Plasma Torches

The plasma in this project will be generated using microwaves (MW). It has the advantage of higher electron kinetic temperature. Also, in comparison to other approaches a MW induced Plasmas provide a high fraction of ionisation and dissociation (Roth, 1995) when created at atmospheric pressures. They can be placed into three categories:

- Resonant Cavity Plasmas (RCP);
- Free Expanding Torches (FET);
- Microplasmas.

Design criteria for the forthcoming MW Cranfield torch :

- Deliver a sub-millimetre plasma jet;
- Operate at atmospheric pressure;
- Operate at a frequency of 2.45GHz;
- Compact to suit dimensions of smaller machines.

Currently, the MW torch design under investigation is produced by Adtec (Figure 4). Figure 5 shows a dedicated nozzle that will be tested on this torch.

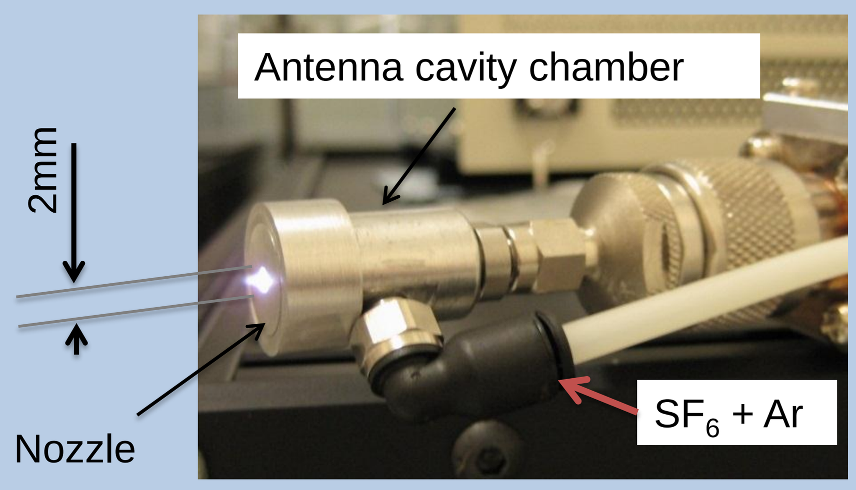

FIGURE 4: Adtec MW torch

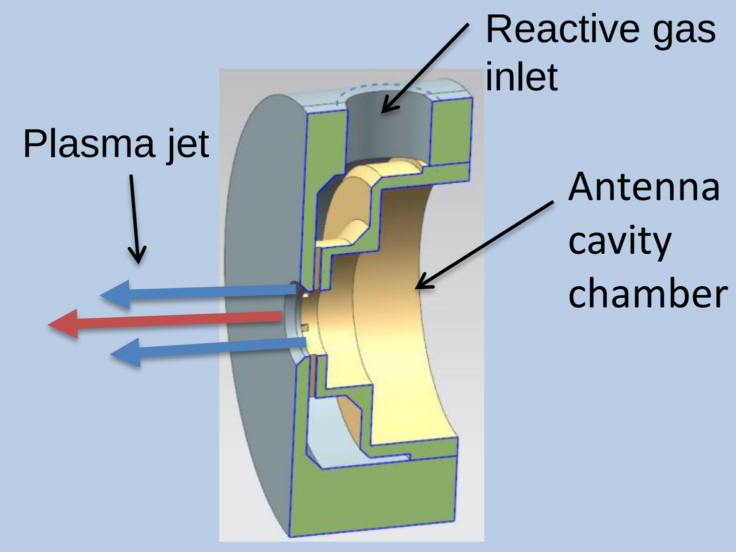

FIGURE 5: Cross section of a Cranfield designed MW plasma torch nozzle (Jourdain, 2013).

5. Plasma Diagnostics

Basic parameters of plasma are gas temperature, gas velocity and active species emission spectrum. These properties of the plasma can be measured using various methods:

- Mass Spectrometer (MS);
- Fourier Transform Infrared (FTIR) Spectroscopy;
- Optical Emission Spectroscopy (OES);
- Enthalpy Probe;
- Langmuir Probes.

It is suggested that Optical Emission Spectroscopy (OES) is the best method for investigating this type of plasma jet. OES plasma diagnostic method is a non-intrusive technique and typically provides meaningful information about the flux of radical species and particle density values.

6. Further Work

This research project is at the 8 month stage and next steps include:

- Experimental work using the Adtec MW plasma torch;
- Further theoretical work on MW plasma torches;
- Design and create dedicated MW plasma torch;
- Test dedicated MW plasma torch
- Assess / optimise processing capability.

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