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Reduction of Mid-Spatial Frequency errors on metre-scale optical surfaces using rapid plasma figuring

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1. Introduction

This project is about the design, fabrication, and characterisation of novel Inductively Couple Plasma (ICP) torch nozzles. These nozzles will enable the creation of highly collimated energy beams characterised by a material removal footprint of a few millimetre in diameter.

This dedicated plasma technology will be used through a dwell time figuring method for the correction of large optical surfaces.

2. Research motivations

Ground-breaking science programmes and research projects, such as European Extremely Large Telescope (EELT), Extreme Ultraviolet (EUV) lithography systems, and laser fusion energy plants, require metre-scale optics. Thus this research focuses on an advanced optical finishing fabrication technique for large and ultra-precise surfaces.

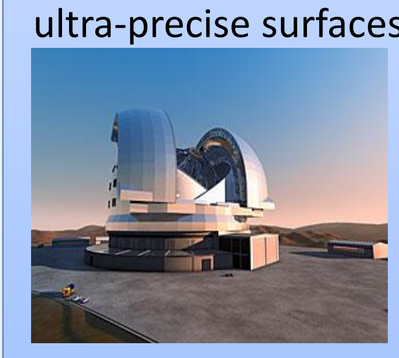

Fig. 1 Large telescope

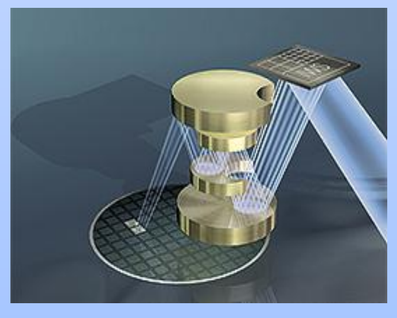

Fig. 2 EUV-lithography

Fig. 3 Fusion energy

3. Research target

The target for this project is:

1. Form accuracy: <λ/60 RMS;
2. Roughness: <2nm RMS;
3. MSF error: < 10nm / (1-5mm);
4. Processing time: < 10h/m².

4. Plasma figuring machine: Helios 1200

Fig. 4 Helios 1200

The most recent plasma figuring facility, called Helios 1200, was setup in 2008. (Fig. 4)

In 2012, the Precision Engineering Institute demonstrated fast figure correction of 400mm optical surfaces. Surface accuracy better than 43nm RMS was obtained within 3 iterations of 45min each (Castelli 2013).

5. Present capability of plasma figuring in MSF errors

The MSF errors will result in effects like hazing, energy loss and pixel cross-talk. So minimization and elimination of MSF is necessary in ultra-precision optical manufacturing. The previous quality achieved by Dr Castelli is shown below.

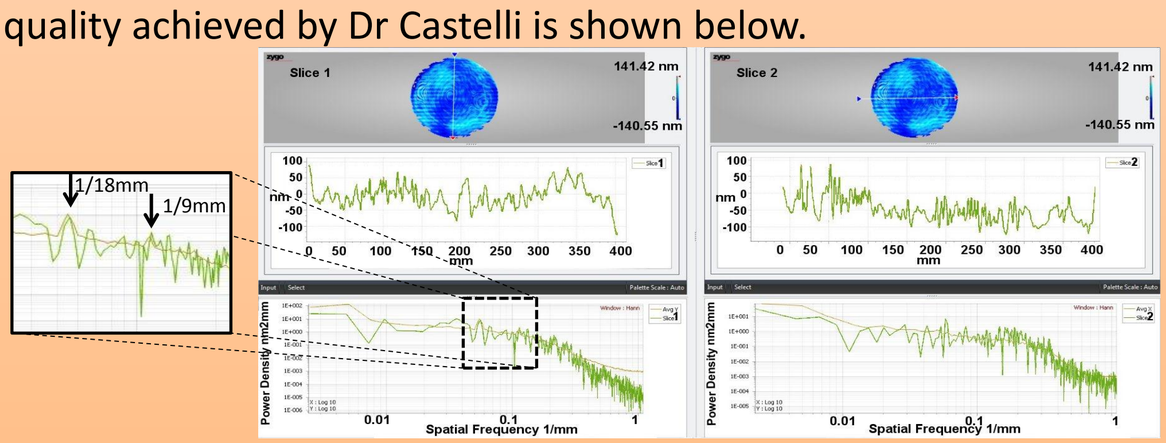

Fig. 5 Surface topography showing the MSF features.

6. Progress

Design of plasma torch nozzles is been investigated based on CFD simulation and removal footprint experiments. These new nozzles are aimed to correct MSF errors. Fig. 6 (left) below shows the existing torch and its nozzle.

CFD simulation

A cross-section of the axis-symmetric De-Laval nozzle model is built in software package FLUENT. The initial condition parameters include: velocity, temperature, pressure distribution, and standoff distance. The gas velocity distribution of the flow between the nozzle and the substrate has been analysed.

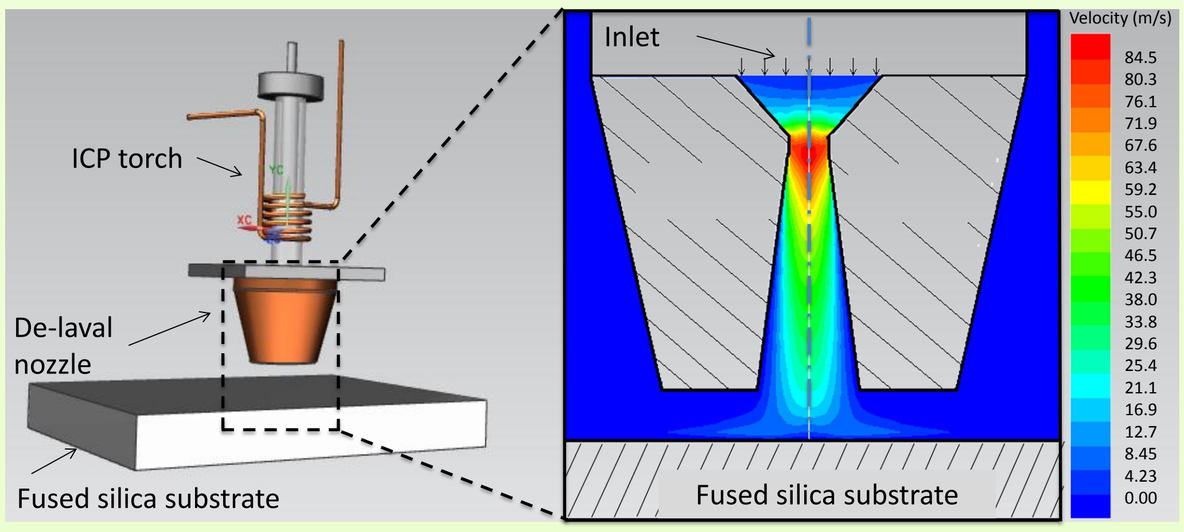

Fig. 6 3D view of Helios 1200 torch (left), Gas velocity distribution viewed through De-Laval nozzle cross section (right)

Fig. 6 (right) shows an initial result of the CFD simulation, in which the inlet flow rate is set as 1.2m/s. This investigation enables to investigate the beam behaviour of different nozzle geometries.

Footprint experiments

In order to investigate the relationship between size of plasma beam and its footprint, footprint experiments were carried out on 200mm x 200mm fused silica substrates. The processed surface was measured using a Twyman–Green interferometer.

To let people have an initial understanding, Fig. 7 shows the footprint profile of ICP torch (without a nozzle). The Full Width at Half Maximum (FWHM) was determined to be 18mm.

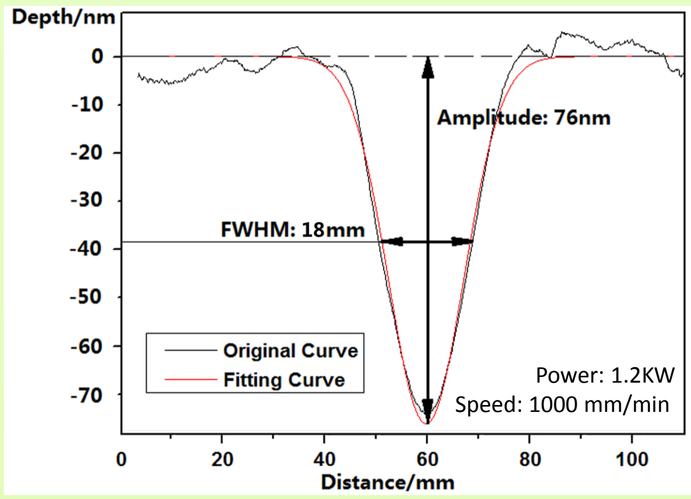

Fig. 7 Fitting curve of the footprint

7. Future work

A set of new nozzles are being designed. Then they will be fabricated and characterized. The performance will be evaluated and Fluent models further developed to determine design rules.

8. Reference

Castelli M. Advances in Optical Surface Figuring by Reactive Atom Plasma (RAP) (PhD thesis), Cranfield University, UK: 2013

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