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Advancement of plasma figuring technology through optimisation of energy beam

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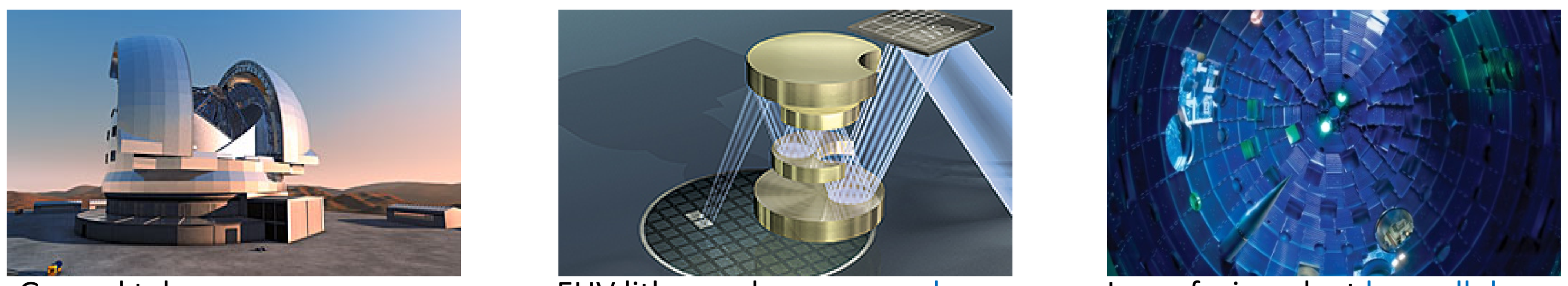
1. Introduction

Ground-breaking science programmes and research projects (see Fig. 1.), such as European Extremely Large Telescope (EELT), Extreme Ultraviolet (EUV) lithography systems, laser fusion energy plants, and compact space based observers, require metre-scale optics. Thus this research focuses on an advanced optical finishing fabrication technique for large and ultra-precise surfaces. This project is about the design, fabrication, and characterisation of novel Inductively Couple Plasma (ICP) torch nozzles.



Ground telescope www.eso.org EUV lithography www.asml.com Laser fusion plant lasers.llnl.gov

Fig. 1 A large market demand for metre-scale ultra-precise optics

In 2012, Castelli demonstrated the fast figure correction capability on a 420mm substrate using Helios 1200 (Fig. 2). 31nm RMS form accuracy from an initial 373nm RMS was achieved within 2.5 hours. However, Mid Spatial Frequency (MSF) errors were induced by the sub aperture process [1]. MSFs were highlighted through Power Spectrum Density (PSD) analysis (Fig. 3).

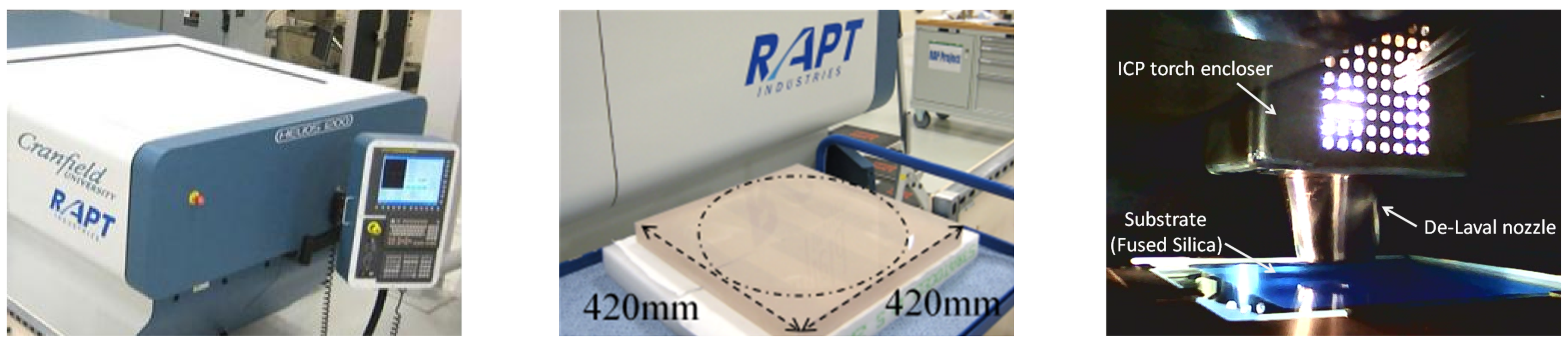


Fig. 2 Helios1200 machine (left), 420mm ULE substrate (middle), Plasma figuring process (right).

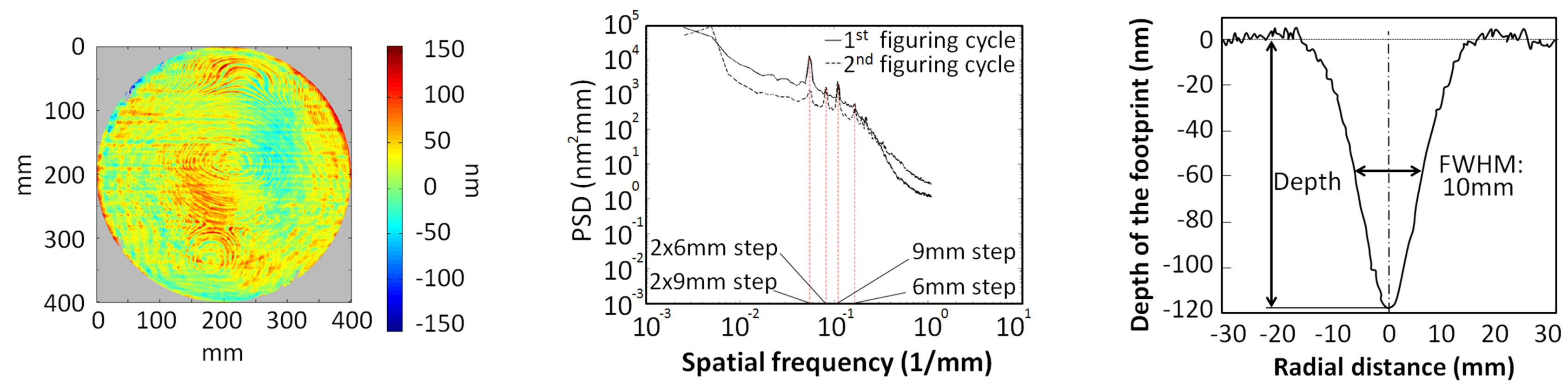


Fig. 3 Topography map (left), PSD showing the MSF (middle), Footprint profile (right).

2. Research target

a. Reduce the width of footprint (FWHM: ~ 5 mm); require → Collimated plasma jet

b. Maintain the etching efficiency (MRR: ~ 15 mm3/min) Effective heat transfer

3. Numerical simulation of plasma nozzle designs

The benefit of a De-Laval nozzle is to amend the energy beam characteristics. Model of High Temperature Gas (HTG) in De-Laval nozzle is created using Computational Fluid Dynamics (CFD). The model enabled the investigation of the entire aerodynamic behaviour of HTG from the nozzle inlet up to the processed surface [2] (Fig. 4). Strong correlations are highlighted between the gas flow velocity near the surface and material removal footprint profiles (Fig. 5). Based on this CFD model, a series of De-Laval nozzles with different internal dimensions are designed and manufactured(Fig. 6). Comparison of two nozzles are carried out in the model.

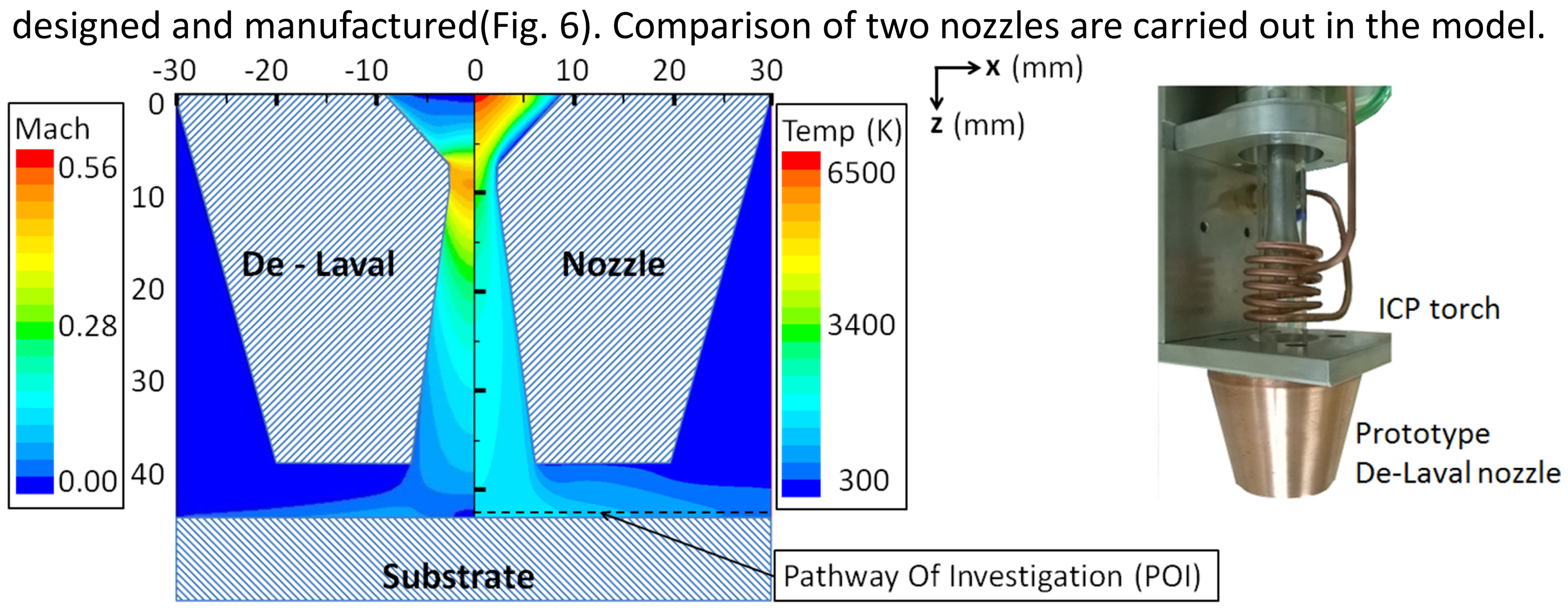


Fig. 4 Calculated distribution of the Mach number (left), temperature of HTG (right)

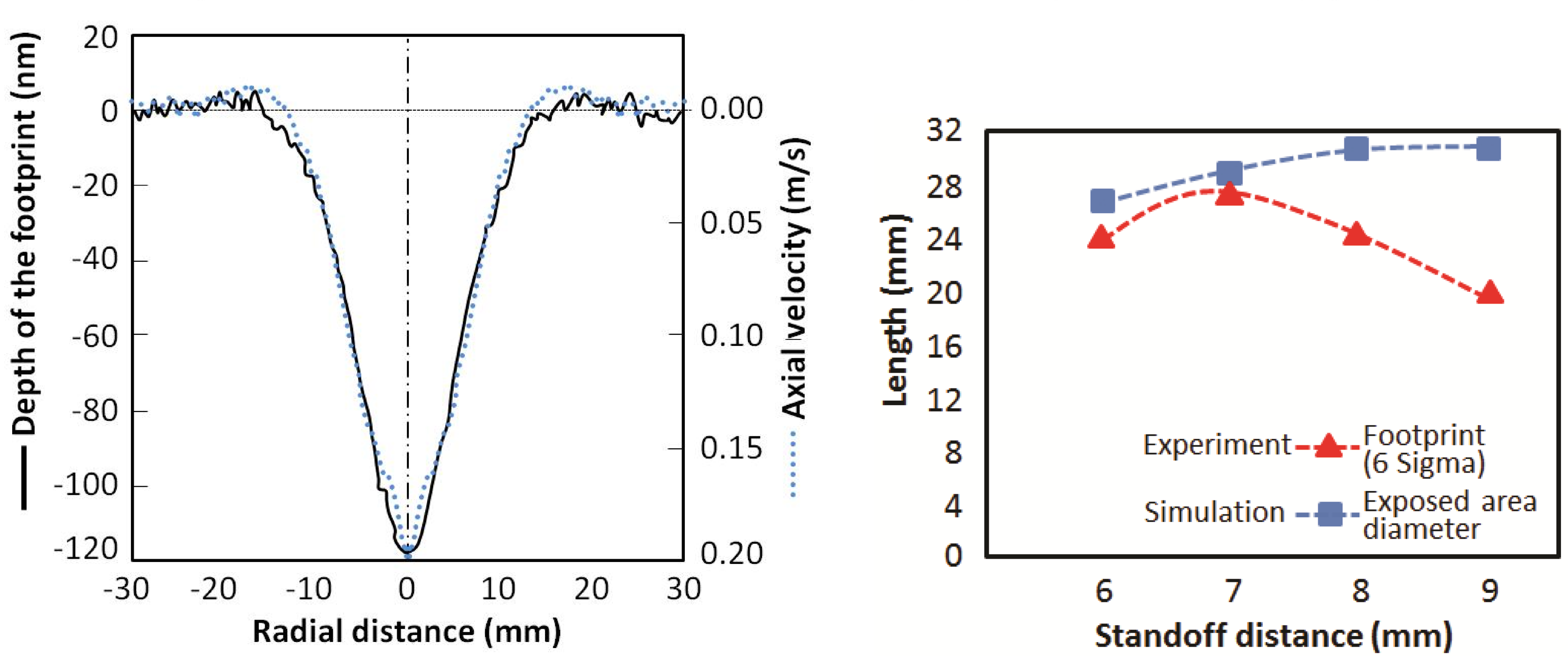


Fig. 5 Curves of the footprint vs axial velocity of HTG along the POI (left); Correlation between footprint 6 sigma values and exposed area diameters (right) [3]

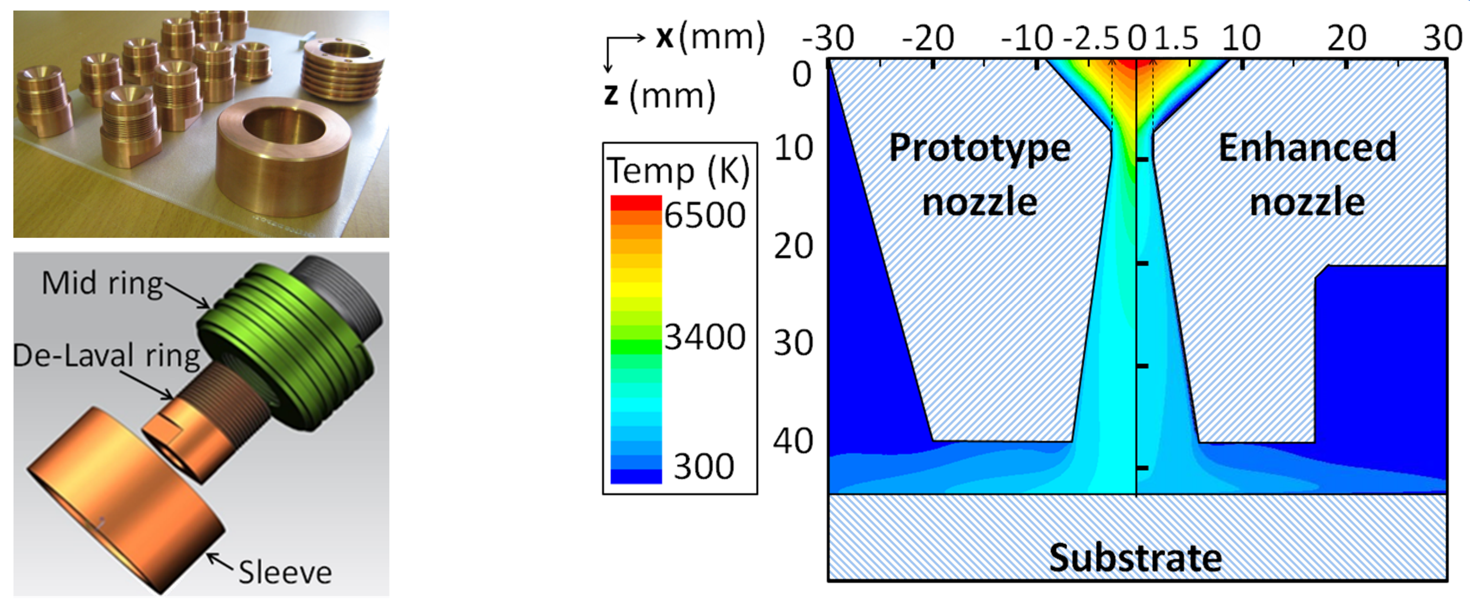


Fig.6 Concept of enhanced nozzle design (left) and temperature distributions of two nozzles (right) [5]

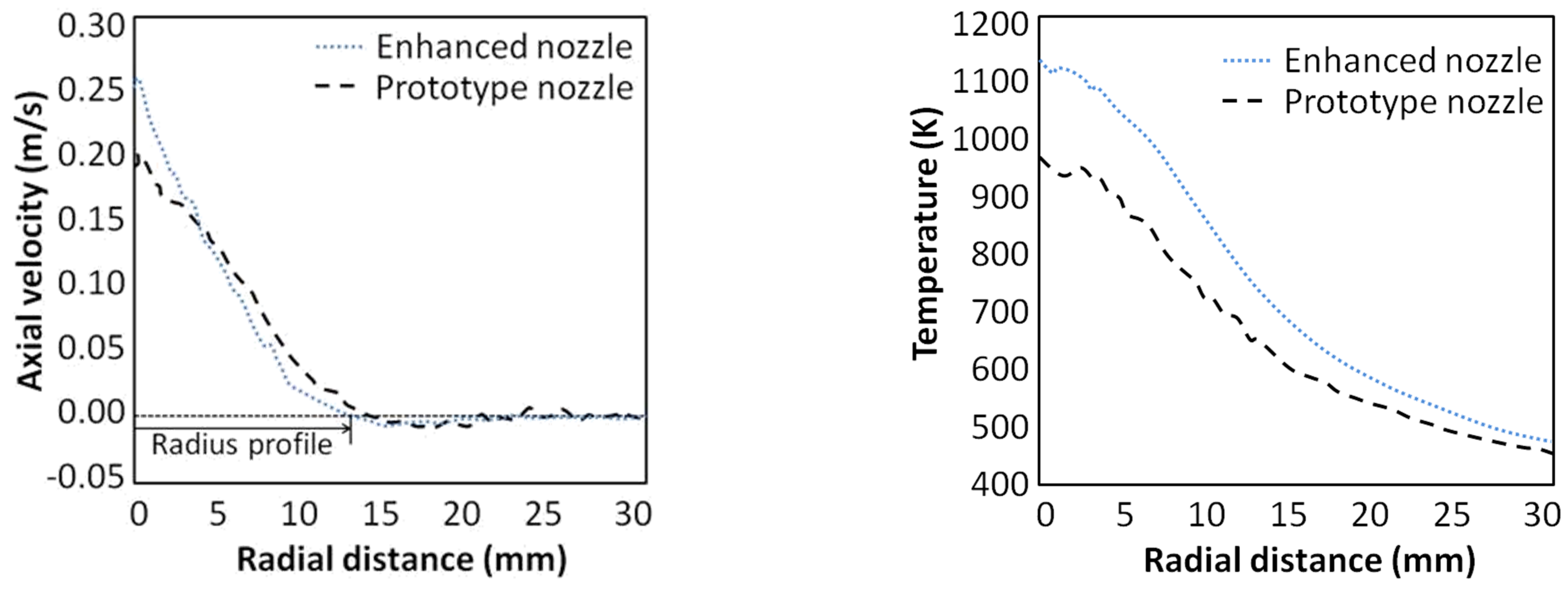


Fig. 7 Radial profiles of axial velocity and temperature along the surface.

4. Power loss analysis of the ICP torch

An experimental setup was created to address the power dissipation of the prototype plasma torch in two modes. The increases in temperatures of the coolant in both coil and De-Laval nozzle were logged and analysed. Energy dissipation rates were derived from these two sets of results. This work enabled to characterise the plasma torch in terms of power dissipation. [4]

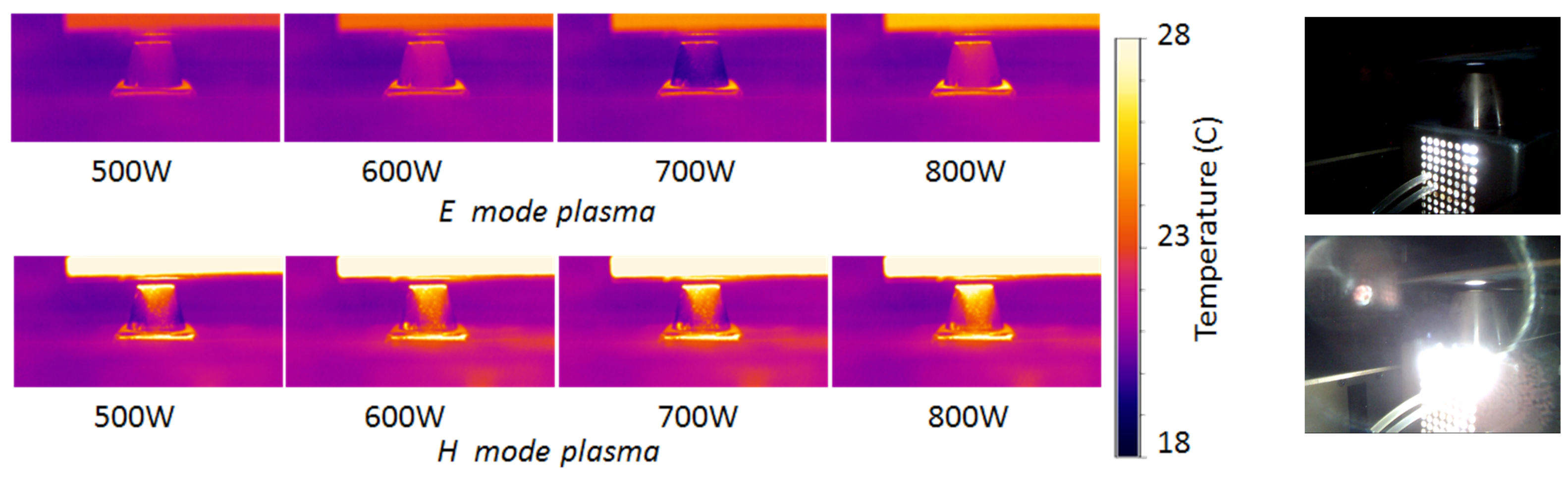


Fig. 8 Images of plasma torch obtained by thermal camera (left) and visible spectrum camera (right)

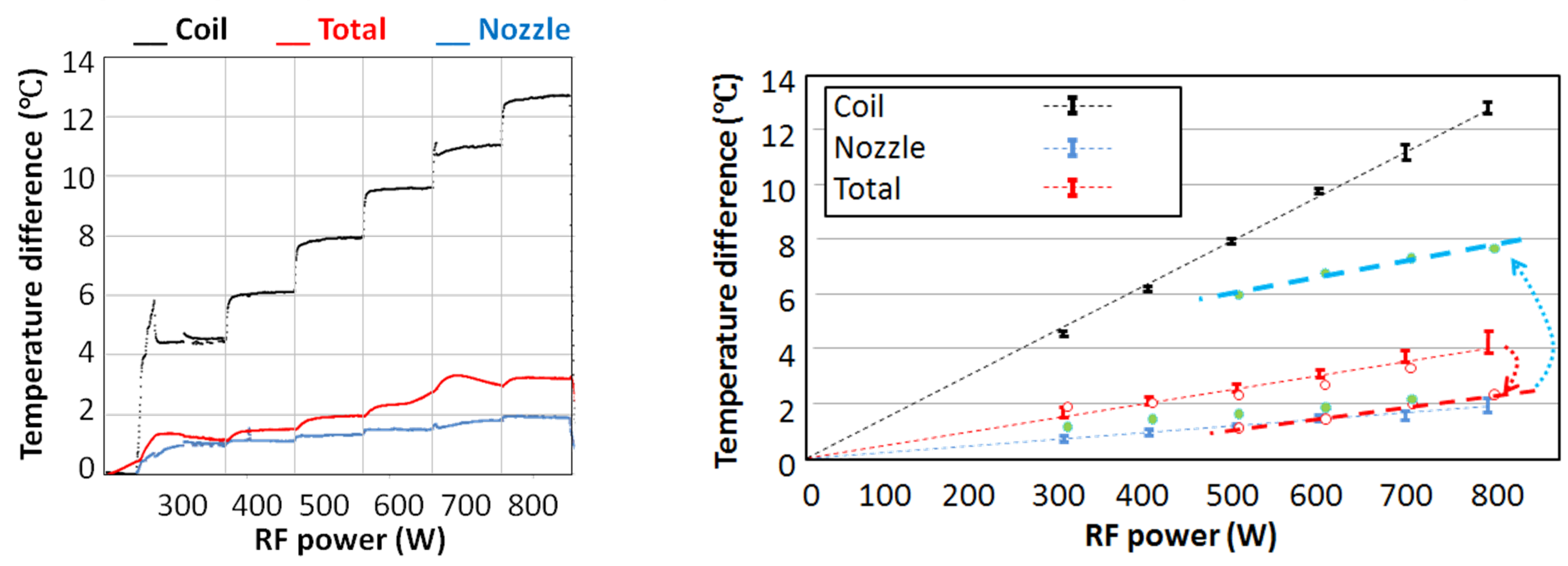


Fig. 9 RF power versus temperature difference of coolant

5. Conclusions

This paper highlights the increased performance of an improved nozzle design. This nozzle is expected to enhance the processing capability of plasma figuring by reducing the MSF errors. This enhanced nozzle is predicted to deliver 12.5% smaller footprint and 15.5% higher temperature. The validation of these results will be carried out shortly in the laboratory.

6. Future works

a. Power loss calculation will be carried out in both E and H mode;

b. The plasma figuring process efficiency will be investigated from heat transfer viewpoint;

c. New designed nozzles will be tested based on the power loss measurement method;

d. Final figuring demonstration will be carried out using the enhanced nozzle.

7. Acknowledgement

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8. Reference

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