6th International Conference of Asian Society for Precision Engineering and Nanotechnology

Investigation of power dissipation in a collimated energy beam

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Cranfield University campus

From:
www.cranfieldmaintenance.com/about-us

Royal Air Force, Cranfield, 1937

From:
www.cranfield.ac.uk/about/cranfield/heritage

CUPE

Cranfield Unit for Precision Engineering

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www.cranfieldprecision.com/cupe.php

Structure

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1. Introduction
2. Methodology
3. Numerical analysis
4. Power dissipation calculation
5. Conclusion and future work

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1. Introduction

Research motivation

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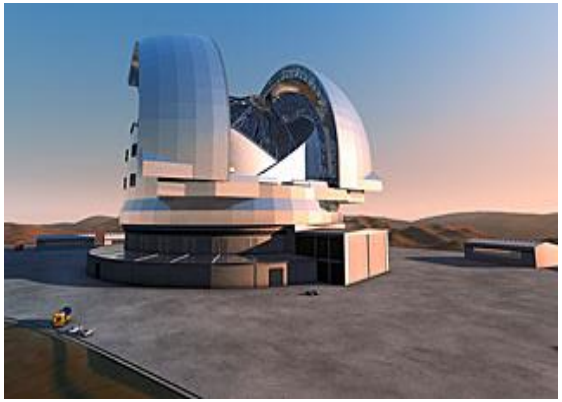
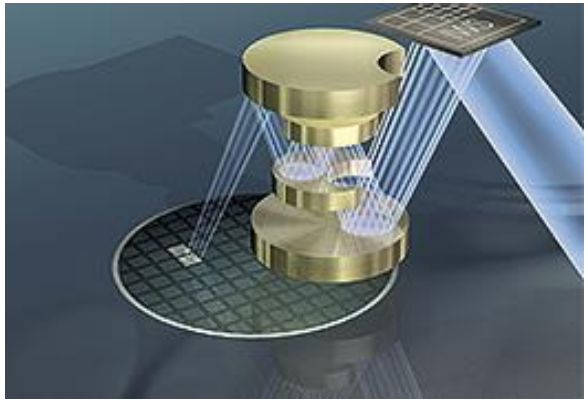
There is a large marketing demand for metre scale ultra-precise optical surfaces



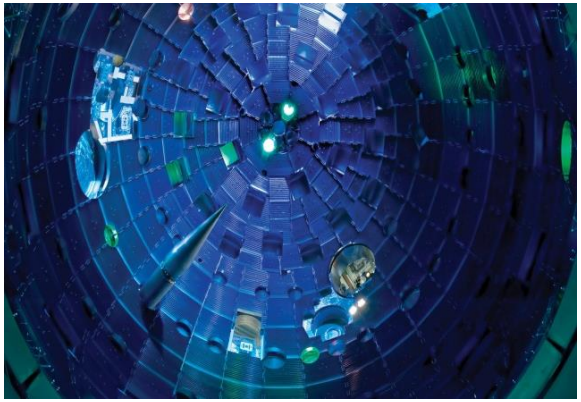
www.eso.org

Ground telescope



www.asml.com

EUV lithography



lasers.llnl.gov

Laser fusion energy

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1. Introduction

Rapid process chain

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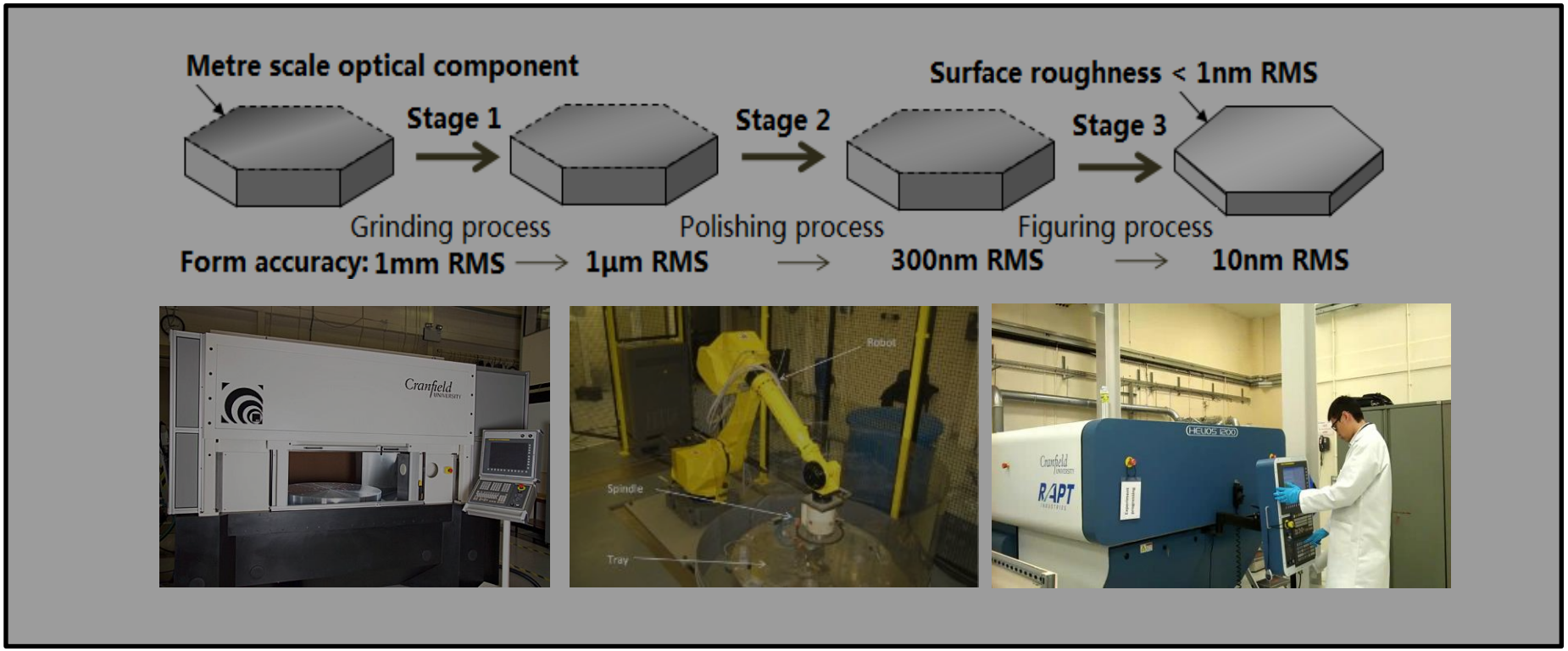
A fast process chain of three sequential machining steps proposed by **Prof Shore**



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1. Introduction

Plasma figuring process

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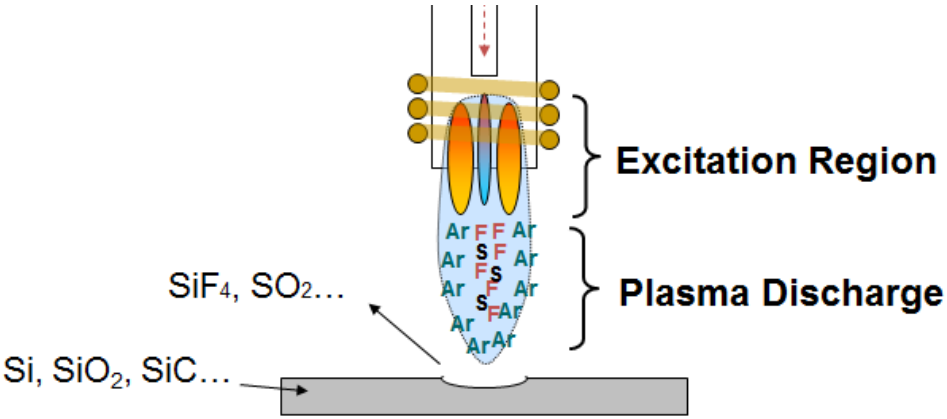
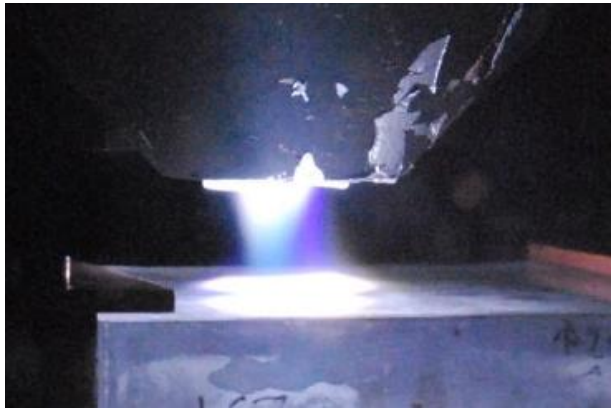
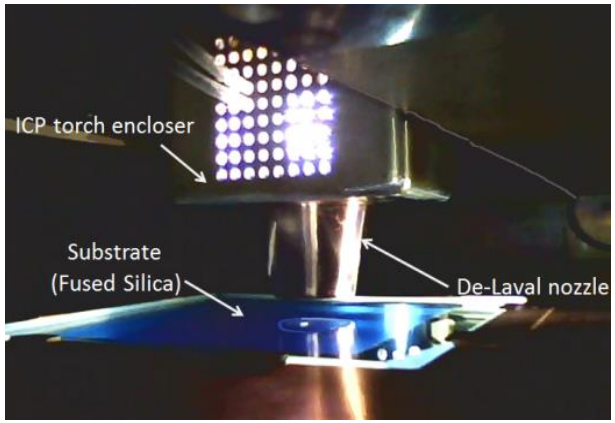
This figuring process uses an **Inductively Coupled Plasma** (ICP) torch that provides a controllable **chemical reaction** for etching local regions of a surface.



State-of-the-art plasma figuring process (Courtesy **Carr et al**)





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1. Introduction

Previous achievement

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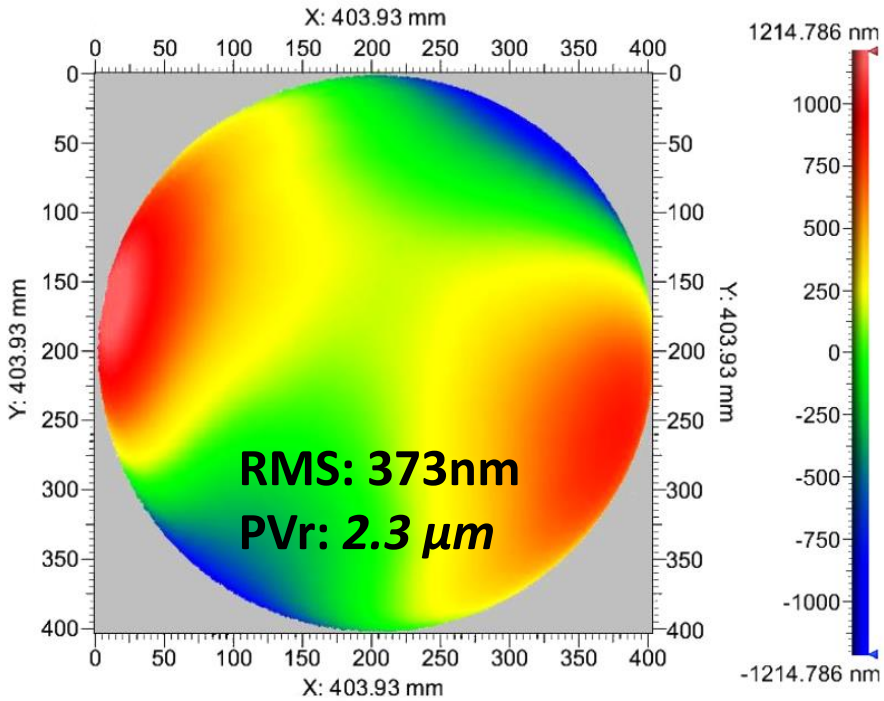
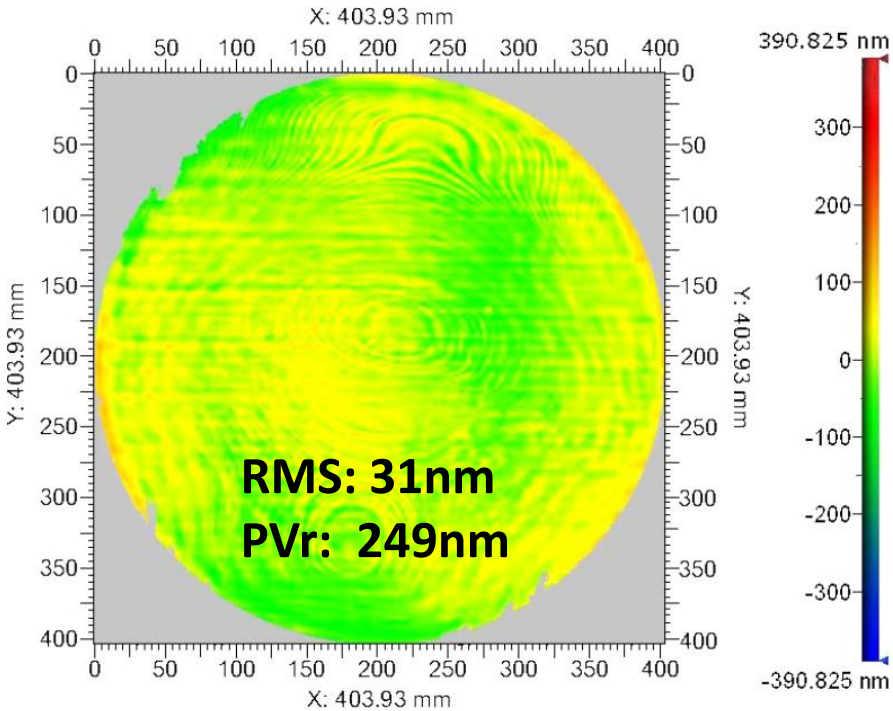
Initial figure error



Residual figure error after second figuring



*(Carried out by **Castelli** [10, 12])*

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1. Introduction

Mid Spatial Frequency (MSF)

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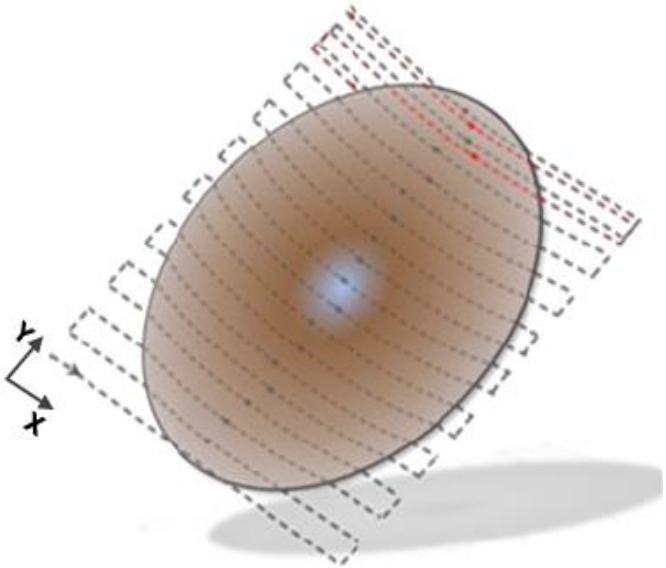
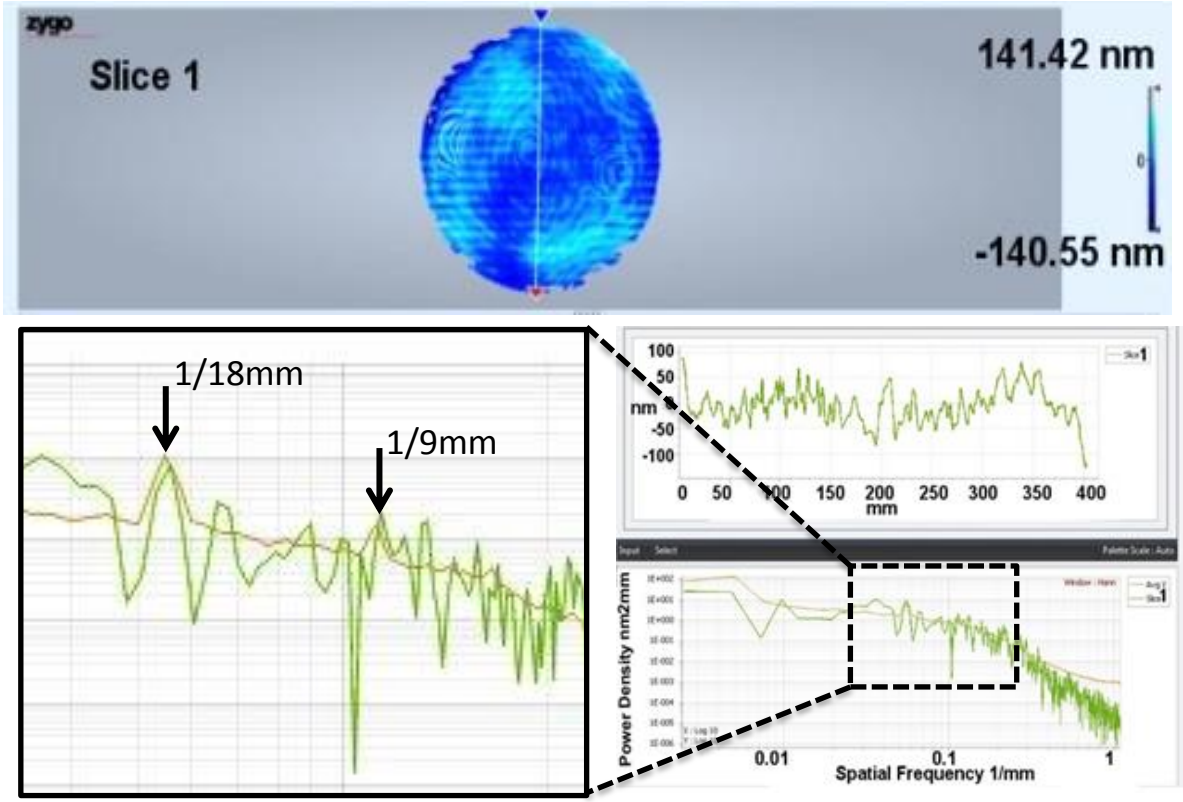
Surface topography and Power Spatial Density (PSD) showing the MSF features





(From **Castelli and Jourdain)**

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2. Methodology

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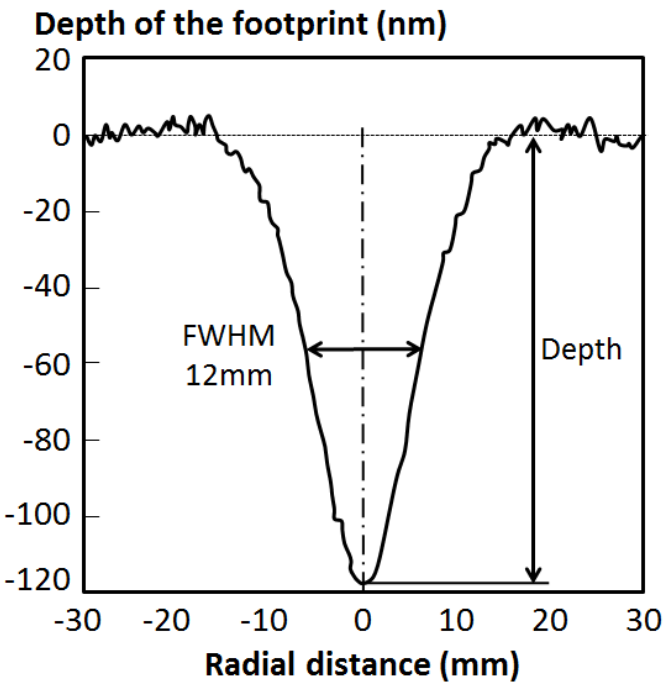
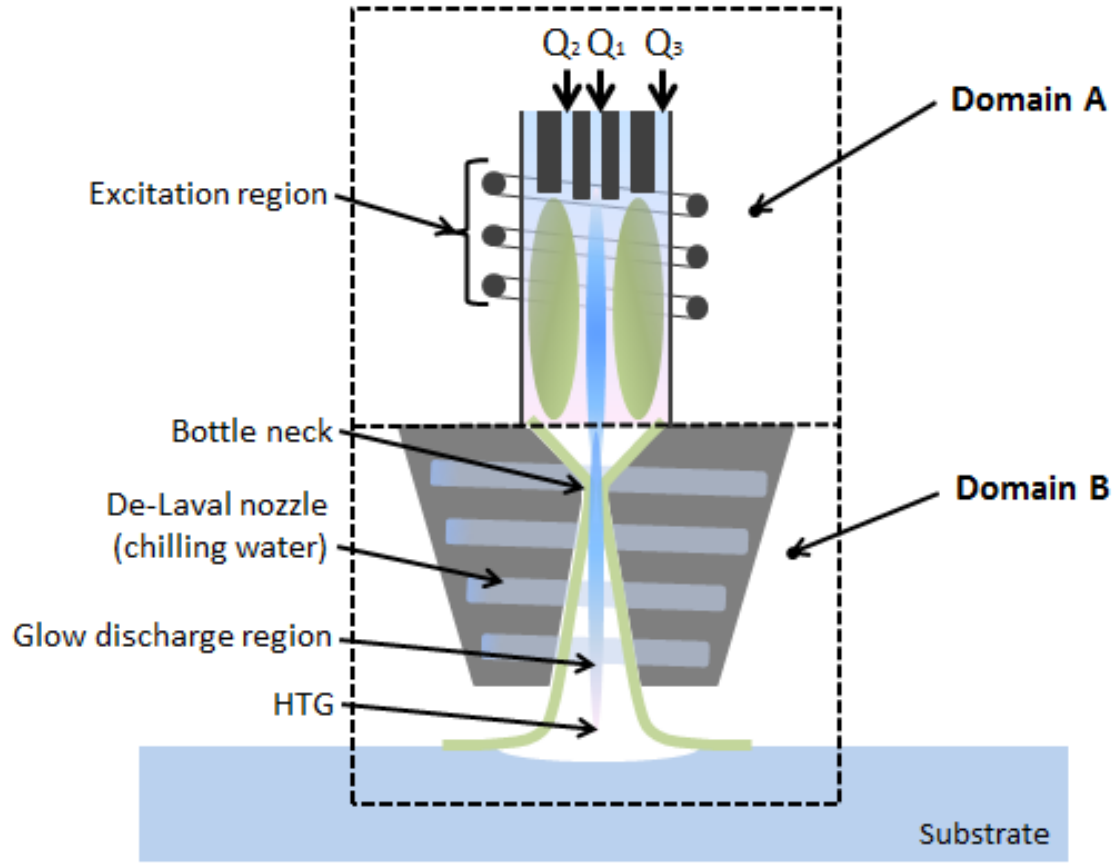
To create highly collimated energy beams to reduce MSF errors



Footprint profile



ICP torch with De-Laval nozzle

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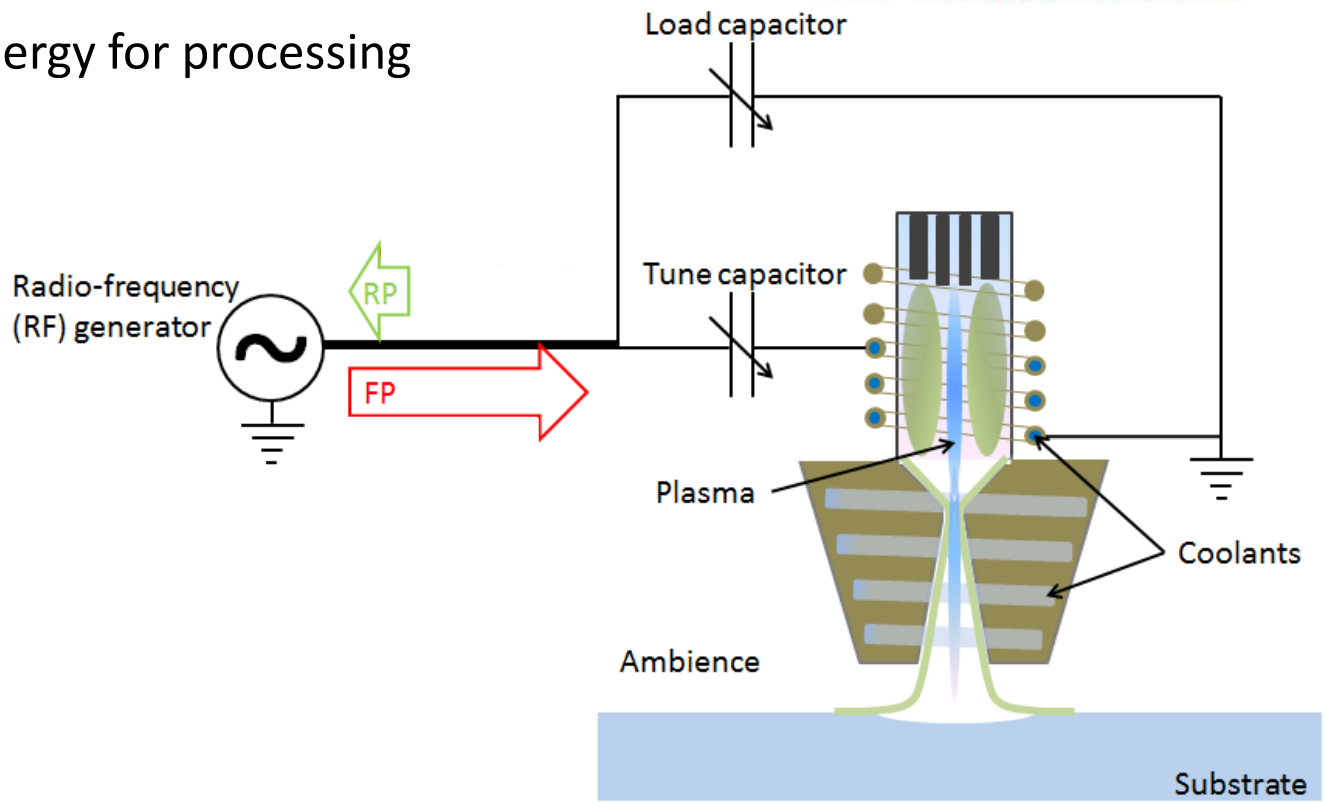
2. Methodology

To guarantee sufficient energy for processing



Energy dissipated items

$$\Delta E_{input} = \text{Forward power} = \Delta E_{coolant} + \Delta E_{gas} + \Delta E_{radiation}$$

Energy dissipation rate (power dissipation)

3. Numerical analysis

Benchmark models vs author's model

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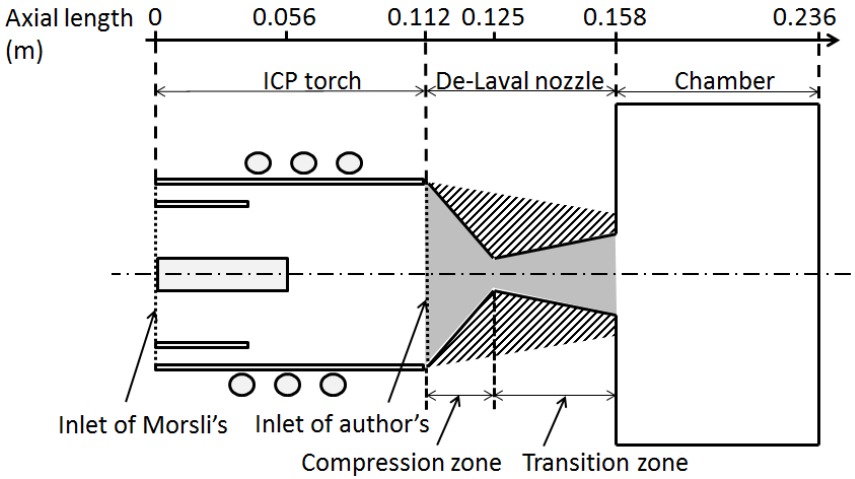
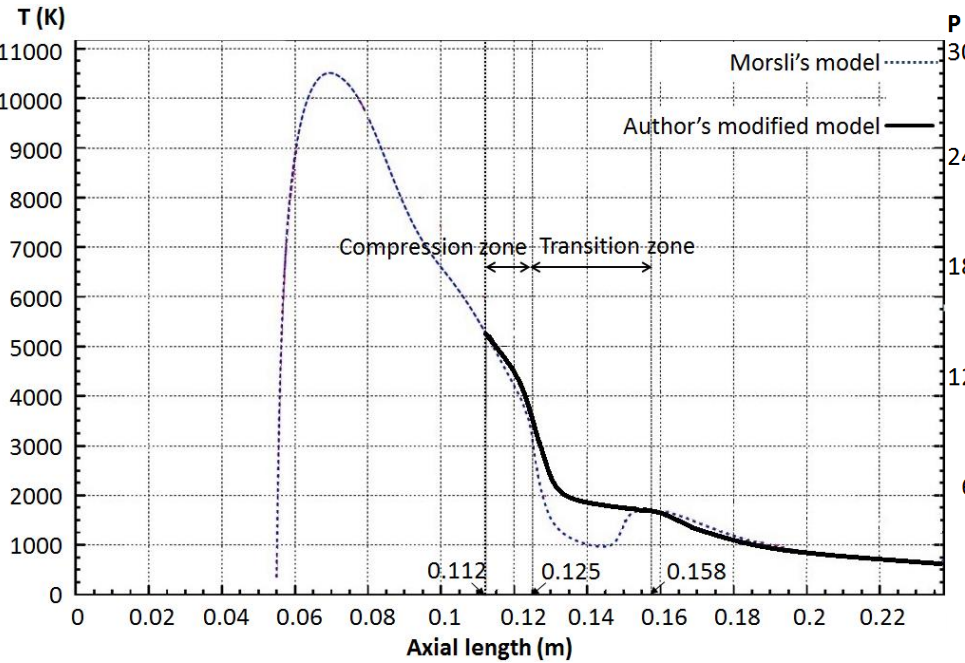
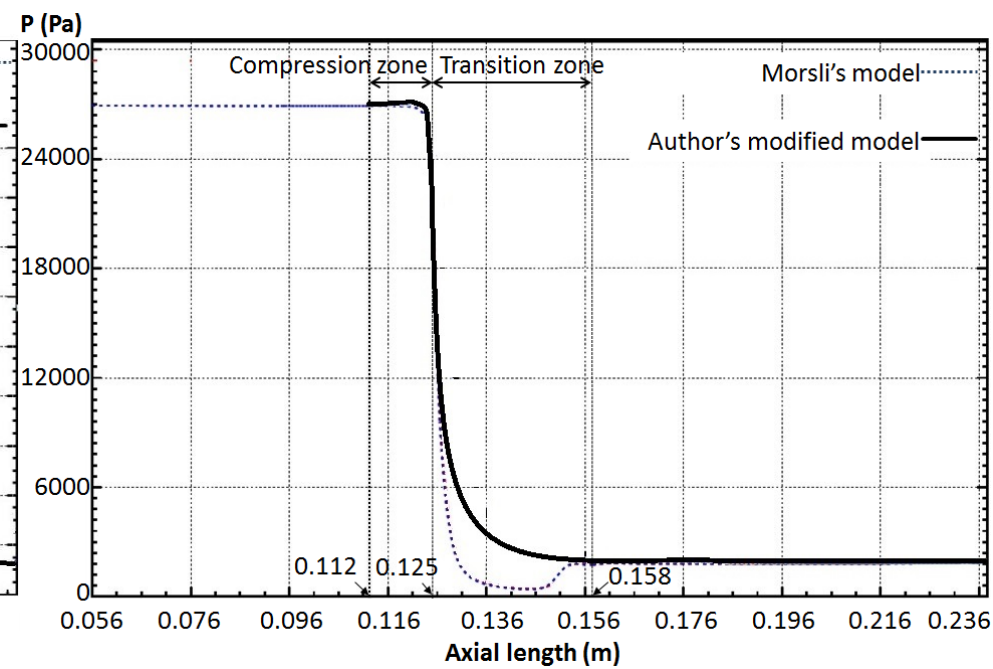
Computation domain



Ref: Morsli, 2007

Comparison of profiles along the symmetric axis





3. Numerical analysis

CFD model of plasma figuring

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Governing equations

Navier – Stokes equations: momentum, mass, and energy conservations

Turbulence characteristics

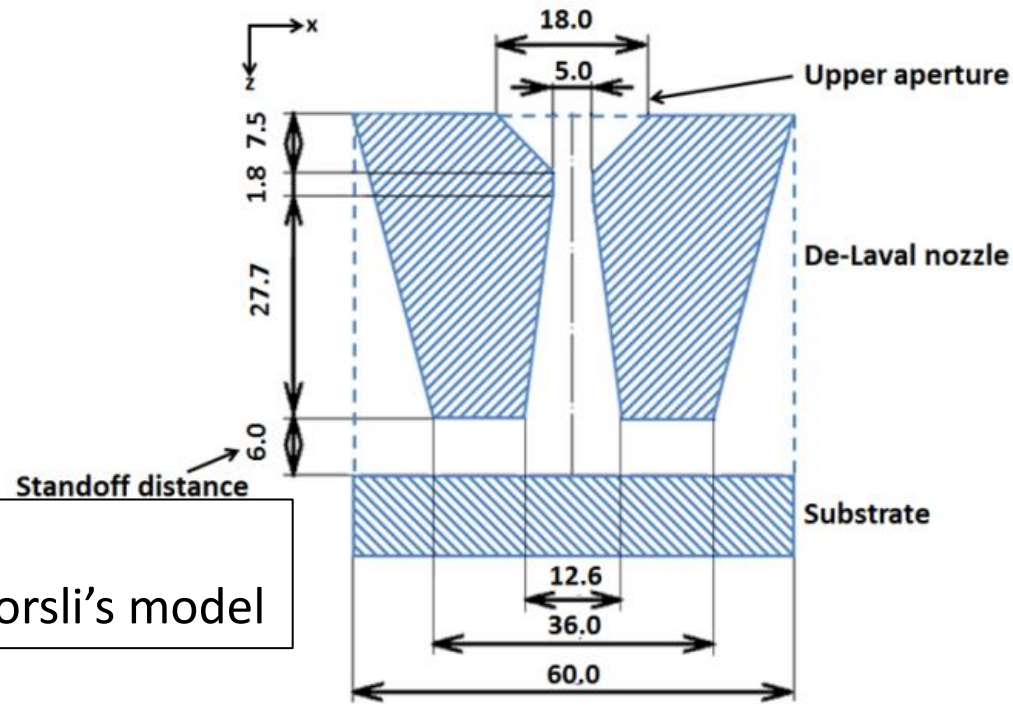
Reynolds number (Re = 3800 ~ 10350)

Literature information [Morsli, 2007]

Boundary condition

Computational domain

Input parameters



Standoff distance :
13 times smaller than Morsli's model

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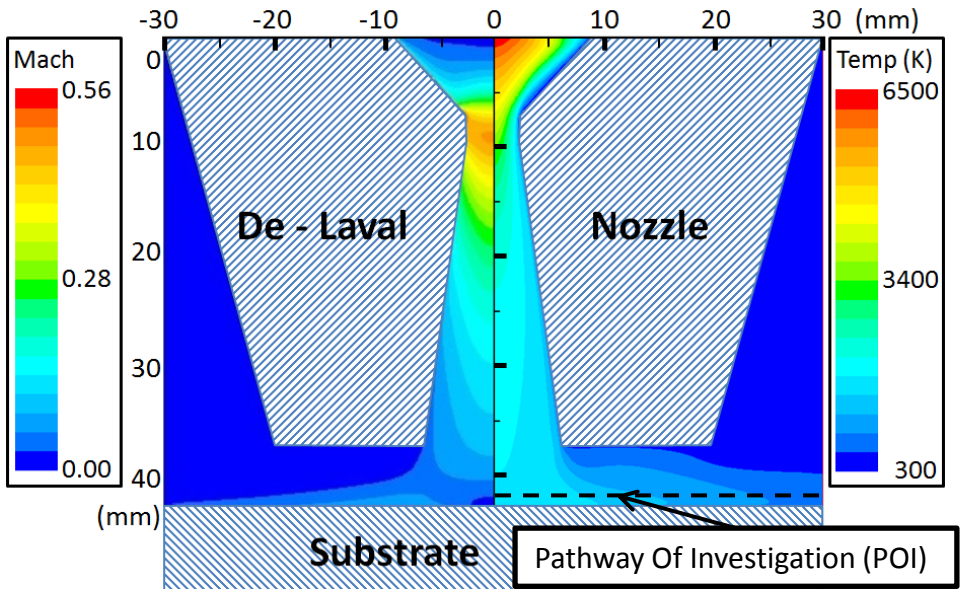
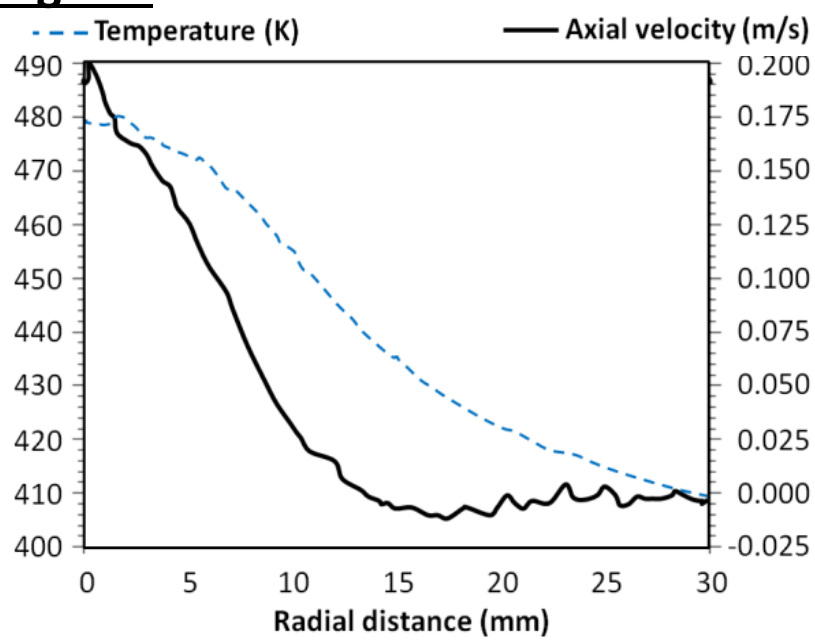
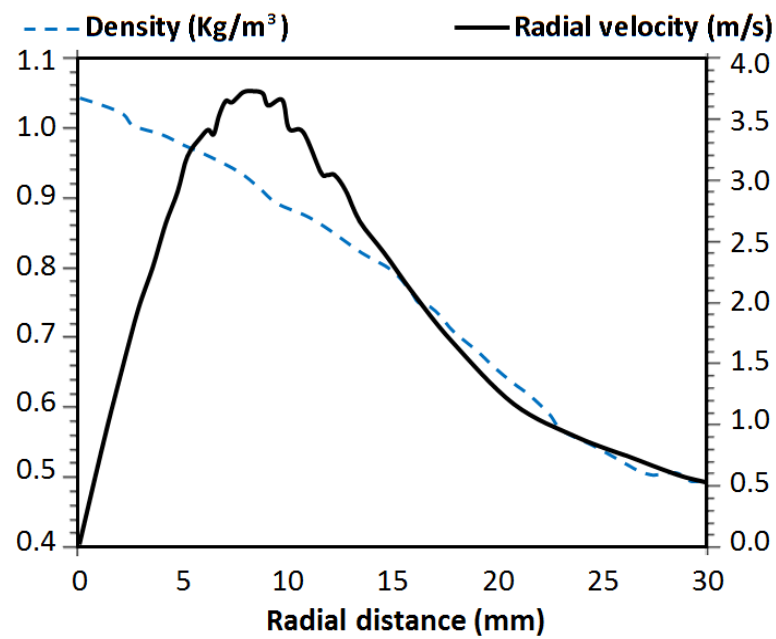
3. Numerical analysis

CFD results



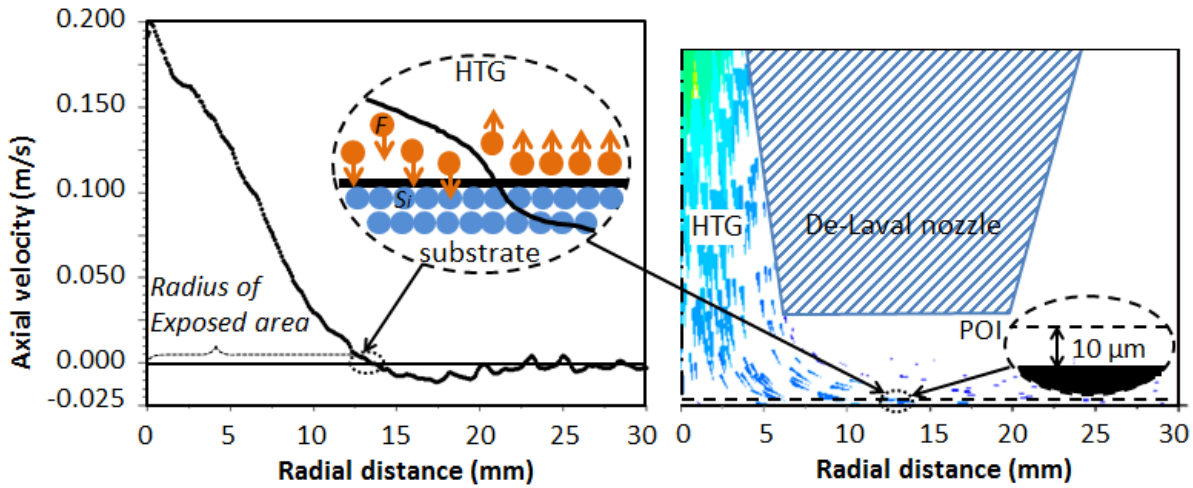
Data along POI

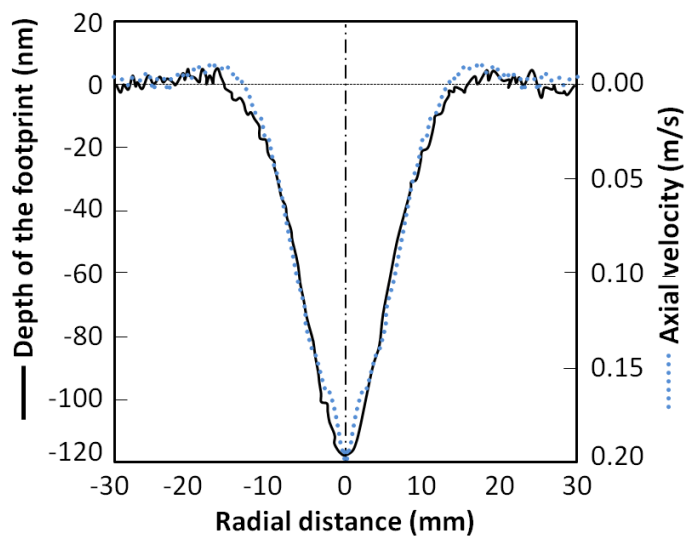


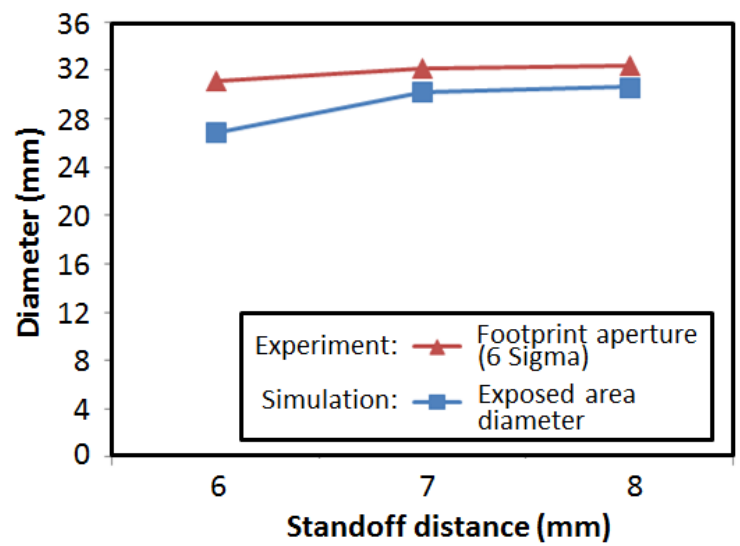


3. Numerical analysis

Correlation between axial velocity and footprint







4. Power dissipation calculation

Flow rate and temperature measurement

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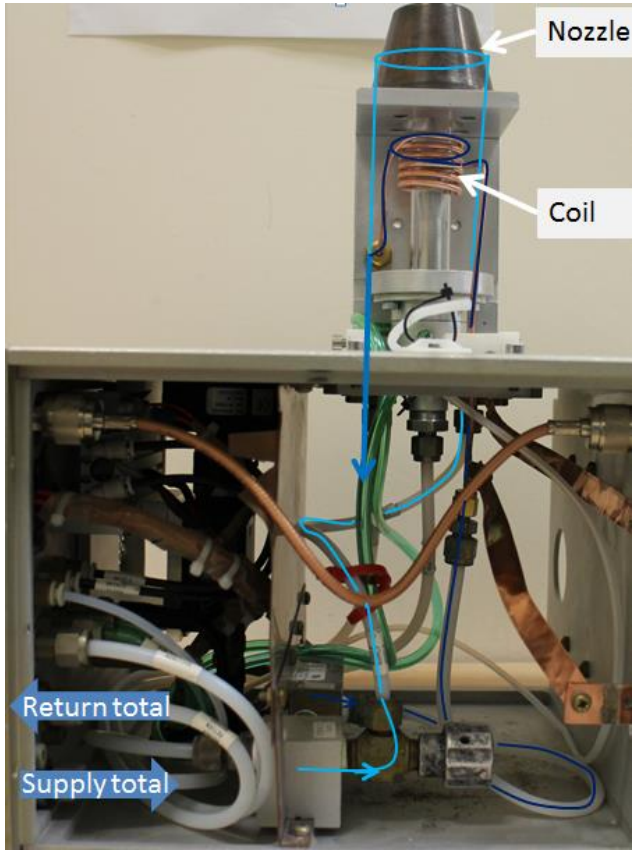

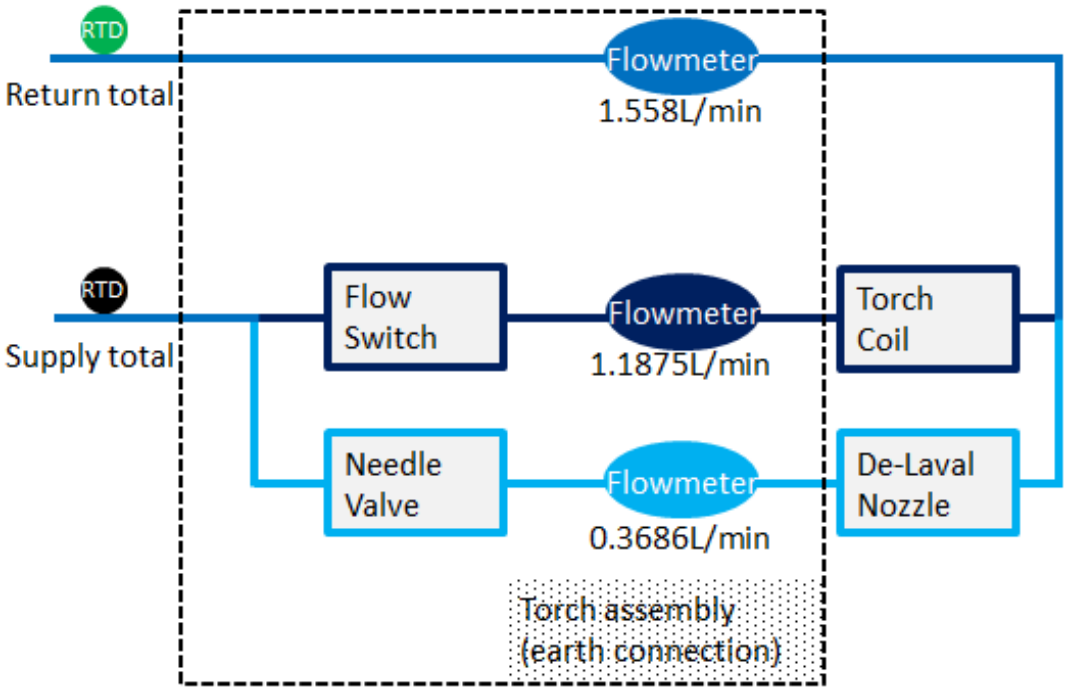

(Flow rates were measured using Platon NGX flowmeter)

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4. Power dissipation calculation

Correlation between TD and FP

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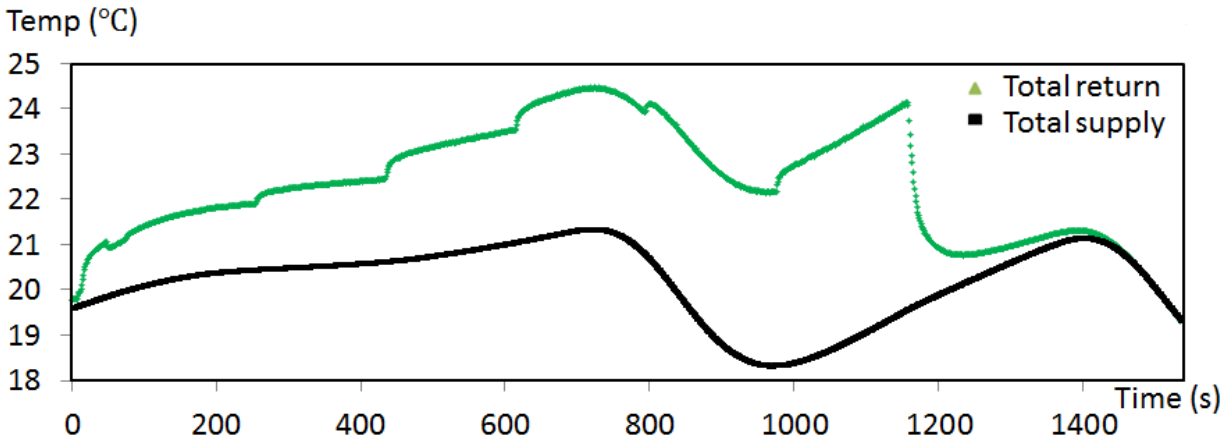
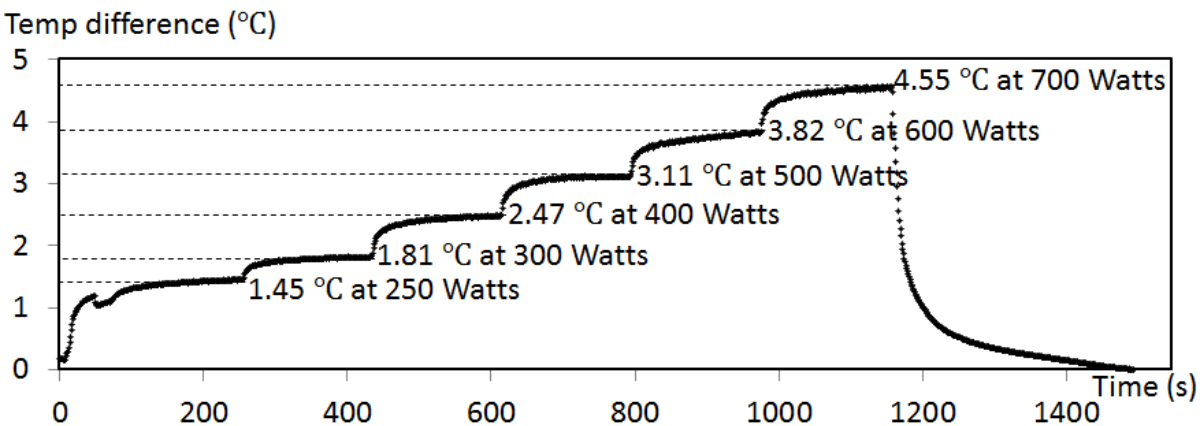
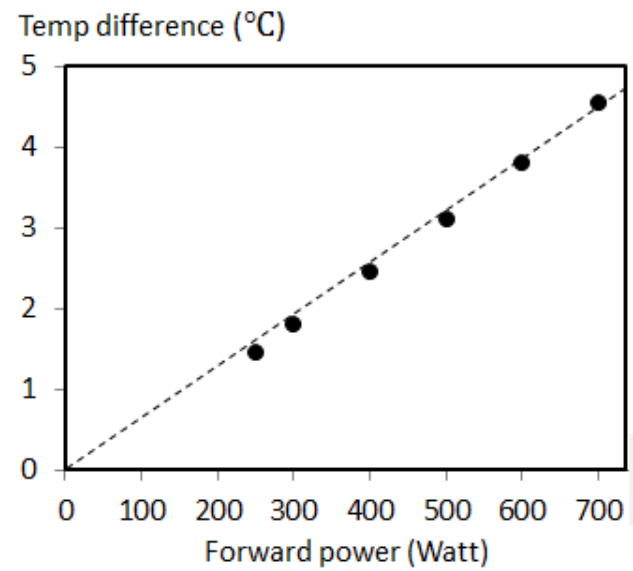


$$TD = T_{Return\ total} - T_{Supply\ total}$$





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4. Power dissipation calculation

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Energy absorbed rate by coolants

$$\Delta E_{\text{coolant}} = C_c \; v_c \Delta T = 664 \text{ watts}$$

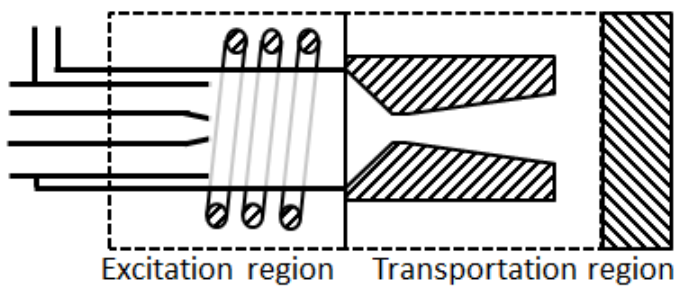
Energy dissipated rate by argon gas

$$E_{\text{argon}} = \int_{T_{room}}^{T} (C_a v_a) dT$$

$$\Delta E_{\text{argon}} = v_a (6090.5 + 20.79T - 1.6 \times 10^{-5} T^2 + 1.72 \times 10^{-8} T^3) = 394 \text{ watts}$$

Energy dissipated rate by radiation

70 to 200 watts



41 watts

(Ref: Wilbers, 1991 & Benoy, 1993)

(Stefan-Boltzmann law)

5. Conclusion and future work

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Pros and cons of the model

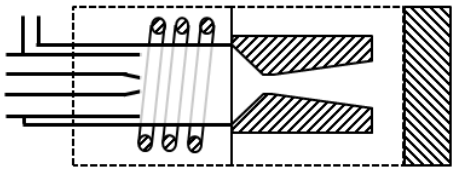
- HTG - plasma;
- No EM effects;

- Meet the demand : aerodynamic property investigation
- Reduced computational time

Discussion of the power dissipation calculation

$$E_{input} = \text{Forward power} = \Delta E_{coolant} + \Delta E_{argon} + \Delta E_{radiation}$$

coil, nozzle, trumpet, air, etc.



Energy dissipated by radiation was double counted

5. Conclusion and future work

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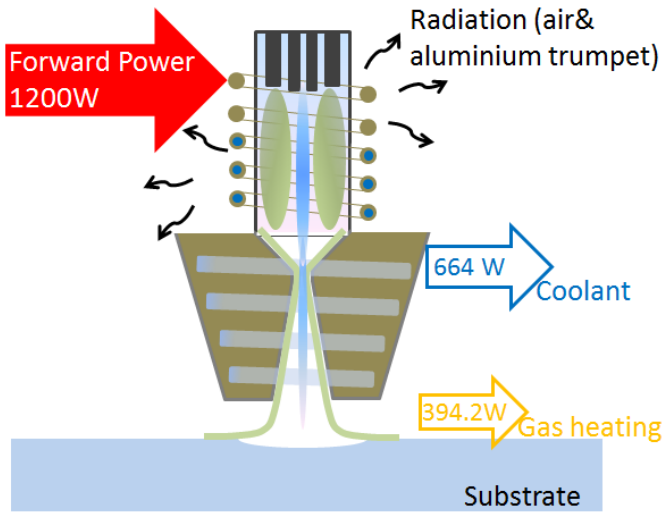
Sketch of the energy dissipation rate



~12%

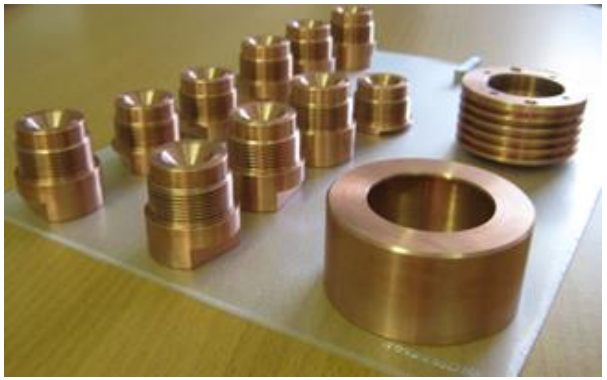
55%

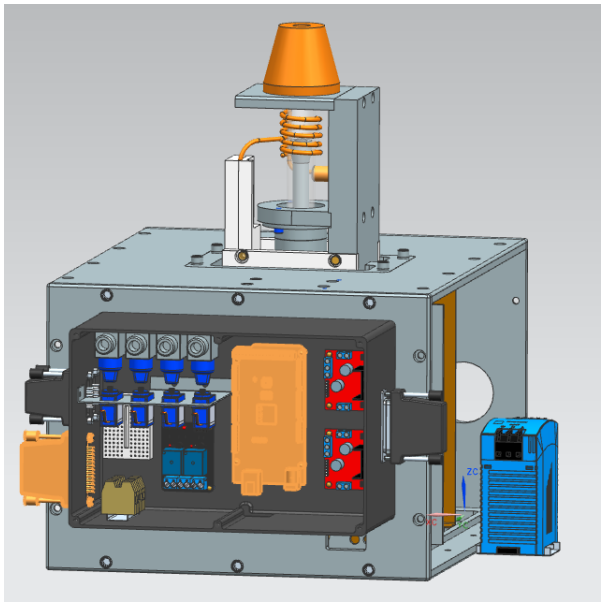
?% to coil

?% to nozzle

33%

Future work





(Courtesy **Serantoni**)

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Thank you!

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