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Special Interest Group Meeting:
Thermal Issues, 17 March, Prague

EPSRC Centre for innovative manufacturing in ultra precision

Energy Balance Investigation of an Inductively Coupled Plasma Torch for Plasma Figuring

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Structure

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1. Introduction
2. Methodology
3. Numerical analysis (briefly)
4. Energy dissipation calculation (in detail)
5. Conclusion and future work

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1. Introduction

Research motivation

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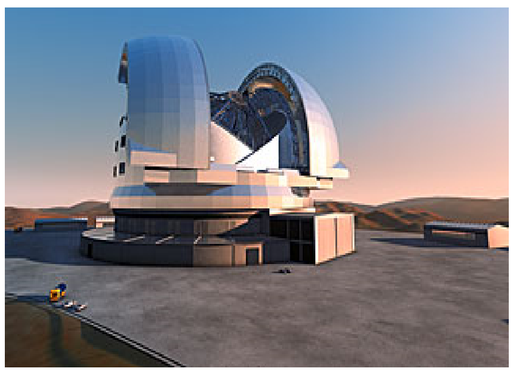
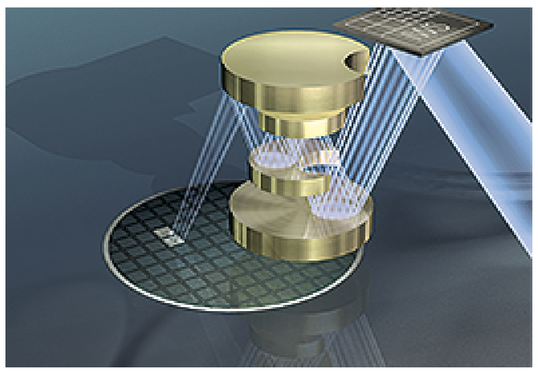
There is a large demand for metre scale ultra-precise optical surfaces



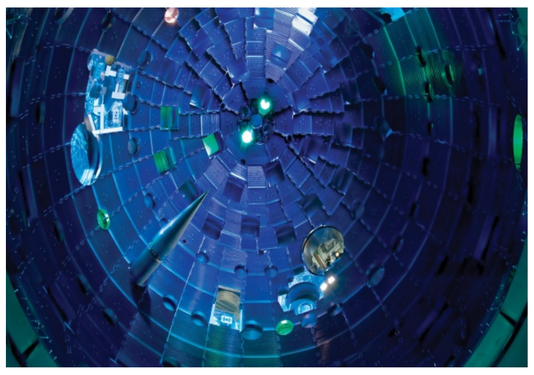
www.eso.org

Ground telescope



www.asml.com

EUV lithography



lasers.llnl.gov

Laser fusion energy

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1. Introduction

Plasma figuring process

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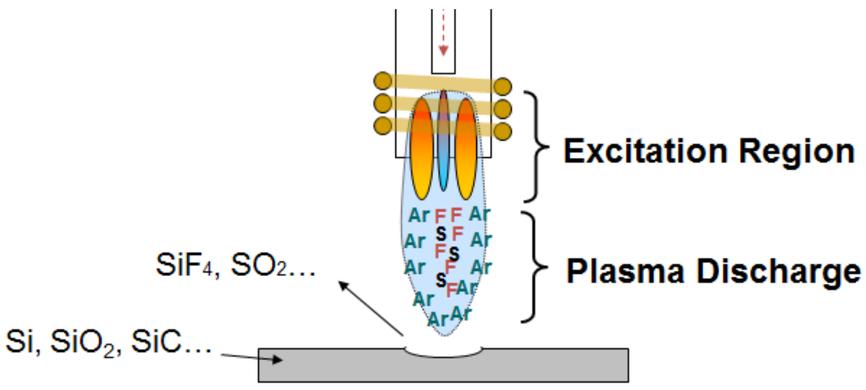
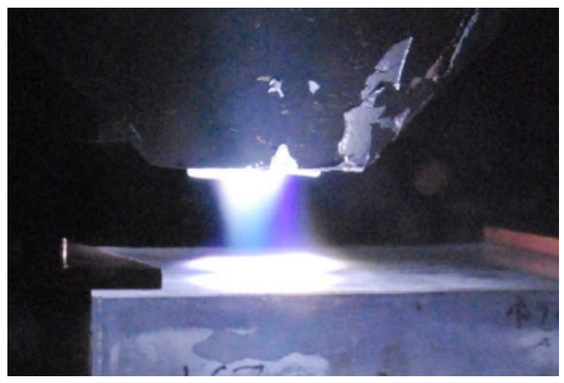
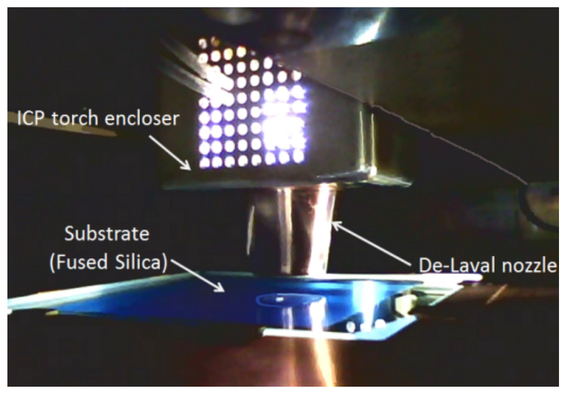
This figuring process uses an **Inductively Coupled Plasma** (ICP) torch that provides a controllable **chemical reaction** for etching local regions of a surface.



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





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1. Introduction

Previous achievement

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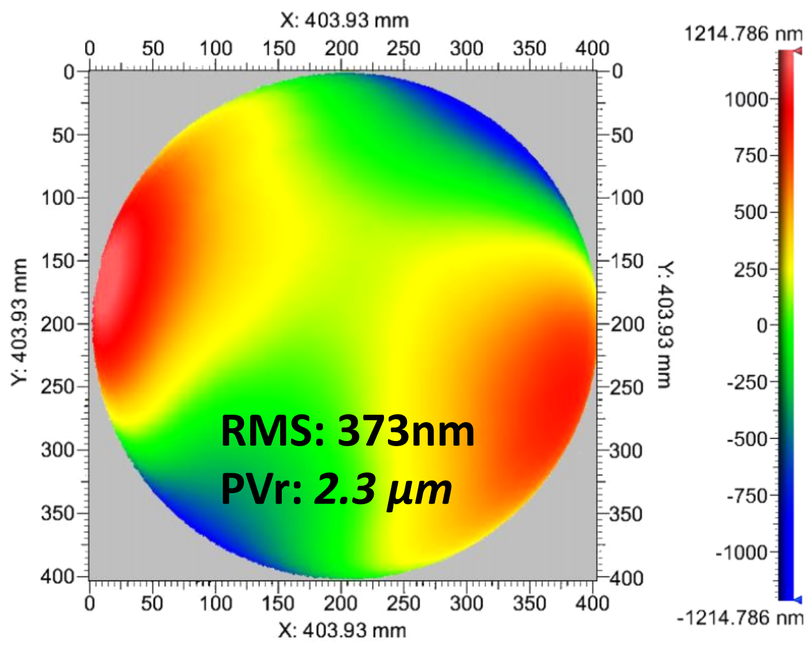
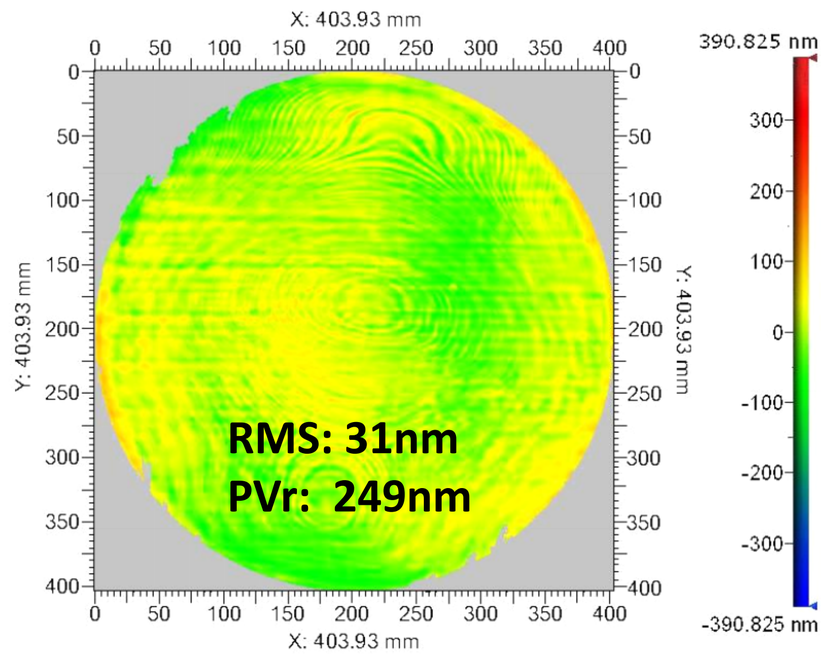
Initial figure error



Residual figure error after second figuring



*(Carried out by **Castelli**)*

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1. Introduction

Mid Spatial Frequency (MSF)

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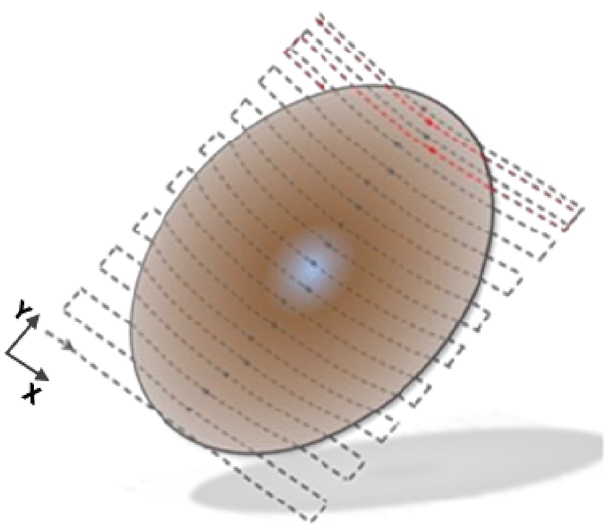
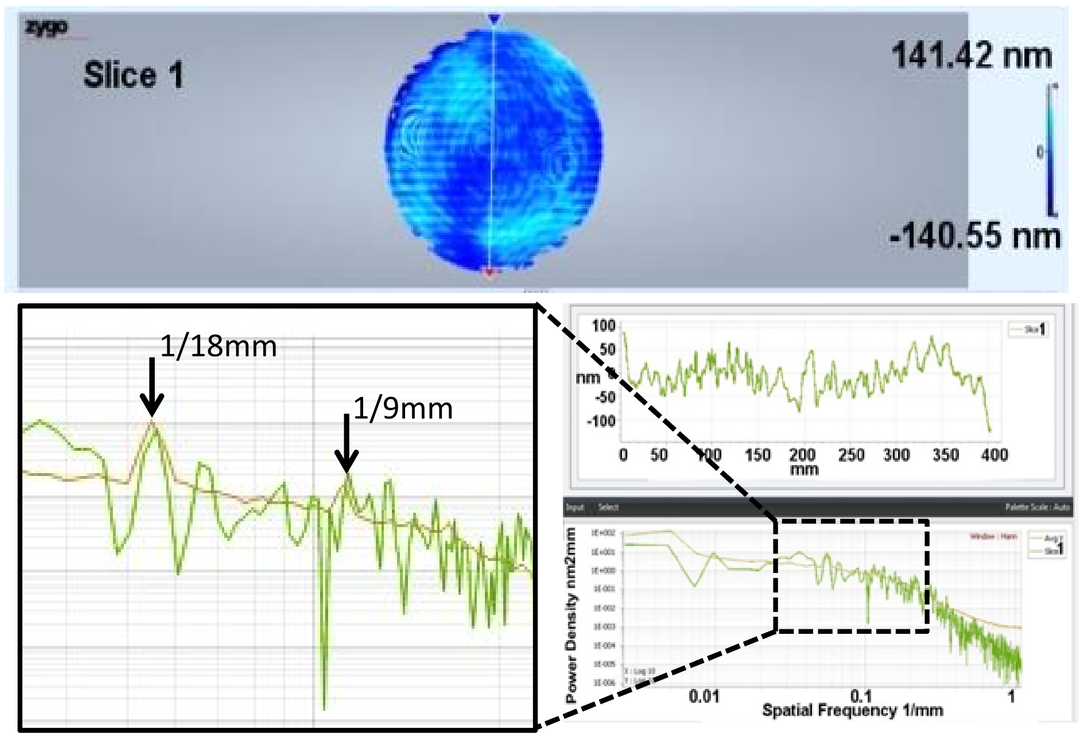
Surface topography and Power Spatial Density (PSD) showing the MSF features





(From **Castelli** and **Jourdain)**

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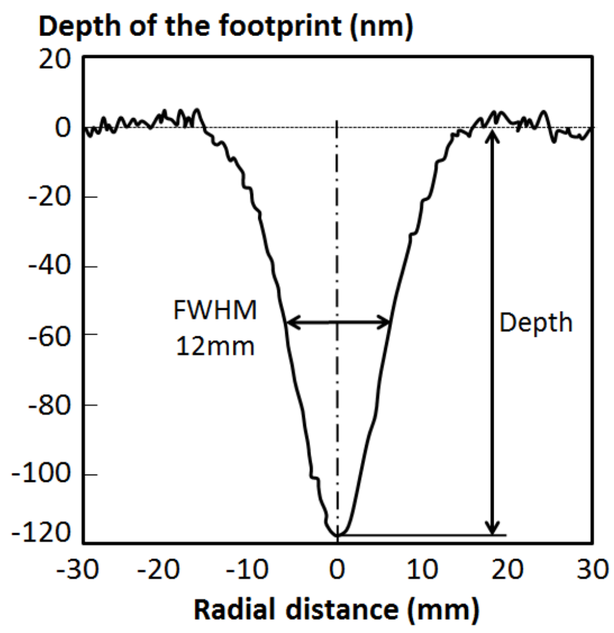
2. Methodology

To reduce MSF errors:

1. Use random tool-path algorithms;
2. Use smaller tool functions

e.g. German IOM group in Leibniz Institute reduces the tool function using RF high-frequency excitation

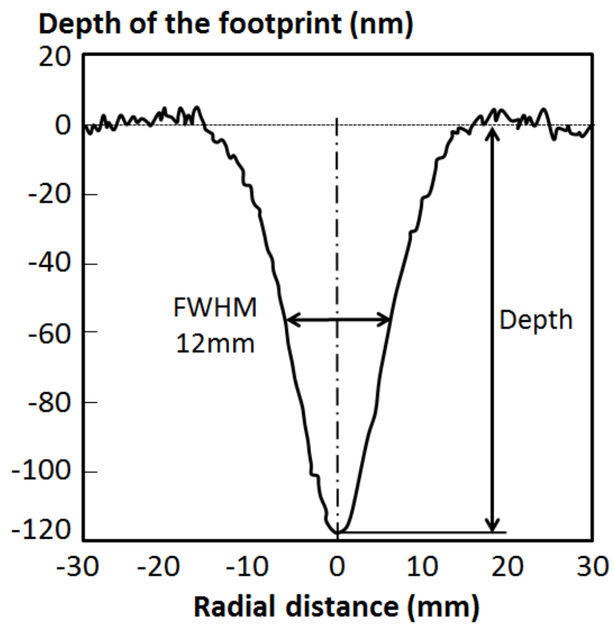


FWHM: 0.2-12 mm
(Full Width at Half Maximum)

MRR: $5x10^{-5}$ - 50^{3} mm/min
(Material Removal Rate)

2. Methodology

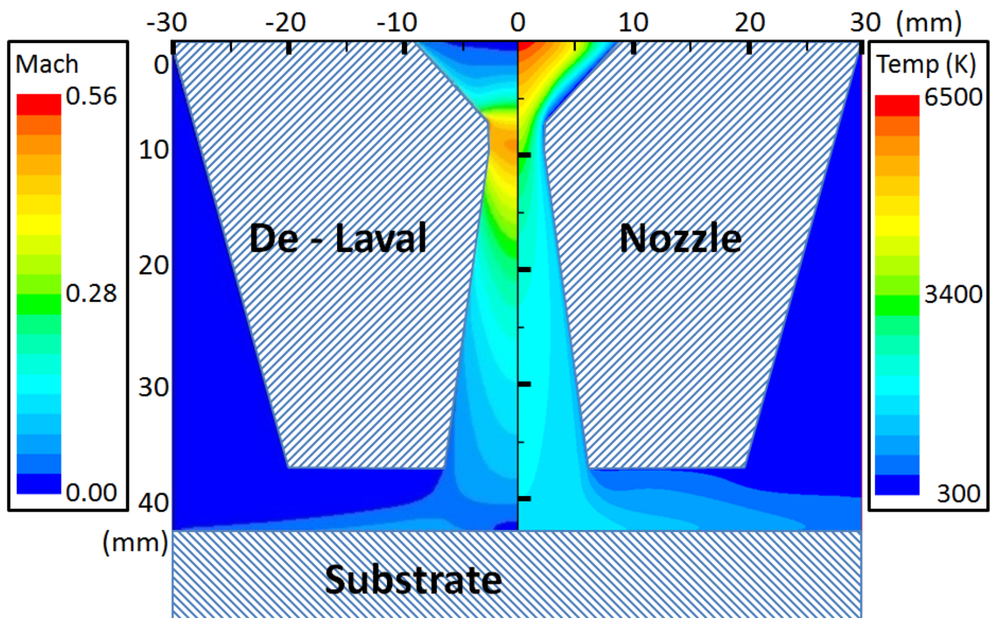
To reduce MSF errors:

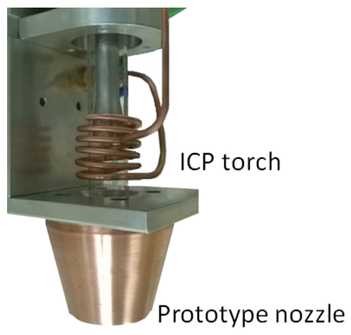


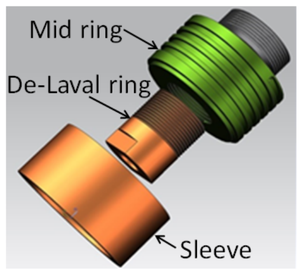
FWHM
(Full Width at Half Maximum) ⇩ Collimated plasma jet
(Numerical analysis)

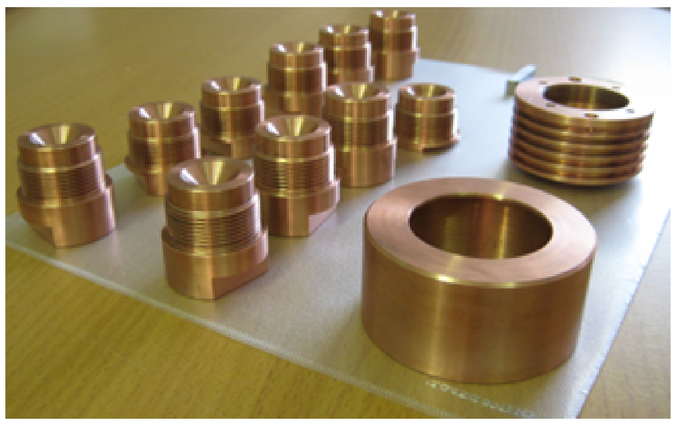
MRR
(Material Removal Rate) ⇨ Effective heat transfer
(Energy measurement)

3. Numerical analysis









CFD results have been validated by

1. Comparing with benchmark modelling results;
2. Comparing with experimental footprint

(*The International Journal of Advanced Manufacturing Technology*, DOI: 10.1007/s00170-016-8502-y)

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4. Energy dissipation calculation

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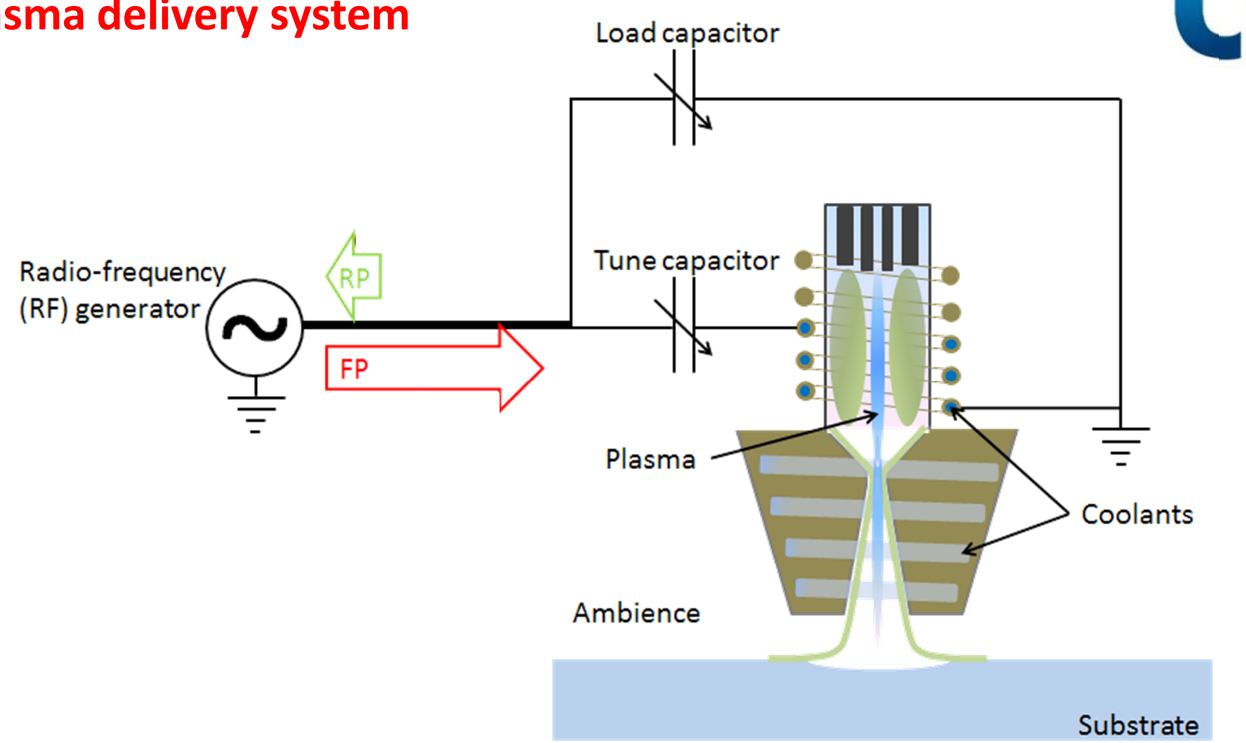
Plasma delivery system



Energy dissipated items

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

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4. Energy dissipation calculation

Flow rate and temperature measurement

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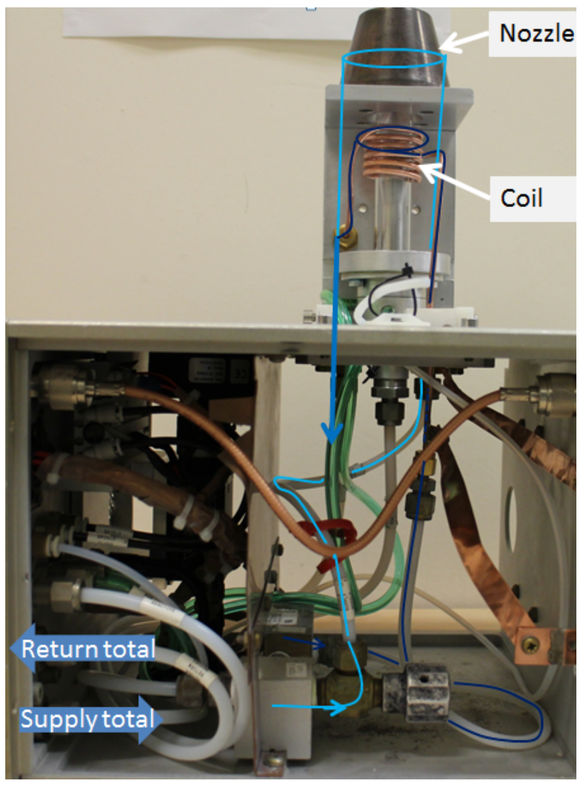

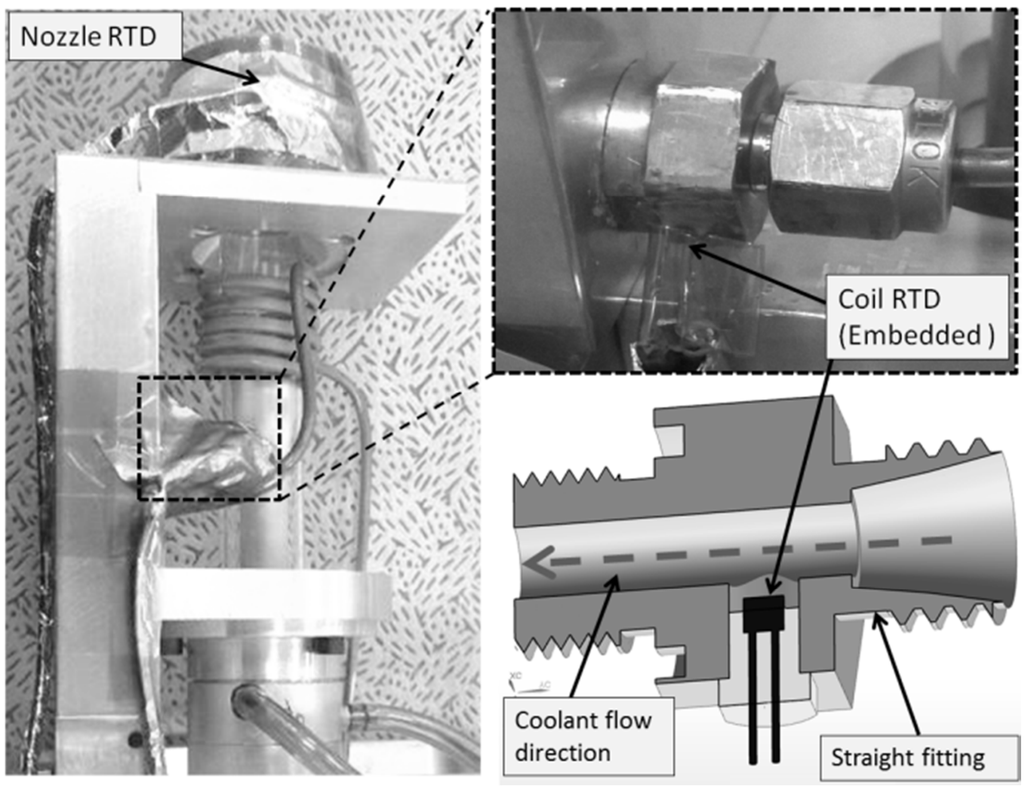

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4. Energy dissipation calculation

Flow rate and temperature measurement

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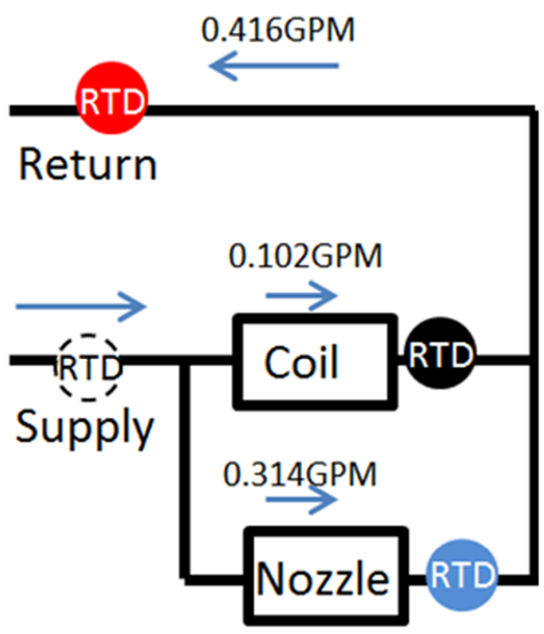

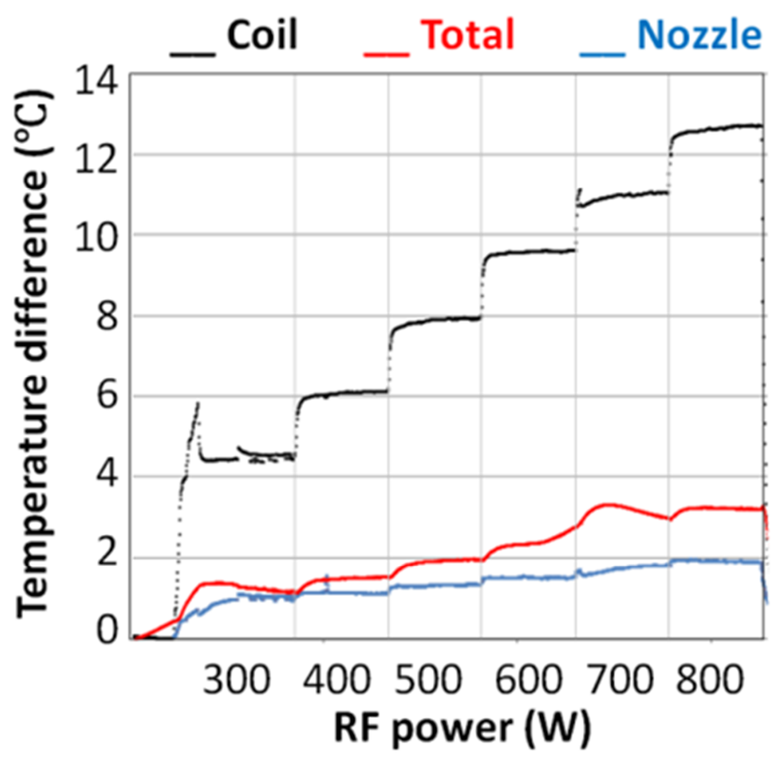

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4. Energy dissipation calculation

Correlation between TD and RF power

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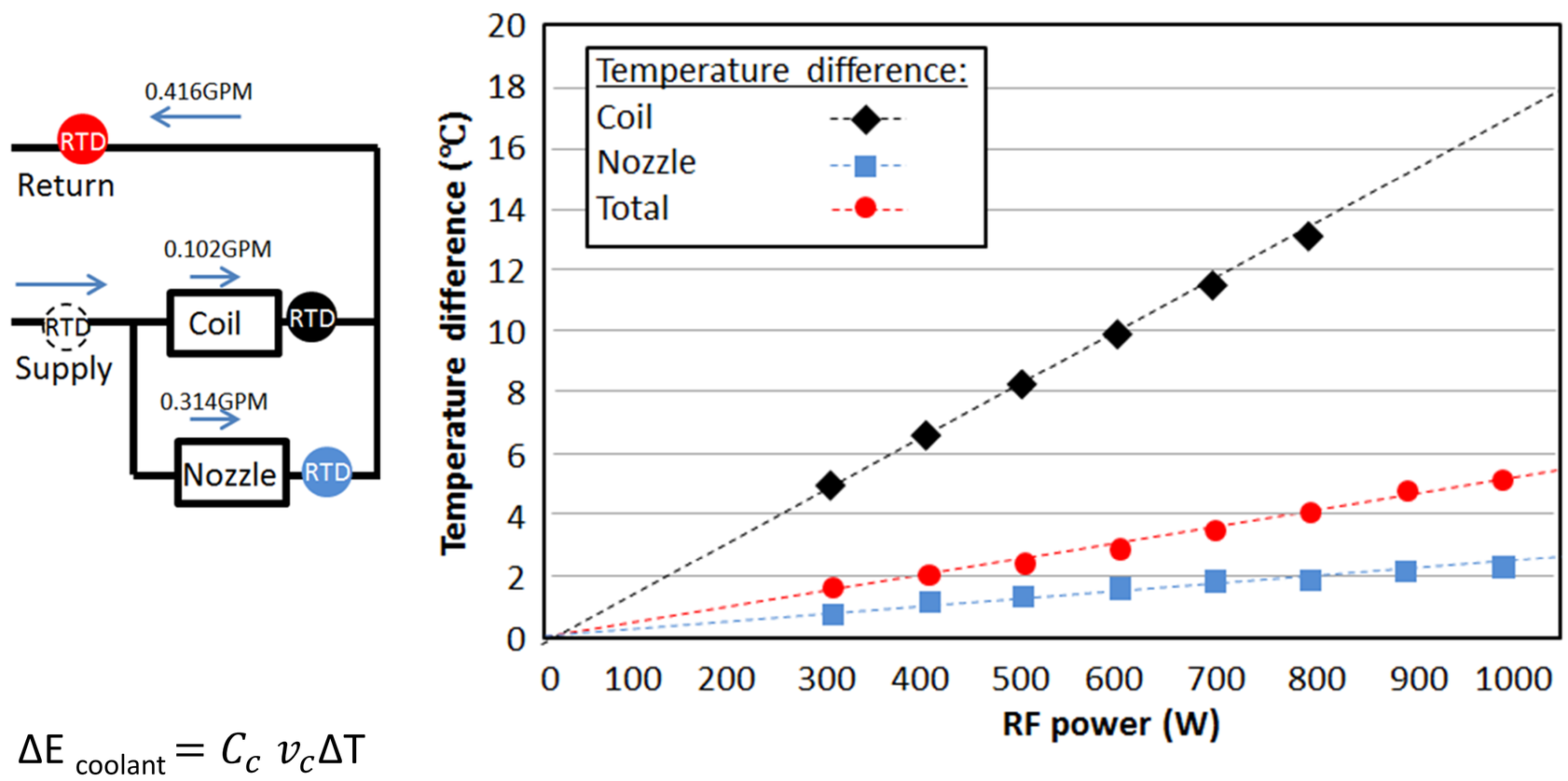

$$\Delta E_{\text{coolant}} = C_c \, v_c \Delta T$$

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4. Energy dissipation calculation

Correlation between energy dissipated rate and RF power

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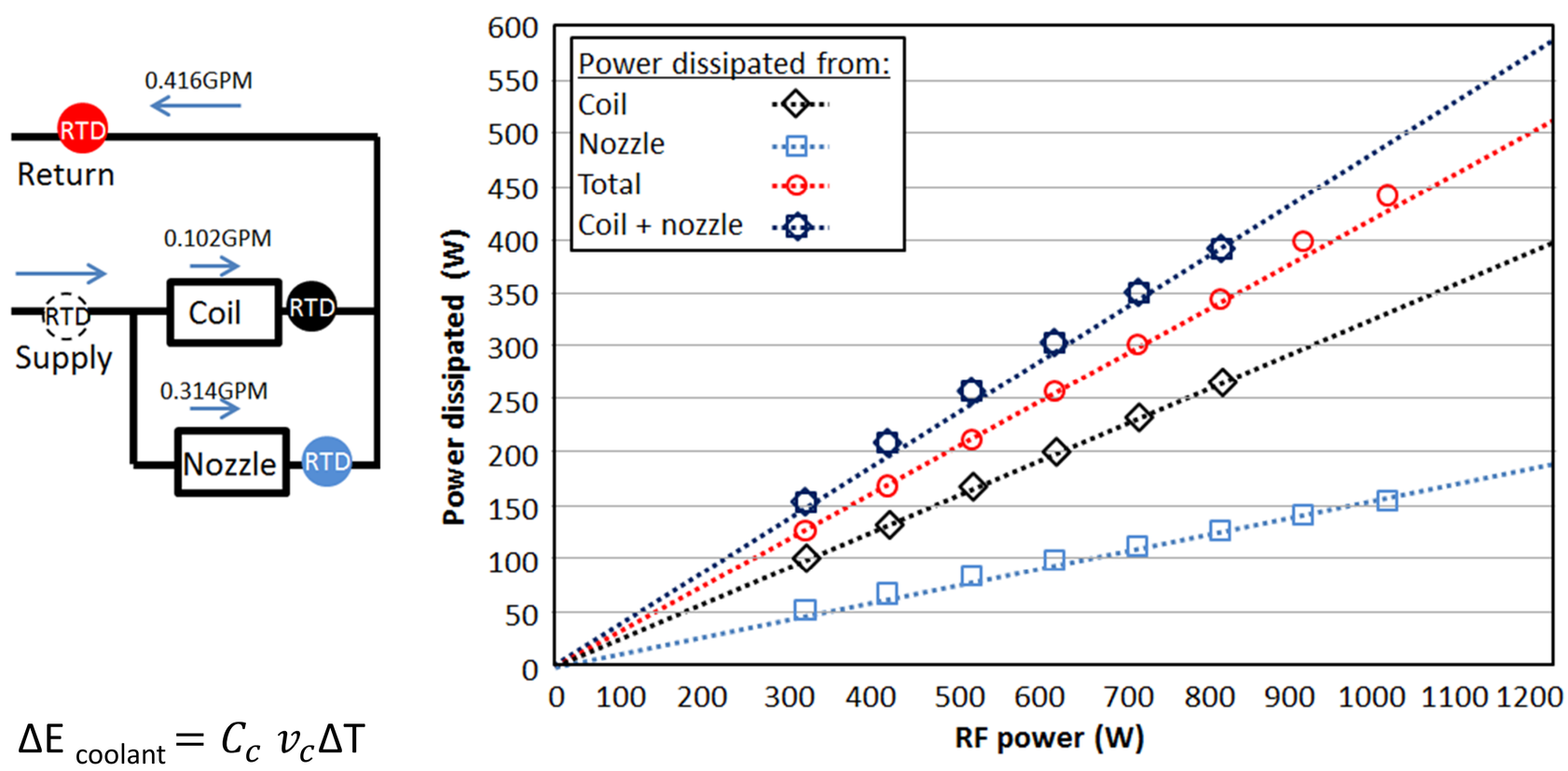

$$\Delta E_{\text{coolant}} = C_c \, v_c \Delta T$$

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4. Energy dissipation calculation

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Energy absorbed rate by coolants

$\Delta E_{\text{coolant}} = C_c\ v_c \Delta T = 585$ watts

Energy dissipated rate by argon gas

$\Delta E_{\text{argon}} = \int_{T_{room}}^{T} (C_a v_a) dT = 394$ watts

Energy dissipated rate by radiation

Not measured yet

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5. Conclusion and future work

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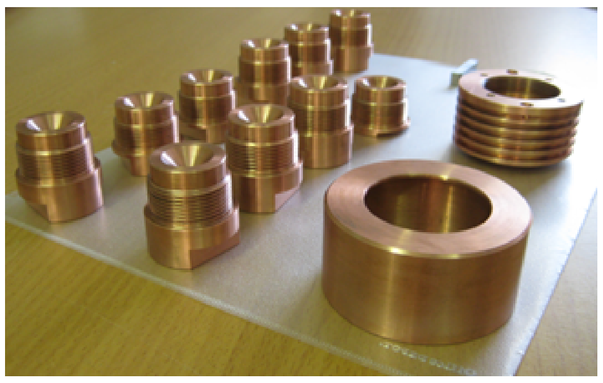
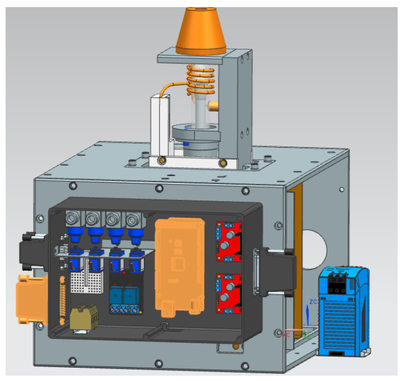
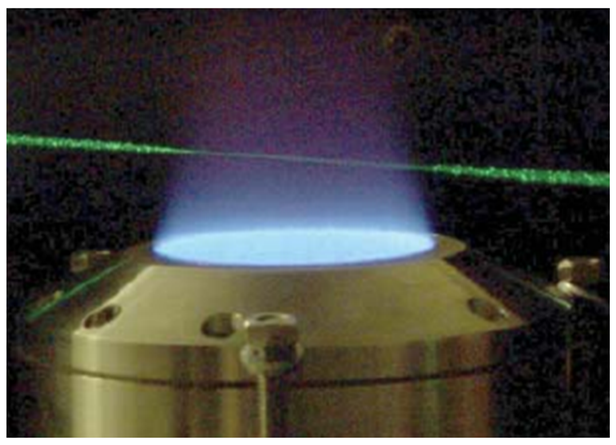
Distribution of the energy dissipation rate

Input: RF power	Energy dissipation rate	
1200W provided by RF generator	Coil coolant Nozzle coolant Heating gas Radiation	400W (33.3%) 185W (15.4%) 394W (32.8%) ~ 18.5%

Future work







The Rayleigh scattering laser
(Picture from NPL, Spring 2006)

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Thank you!

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