Predicting Heat Flux to TCP Window in Etch Chambers

Using COMSOL to obtain fast estimates of heat flow and temperature distribution in inductively-coupled plasma chambers during operation

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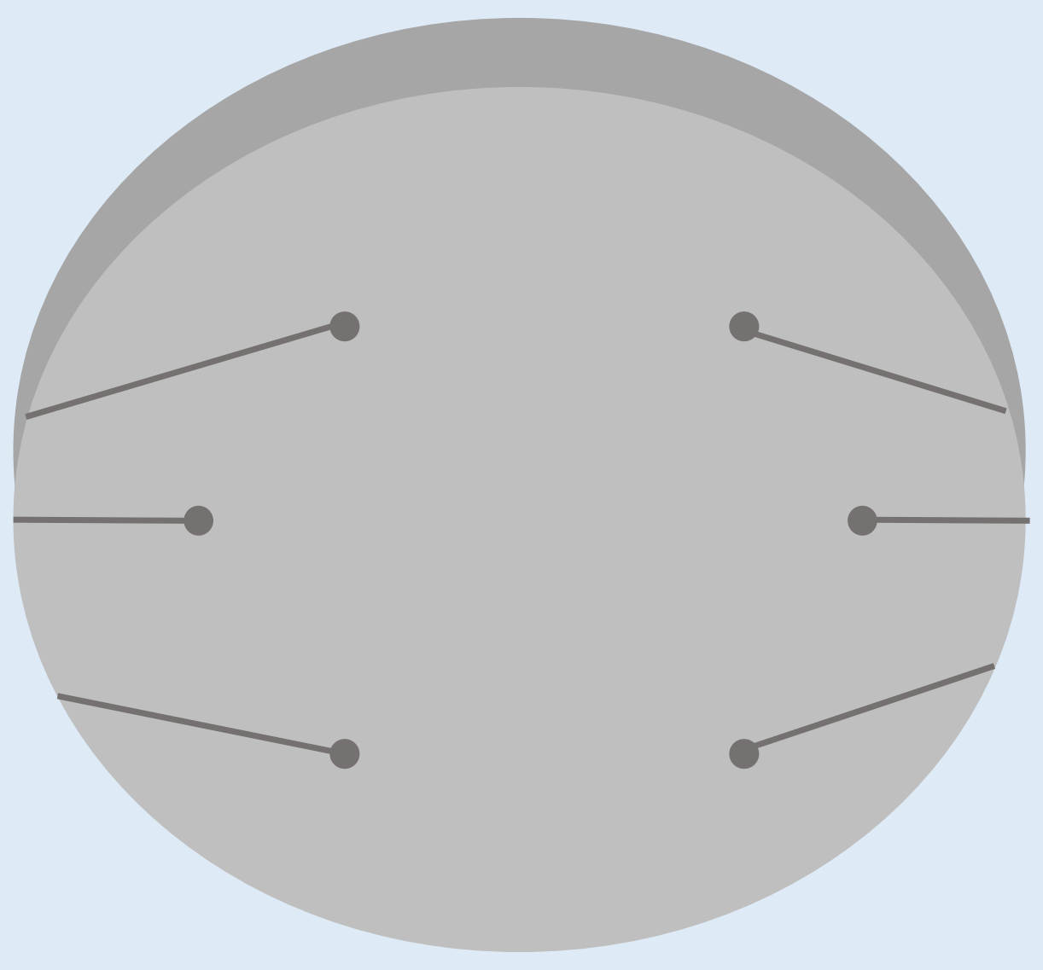
From: 2-3 days
Calorimetry Experiments



Thermocouple fitted TCP window

To: few hours
COMSOL Model

Plasma
Magnetic Fields
Laminar Flow
Heat Transfer

Introduction

To minimize transformer-coupled plasma (TCP) window thermal stresses and cracking incidents, air-cooled plenum design must be optimized considering the heat-flux to the TCP window. Currently, heat flux to the TCP window is estimated from calorimetry experiments with run-time of several days. This project aims to develop a time and cost-efficient modeling solution to estimate TCP window heat-flux as an alternative to calorimetry experiments. Results demonstrate COMSOL can provide fast estimates TCP window heat-flux in Etch chambers and further highlight the significant contribution of surface reactions to TCP window heat-flux.

**Normalized values*

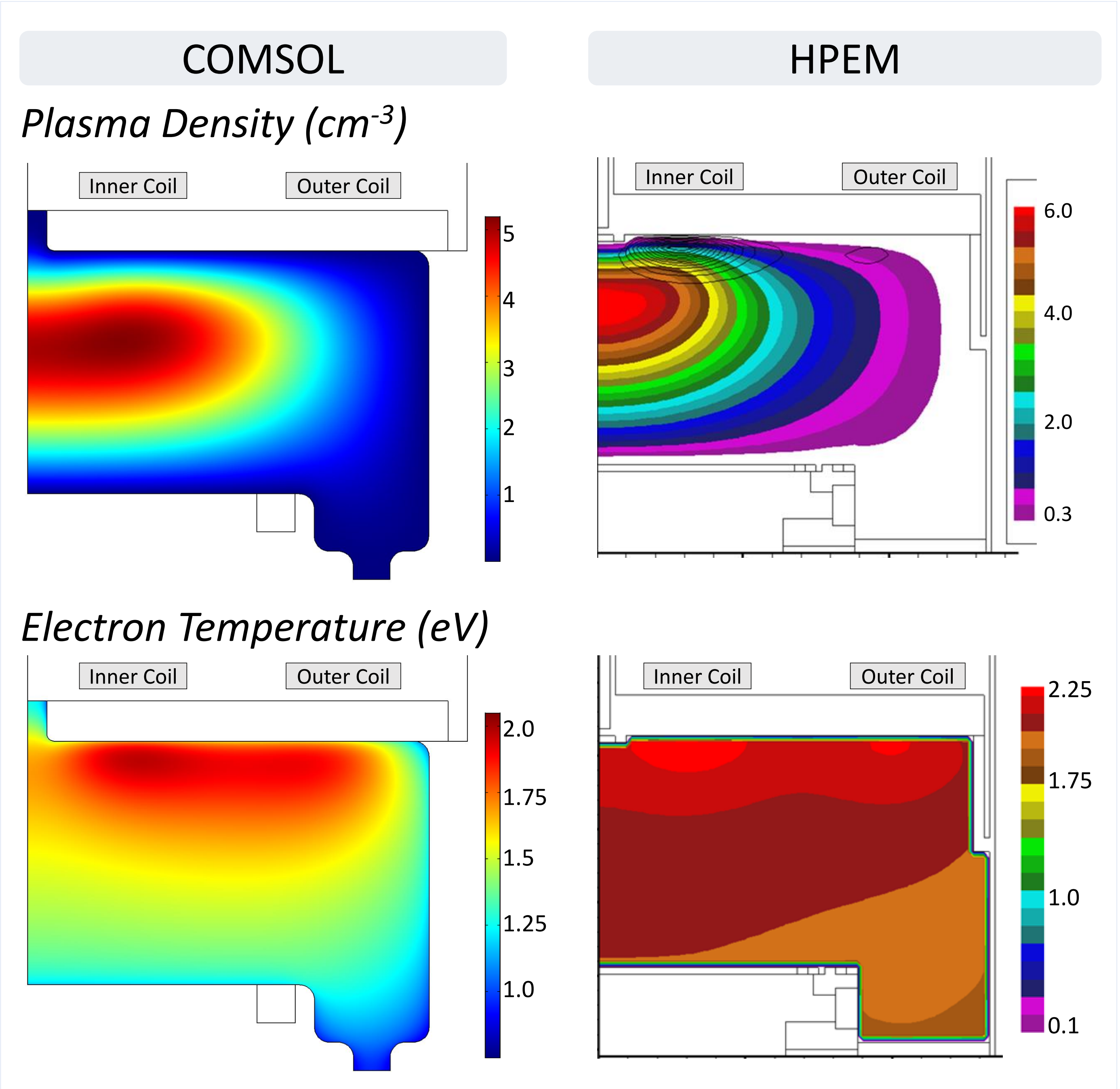


Figure 1. Electron density and temperature from COMSOL simulations (on left) compare favorably against HPEM results (on right). HPEM demonstrates a centered core, while COMSOL has a slightly shifted core

Results

COMSOL 2d models have **run-time less than 30 minutes!**

COMSOL results highlight the peak heat-flux locations in dielectric window thus guiding colling system design.

- Results provide good agreement with HPEM and experimental data
- Surface reactions are the primary contributors to dielectric window heat flux

  $Ar^* \rightarrow Ar \;\; \Delta \mathrm{H}_{\mathrm{rxn}} = 1110\,\mathrm{kJ/mol}$ (~8% TCP heat flux)

  $Ar^+ \rightarrow Ar \;\; \Delta \mathrm{H}_{\mathrm{rxn}} = 1520\,\mathrm{kJ/mol}$ (~85% TCP heat flux)
- Next Steps:
  - Extend model to include EEDF from Boltzmann equation and energy dependent mobilities
  - Further validation using different chemistries and effects (*e.g.*, wafer-bias *etc.*)

Methods

Simulations done in COMSOL 5.5 coupling different modules:

Plasma **Magnetic Field** **Laminar Flow** **Heat Transfer**

- Drift-diffusion equations[1] for e- mass and energy conservation
- Multi-component diffusion equation for heavy species transport
- Reactions implemented for Ar chemistry using cross-sectional reaction rates and Druyvesteyn EEDF
- Surface reactions to model species de-excitation
- Ampere's law solved in each domain
- Coils excited with a given power input
- Compressible flow with no slip boundary
- Energy conservation for heavy species – with heat input from plasma reactions and joule-heating (under electric field)
- External boundaries at constant temperature

**Normalized values*

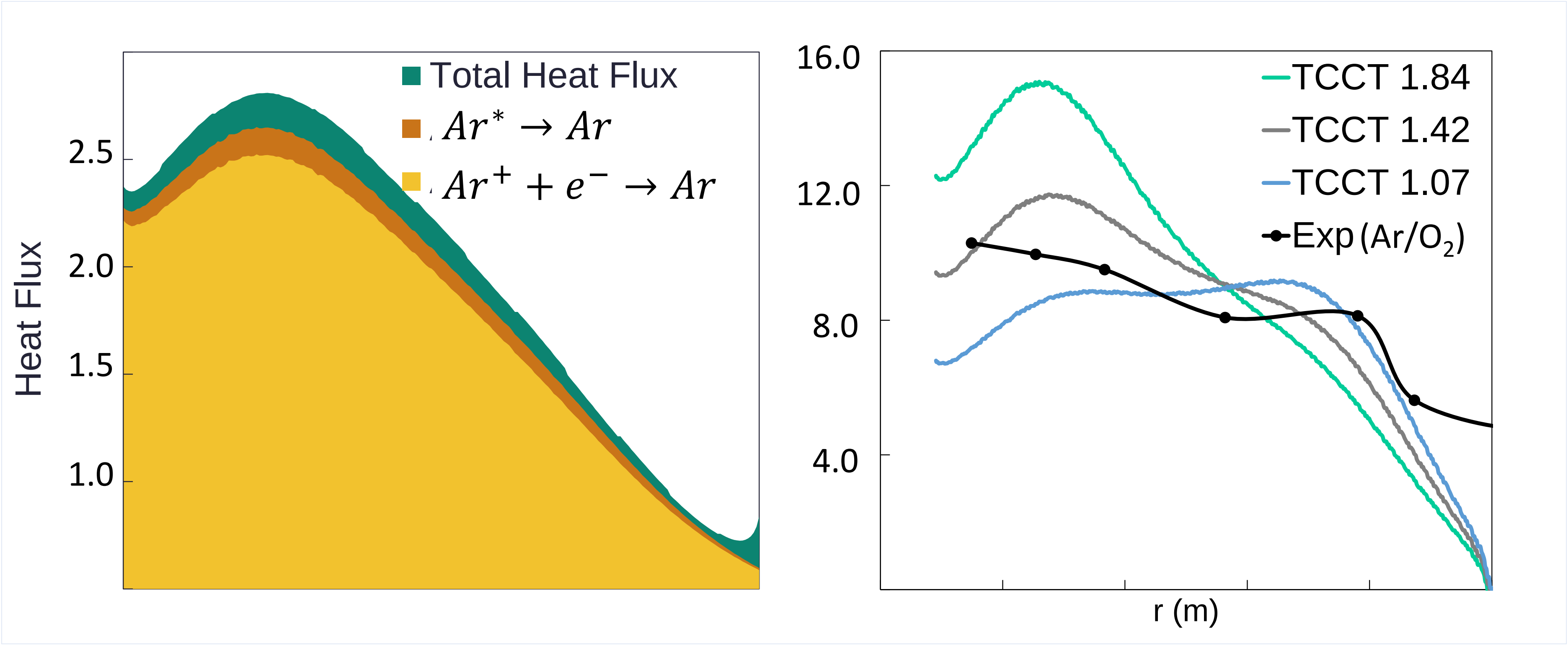


Figure 2. (Left) Contributions to TCP-window heat flux with TCP power = 800W TCCT 1.84. (Right) Comparison of heat-flux predictions from COMSOL simulations for various TCCTs against experimental data with TCP power = 2500W.

REFERENCES

1. P Baille et al 1981 J. Phys. B: Atom. Mol. Phys. 14 1485
2. COMSOL 5.5 User's Manual: Plasma Module
3. Kushner, Mark J. Journal of Physics D: Applied Physics 42.19 (2009)

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