Measuring the electron density in an Extreme Ultra-Violet generated plasma

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Elementary Processes in Gas discharges

Measuring the electron density in an Extreme Ultra-Violet generated plasma

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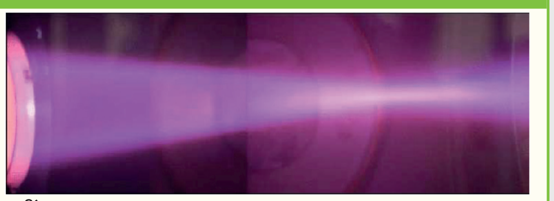
Introduction

Industries are continuously striving to reduce the size of computer chips in order to meet the demand of increasing computer speed and memory capacity. One way to miniaturize the chips is by reducing the wavelength used in lithography machines by using Extreme Ultra-Violet (EUV, 92 eV) light. Background gas in the lithography machine is partially ionized by the absorption of EUV photons. The study of this small low-density (10^{15} m^{-3}) pulsed plasma is experimentally challenging.

Goal

Determine the temporally resolved electron density in an EUV generated plasma.

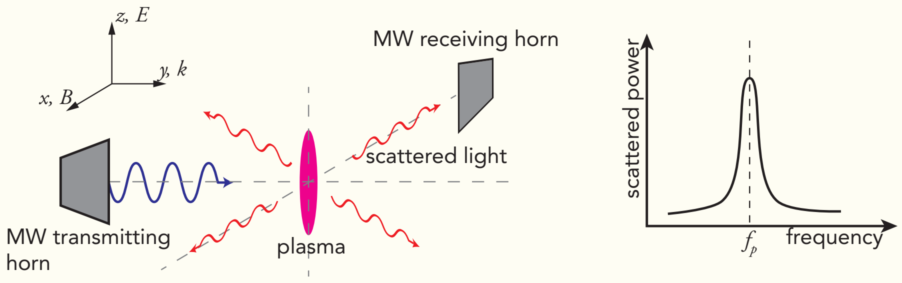
EUV plasma parameters



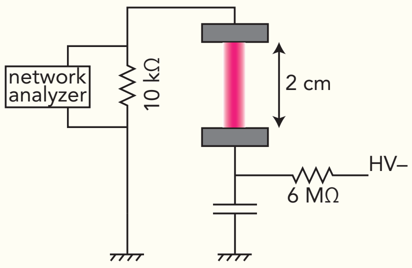
- Short (sub-μs) EUV pulse
- EUV transparent gasses (e.g. H_2 and He)
- Pressures < 1Pa
- Low electron density (10^{15} m^{-3})
- A DC discharge is used as a simulation plasma to test the diagnostics

Microwave scattering

- Oscillating dipole moment in plasma due to MW [1]
- Scattered power has maximum @ f_p



- As a first test: determine impedance of the test plasma [2]
  - Dip in reflectivity @ $a{\cdot}f_p$, $a<0$
  - Peak in impedance @ f_p
- Neither are observed



Conclusion and Outlook

- No plasma effects visible in plasma scattering measurements
  - Improve set-up to suppress non-plasma related effects
- MCRS proved to be able to measure 10^{14} m^{-3} in a small plasma
  - Characterize EUV cavity
  - Measure electron density in EUV generated plasma

Acknowledgements

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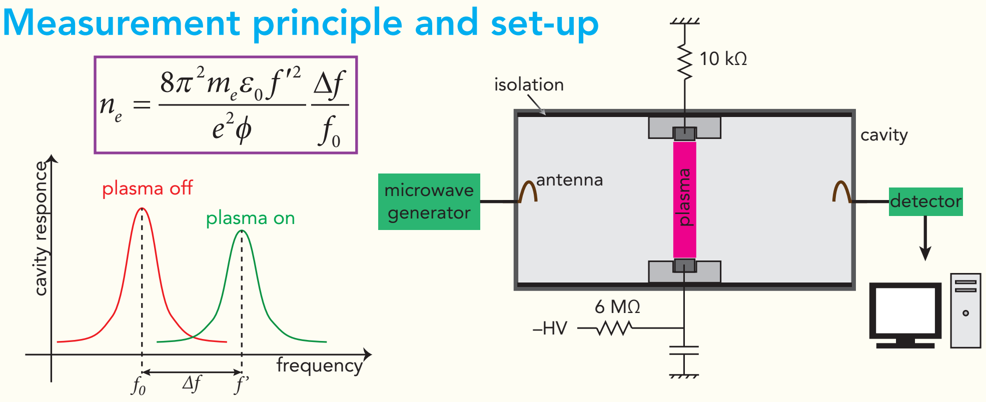
Microwave cavity resonance spectroscopy

Measurement principle and set-up

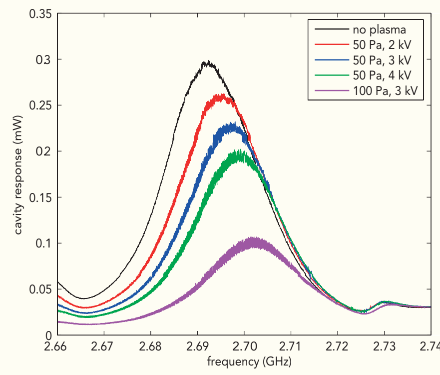
$$n_e = \frac{8\pi^2 m_e \varepsilon_0 f'^2}{e^2 \phi} \frac{\Delta f}{f_0}$$



Results of DC discharge in DC cavity

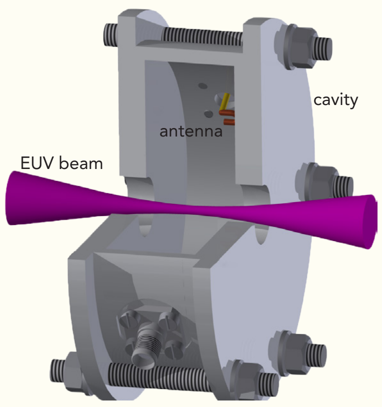
- Accuracy of frequency shift: 100 kHz
  - Detection limit: $n_e = 10^{14}$ m^{-3}
- Shift observed due to plasma
  - Lower response

pressure	voltage	density
50 Pa	2 kV	$1.8{\cdot}10^{15}$ m^{-3}
50 Pa	3 kV	$2.2{\cdot}10^{15}$ m^{-3}
50 Pa	4 kV	$2.3{\cdot}10^{15}$ m^{-3}
100 Pa	3 kV	$5.8{\cdot}10^{15}$ m^{-3}

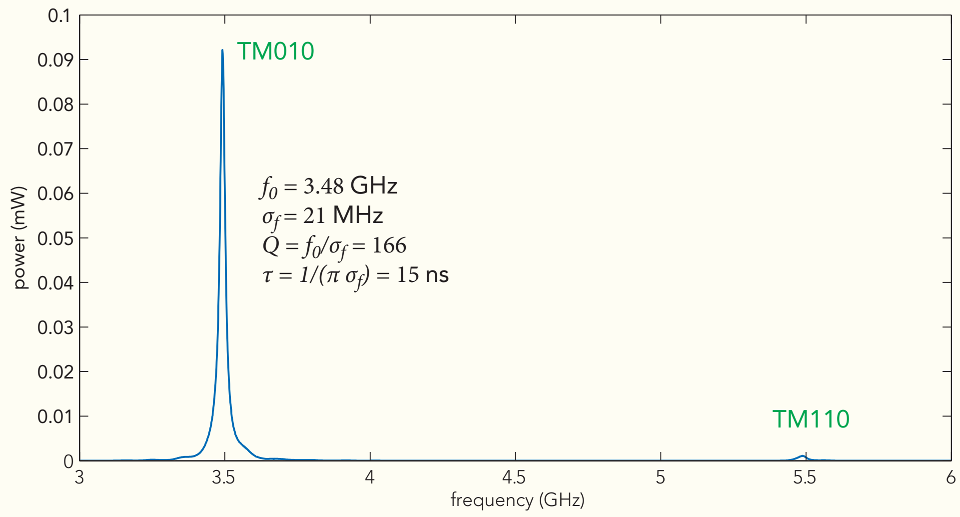


Preliminary spectrum EUV cavity

- Accuracy of frequency shift: <20 kHz
  - **Detection limit: $n_e < 3 \cdot 10^{13}$ m^{-3}**
- **Response time: 15 ns**
- Resonance frequencies correspond to theoretical values



Mode	Theory	Experiment
TM010	3.477 GHz	3.482 GHz
TM110	5.54 GHz	5.49 GHz



References

[1] Z. Zhang, *IEEE Trans. Plasma. Sci.* **39**:593-595 (2011)
[2] W.E. Amatucci, D.N. Walker, D.D. Blackwell, Navel Research Laboratory, NRL/MR/6750-04-8811 (2004)