The SOARING High Repetition Rate Discharge EUV Source

RISING ABOVE THE CHALLENGE

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Abstract

Within the EU IST project SOARING, a new concept for a high frequency discharge based EUV radiation source is being developed.

Compared with current devices, the new device applies a substantially smaller amount of electrical energy (<<1J) into a smaller plasma volume but in a much shorter time scale (< 10 ns), with current rate of rise exceeding 10^{12} A/s. This high rate of energy input in a short pulse leads to a higher overall energy efficiency in radiation production, and as a direct result, permits operating frequency in the multi-kHz regime without reaching thermal loading problem.

Current technology developed for discharge based plasma sources is expected to be limited by thermal loading and scaling to the required high frequency operation could be a show stopper.

Detailed numerical modelling using the 2-D radiation MHD code Z* has been carried out to allow tuning of the operating parameters in terms of operating pressure, discharge current, discharge geometry and gas mixture. The results are compared with experimental measurements in different admixture of Xe, Kr and He.

The plasma characteristics and radiation performance in the EUV region obtained in both simulation and experiments are presented.

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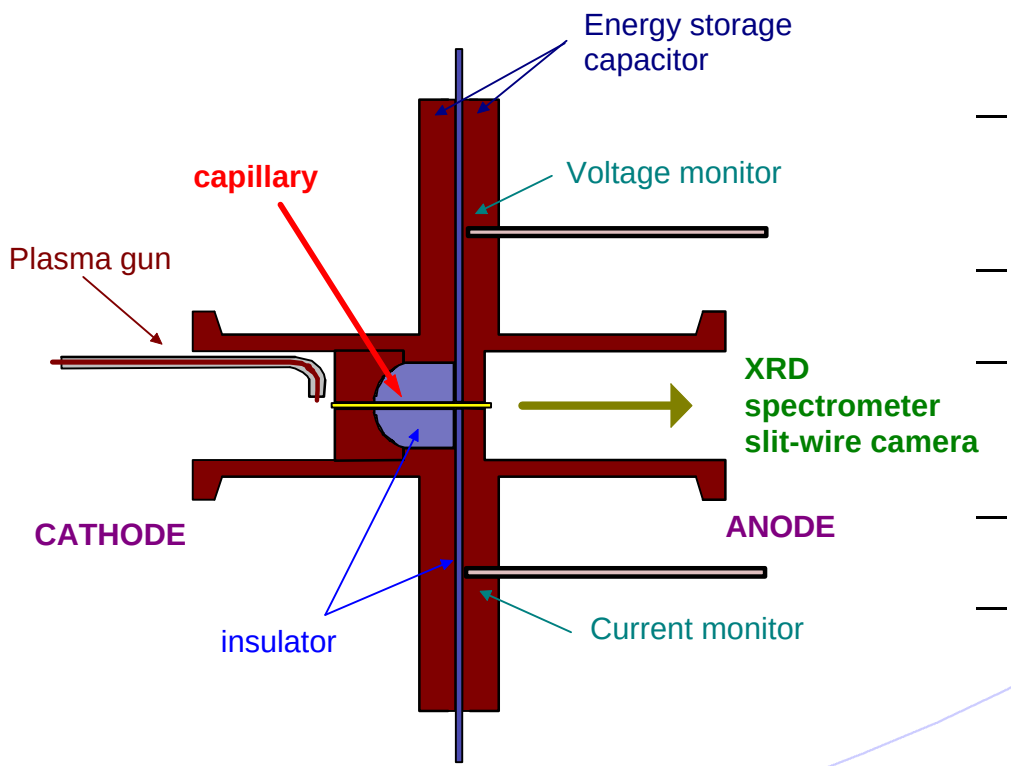
Ultra-bright EUV Source

pulsed hollow cathode capillary discharge



- pulse charged local energy storage
- sub-mm diameter capillary
- hollow cathode e-beam for on-axis discharge initiation
- rapid current heating
- ultra-bright high energy density radiator

Repetitive EUV Lithography Source

optimum solution

Micro Plasma Pulse Discharge Radiation Source

- micro plasma pinch configuration
- 10^5 μm^{-3} radiation source
- 0.25 mJ collectable in 2% band at 13.4 nm
- 0.1 J stored energy per pulse
- 5 kHz repetition rate
- scalable multiple units multiplex structure

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SOARING Repetitive EUV Source

programme of investigation

- ionization growth and discharge formation
  - optimize on-axis discharge formation
- plasma dynamics
  - optimize plasma properties for in-band radiation
- radiation dynamics
  - optimize radiation yield and stability
- pulsed power
  - optimize current coupling & energy efficiency

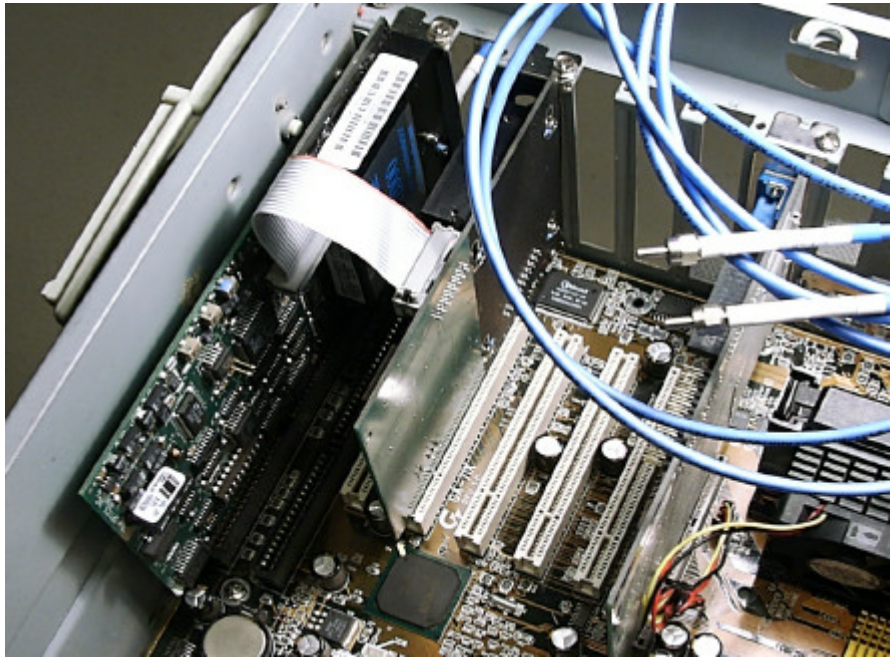
Repetitive EUV Source

current tasks

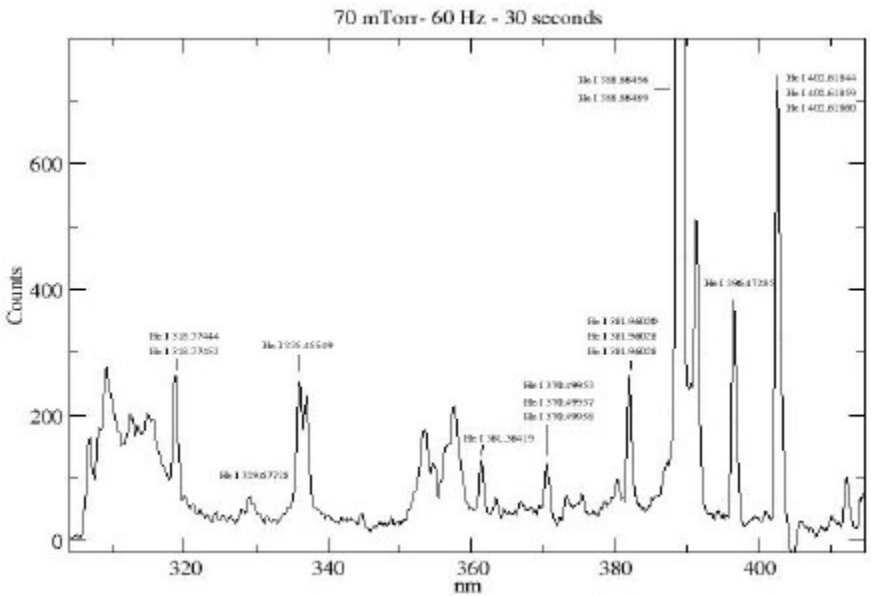
- HCR control
- HCD plasma spectroscopy
- EUV flux measurement
- Erosion studies - residual gas analysis
- He:Xe / He:Kr mixture studies
- pulsed power driver development

HCR Control

HCD plasma spectroscopy



He Spectrum



OceanOptics UV/Visible FO spectrometers

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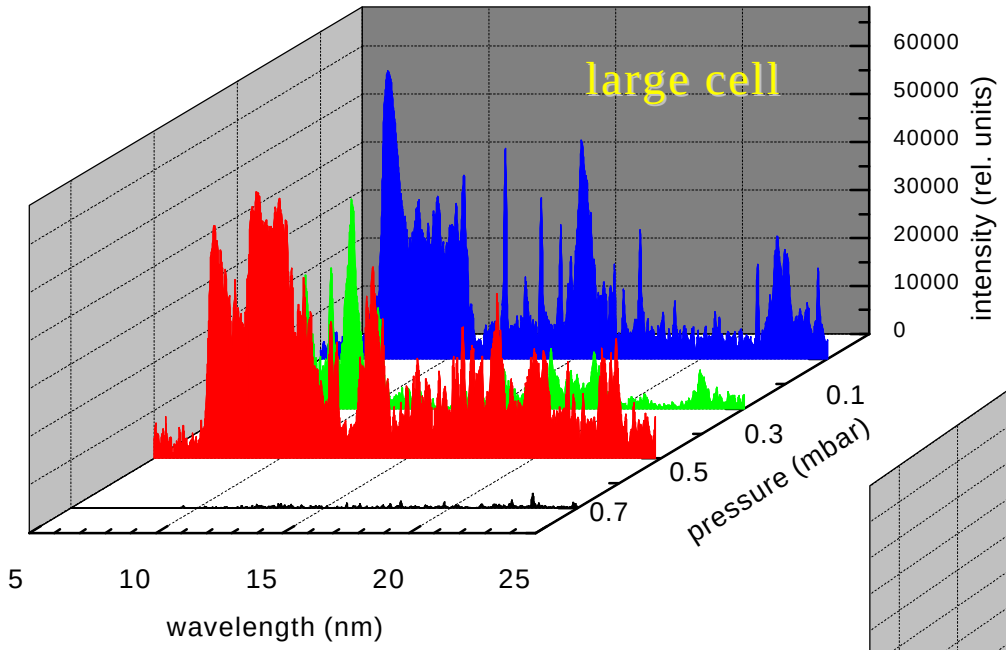
Repetitive EUV Source

EUV flux measurements

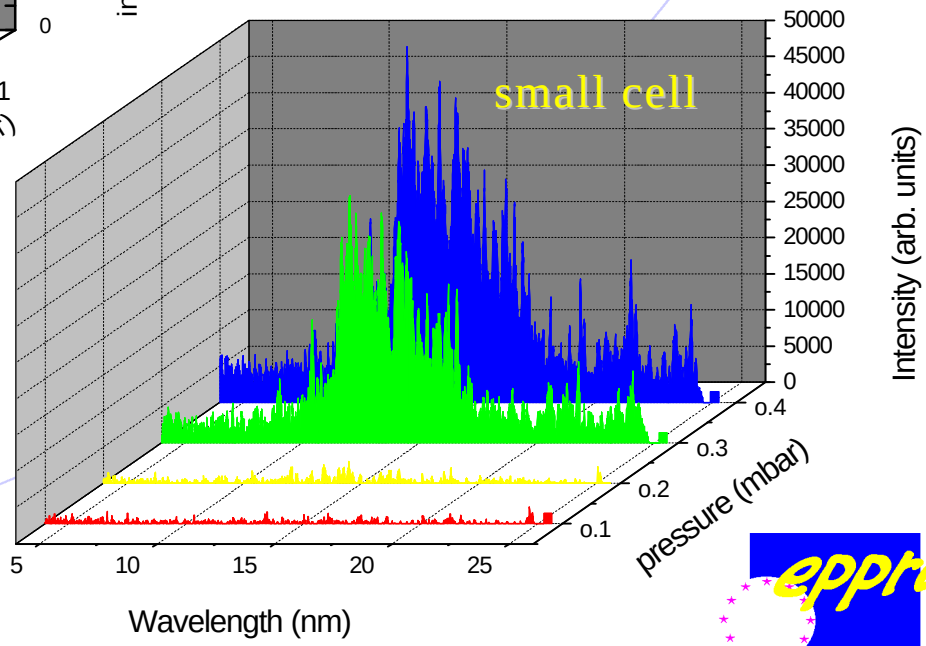
- Detectors
  - bare surface XRDs
  - AXUV diodes
  - micro channel plate detectors
- Measurement Schemes - time resolved
  - transmission filters
  - multilayer spectrometer I
  - multilayer spectrometer II
  - VUV spectrograph

EUV Measurement

VUV spectrograph



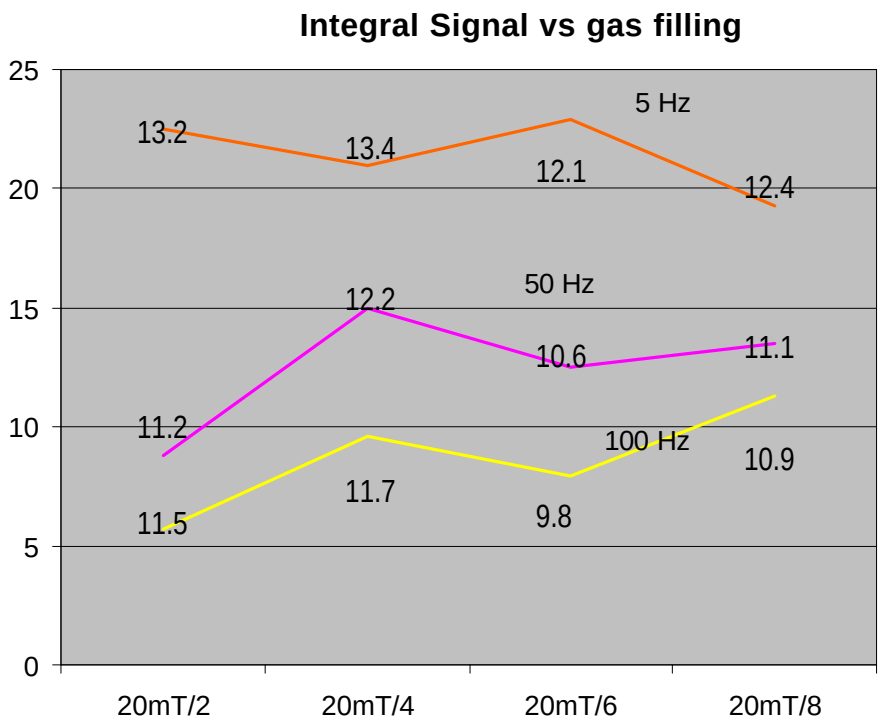
Xe

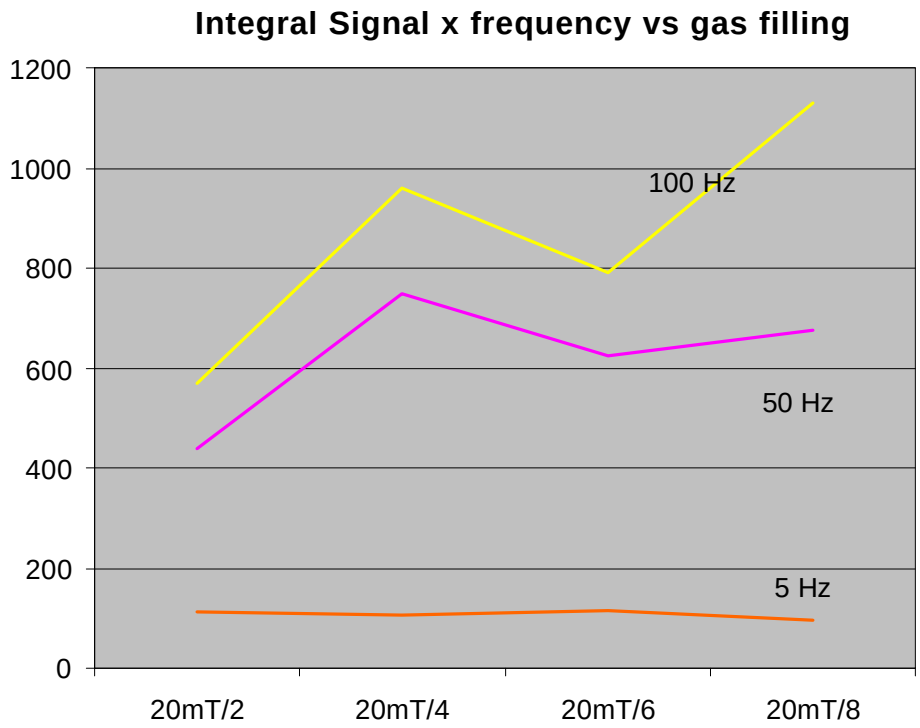


high and low energy store

EUV Measurement

bare cathode XRDs



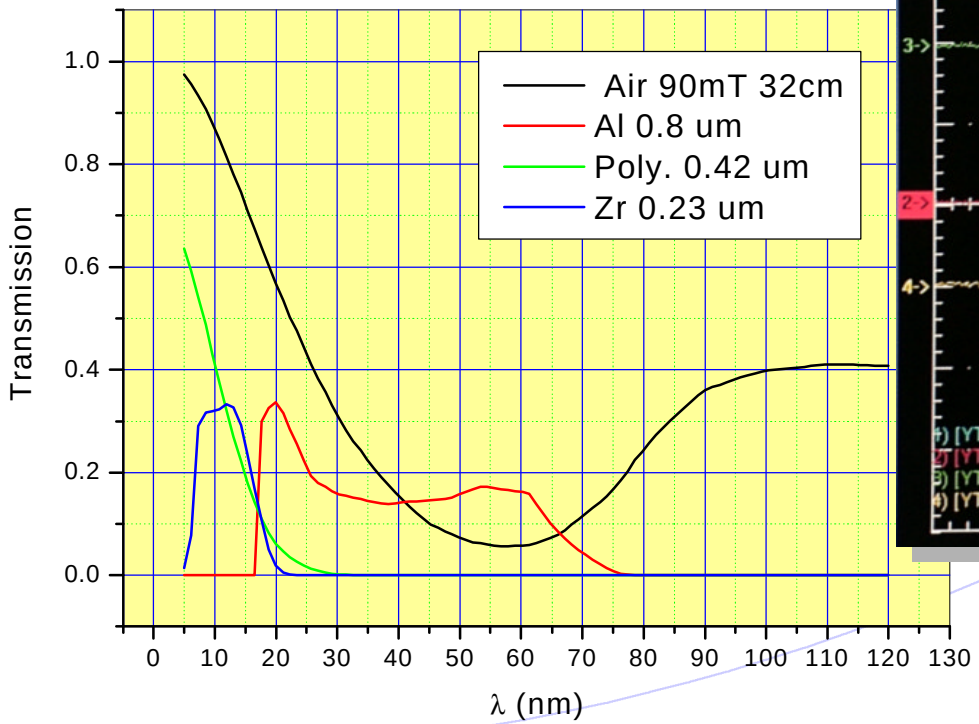


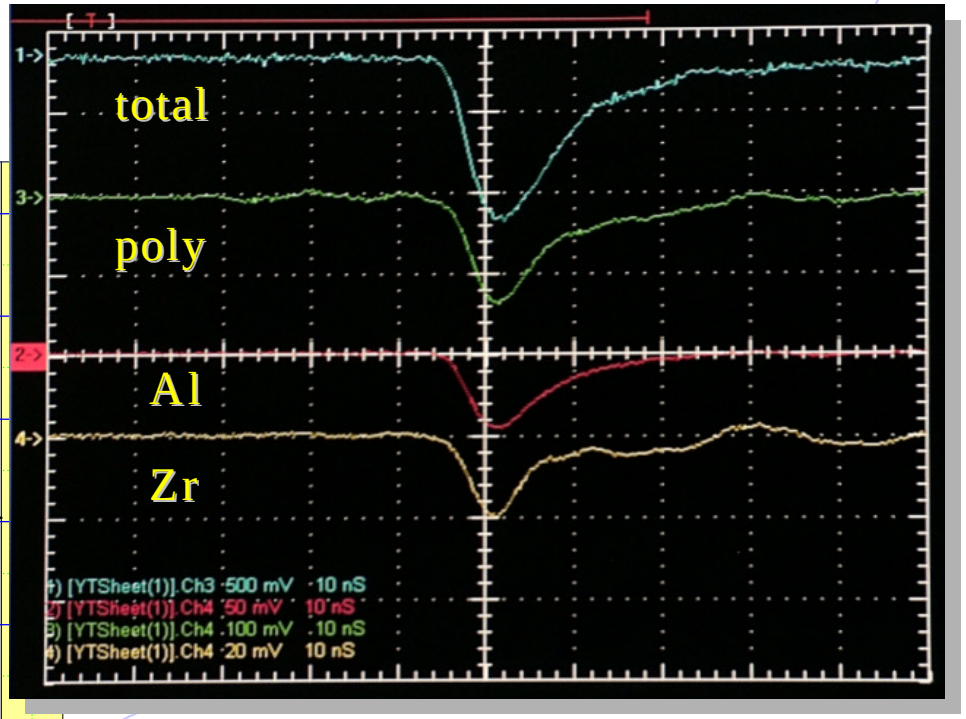
He:Kr mixtures

EUV Measurement

filtered AXUV diodes

spectral distribution

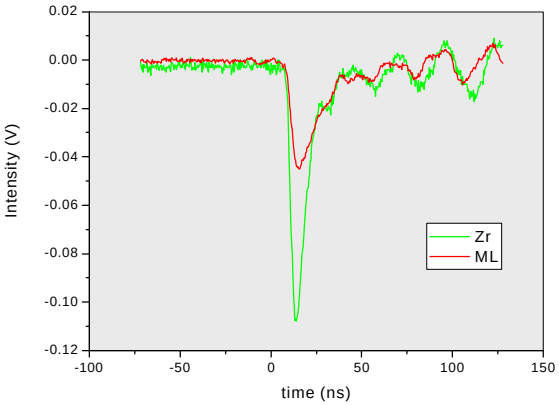


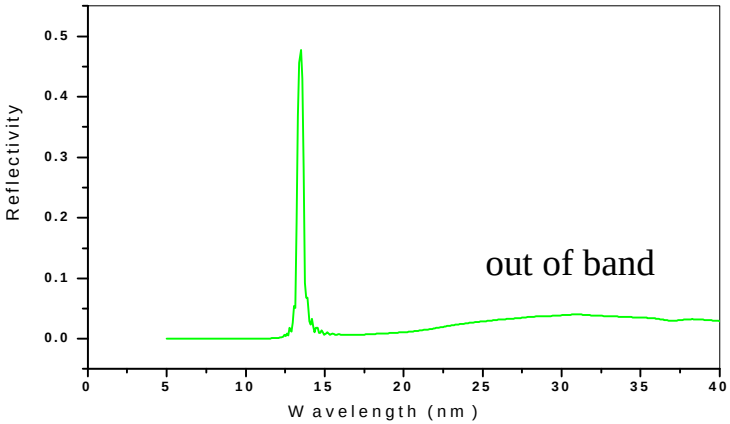


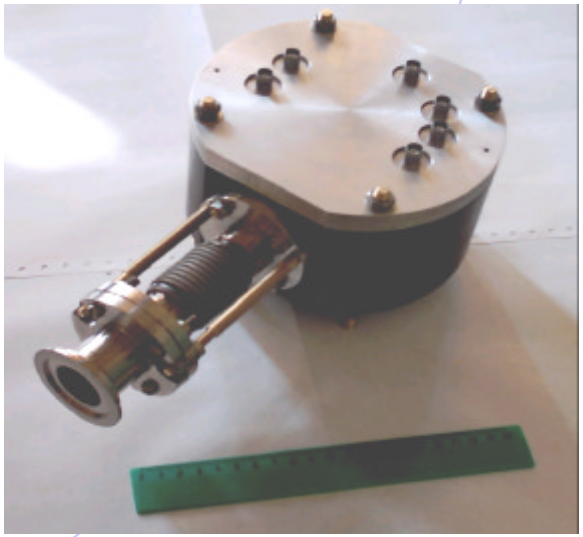
Xe:He

EUV Measurement

2 channels multilayer mirror spectrometer I

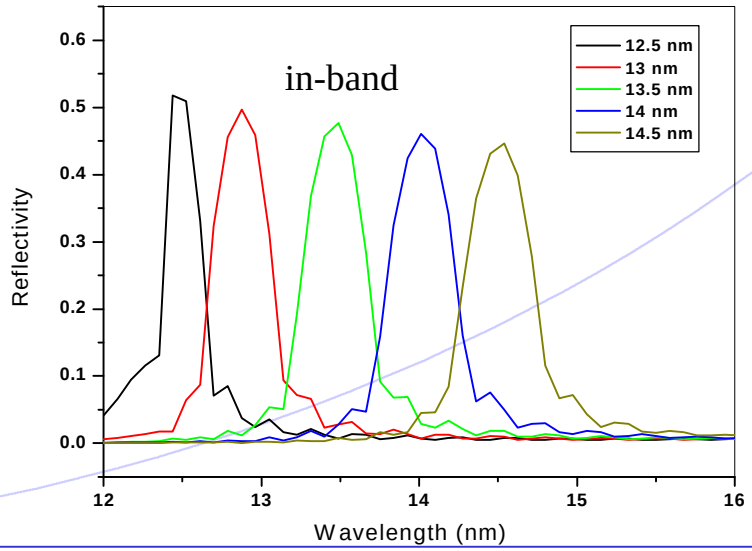






Xe:He

λ(nm)	ML/Zr
12.7	.33
13	.31
13.5	.32
14	.34

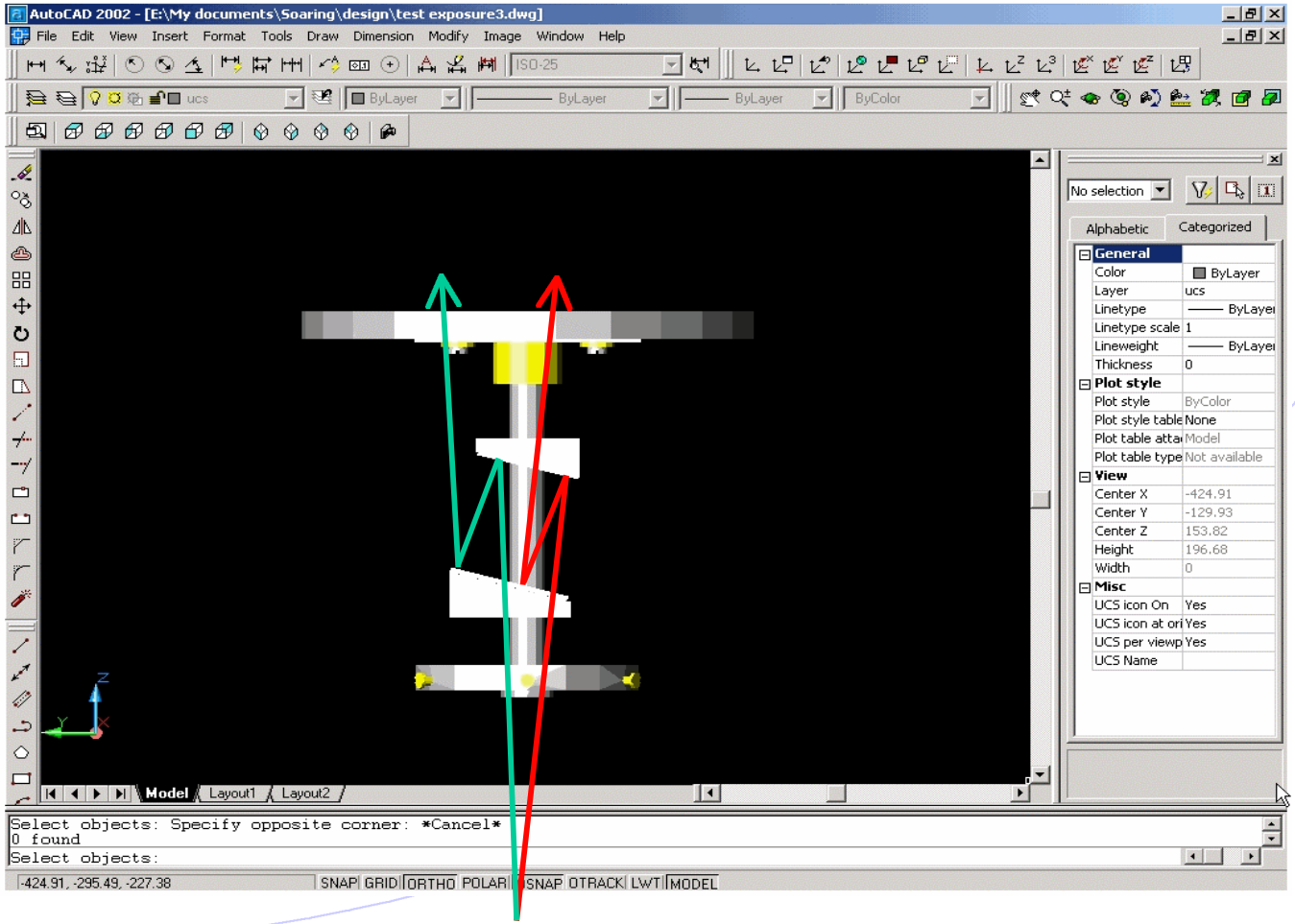


channel 1 - Zr filtered

channel 2 - tunable ML

EUV Measurement

2 channels multilayer mirror spectrometer II



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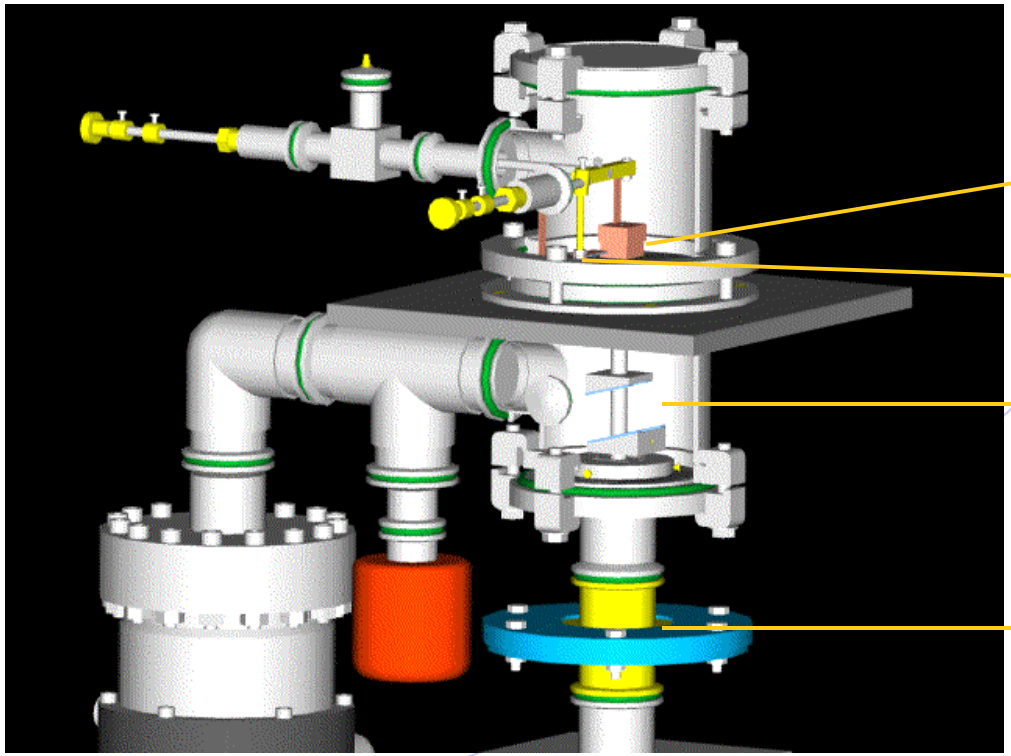
EUV Application

compact resists exposure station

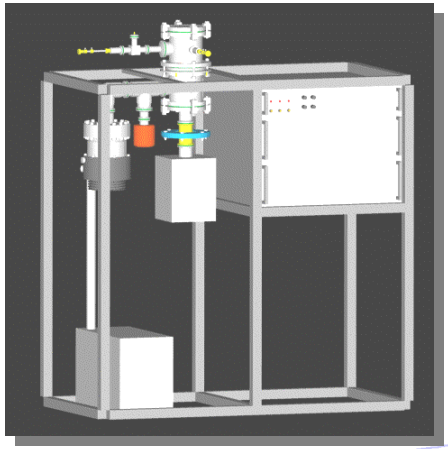


tunable EUV monitor

stepping resists stage

2 channels
Double ML stage

EUV source



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Z* for EUV source optimization

Simple changes in discharge geometry can make strong influences on Plasma and Radiation characteristics

Further details on accompanying poster on Z*

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Code Z*

2-D plasma modelling

Core-processor ZERMHD

2D RMHD with finite conductivity and displacement current

- 2D cylindrically symmetric geometry; (r, φ, z) field components
- plasma & solid dynamics, Lagrange-Euler fully conservative scheme
- multi-group radiation transport, non-equilibrium

Pre-processor THERMOS

LTE, non-LTE tables, EOS of complex ion compositions

- plasma kinetic coefficients
- detailed spectral radiation coefficients (opacity, emissivity)

Post-processor RAY

3 dimensional radiation transport

- detailed radiation spectra for complex ions

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Z* Optimization

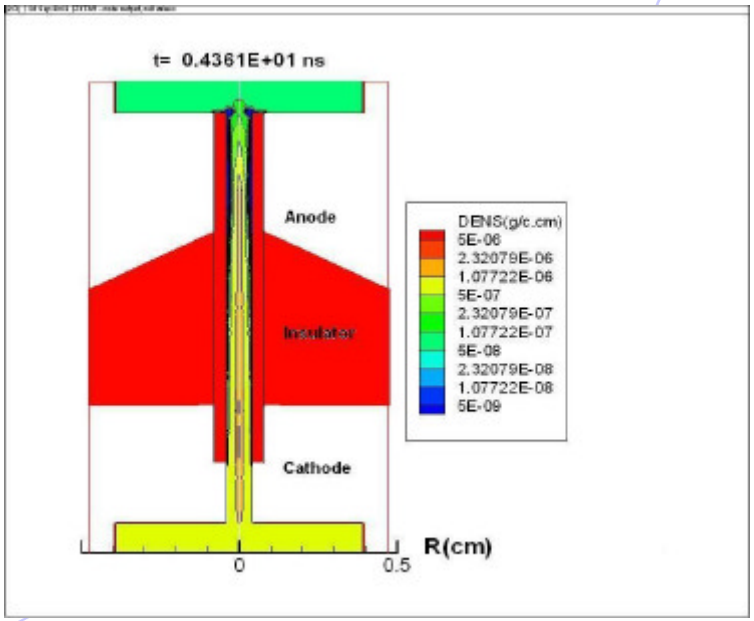
modelling parameters

Power source

Charge energy	80mJ
Current	3 - 6kA
Pulse	6ns

Capillary	∅ 0.8-1.6mm
dimension:	L = 6-12mm

Gas: 0.1-1mbar, Xe, 10%Xe+90%He
Kr, 10%Kr+90%He



CD radiation source features

In-band (13-14nm) emission 0.1mJ

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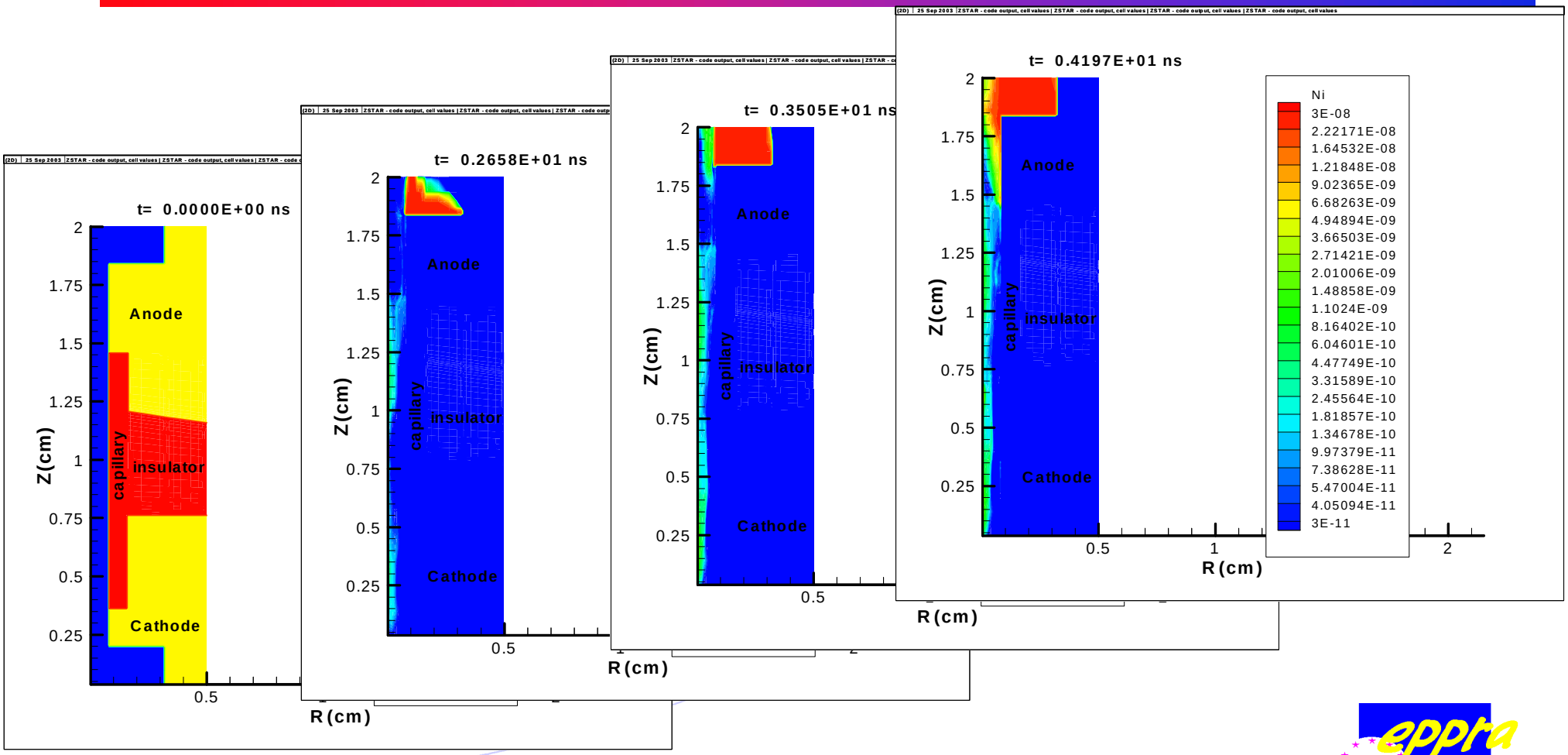
Initial ionization

ionization waves formation



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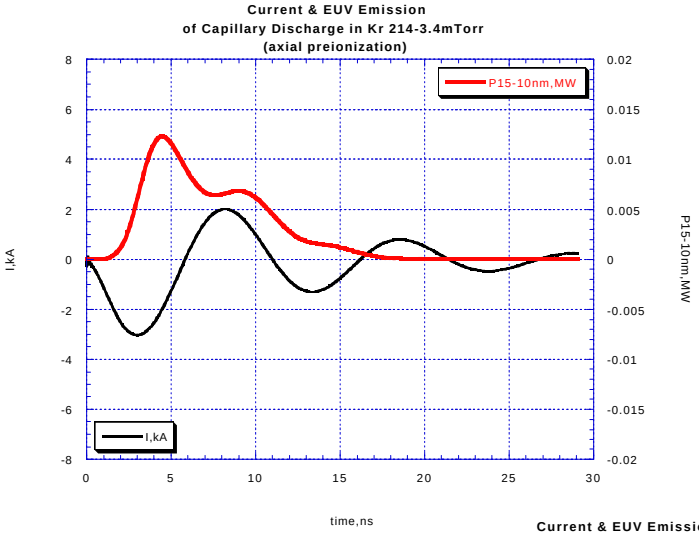
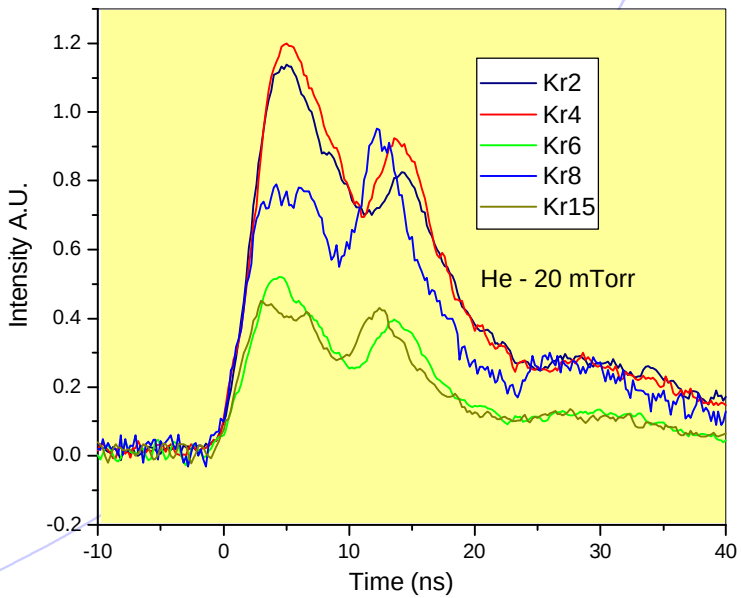
Z* Simulation

radiation history

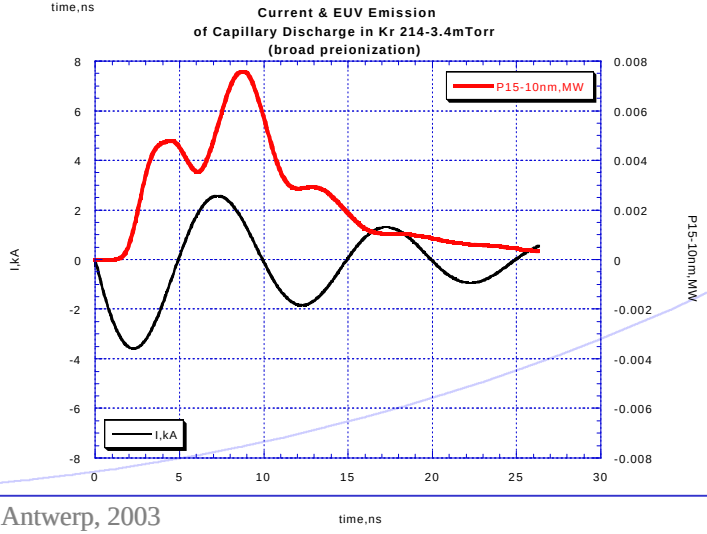


He:Kr mixtures

Experimental XRD signals



Effect of preionization



Effect of gas mixture

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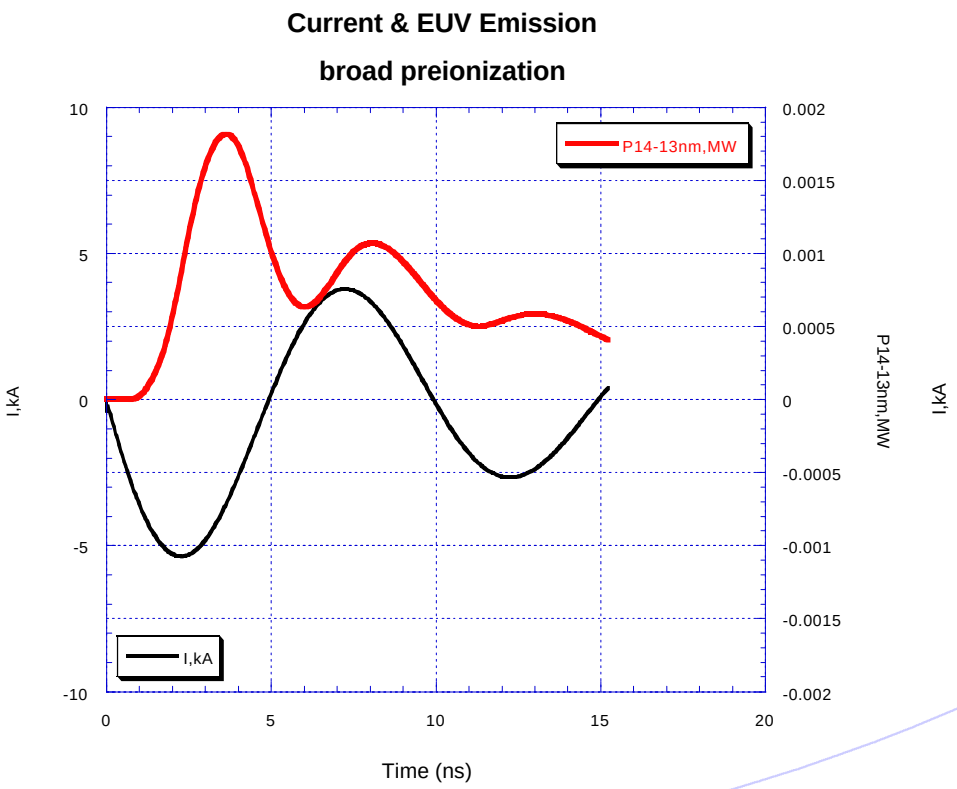
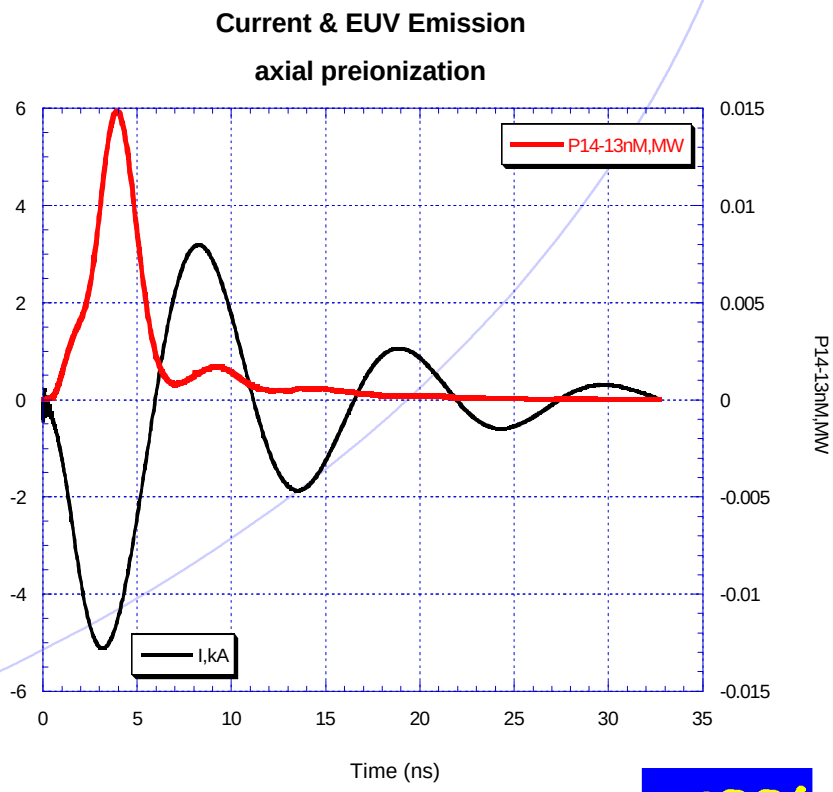
Z* Simulation

radiation history

He:Xe mixtures





He - 107 mtorr : Xe - 1.7 mtorr

Hitting The Right Condition

controlling parameters

- Electron Density
- Electron Temperature
- Ion Density
- Ion Population
- Current density distribution

all varying rapidly in time

Putting in
the Right amount of energy
when it counts,
where it counts.

Acknowledgement

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