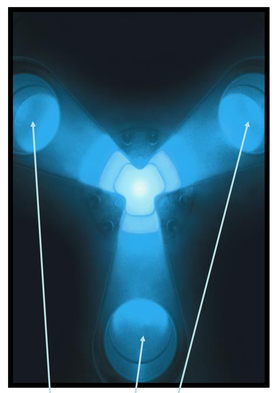
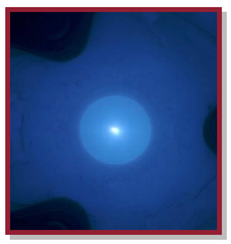
Simulation of a Discharge Produced Plasma (DPP) for Blue-X (6.x nm) EUV radiation

David Reisman, Kosuke Saito, Wolfram Neff
Energetiq Technology, Inc.

INTRODUCTION

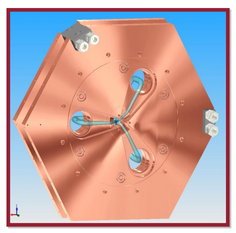
The EQ-10 Electrodeless Z-pinch™ source uses Xenon plasma to produce 13.5 nm (±1% BW) radiation. The source is used for metrology, mask inspection, and resist development. In this talk we will present modeling of the EQ-10 Z-pinch using the Trac-II radiation magnetohydrodynamic (RMHD) code. Specifically, we use RMHD calculations to explore development of the Electrodeless Z-pinch as a source of Blue-X (6.x nm) radiation. We revisit previous experimental attempts at obtaining Blue-X EUV radiation with neon gas. Having established a baseline of performance on our present Z-pinch system, we use RMHD calculations to scale to higher EUV power outputs of potential interest to the EUV community.



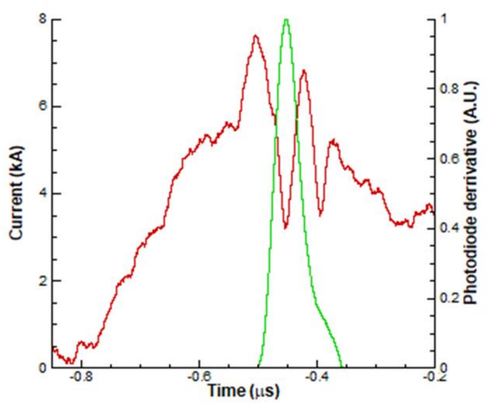


Electrodeless Z-pinch source developed to enable EUV lithography for semiconductor fabrication.

20 watts/2π, 13.5 nm, +/- 1% bandwidth. Xenon plasma. (Xe 10+) [1].



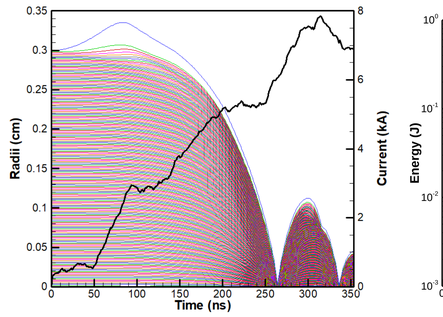
Blue-X results: 70 mW/2π, 6.7 nm, +/- 0.375% bandwidth. Neon plasma. (Ne 7+) [2].

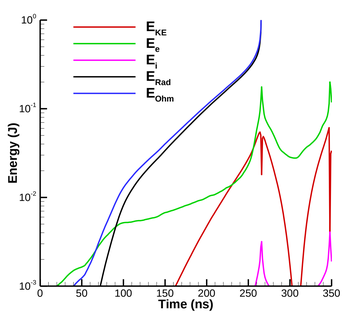


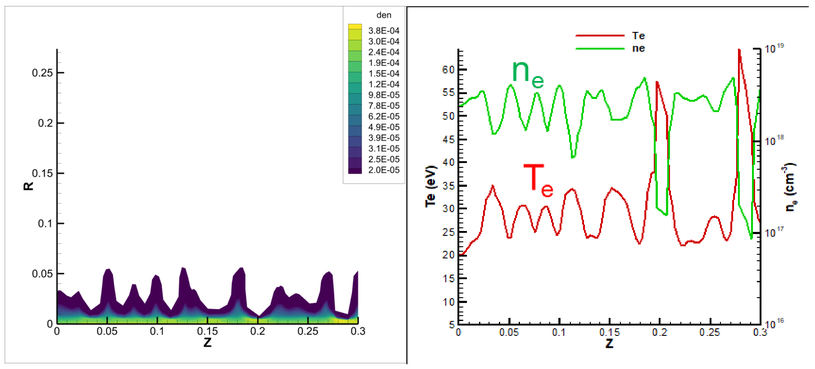
Typical current waveform for a Xenon pinch on the EQ-10. Also shown is the derivative of the photodiode signal.

METHODS

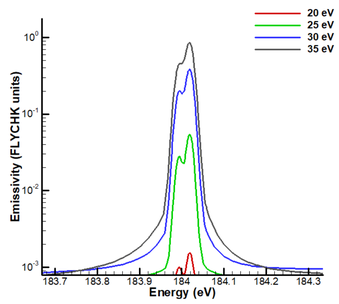
Calculations were performed with TRAC-II, a 2D azimuthally symmetric RMHD code. Shown are 1D/2D results for Xenon.



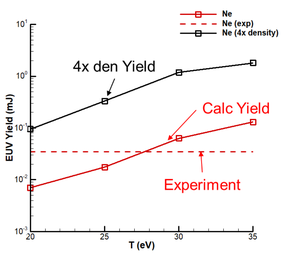




Neon results were reconsidered using the FLYCHK collisional radiative code [3]. Using experimental parameters, the EUV yield was calculated [4].



Pinch Quantity	Ne
ρ	1.0×10^{-5} g/cm^3
m	2.0×10^{-8} g/cm
r_0	3 mm
N_i	2.9×10^{17}cm^{-3}
N_e	2.1×10^{18}cm^{-3}
r_f	0.25 mm
length	13 mm
τ_d	10-20 ns

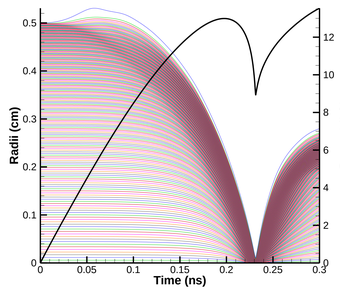


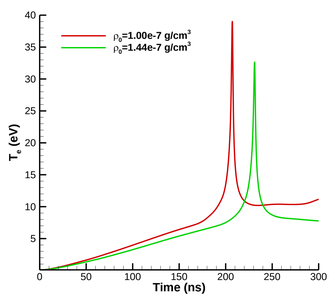
$$E_{EUV} = \int_{E_{min}}^{E_{max}} \varepsilon(E)dE \cdot e/h \cdot V \cdot \Omega \cdot \tau_d$$

FLYCHK shows previous results (70 mW/2π)are reasonable considering density of plasma. Need to attain higher final densities for >1 W /2π

RESULTS

Perform calculations with a “scaled” EQ-10 for increased pulse energy – circuit energy $E_c = \frac{1}{2}CV^2 = 6.2$ J. Increase mass of plasma (4-5x) to obtain higher density conditions.





Plasma density can be increased to obtain optimal conditions for 6.7 nm EUV

CONCLUSIONS

1. **The Blue-X EUV results for neon on the EQ-10 are reasonable based on FLYCHK estimates**
2. **Pinch density must be increased 3-4 times in order to obtain results in 1 W/2π range**
3. **This could be achieved with a more powerful driver in the range of 6 J/pulse electrical energy**

Ultimately these results will be refined by experiment and more accurate calculations using an inline CR treatment of EOS and radiation in a RMHD code. These efforts are currently underway with the goal of reaching useful power levels for the EUV community.

REFERENCES

1. S. F. Horne *et al.*, “Application of a high-brightness electrodeless Z-pinch EUV source for metrology, inspection, and resist development,” in Emerging Lithographic Technologies X, J. Proceedings of the SPIE, Volume 6151, pp. 201-210 (2006).
2. S.F. Horne *et al.*, “The Energetiq EQ-10 EUV source for metrology - Review of recent data” [Poster presentation], 2013 International Workshop on EUV and Soft X-Ray Sources (2013). https://www.euvlitho.com/2013/S29.pdf.
3. H.-K. Chung, M. Chen, W. Morgan, Y. Ralchenko, and R. Lee, High Energy Density Phys. 1, 3 (2005).
4. F. Conti *et al.*, Journal of Applied Physics 130, 023301 (2021).