Study of Z-pinch plasma dynamics for EUV source *

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Abstract

Extreme ultraviolet lithography (EUVL) using EUV radiation can provide a solution for high-volume manufacturing of semiconductor fabrication. EUV sources rest on Xe, Sn and Ar plasma has been investigated from all over the world. We studied simulation for discharge produced plasma (DPP) EUV source. Dependence of plasma conditions for EUV radiation were studied using a simulation code. To understand z-pinch plasma, its dynamics was numerically studied using one-dimensional Lagrangian code. In this code, ionization balance equation joined with single fluid, two-temperature magnetohydrodynamics (MHD) equations were solved. In case of Ar plasma, the transition 3p-3s of Ne-like Ar radiates 46.9 nm EUV. Plasma parameters such as plasma temperature, density of each ionized state and pinch time which give maximum Ar^{8+} density were evaluated using this code.

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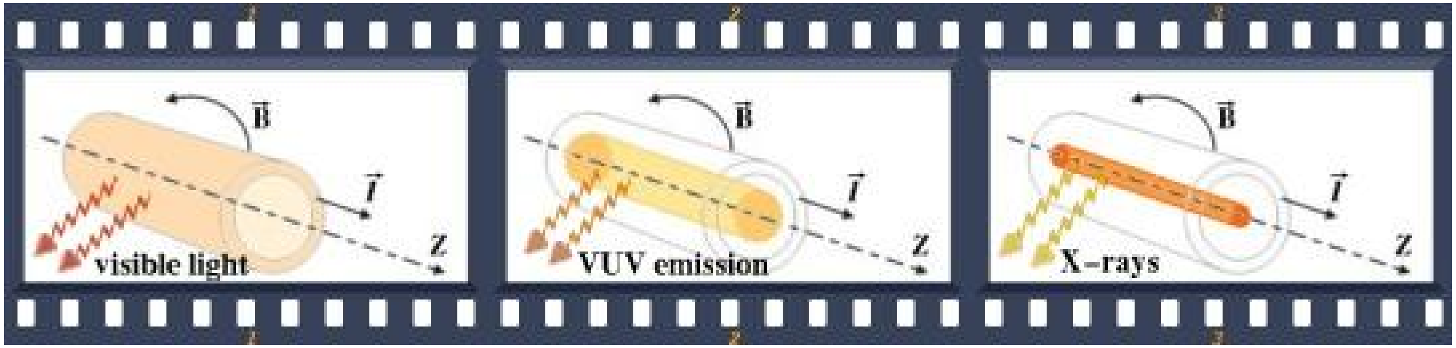
Introduction

In the Z-pinch system, hot and dense plasma is produced by applying a high voltage pulse across an anode-cathode gap of cylindrical geometry. The plasma is imploded by the azimuthal magnetic field produced by the axially flowing discharge current. During compression and stagnation, the kinetic energy is converted to thermal energy and radiation, and a hot and dense core is formed at the center. At this stage the plasma becomes highly unstable, resulting in disassembly, expansion and cooling. The duration of the implosion process is typically between 100 ns to 1 s. Highly stripped ions are formed during the thermalization phase, and the plasma emits mostly in the x-ray regime. This pulsed X-ray emission has many important future applications, being the main reason for current worldwide interest in Z-pinch plasmas.



Z-Pinch Plasma Simulation

Data set of Ionized States

CR code

- Screened H-Ion model

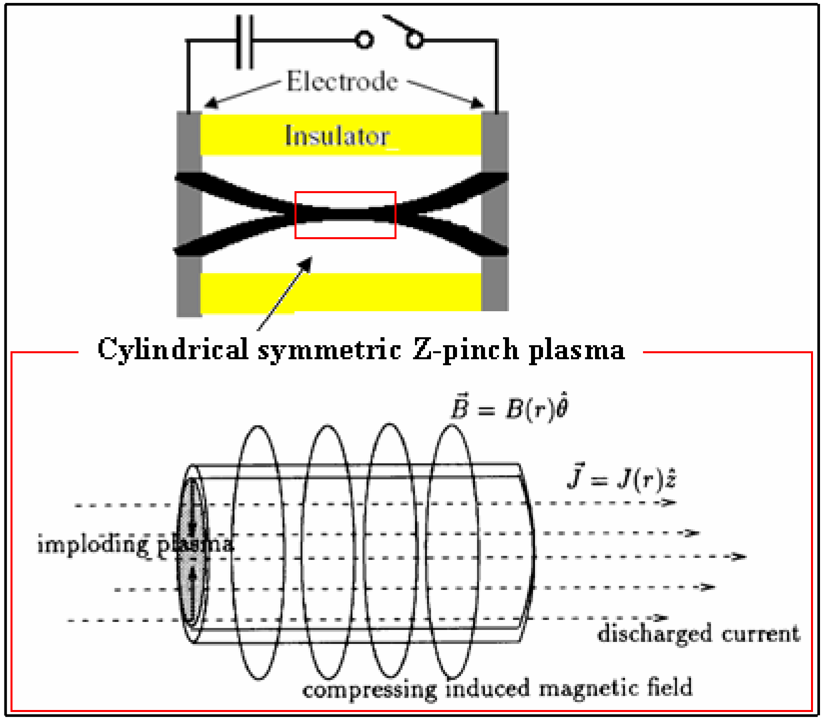
CR rates coefficients
population density
of each atomic levels
of H-like ion

Initial Condition
species & Initial j,
Initial n_e, n_i,
peak current,

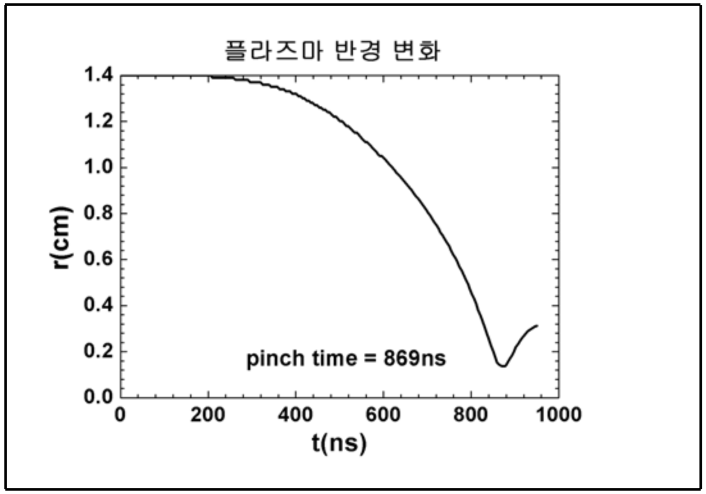
POSLAG Code

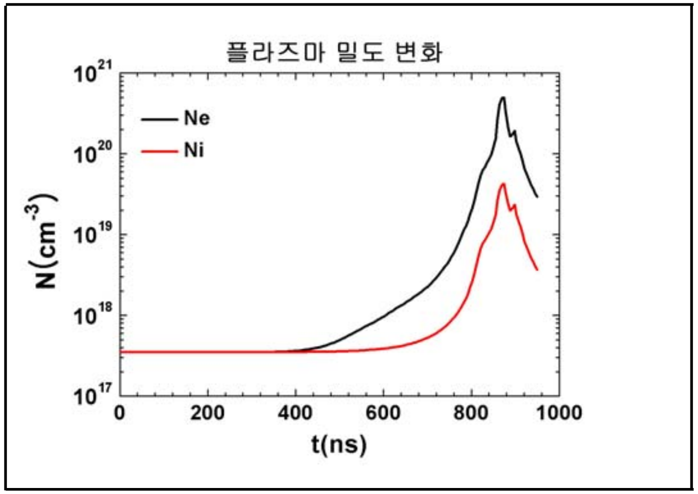
- 1D Lagrangian MHD
  - Continuity eqn
  - Momentum balance eqn
  - Energy balance eqn
  - ionization balance eqn
  - B field transport & diffusion eqn

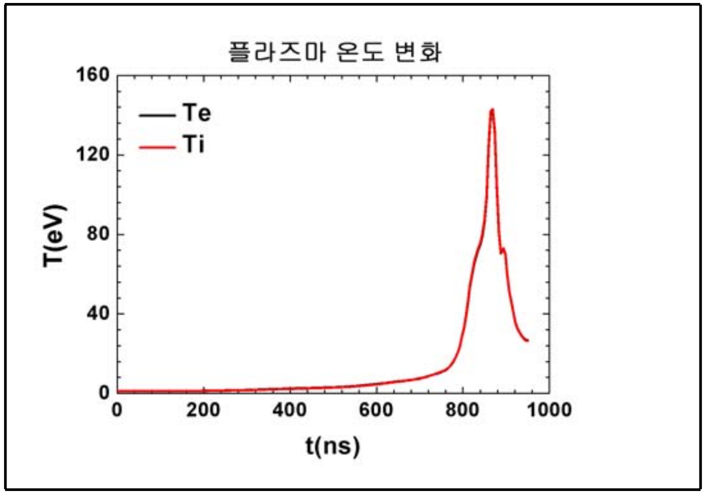
Plasma properties
at each Lagrange cell
(r, n, T, v, B, j, power, etc)

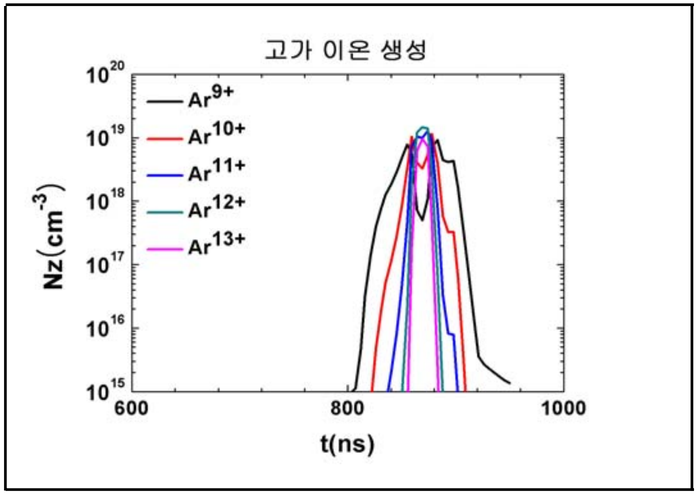


Temporal Variation of Argon Plasma on Axis

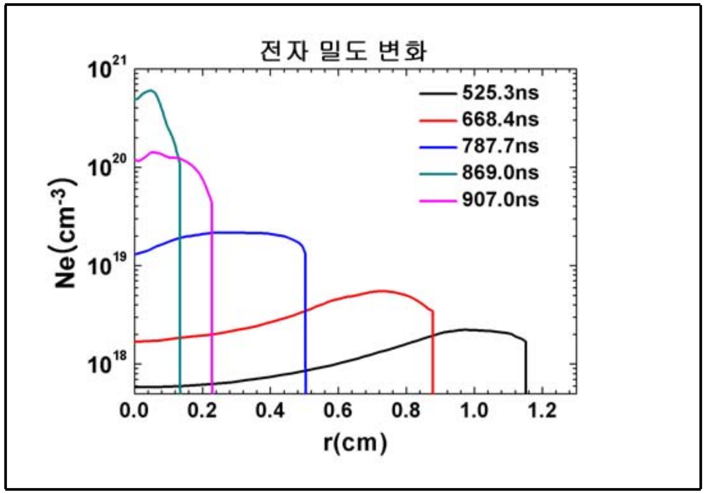


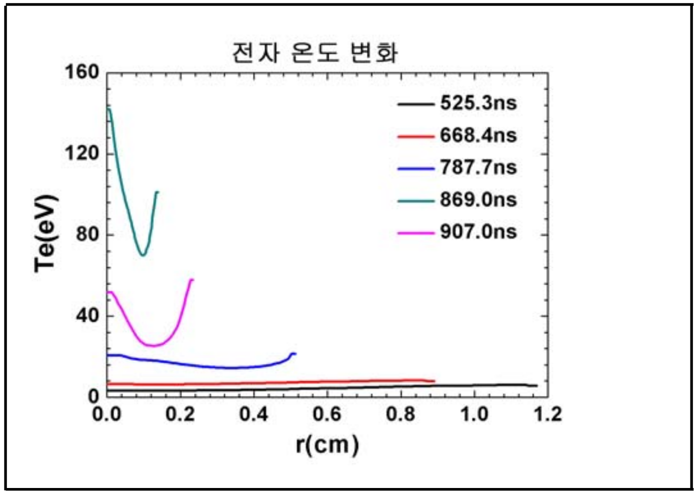


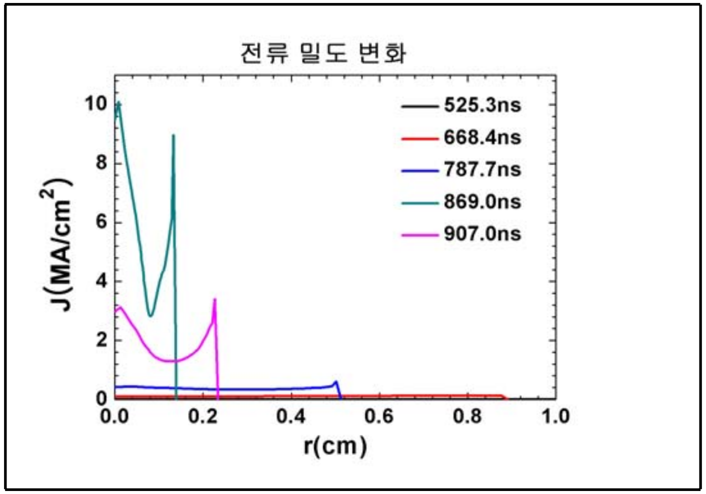


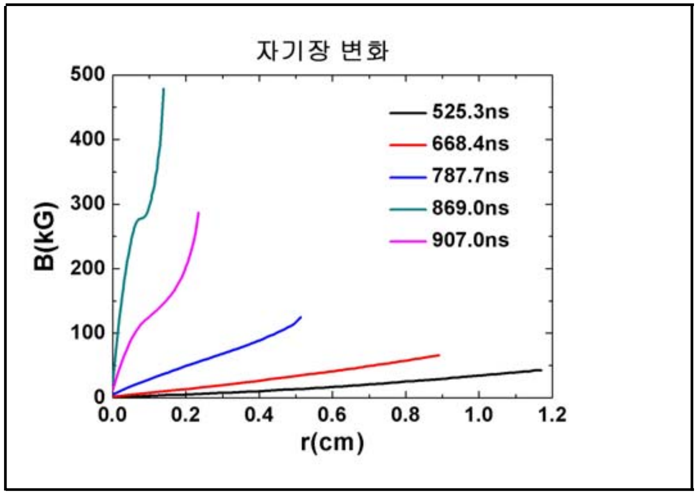


Spatial Distribution of Argon Plasma on Various Times

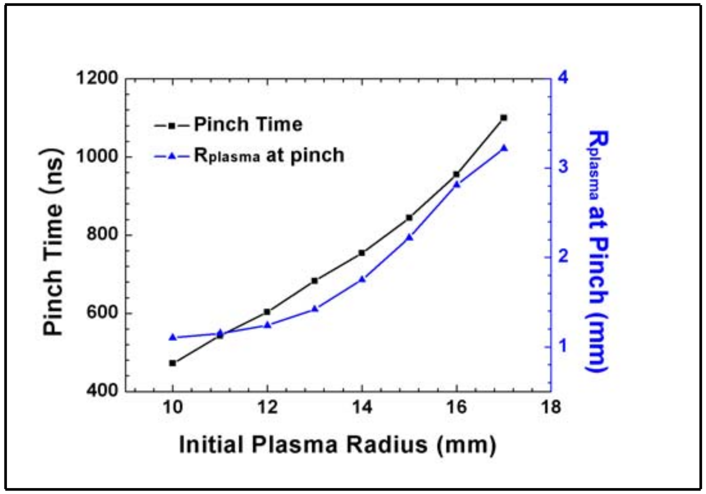








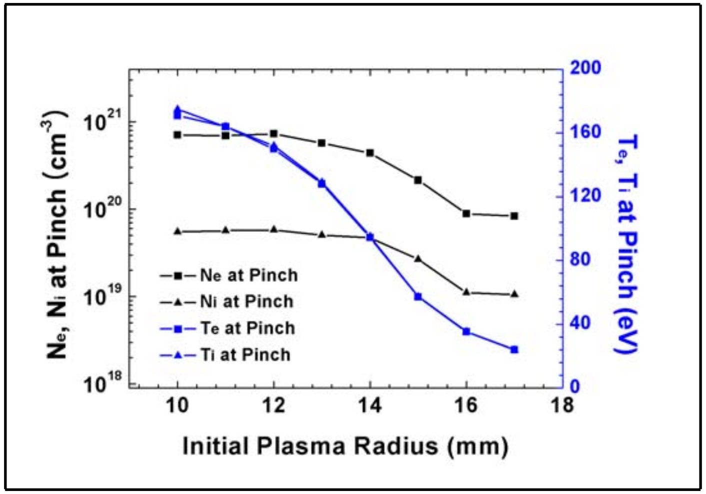
Effect of Initial Radius on Z-Pinch Dynamics

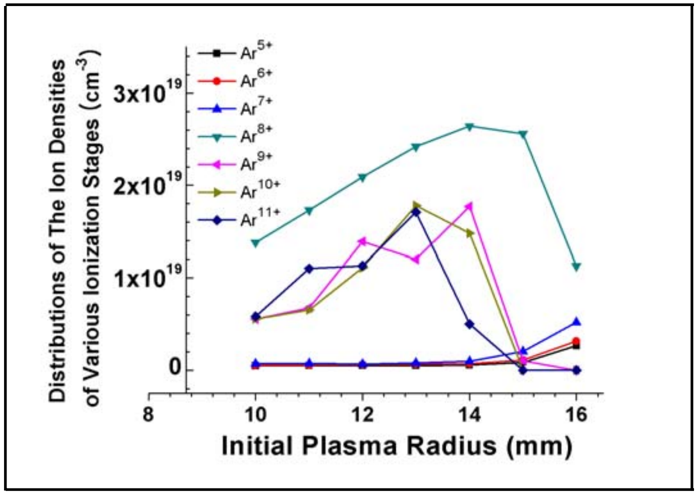


Initial Pressure : 0.7 mTorr

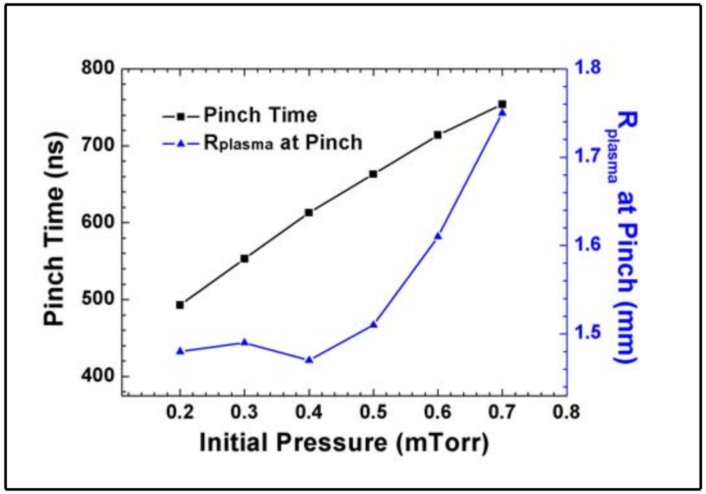
T = 2π/ω : 2 μs

Pulse Amplitude : 370 kA





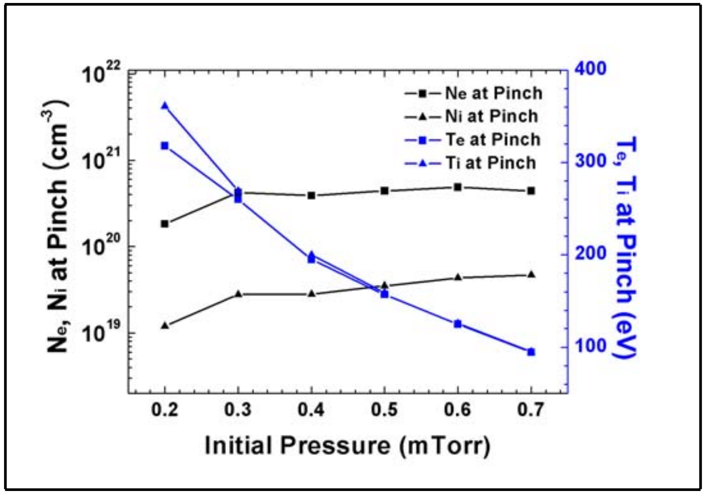
Effect of Initial Pressure on Z-Pinch Dynamics

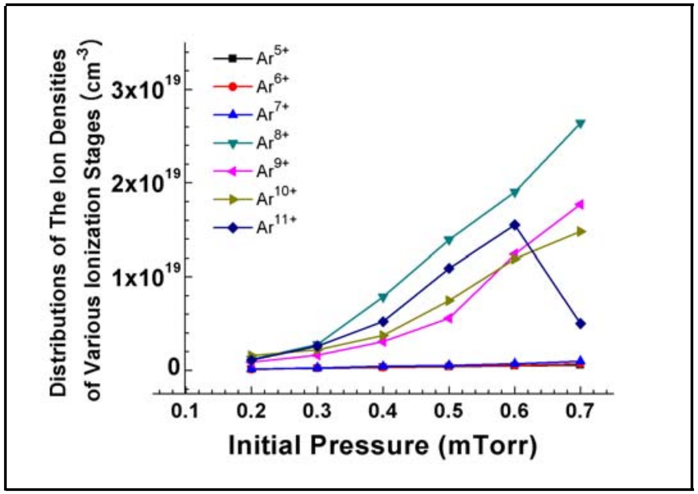


Initial Radius : 1.4 mm

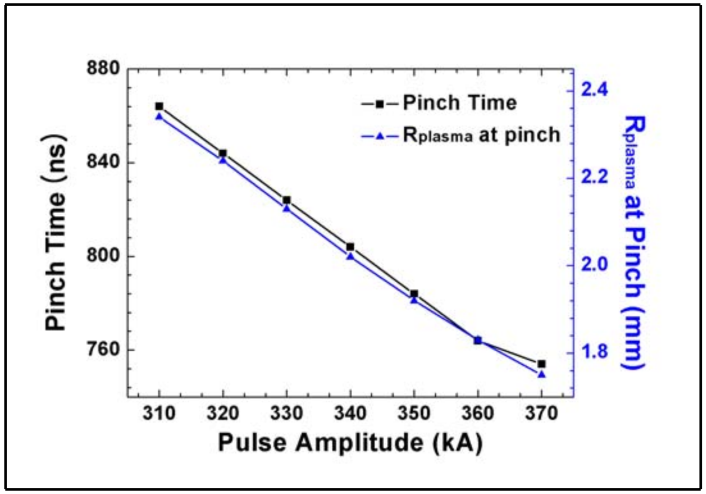
T = 2π/ω : 2 μs

Pulse Amplitude : 370 kA





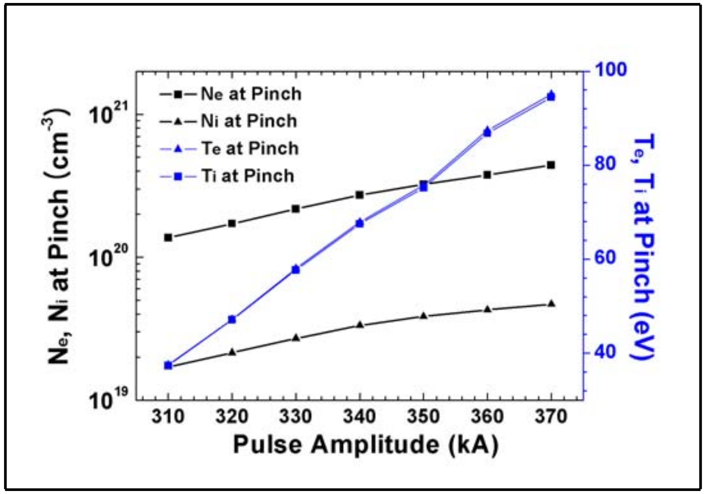
Effect of Pulse Amplitude on Z-pinch Dynamics

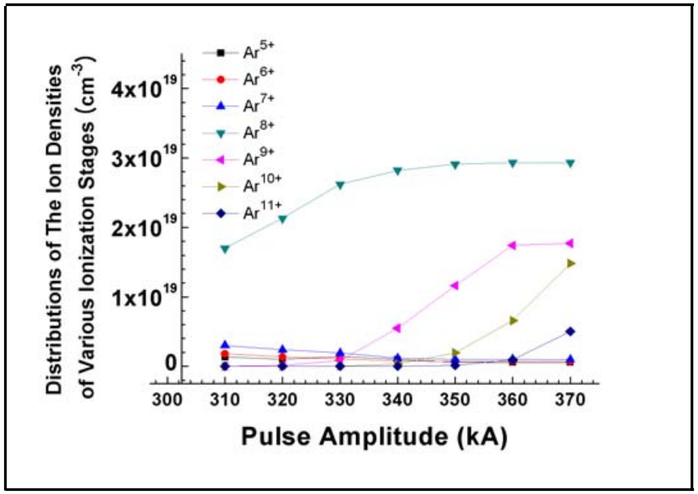


Initial Radius : 1.4 mm

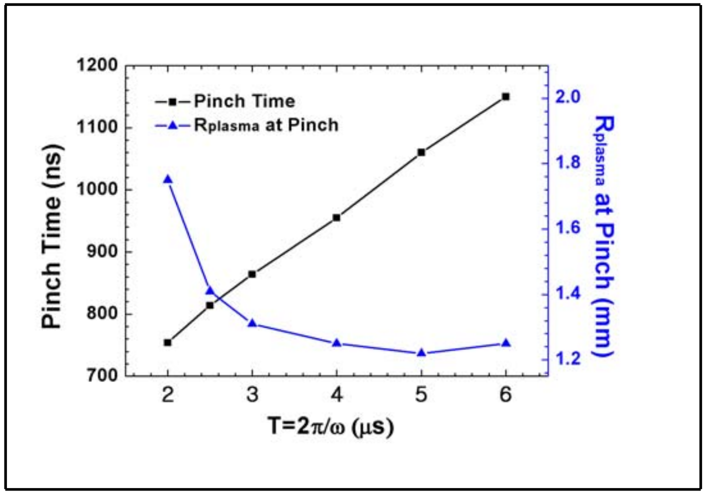
Initial Pressure : 0.7 mTorr

$T = 2\pi/\omega$: 2 μs





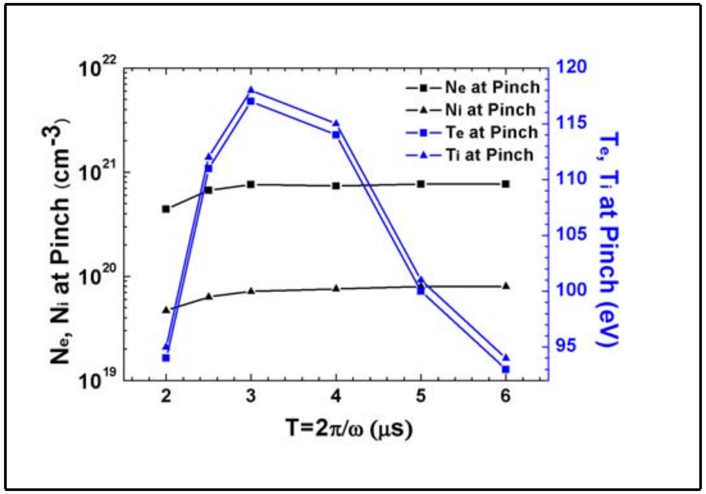
Effect of Pulse Width on Z-pinch Dynamics

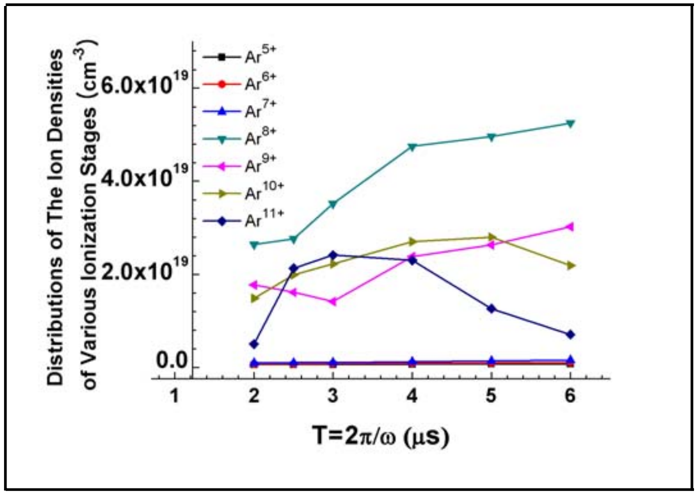


Initial Radius : 1.4 mm

Initial Pressure : 0.7 mTorr

Pulse Amplitude : 370 kA





Conclusion

- N_e, N_i increases as initial plasma radius decreases and initial pressure, pulse amplitude increases.
- T_e, T_i increases as initial plasma radius, initial pressure decreases and pulse amplitude increases.
- Initial plasma radius, initial pressure, pulse amplitude has optimum conditions for producing high density of Ne-like Argon.
- As the pulse current amplitude exceeds 340 kA, Ne-like argon density is saturated and density of higher ionized states starts to increase.
- Further work

  - Obtaining simulation results considering excited ionized states.
  - Experiments and comparing experiment data with simulation data.