Importance of Capillary Plasma-dynamics for Lasing and Guiding

Kazuhiko Horioka

Department of Energy Sciences, Tokyo Institute of Technology
Nagatsuta 4259, Yokohama Japan

In collaboration with ;
Eiki Hotta, Maid Masnavi, Nobuhiro Sakamoto, Mitsuo Nakajima, Yasushi Hayashi (TIT)
Kazuhisa Nakajima (KEK; High Energy Accelerator Research Organization)
Tomonao Hosokai (JAERIKansai, Univ. Tokyo)

Tokyo Institute of Technology

Outline

- Introduction
- Lasing Condition and Plasma Dynamics
- Laser Guiding Experiments using a Capillary Pinch Plasma
- Simplified analysis on the ionization relaxation and importance of Zeff estimation on the plasma dynamics
- Summary
  - Importance of non-equilibrium ionization effect on the plasma dynamics
  - for Energetic Lasing at Shorter Wavelength and for Formation of Robust Guiding Channel by Capillary Plasma

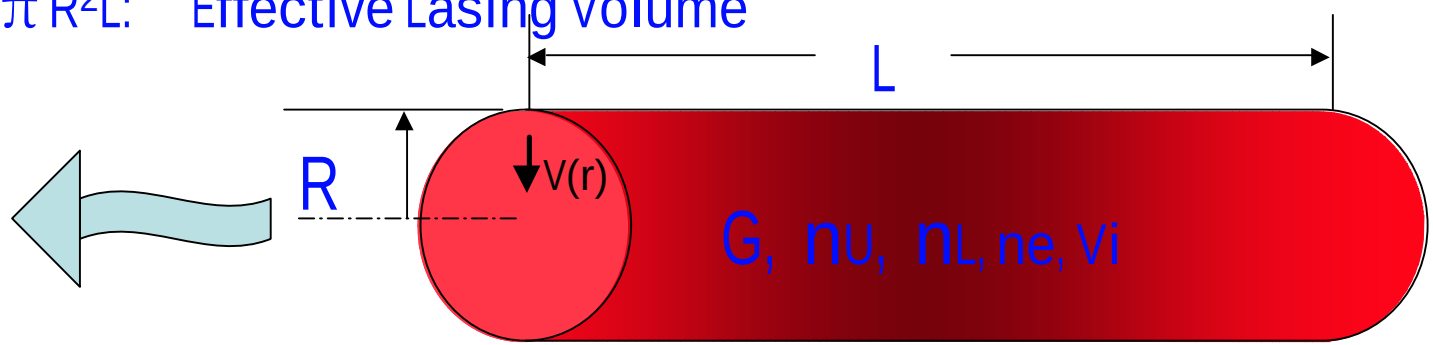
Background

- Population distribution of pinching-plasma strongly depend on the plasma dynamics
- Structure of core plasma is decided by the interaction of imploding shock wave and the current sheath; i.e., the plasma dynamics
- $G \sim (n_u - n_L) = f(T_e, n_e, T_i, v[r], dT_e/dt)$
- $E = A \cdot I \cdot \tau \sim h\nu \cdot (N_U - N_L) \cdot \tau$

  $\sim h\nu \cdot (n_u - n_L) V \sim G \cdot R^2 \cdot L \cdot \tau \sim f(G, V_i)$

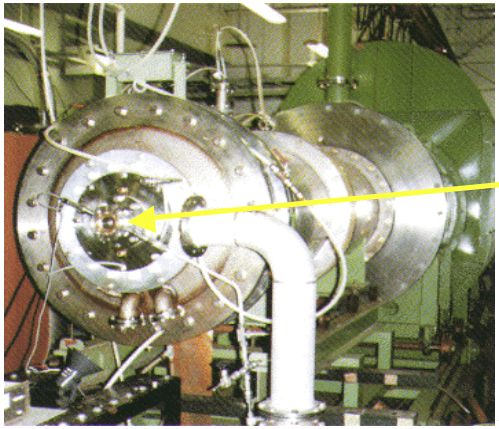
G: Gain Coefficient, E: Energy Output [J]

$V = \pi R^2 L$: Effective Lasing Volume



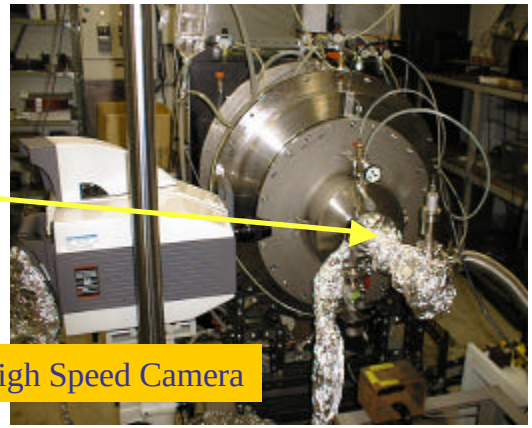
Fast Pulse Power Devices in TITech

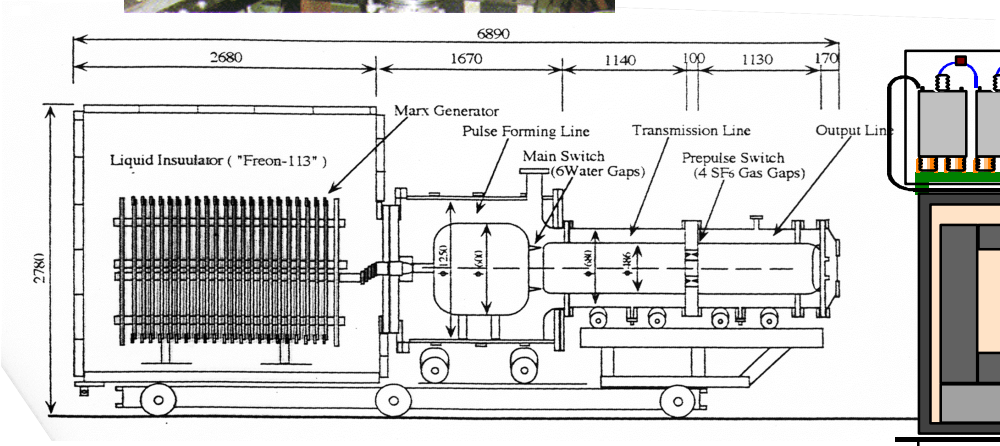
High current device

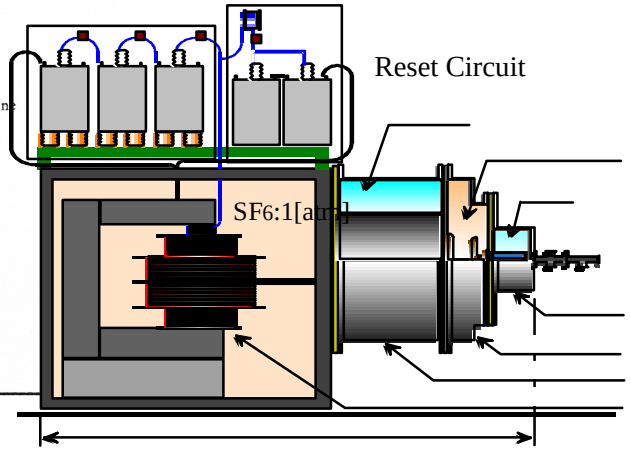


Capillary

High rep. device



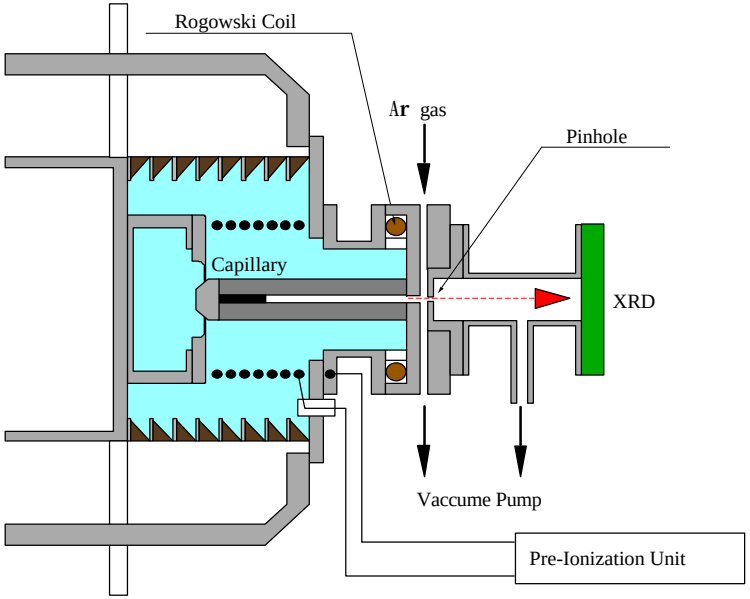


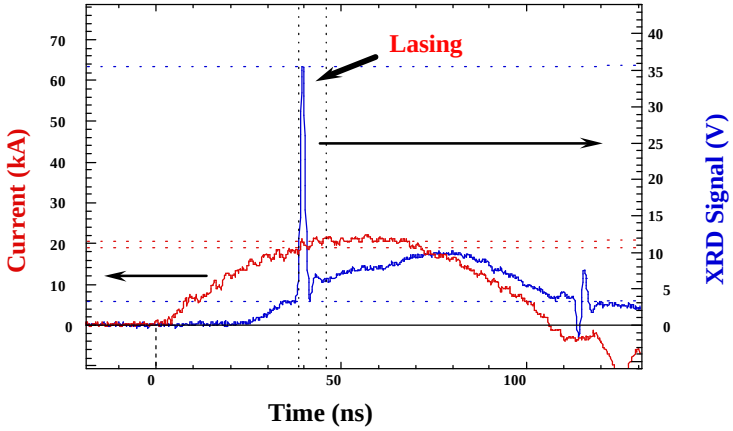


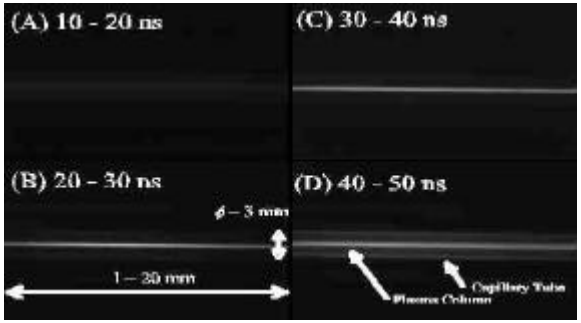
Peak Current 200 kA, dI/dt～10^{12}A/sec

3nF, Max. 900 kV (1.2 kJ)

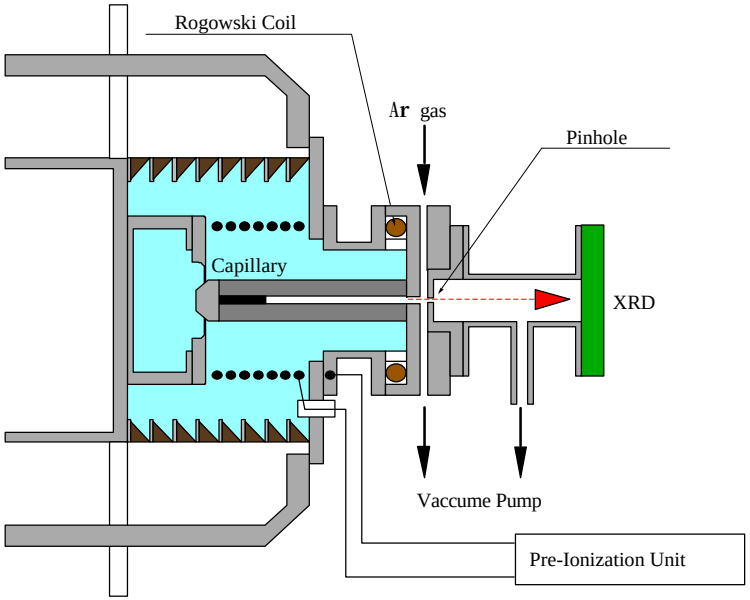
Lasing Signal

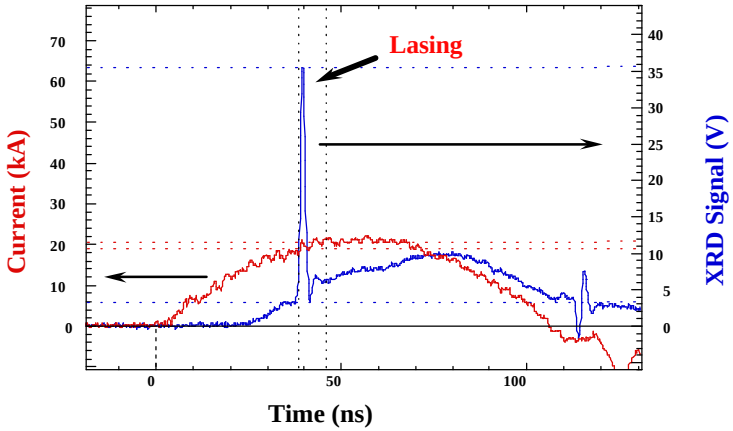


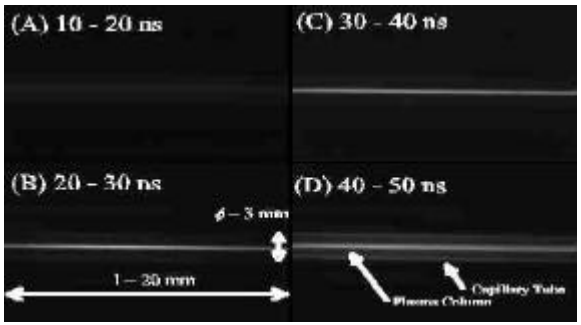


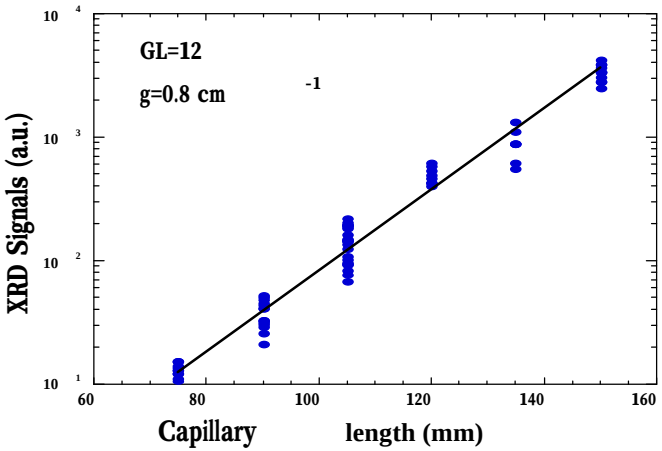


Lasing Signal



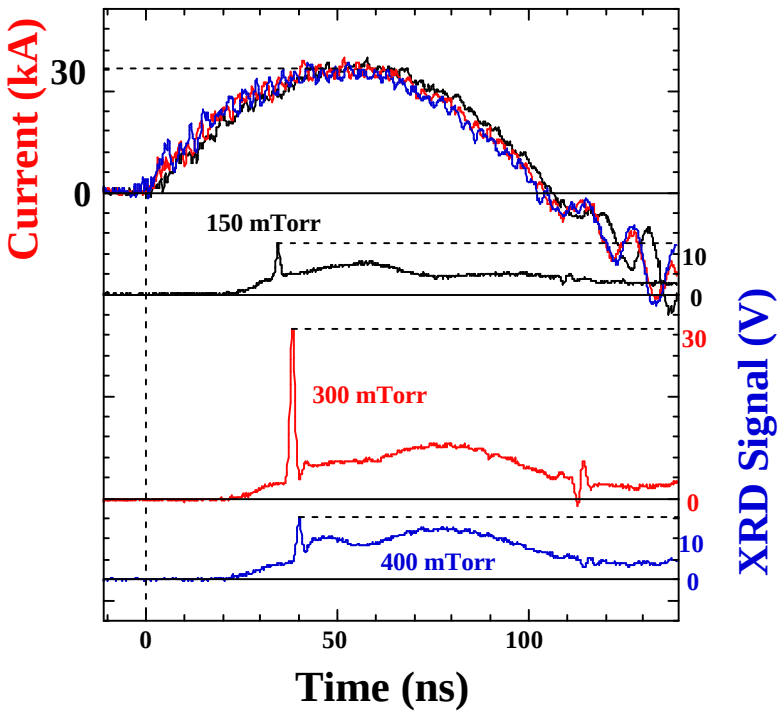


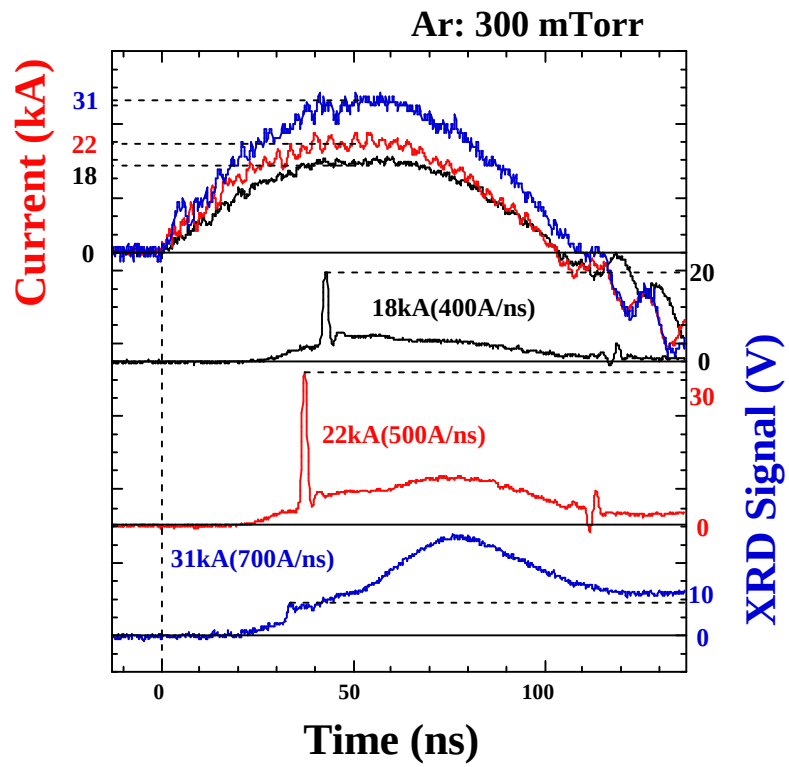




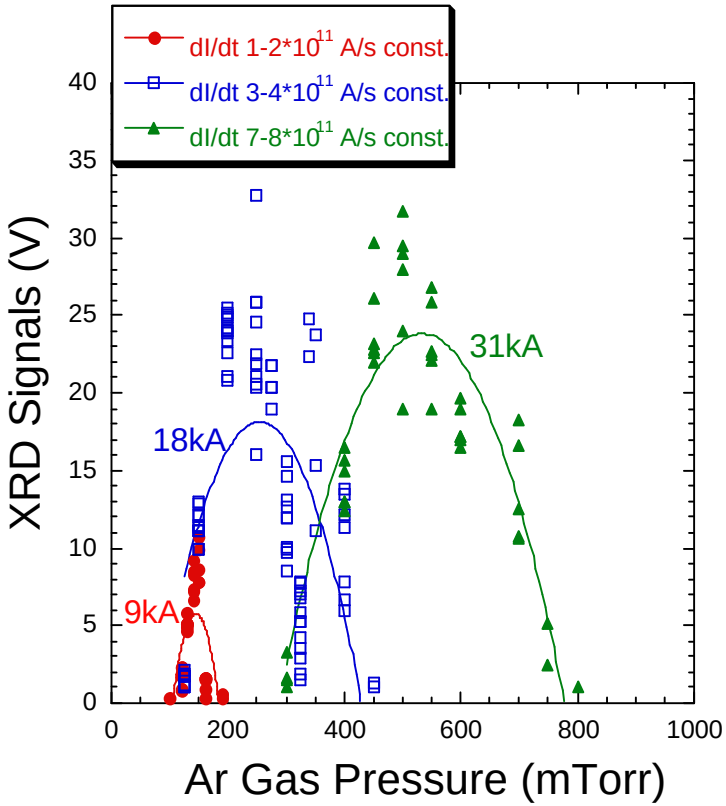
Lasing Time and XRD Peak Value depend on P0 and dI/dt

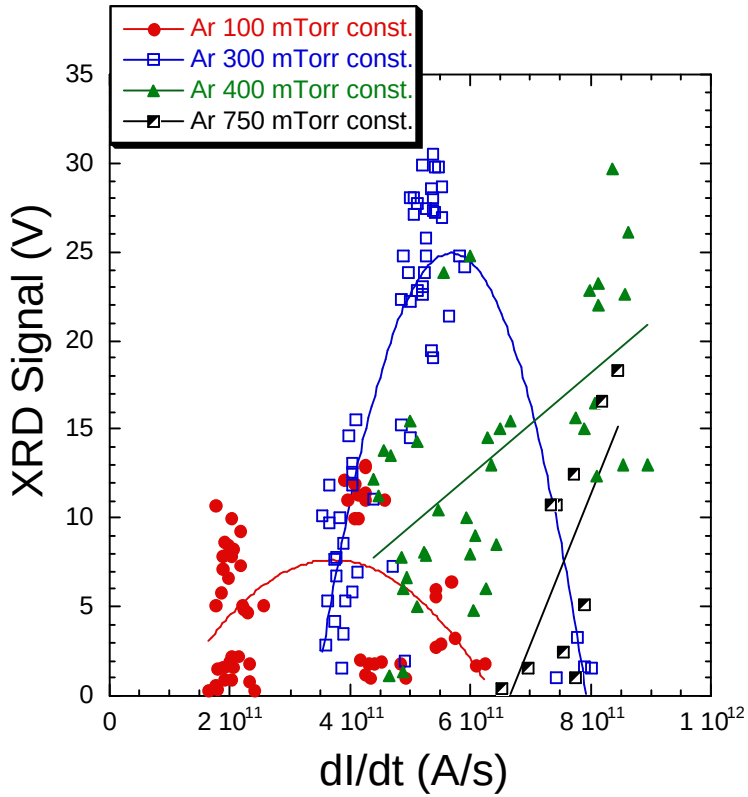
d = 3 mm, l = 150 mm, I(pre) = 10 A



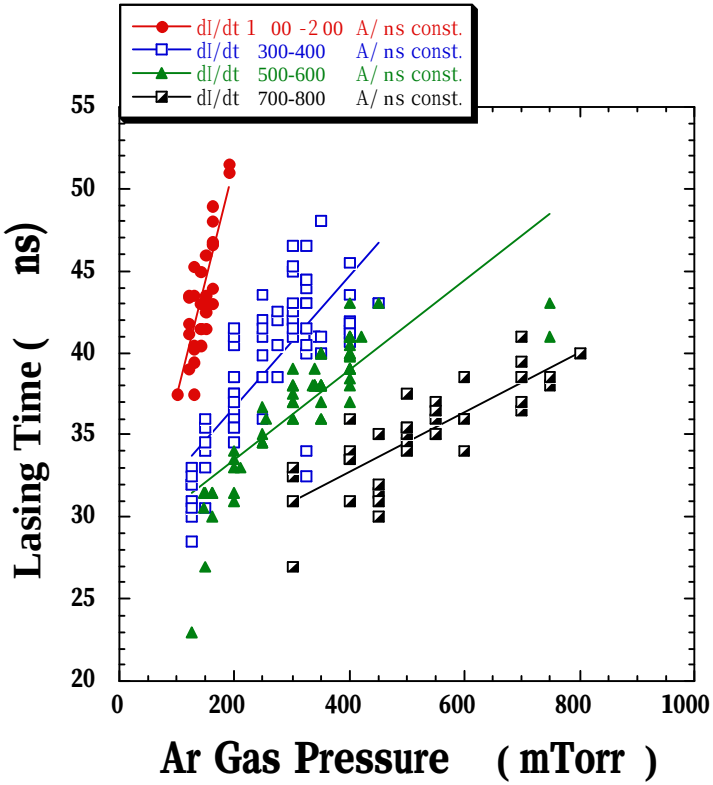


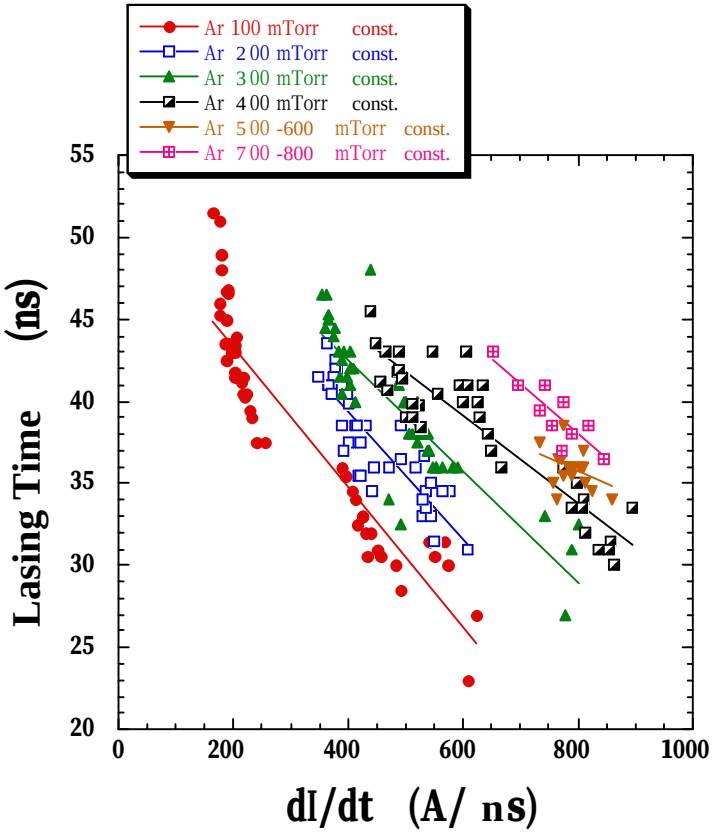
Lasing signal depend on initial pressure and dI/dt





Lasing Time Depend on Discharge Condition

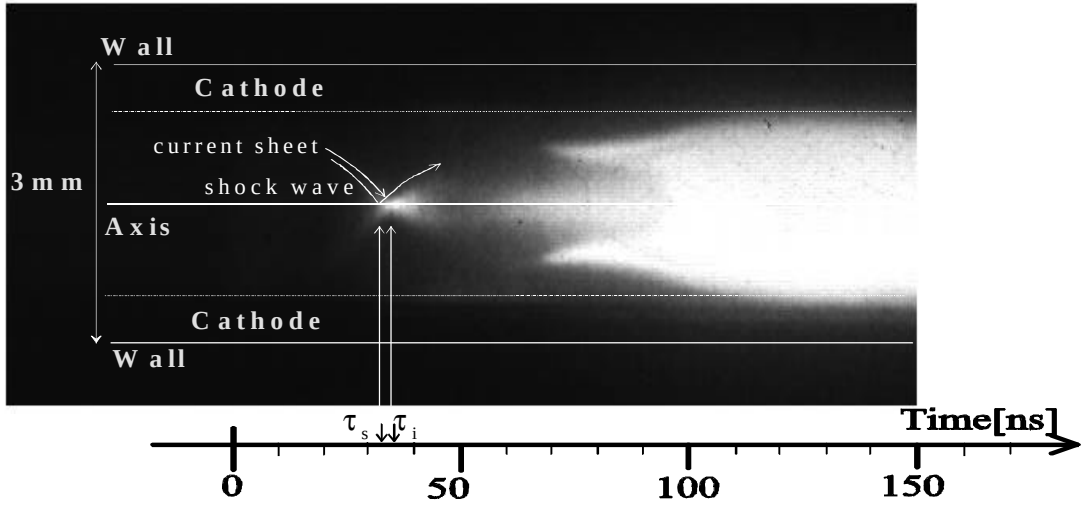




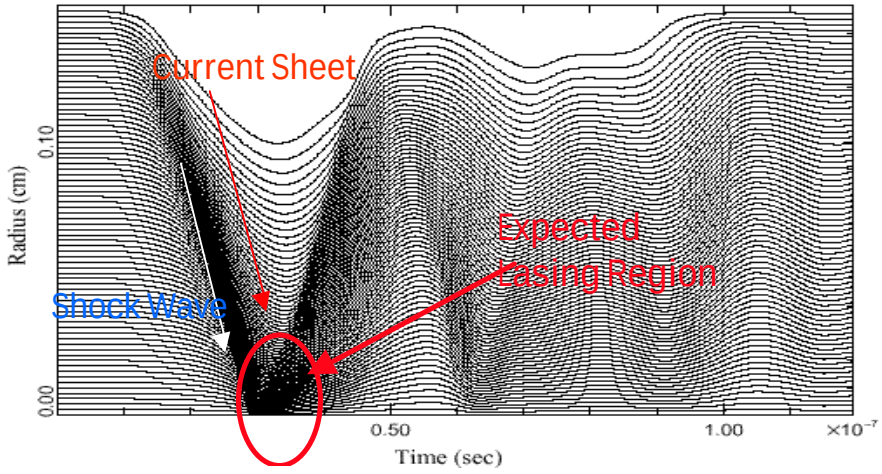
Typical Streak Photograph and MHD-Simulation

Streak Photograph and 1D-MHD Simulation Result

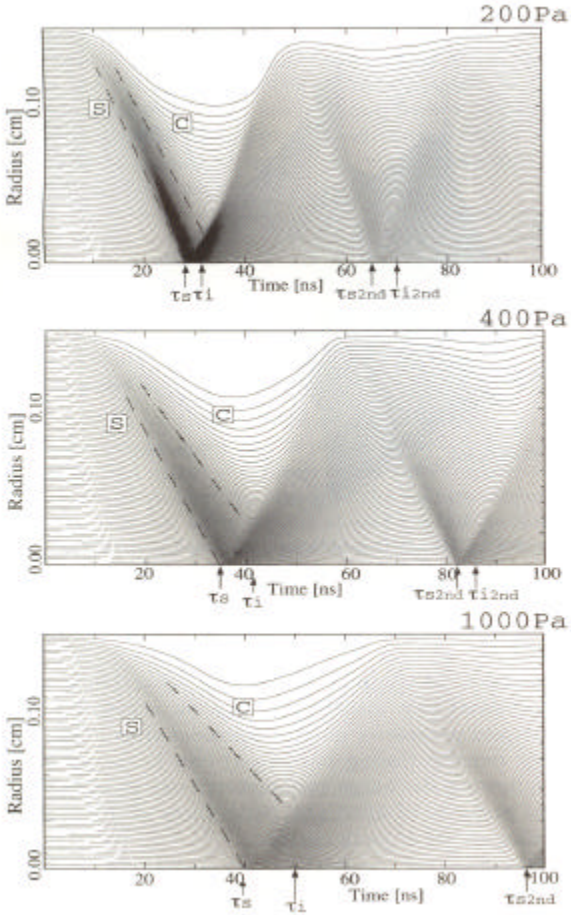
Initial Pressure :
500 mTorr Ar
Capillary Diameter :
3 mm

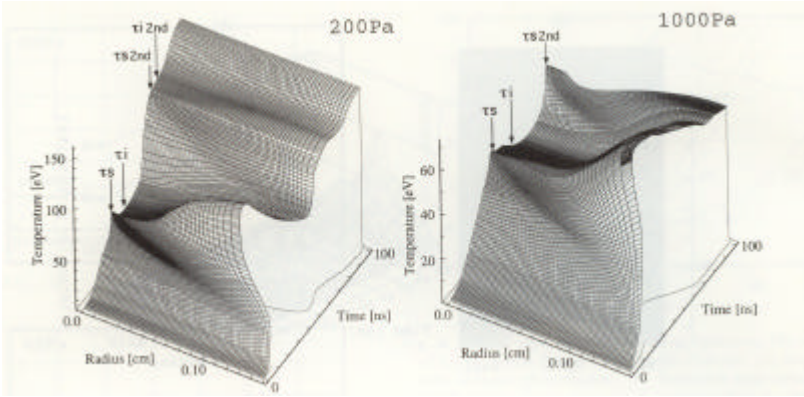


Shock wave heating and magnetic compression
→ High Temperature Internal Structure

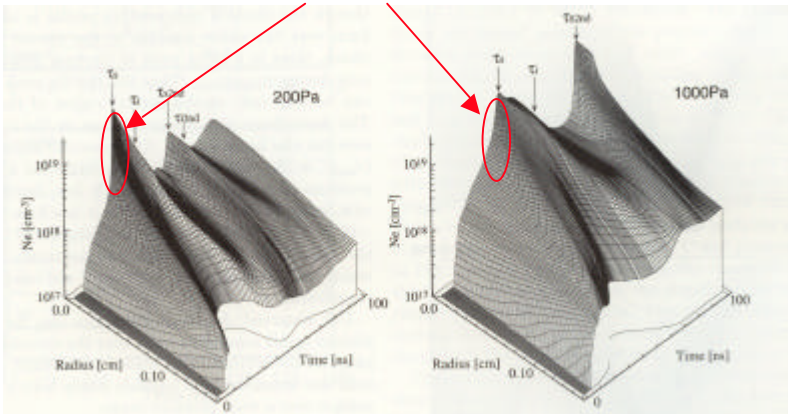


MHD Simulation predicts that a robust concave density structure is produced in capillary pinch plasma



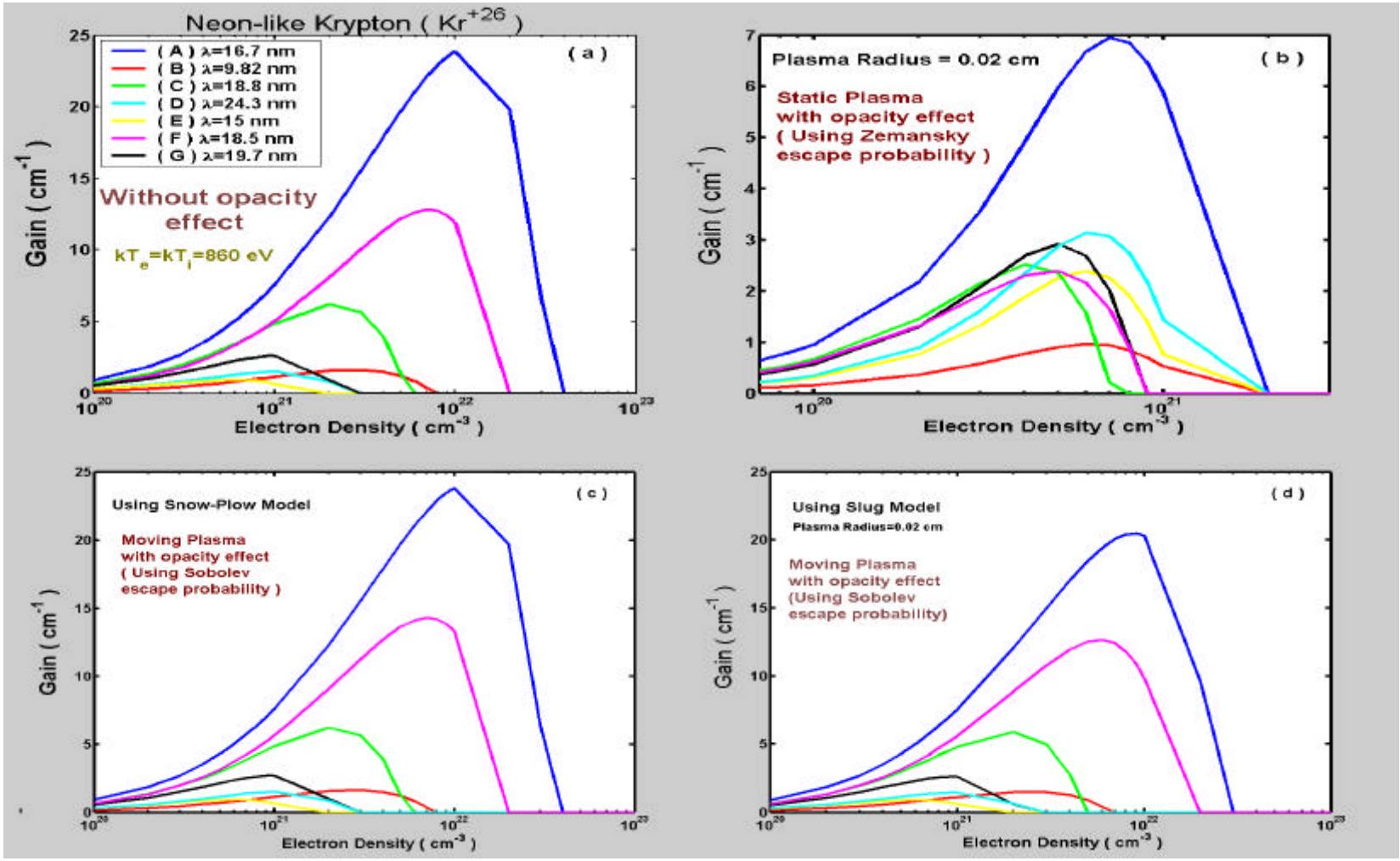


Concave density struture



T.Hosokai, M.Nakajima, K.Horioka et.al., Jap. J. Appl. Phys., 36, p.2327 (1997)

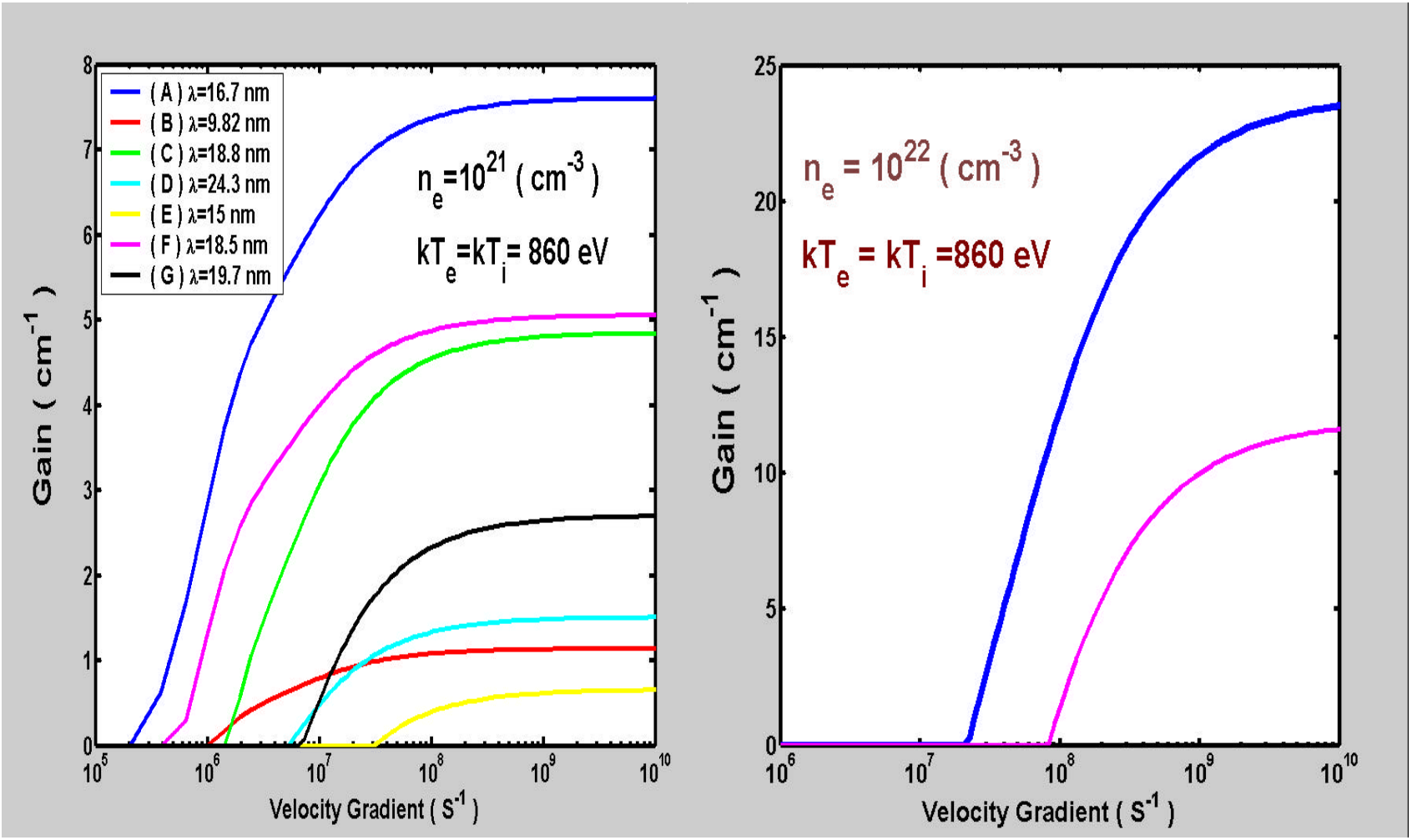
Estimation of opacity effect on gain coefficient indicates the importance of plasma dynamics



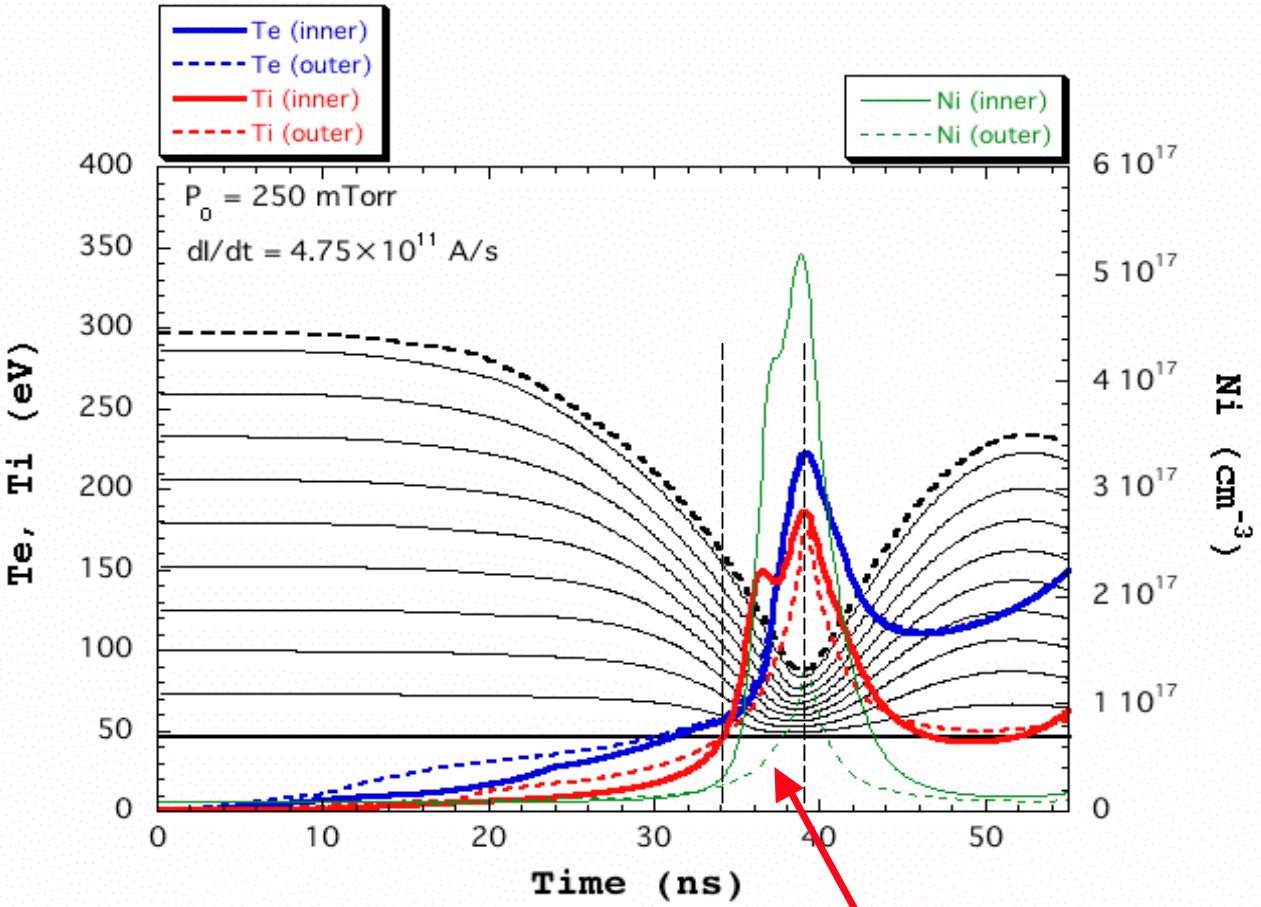
M.Masnavi, M.Nakajima and K.Horioka, J. Appl. Phys., (2002)

Tokyo Institute of Technology

Gain coefficient strongly depend on the velocity gradient of imploding plasma

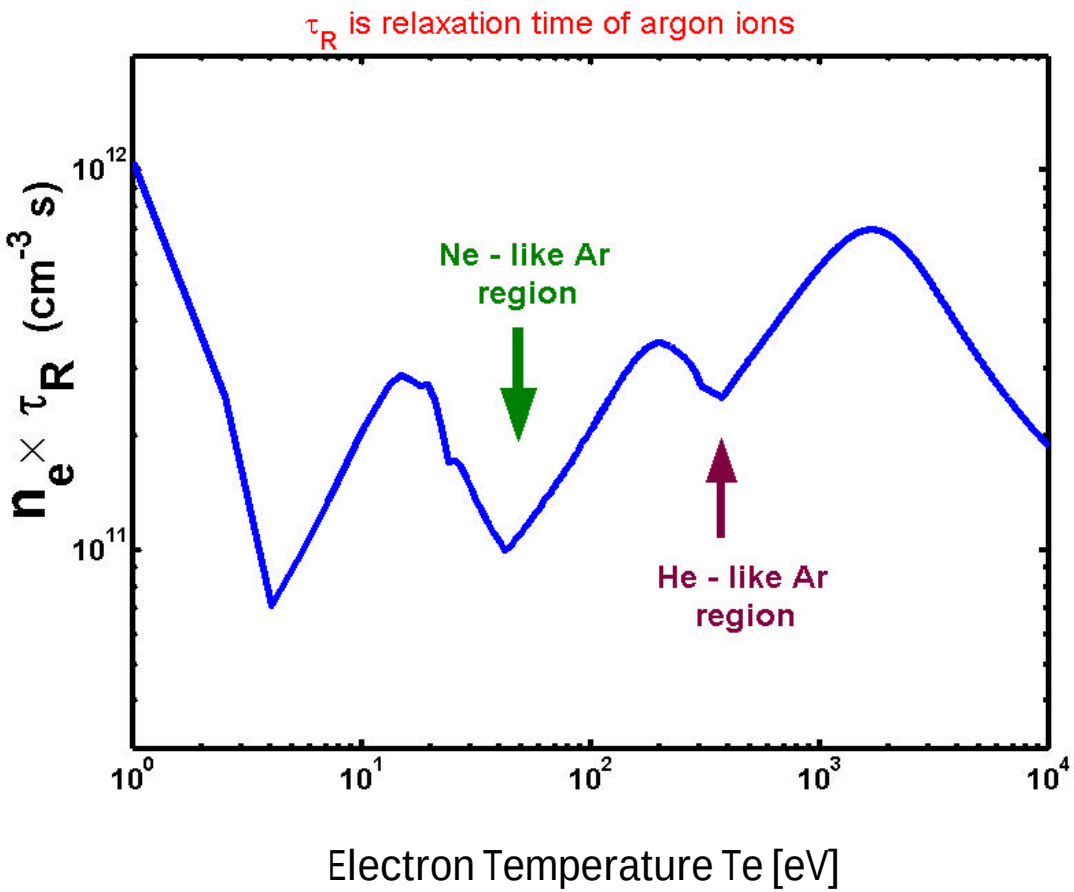


Evolution of Ti, Te and Ni in pinching plasma shows that it always far from equilibrium



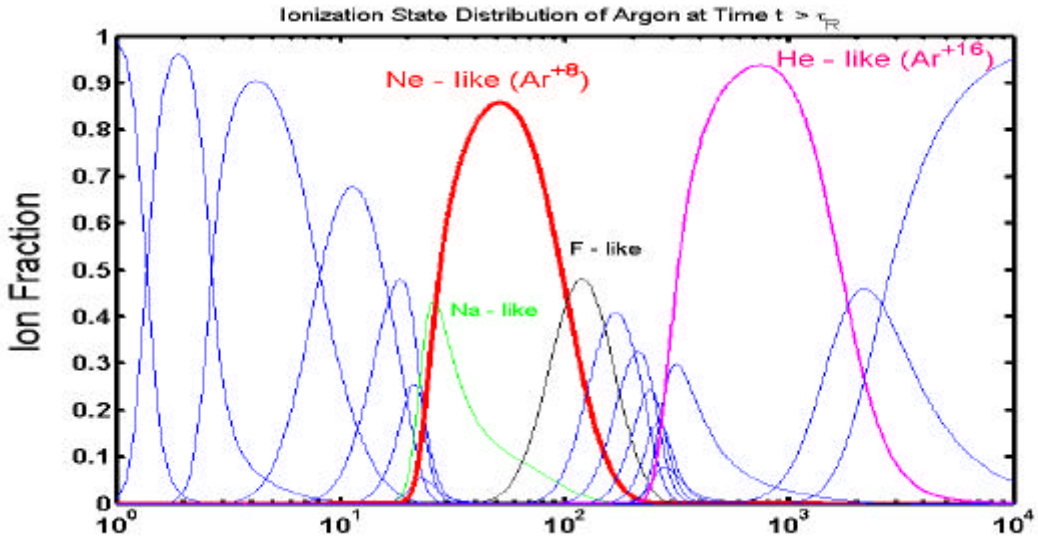
Expected Lasing Region

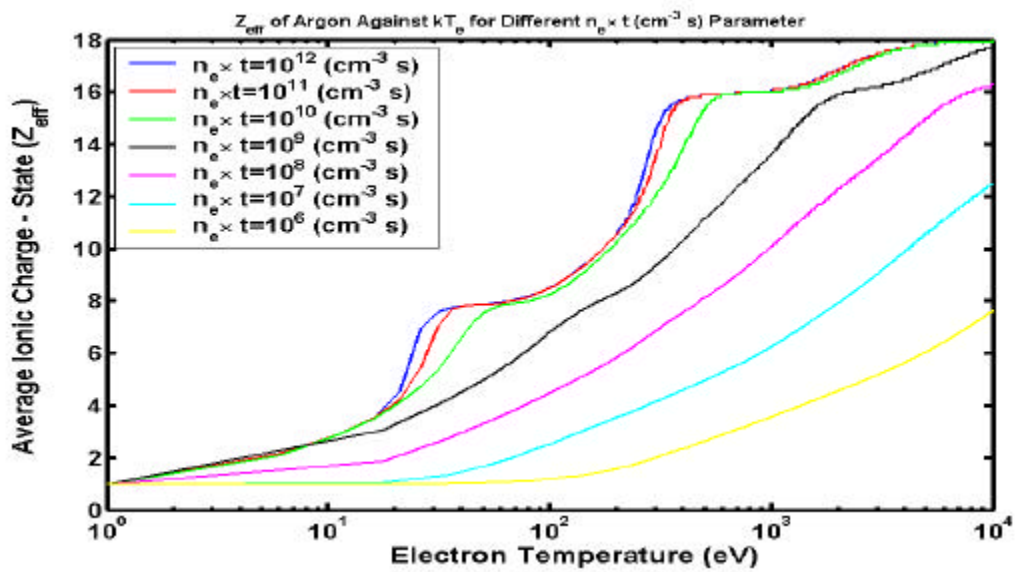
Effective Ionization Relaxation Time of Ar Plasma



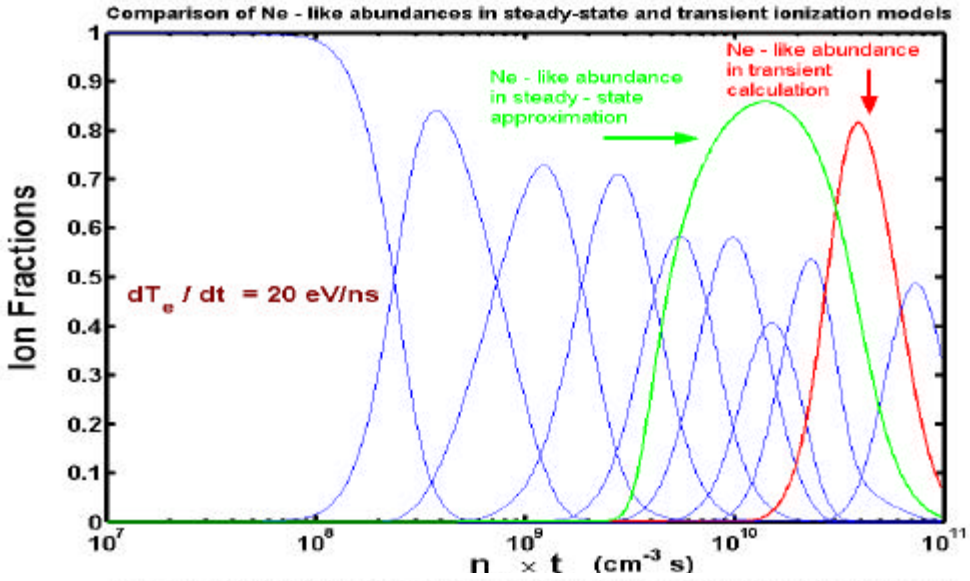
M.Masnavi, M.Nakajima and K.Horioka; to be appear in J. Appl. Phys.,

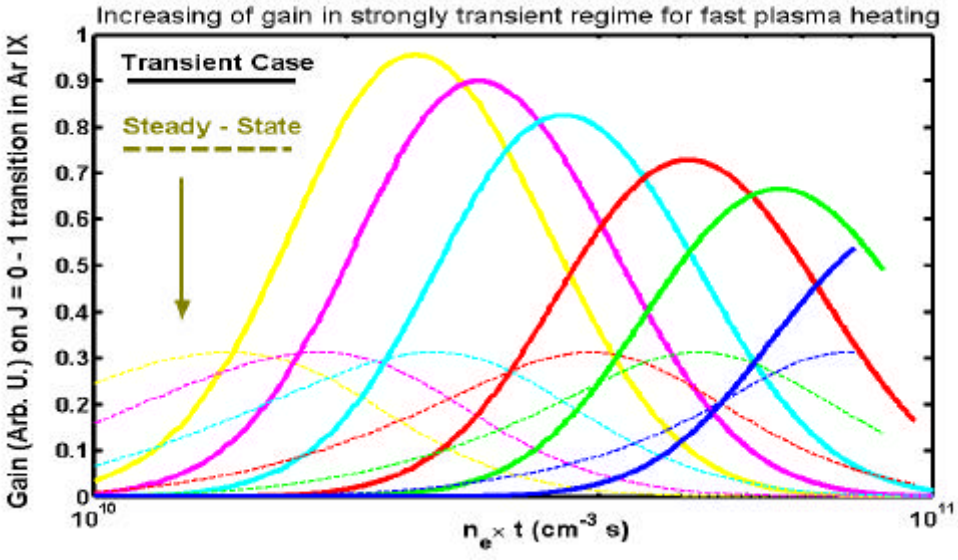
Estimated ionization distribution and Z_{eff} of Ar on plasma indicate non-equilibrium ionization state





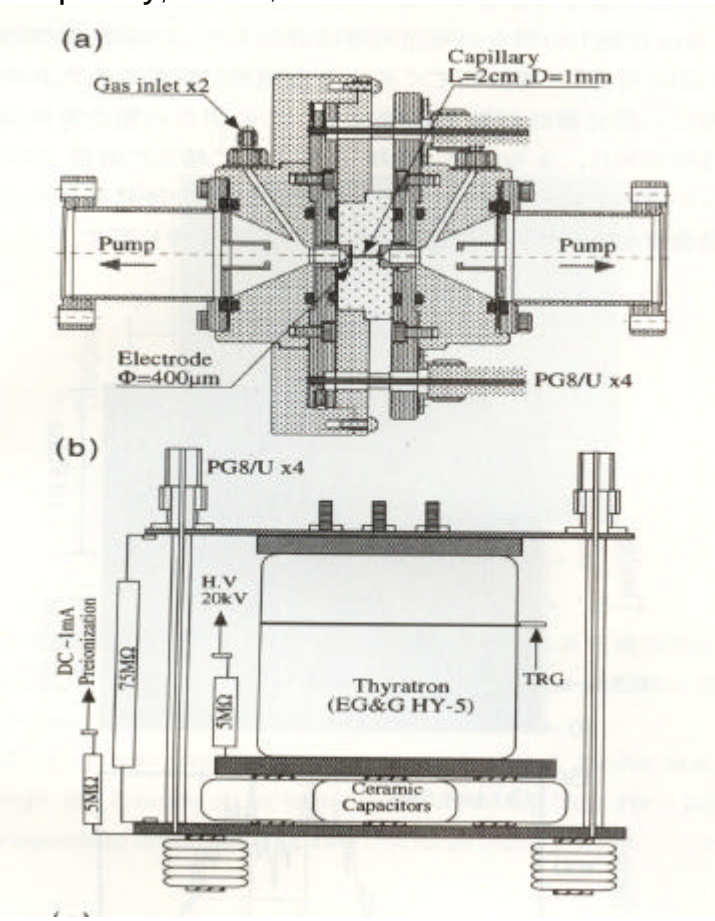
Effect of Transient Ionization on Ion Abundance and Gain for Heating Plasma



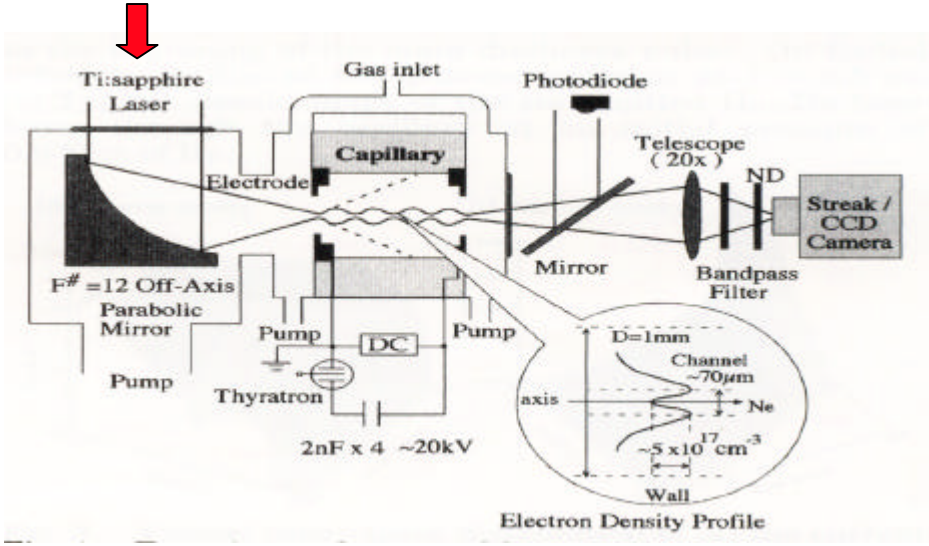


Experimental Arrangement for Laser Guiding through Capillary Pinch Plasma

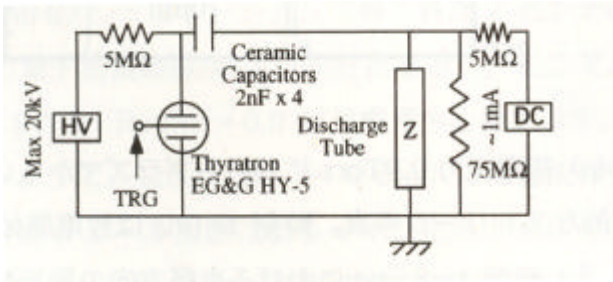
Capillary; 1mmD, 20mmL



2.2TW, 90fs, 10^{17}W/cm^2



4.8kA, 15ns, through pre-ionized He (0.9torr)

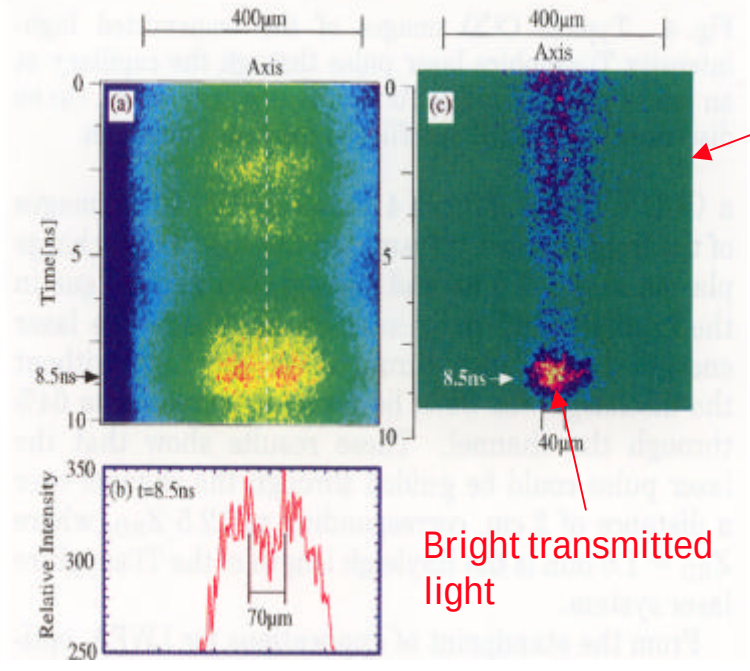


T.Hosokai, K.Nakajima, K.Horioka et.al., Optics Letters, 25, p.10 (2000)

Streak photo and MHD simulation predict the concave density structure in the capillary pinch plasma

Streak photograph of capillary discharge

(at pressure of 0.9torr He)



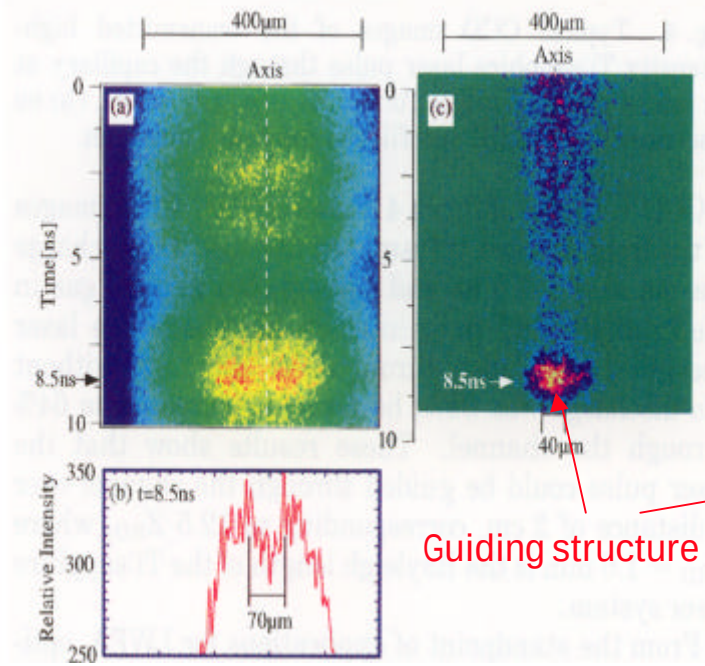
Streak image of transmitted signal of He-Ne probing laser

Bright transmitted light

Streak photo and MHD simulation predict the concave density (guiding) structure in the capillary pinch plasma

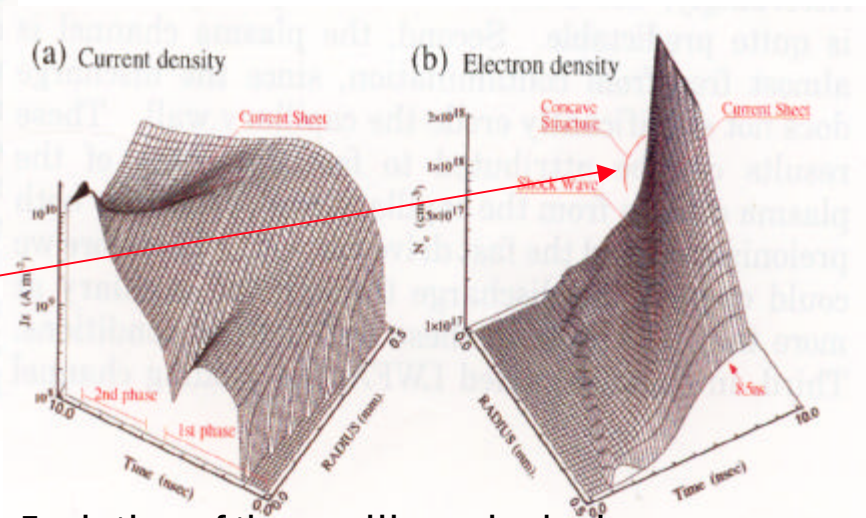
Streak photograph of capillary discharge

(at pressure of 0.9torr He)



Guiding structure

Current sheet implodes to the axis with a strong shock wave ahead of it, which makes a concave density structure on 8.5nsec from current rise, corresponding to the bright spot image



Evolution of the capillary pinch plasma

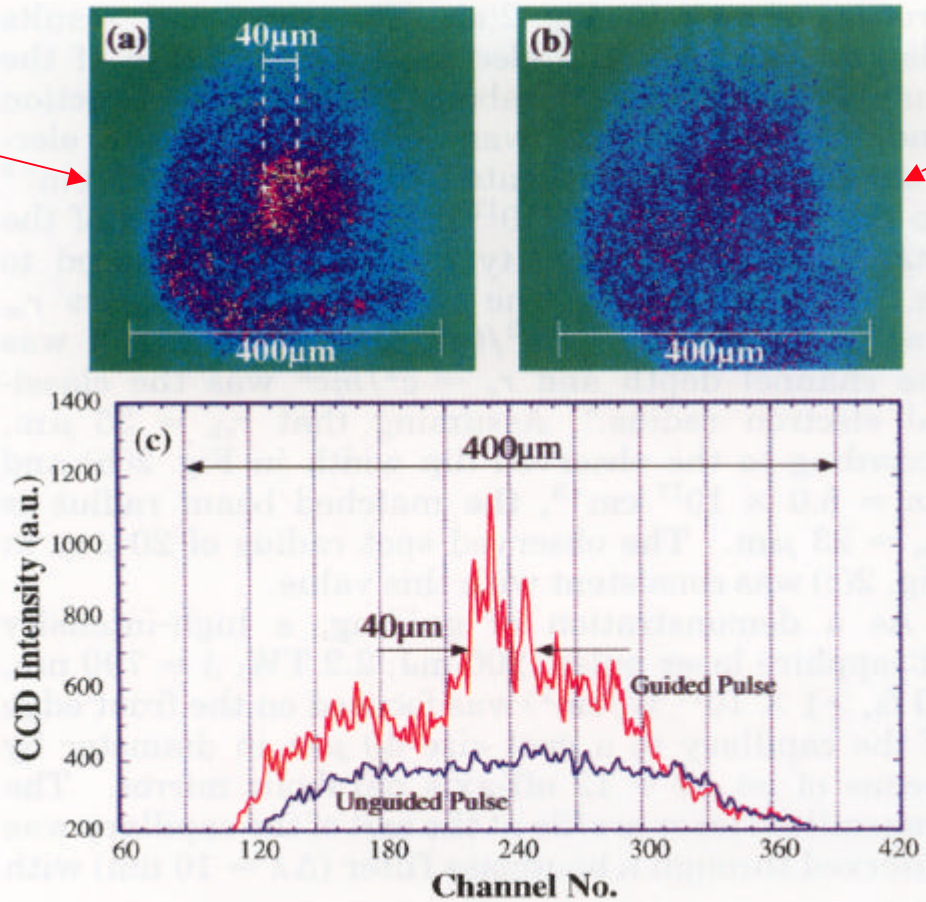
Imploding plasma makes waveguide structure

Terra-watt laser was guided by the implosion phase of Z-pinch discharge in gas-filled capillary

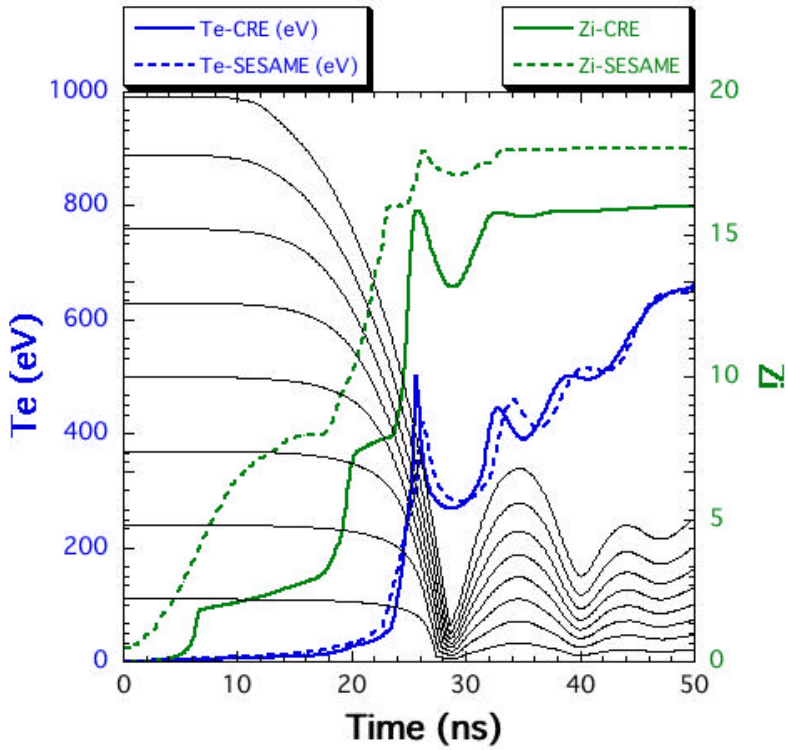
CCD images of transmitted Ti-sapphire laser pulse through the 20mm capillary; (a) with discharge plasma and (b) without the plasma

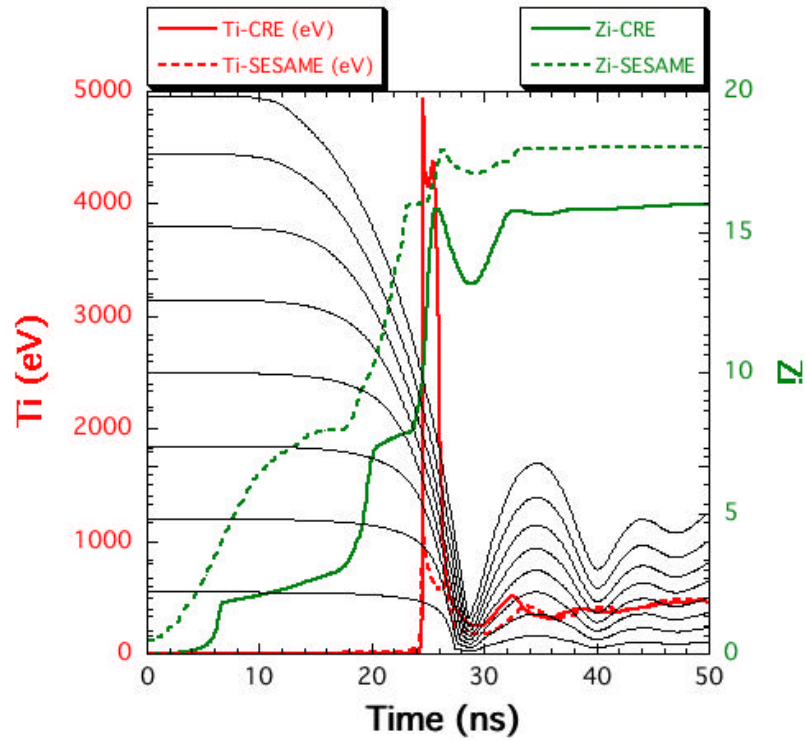
With discharge plasma

Without plasma



Evolution of pinching plasma and, naturally, its structure strongly depend on ionization dynamics





Examples of MHD simulation results based on Sesame table and CRE model for Ar filled capillary pinching

Summary

Lasing and guiding were demonstrated using capillary pinch discharge

- Lasing strongly depends on the pinch dynamics
- Pinching plasma in capillary almost always far from equilibrium
- Non-equilibrium ionization effect in heating plasma can increase the gain value
- Ionization relaxation should strongly affect the dynamics of capillary pinching plasma; naturally its structure

- For scaling of (Wavelength, power and output energy) VUV Lasers and optimizing the guiding condition in capillary plasmas, analysis on the non-equilibrium ionization process and shock induced structures is of crucial importance