TOKYO INSTITUTE OF TECHNOLOGY

Dobré ráno

DEPARTMENT OF ENERGY SCIENCES

Observation of Ne-like Ar Soft X-ray Lasing in Fast Capillary Discharge

Eiki Hotta, Yasushi Hayashi, Yifan Xiao[a], Gohta Niimi[b], Masato Watanabe, Akitoshi Okino, Nobuhiro Sakamoto and Kazuhiko Horioka

Department of Energy Sciences, Tokyo Institute of Technology

[a]Department of Electronic Science and Technology, Harbin Institute of Technology

[b]Advanced Semiconductor Research Center,

National Institute of Advanced Industrial Science and Technology (AIST)

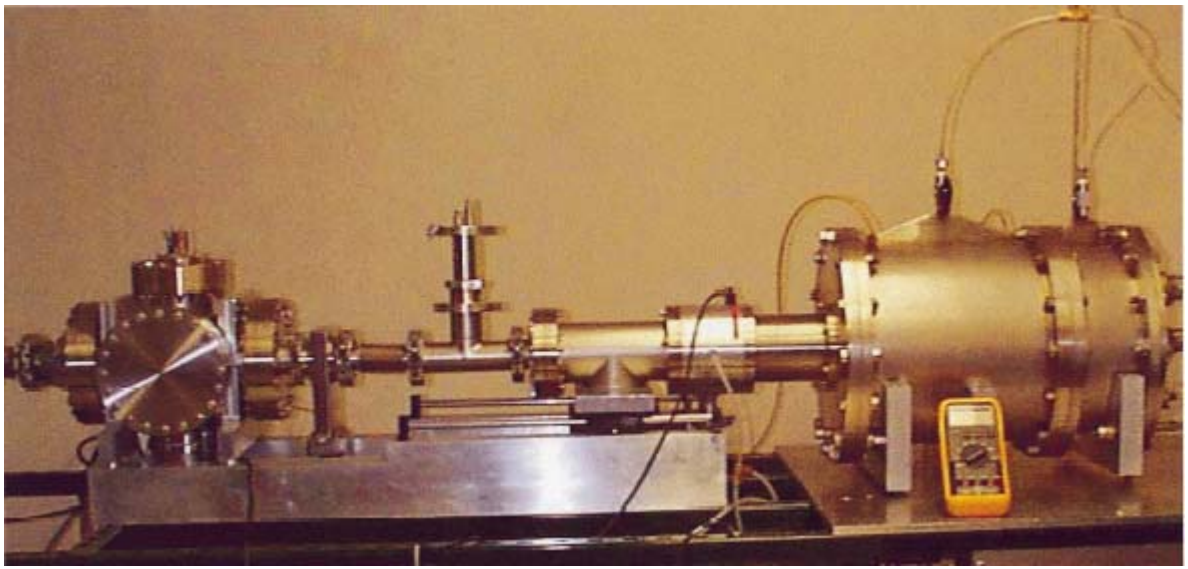
Outline of Talk

- Objective
- Experimental Setup
- Experimental Results
  - Pre-ionization
  - Lasing properties – Directivity, Gain, Spectroscopy
  - Parameter region – Current, Pressure
- Summary

Objective

- **Construction of compact X-ray laser**
  - **High rep-rate, compact X-ray laser : Metrology**
  - **Lasing by minimum input energy**
    - **Minimum current, Initial filling pressure?**
- **Effect of pre-ionization**
  - **Suppression of instability**
    - **Observation with high speed camera**
  - **Output laser energy**
- **Property of soft X-ray laser**
  - **Directivity**
  - **Gain**
  - **Wavelength – Spectroscopic measurement**

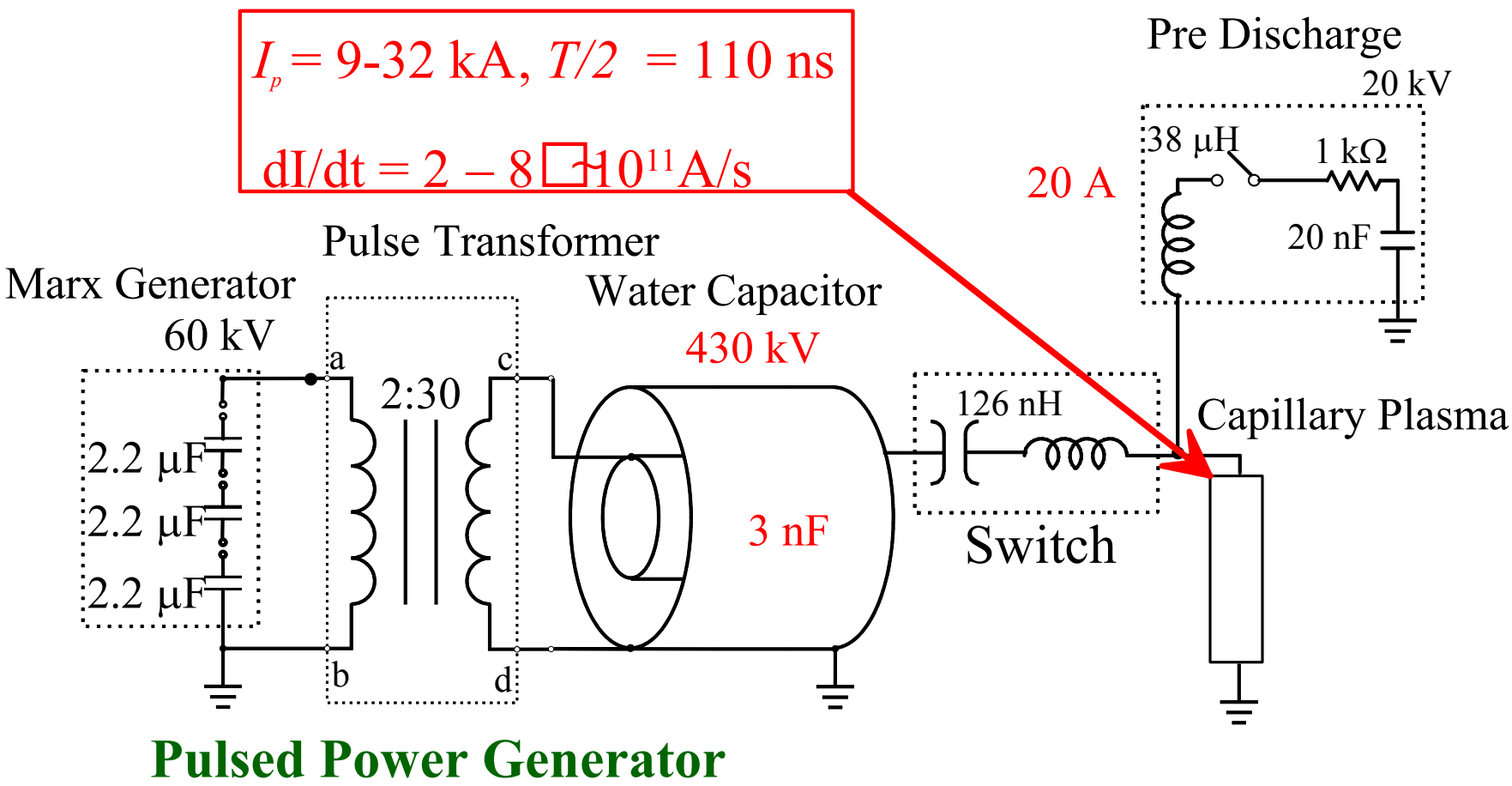
Compact Soft X-ray Laser by J.J.Rocca et al.



Laser parameter	
Pulse energy	0.88 mJ @ 4 Hz
Average pulse power	3.5 mW
Peak pulse power	0.6 MW
Divergence	$\approx$ 4.6 mrad
Pulse width	1.2–1.5 ns
Pulse spectral brightness	$2 \cdot 10^{25}$ photons/(s·mm^2·mrad^2·0.01% bandwidth)

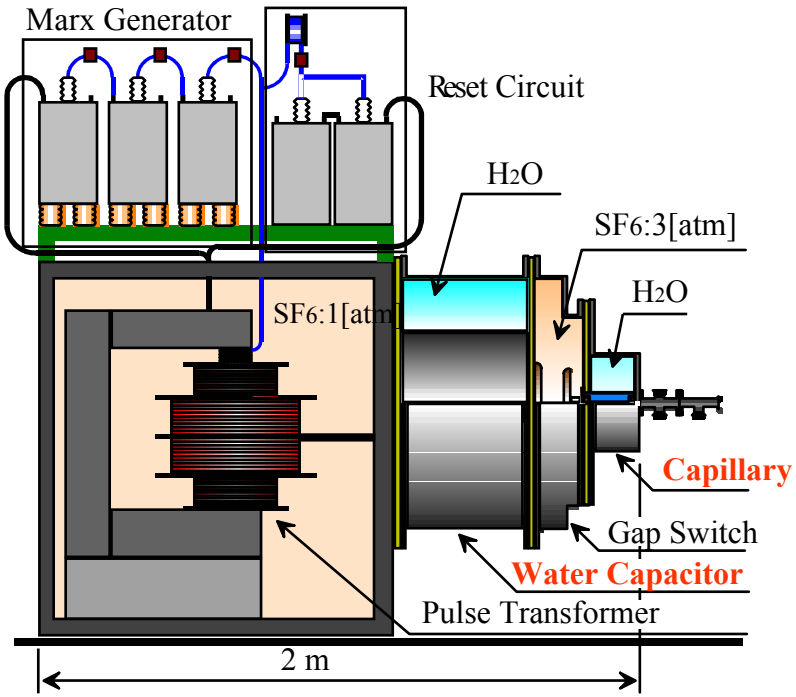
J.J.Rocca et al., C. R. Acad. Sci. Paris, t. 1, Série IV, p. 1065–1081, 2000

Electrical Circuit of Experimental Device

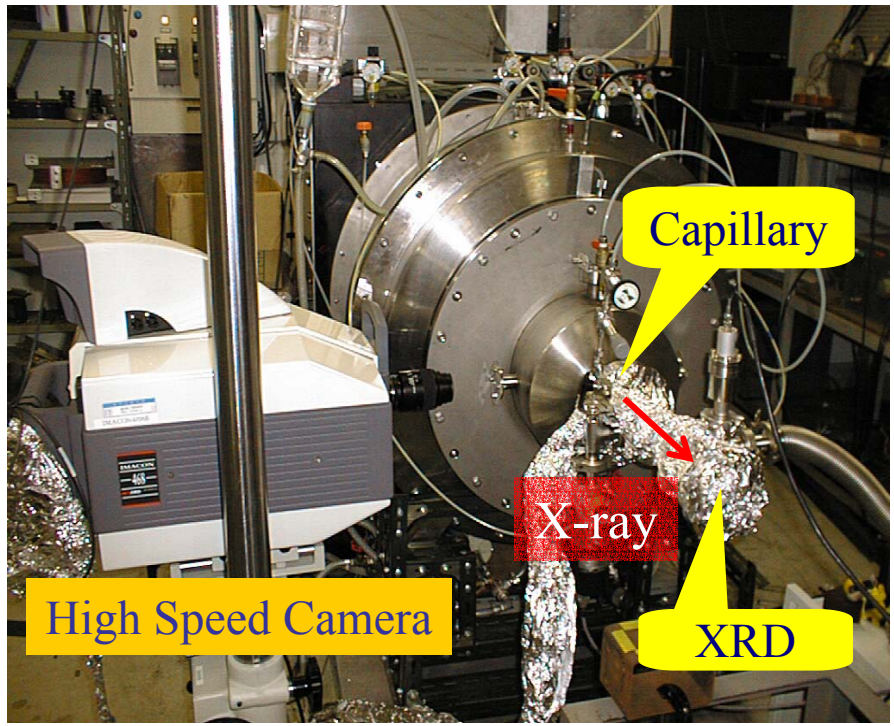


Experimental Setup

Capillary Z pinch (Soft X-ray Laser)



Photograph



Specification

Water capacitor: 3nF, Max. 900 kV (1.2 kJ)

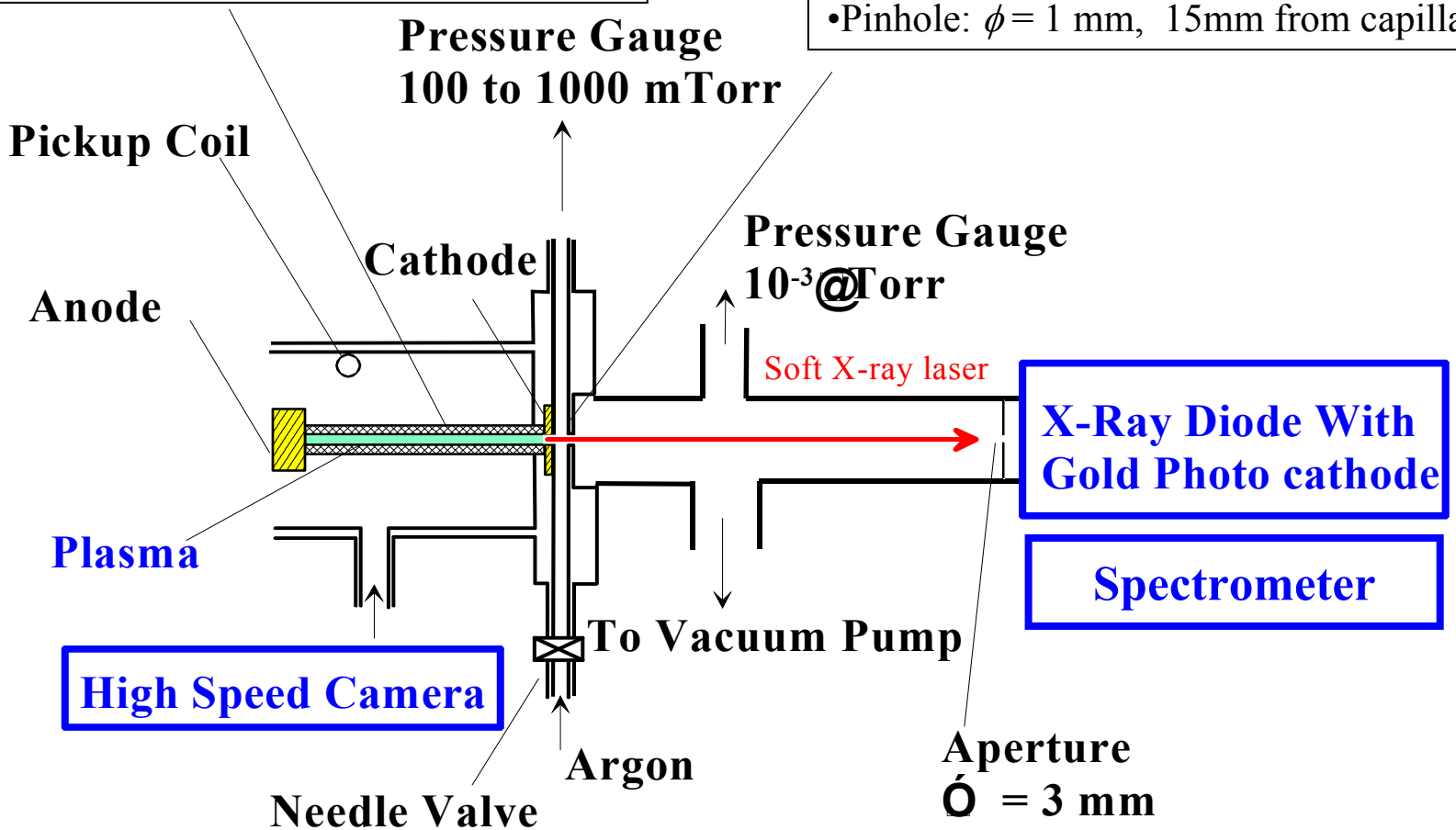
Capillary: Polyacetal, Pyrex or Almina Ceramics, φ3mm, 60-200 mm long

Filling gas: 100-1000 mTorr Ar

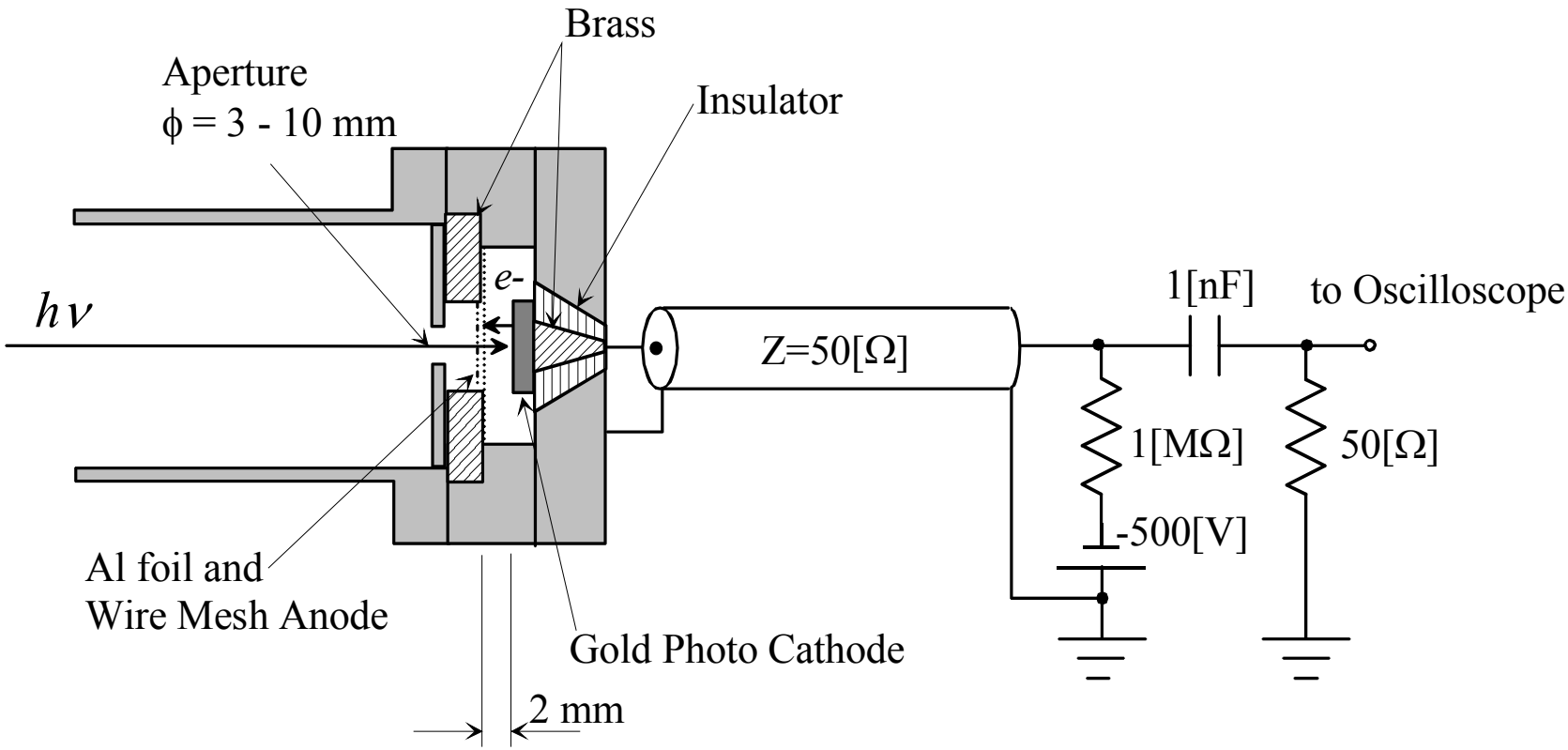
Measurement System

Capillaries
- **Al_2O_3 Capillary**: d = 3mm, l = 200 mm
- **Pyrex Capillary**: d = 3mm, l = 60 mm

•Pinhole: ϕ = 1 mm, 15mm from capillary



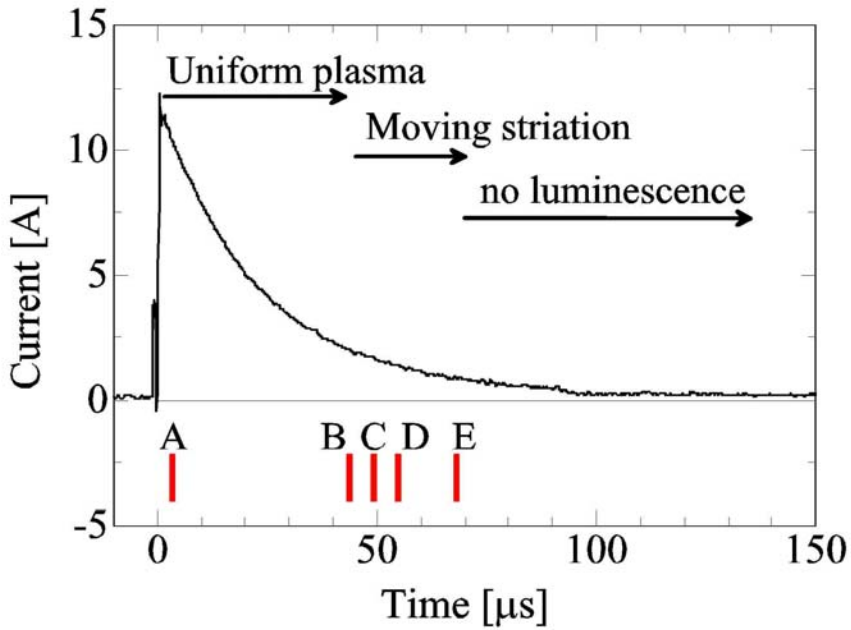
Electrical Circuit of XRD



Aluminum foil filter of 0.8 or 2 μm thick is used.

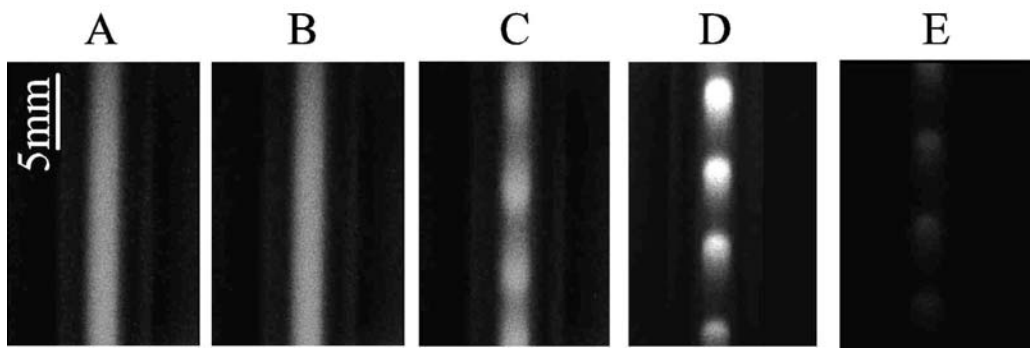
Time Evolution of Pre-Discharge Plasma

Waveform of predischarge current



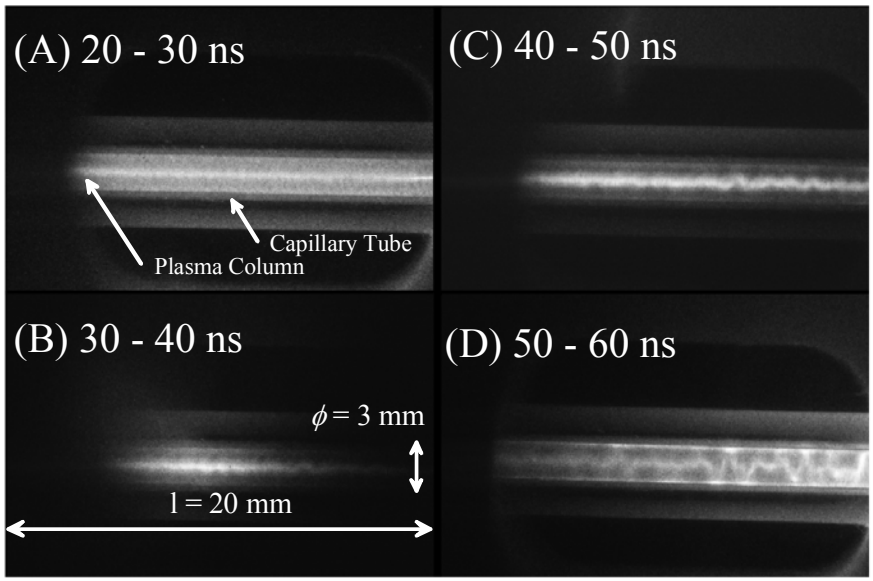
Discharge condition
- Pyrex Capillary: l = 60 mm, d = 3mm
- Argon: 500 mTorr
- Predischarge Current: 12 A

Side-on Framing Photographs

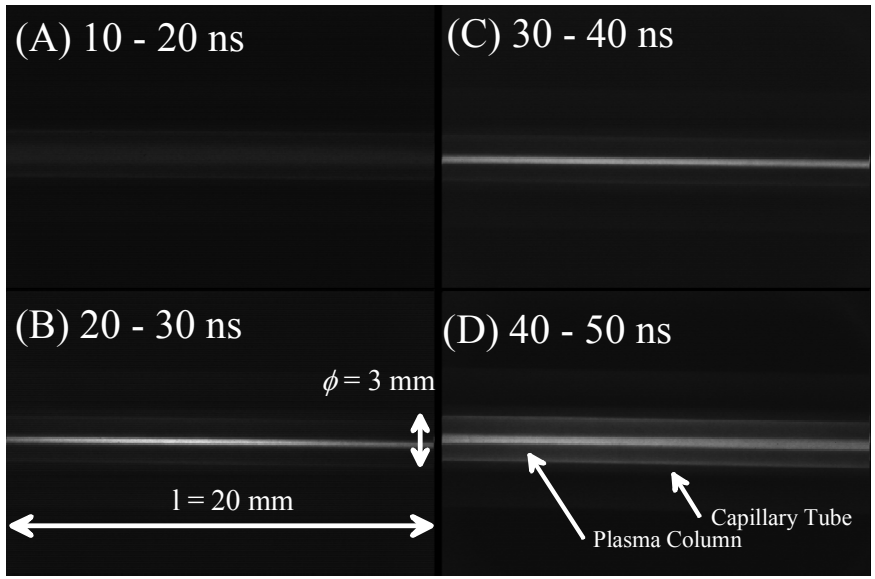


Effect of Pre-ionization

Without predischarge current



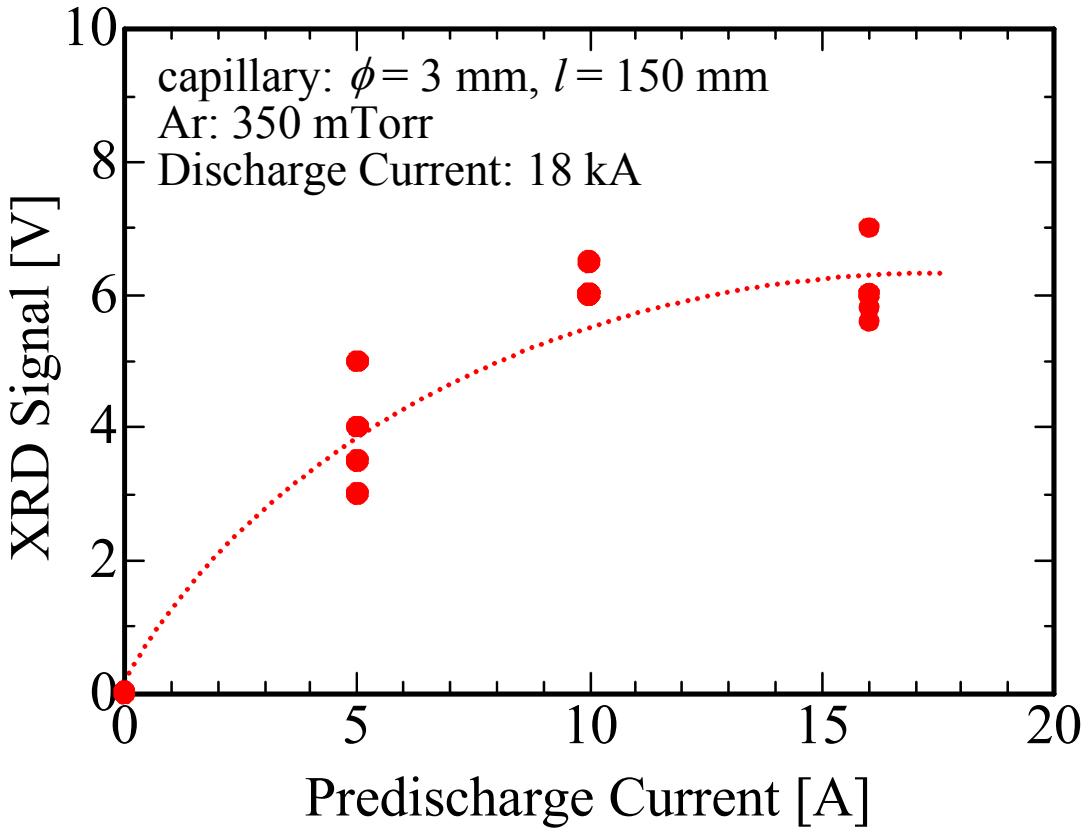
With predischarge current of 10 A



- Helical instabilities are observed
- Poor reproducibility

- Stable
- Highly repeatable
- Diameter of pinched plasma: 300μm

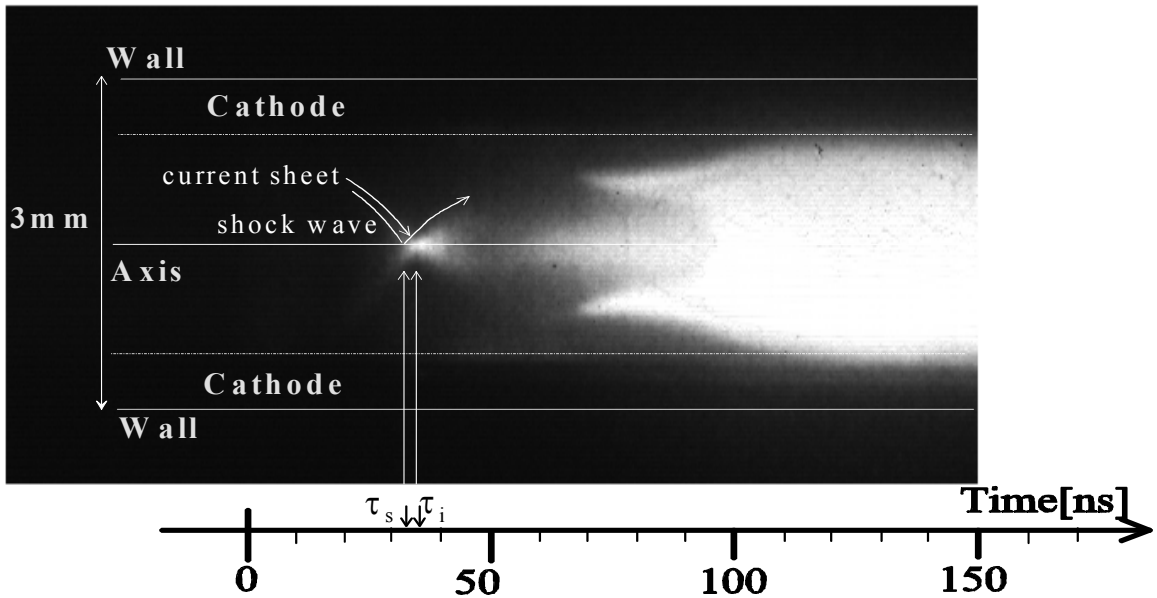
Dependence of XRD Signal on Pre-discharge Current



The unstable and low laser output at low pre-discharge current is possibly related to the growth of instabilities.
Uniform pre-ionized plasma is essential for lasing.

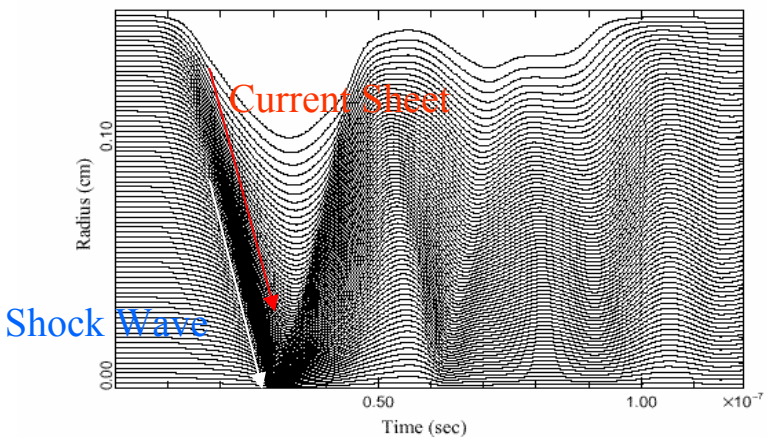
Streak Photograph and Simulation Result

Streak Photograph and 1D-MHD Simulation Result



Initial Pressure : 500 mTorr Ar
Capillary Diameter : 3 mm
(T_{ei} = 0.5 eV, T_{ii} = 0.1 eV)

Shock wave heating and magnetic compression
→ High heating efficiency

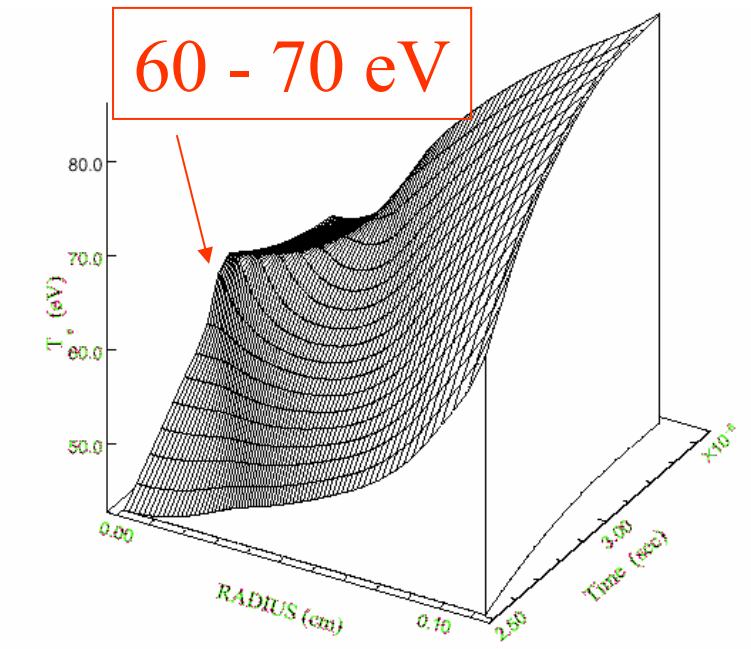


Ne-like Ar (469 Å)

Te ~ 60 – 90 eV

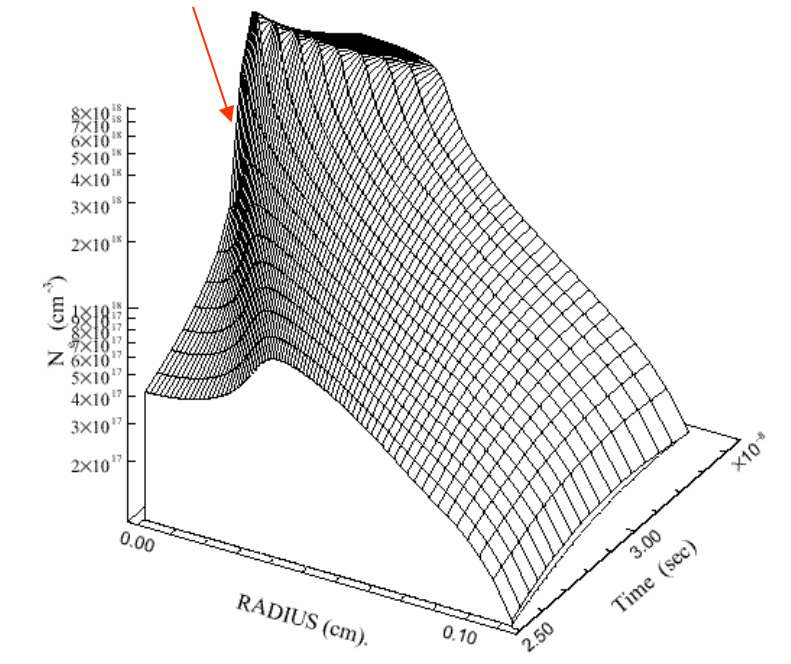
Ne ~ 0.5 – 2 ×10^{19} cm^{-3}

60 - 70 eV



Time-spatial evolution of electron temperature

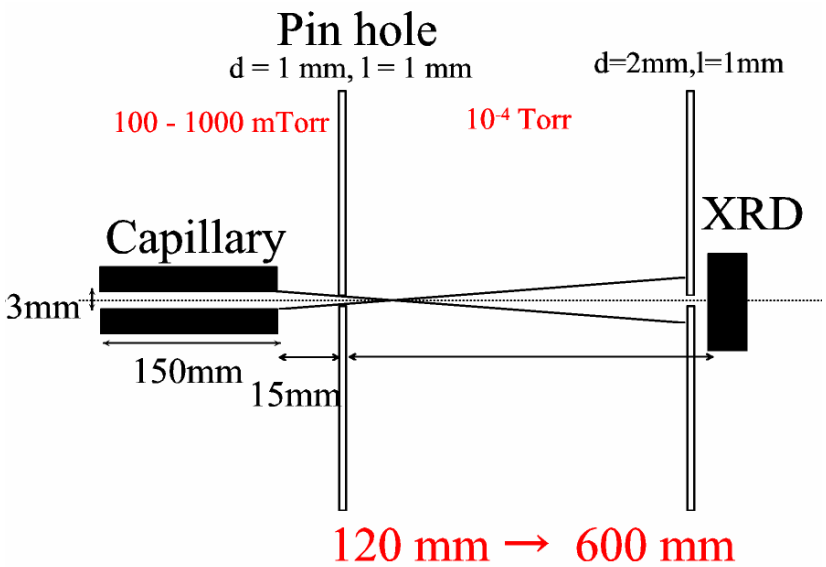
2 – 8 ×10^{18}cm^{-3}



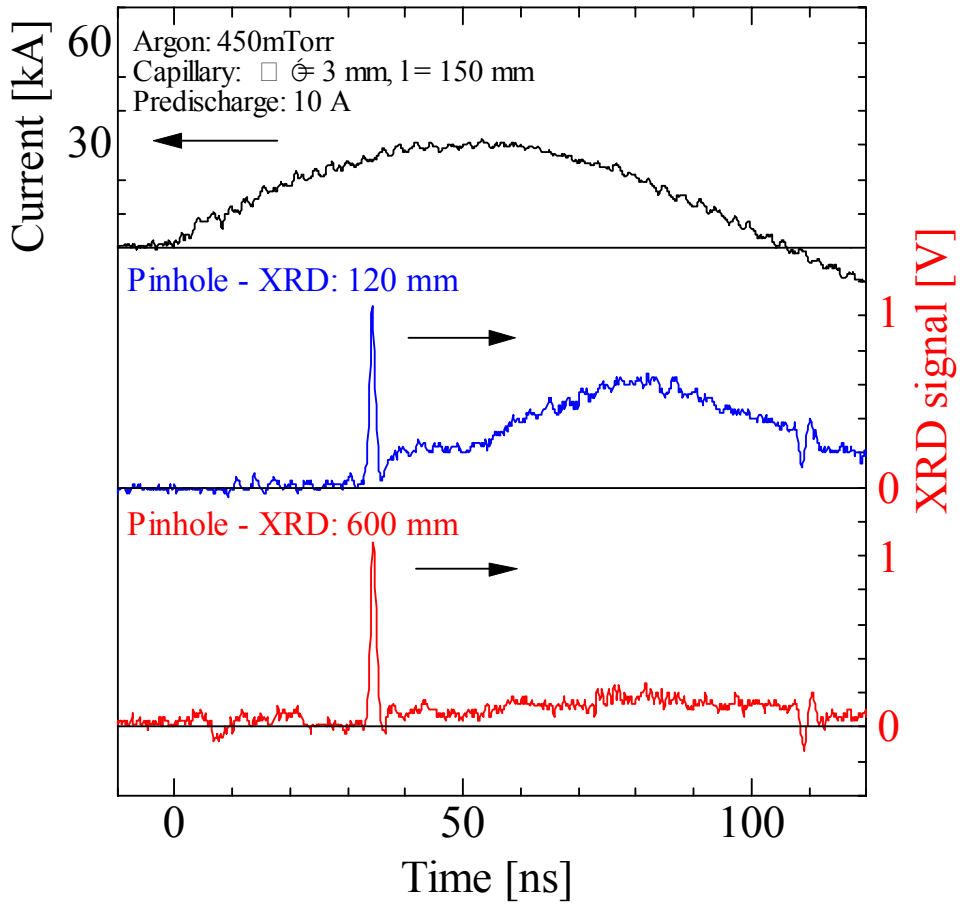
Time-spatial evolution of electron density

Directivity of Spike Output

Discharge conditions
- Ceramics Capillary:l = 150 mm, d = 3mm
- Argon: 450 mTorr
- Predischarge: 10 A

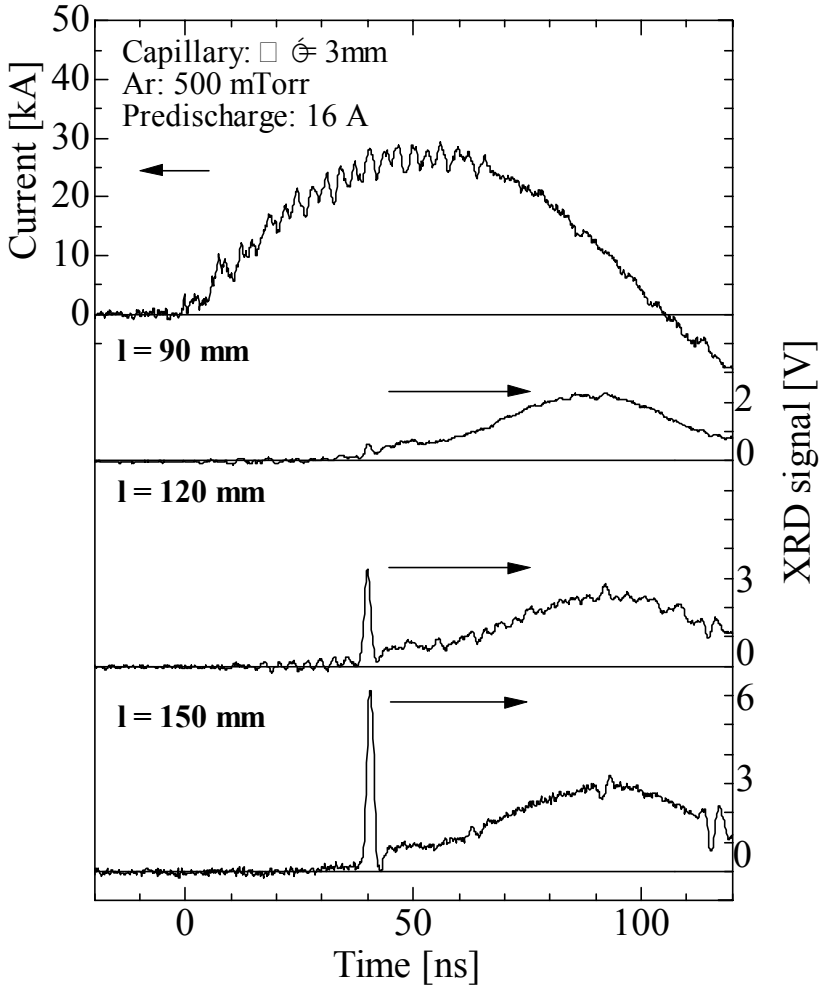


To confirm the directivity of laser, the distance from the capillary to the XRD is changed from 120mm to 600mm

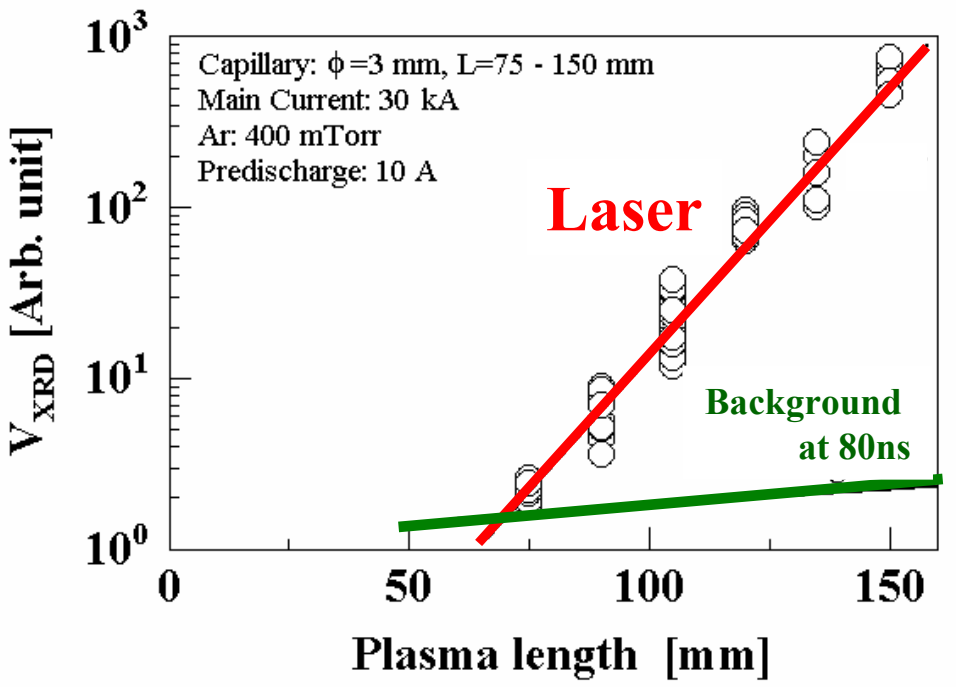


XRD output dependence on distance between capillary and detector

Gain-Length Product

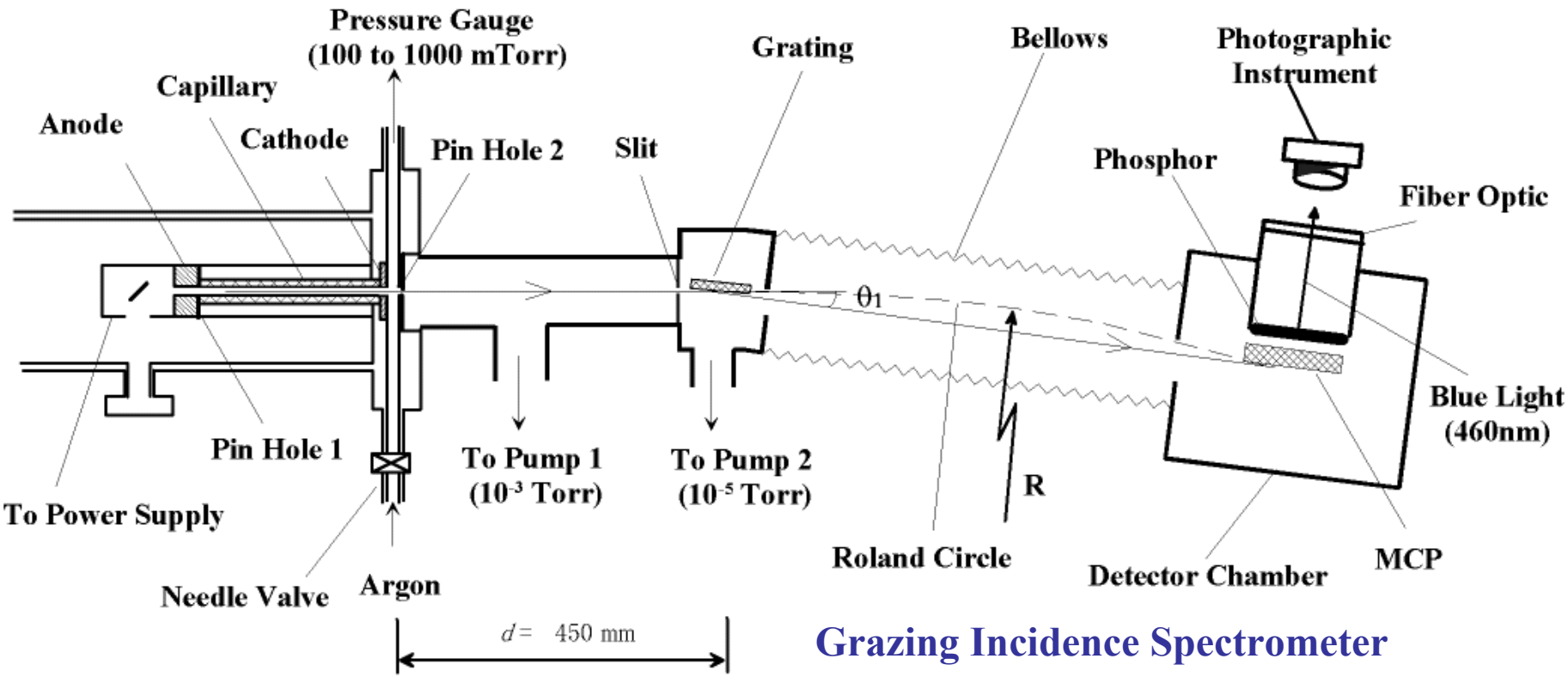


XRD output dependence on capillary length



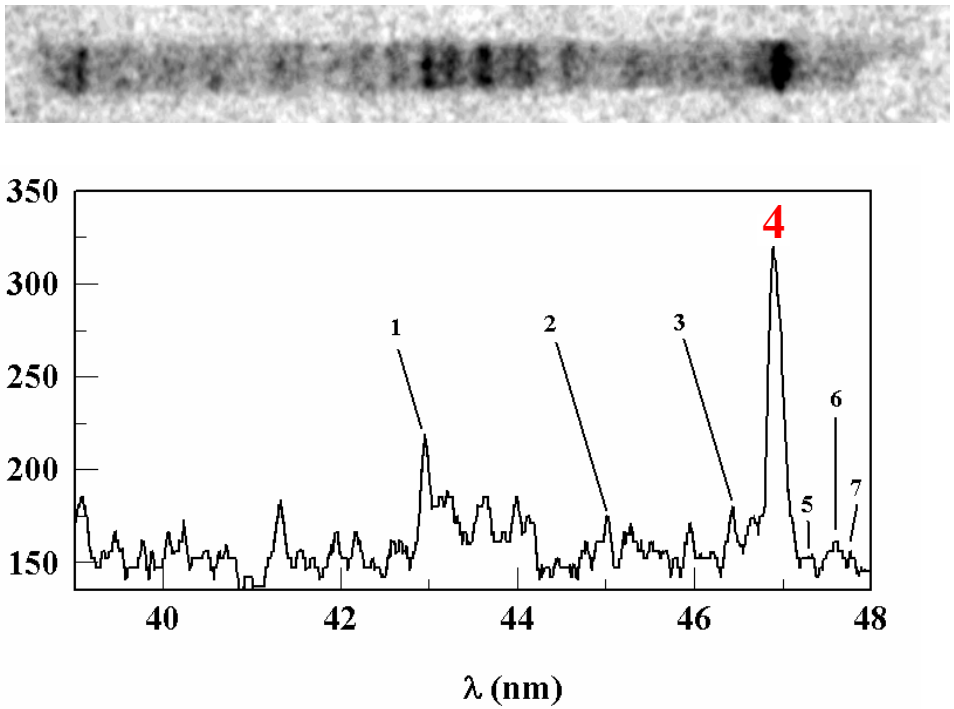
Maximum gain-length product gl of 12 (g = 0.8 cm^{-1}) and Laser output energy of 5 - 6 μJ are obtained.

Spectroscopic Measurement



Grazing Incidence Spectrometer (McPherson 248/310G)

Spectrum

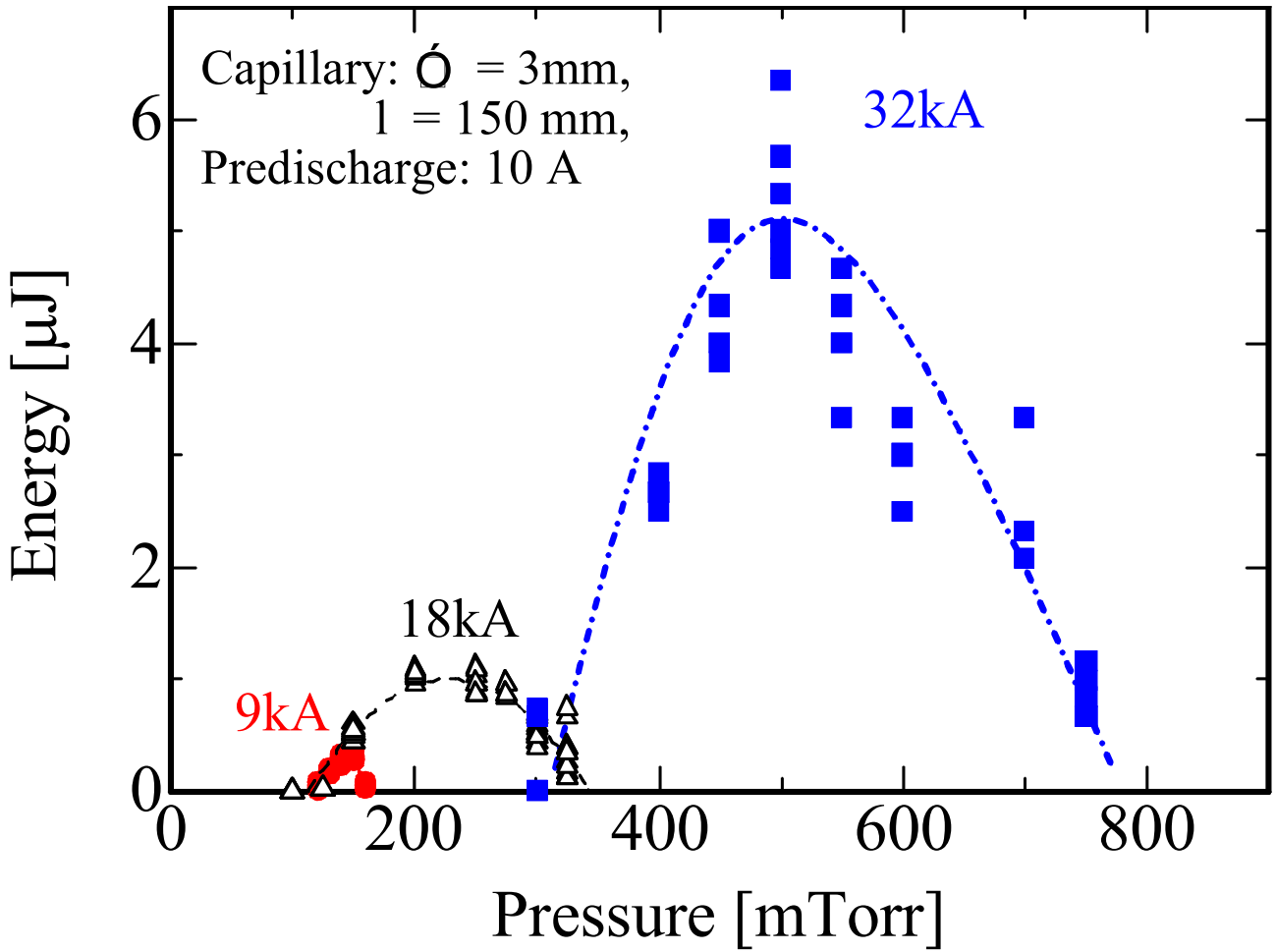


Label	Series	Transition	λ (Å)
1	*Ar IX*	$3s\ ^3P_1 - 3p\ ^1S_0$	431.123
2		$3p\ ^1P_1 - 3d\ ^1P_1$	450.660
3		$3p\ ^1P_1 - 3d\ ^1P_1$	465.118
4		$3s\ ^1P_1 - 3p\ ^1S_0$	468.793
5	*Ar VII*	3s3p – 3s3d (J = 0-1)	473.934
6		3s3p – 3s3d (J = 1-2)	475.654
7		3s3p – 3s3d (J = 2-3)	479.379

Discharge condition
Capillary : φ3, *l* =150 mm
***I* = 22 kA**
***p* = 300 mTorr**

After P.S.Antsiferov et al.,
***Physica Scripta*, Vol.62, pp.127-131, 2000**

Current and Pressure Range of Lasing

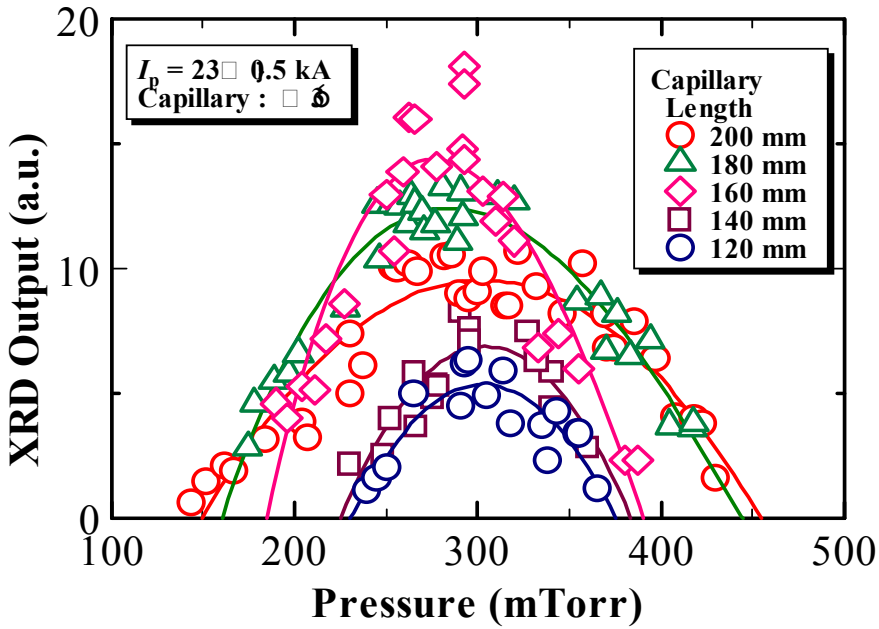


Lasing may be obtained with a current of below 9kA and over 32 kA, with adequate gas pressure.

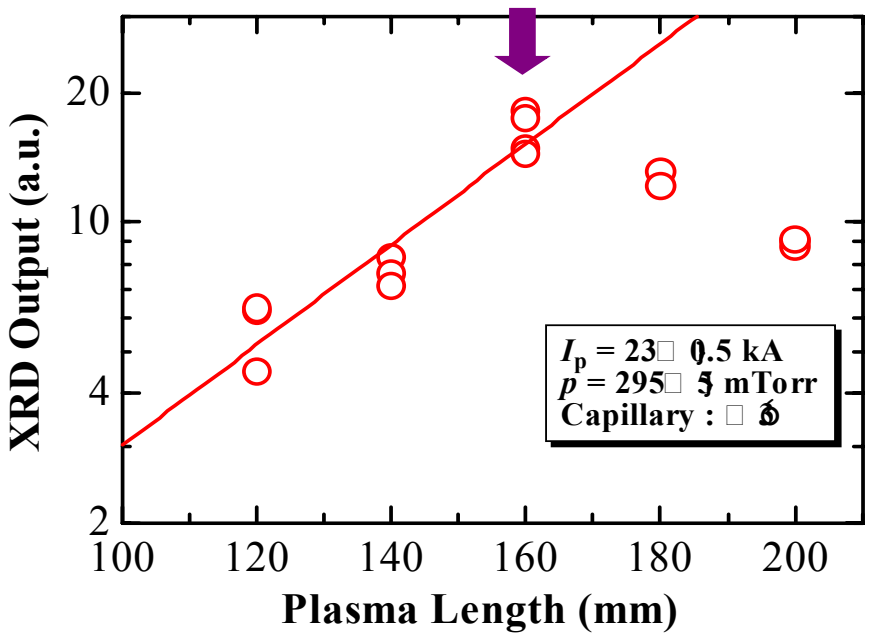
Saturation of Laser Output

Capillary : φ3, l =200 mm
I = 23±0.5 kA

SATURATION?
Capillary condition may affect



XRD Output vs Pressure



XRD Output vs Plasma Length

Summary

- **Ne-like Ar Soft X-ray Lasing was observed**
  - Current of 9-32kA and half period of 110ns
  - Ceramic capillary : φ=3mm, l = 150, 200mm
  - Argon gas pressure: 150-800mTorr
  - Maximum gl =12 (g=0.8cm^{-1}) at 32kA, 500mTorr
  - Pre-discharge current: 5-15A
- **Sufficient pre-discharge current is essential for**
  - Production of uniform pre-ionized plasma
  - Suppression of instabilities of pinched plasma
  - Increase of laser output and improvement of reproducibility
- **Lasing at current of less than 10 kA may be possible**
  - Lower laser output energy
  - Compact power supply
  - Higher rep-rate operation


Děkuju vám
Thank you