Excitation Temperature Measurement of Z-pinch Plasmas with Different Discharge Current*

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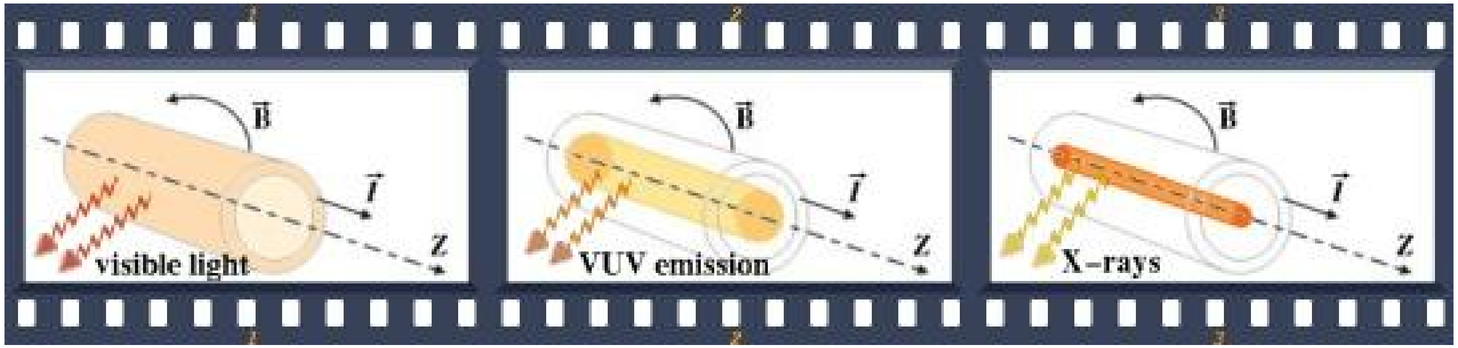
Abstract

Extreme ultraviolet lithography (EUVL) using EUV radiation can provide a solution for high-volume manufacturing of semiconductor fabrication. Among several techniques investigated for achieving short wavelength lasing, the capillary discharge has the advantage of being relatively simple, efficient and compact. We present the characterization of a z-pinch produced plasma in a capillary discharge channel filled by argon gas. The discharge is driven by low inductance capacitor bank charged up to 15 ~ 35 kV and switched by spark gap switch. In order to understand the z-pinch produced plasma, the excitation temperature is measured for different discharge currents, by spectroscopic measurements. Temporal variation of excitation temperature have similar tendency with light intensities. Excitation temperature is increased as discharge voltage increases.

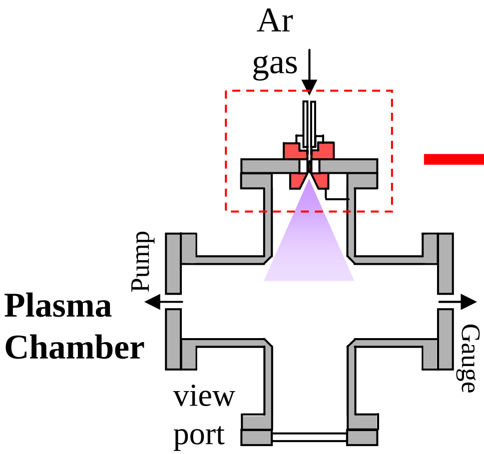
Contents

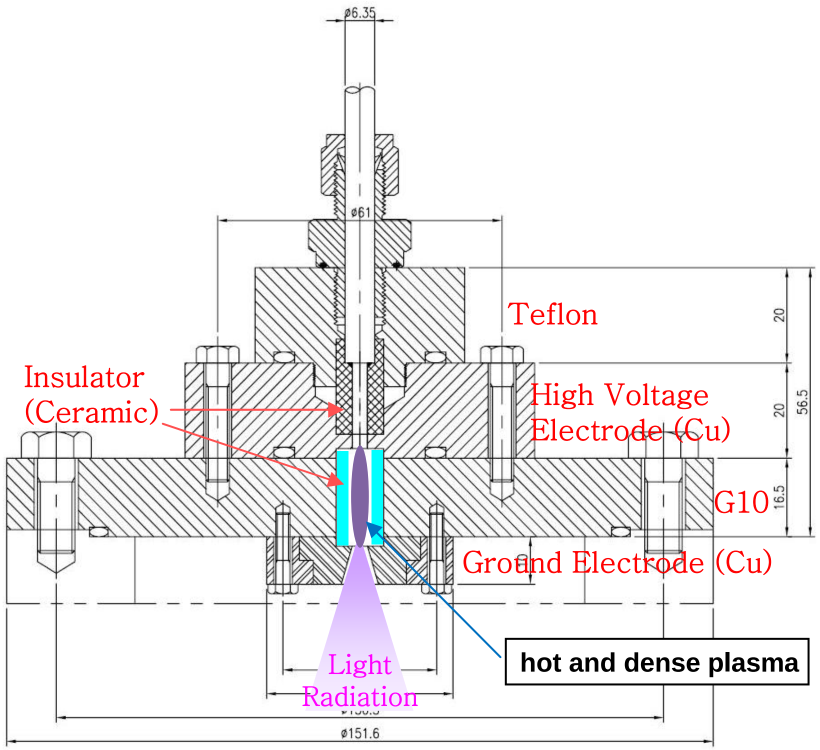
Z-pinch

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.



Electrode Configuration

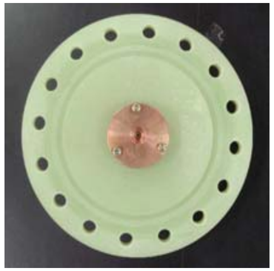




Electrode Configuration

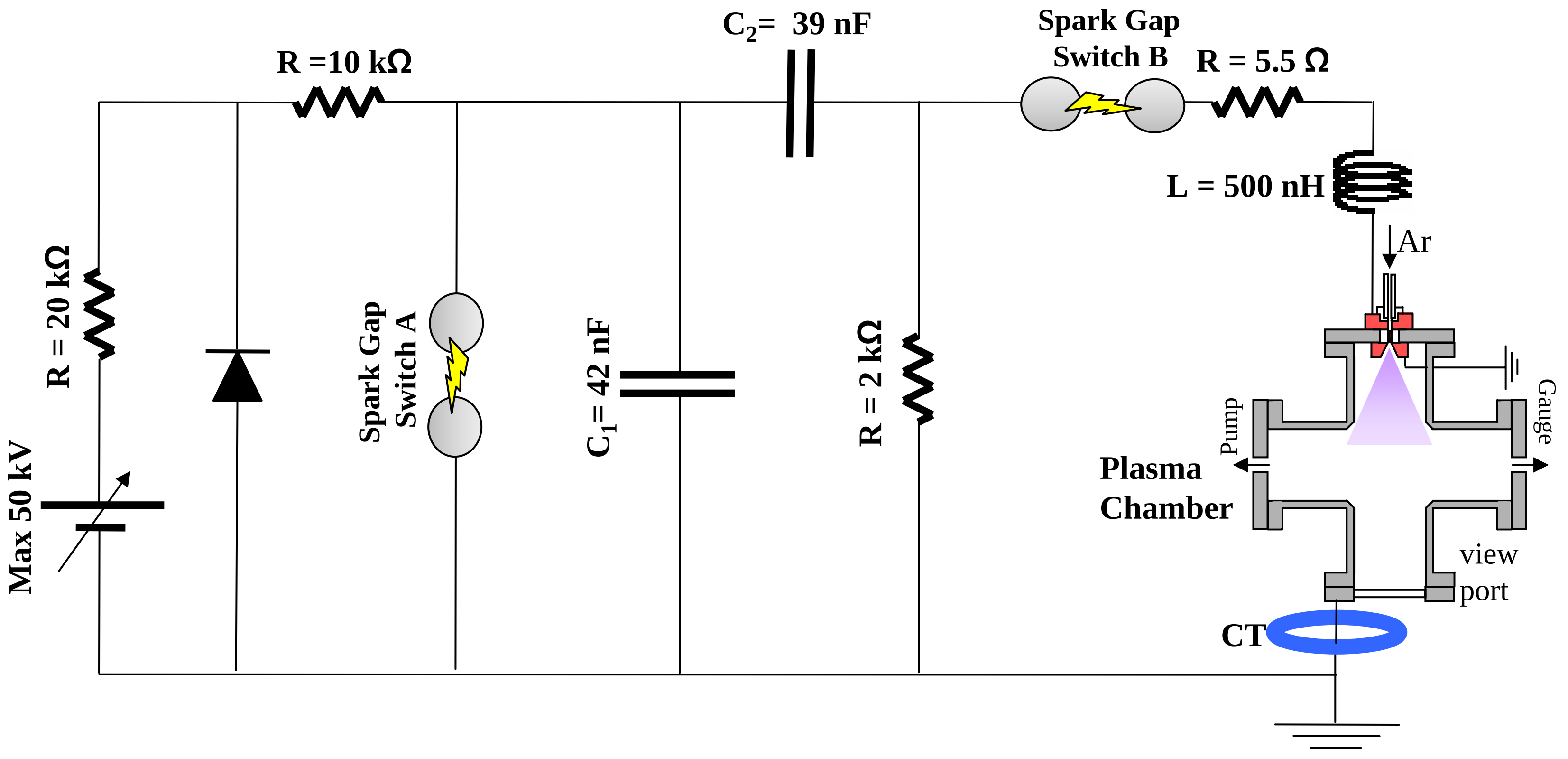
[Top view]

[Side view]



[Down view]

Circuit Design



Boltzmann Plot Method

Boltzmann Equation

$$I = \frac{hc}{4\pi\lambda} N(T) \frac{A_{ki}\, g_k}{U(T)} \exp\left(-\frac{E_k}{KT}\right)$$

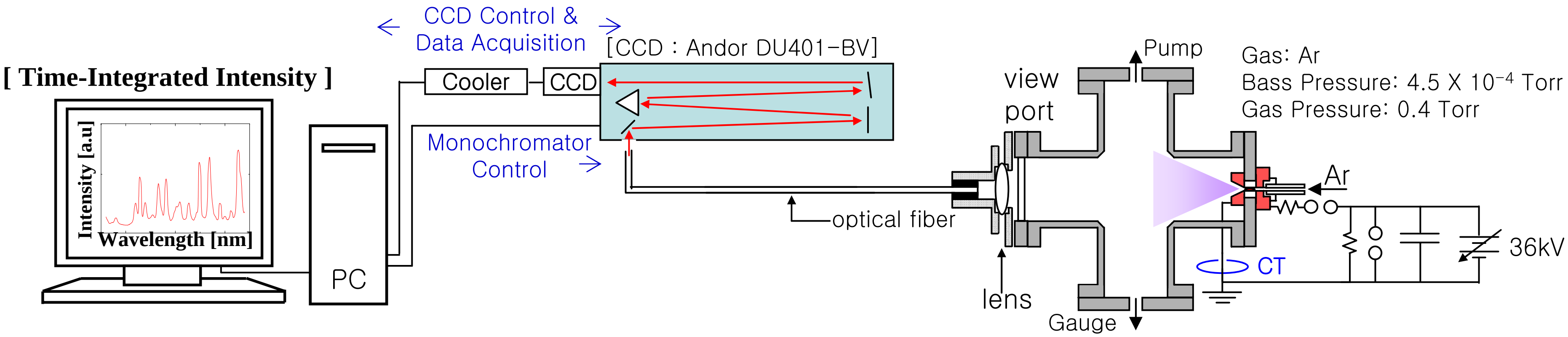
I: Intensities
λ: wavelength
A_{ki}: the transition probability
g_k: statistical weight for the upper level
E_k: the excited level energy
T: Excitation temperature
K: Boltzmann const
U(T): the partition function

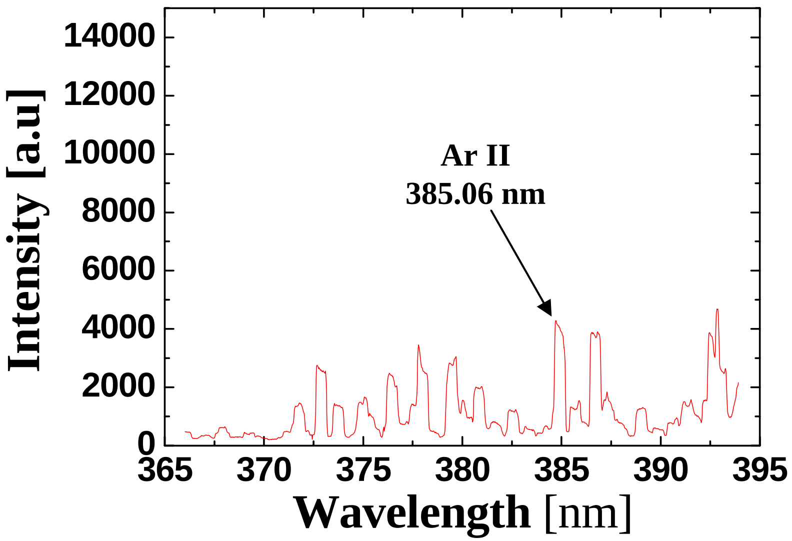
Reformulating Boltzmann Equation gives

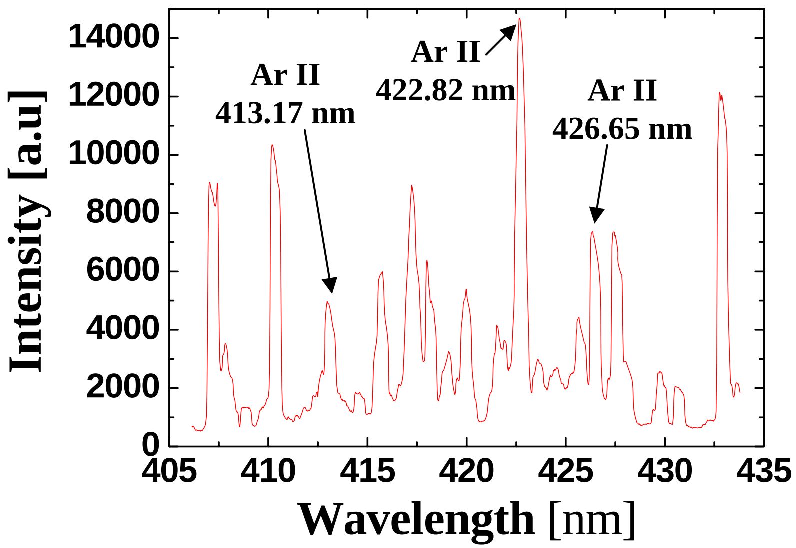
$$\ln \frac{I\lambda}{A_{ki}\, g_k} = -\frac{1}{KT} E_k + \ln \frac{C\,F}{U(T)}$$

By plotting the left hand side of above equation vs. the excited level energy E_k, the plasma temperature can be obtained from the slope.

Argon Emission Line Selection







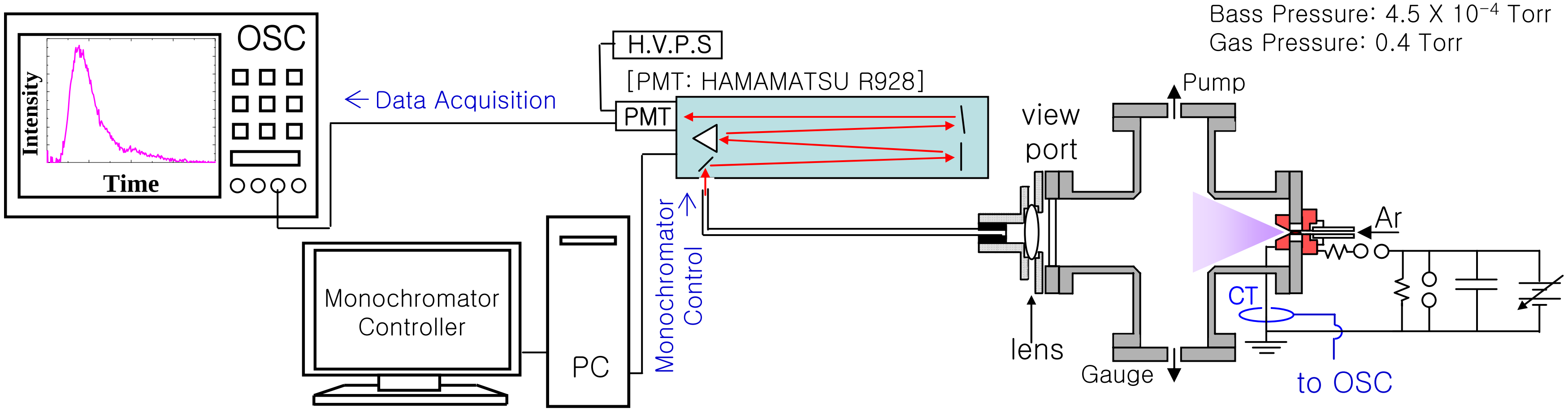
Selected Ar Emission Spectrum Line Information

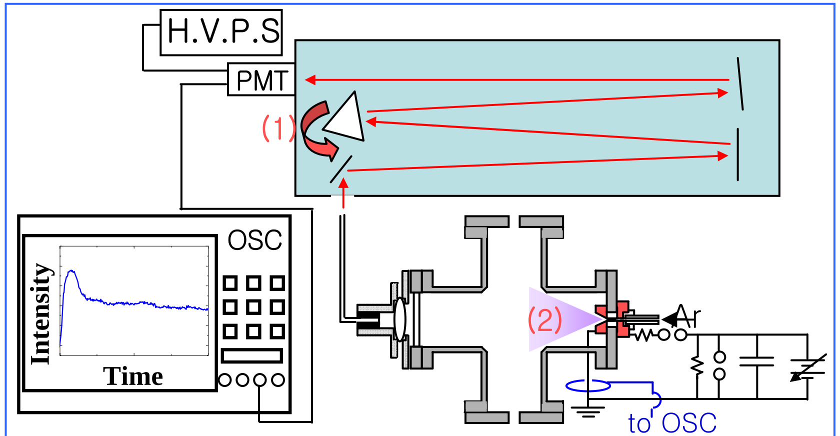
Wavelength (nm)	Transition Array	Multiplet	E_k(eV)	g_k	$A_{ki}(10^7 s^{-1})$
385.06	$3s^2 3p^4(^3P)4s$ — $3s^2 3p^4(^3P)4p$	^4P — $^4S°$	19.97	4	3.87
413.17	$3s^2 3p^4(^1D)4s$ — $3s^2 3p^4(^1D)4p$	^2D — $^2P°$	21.43	2	8.50
422.82	$3s^2 3p^4(^3P)4s$ — $3s^2 3p^4(^3P)4p$	^4P — $^2D°$	19.68	6	1.12
426.65	$3s^2 3p^4(^3P)4s$ — $3s^2 3p^4(^3P)4p$	^4P — $^4D°$	19.55	6	1.64

Excitation Temperature Measurement

1. Measurement of Specific Line Intensity Time Variation

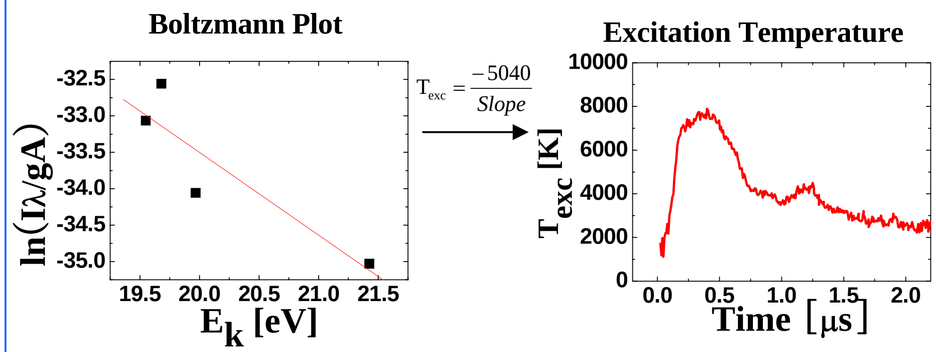
Gas: Ar
Bass Pressure: 4.5 X 10^{-4} Torr
Gas Pressure: 0.4 Torr





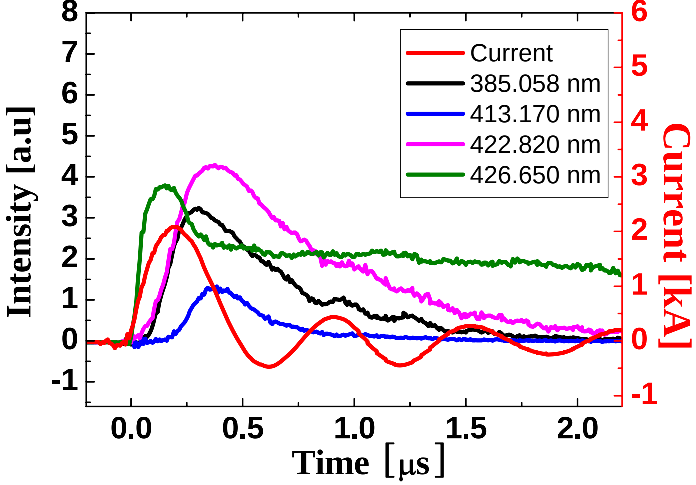
2. (1) Rotate Grating
(2) Measure Specific Line Intensity Time Variation

3. Excitation Temperature Calculation Using Boltzmann Plot Method

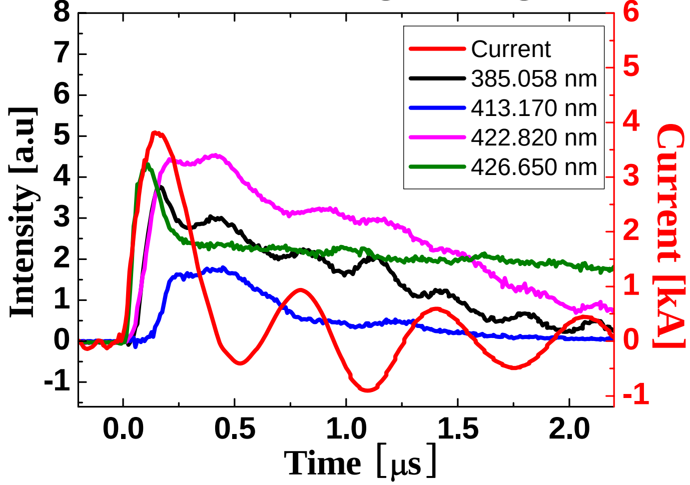


Time Evolution of Spectral Intensities & Excitation Temperature

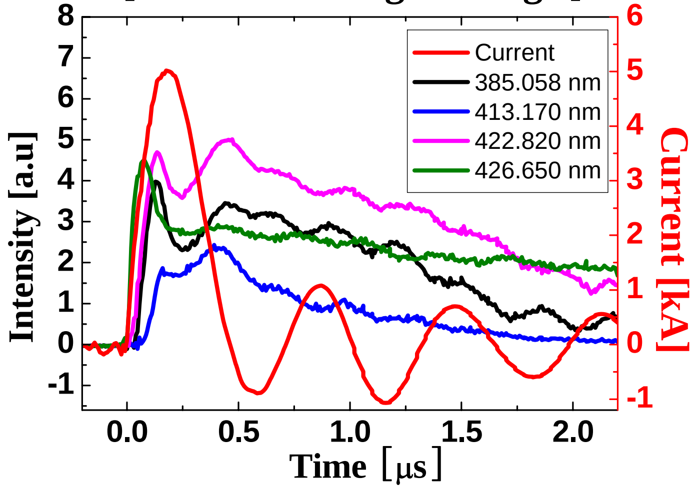
[15 kV Discharge Voltage]



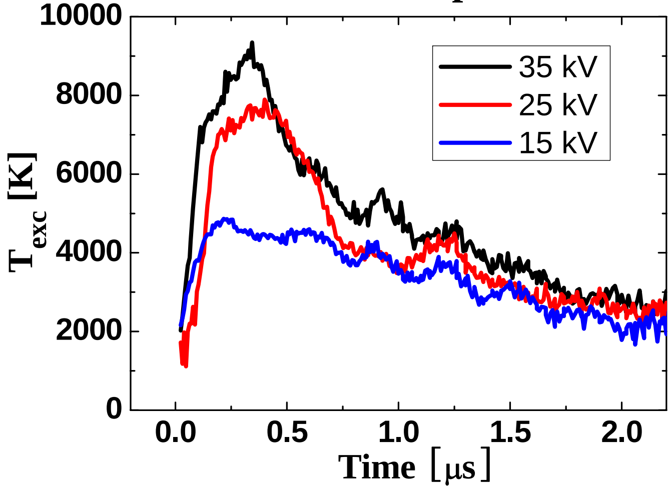
[25 kV Discharge Voltage]



[35 kV Discharge Voltage]



[Excitation Temperature]



Conclusion

- Temporal variation of excitation temperature have similar tendency with light intensities.
- Excitation temperature is increased as discharge voltage increases.
- Effect of the capillary size, initial pressure on the excitation temperature will be investigated.
- We will apply pre-ionization circuit to confirm the plasma stability.