# *Extreme ultraviolet alkali metal source at 40 nm*

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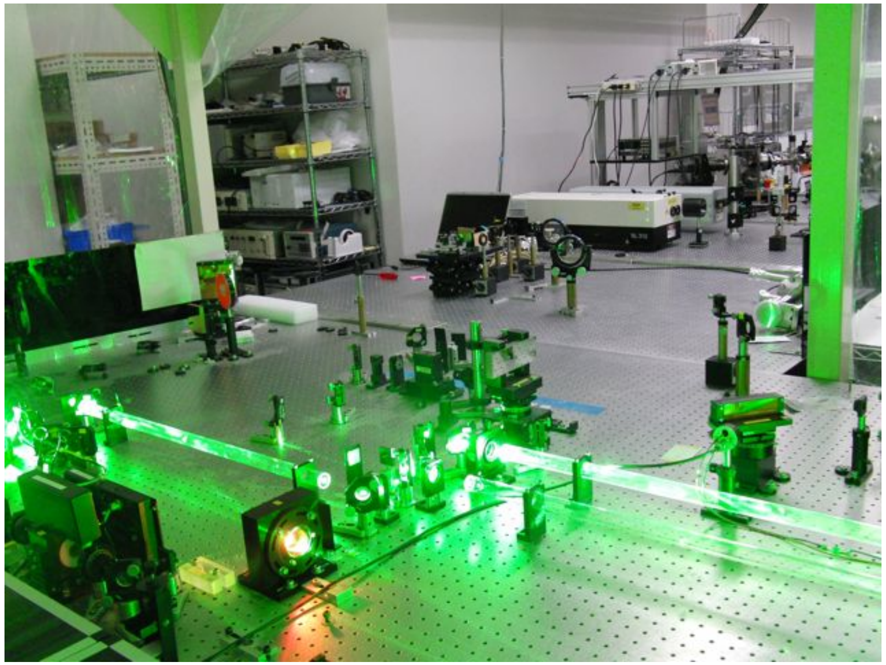
Research Centre of the Polish Academy of Sciences in Paris
14:35-15:00, Thursday 17 November, 2011

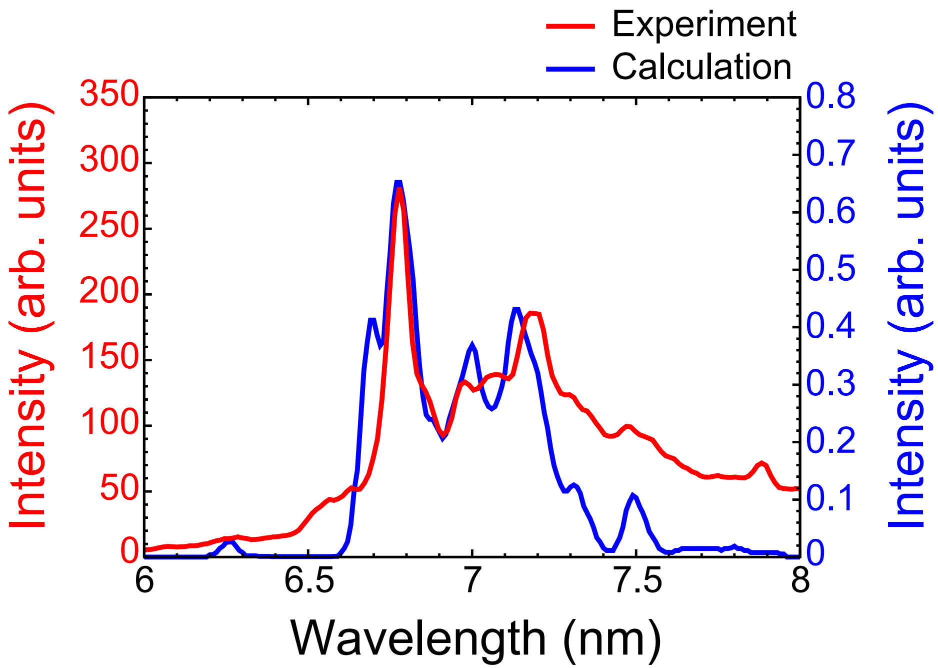
# *6.X nm with UCD*

(1) Laser-produced plasmas for 6.7 nm using fs, ps, and ns

(2) Discharge-produced plasma with laser-ablated Gd/Tb vapors

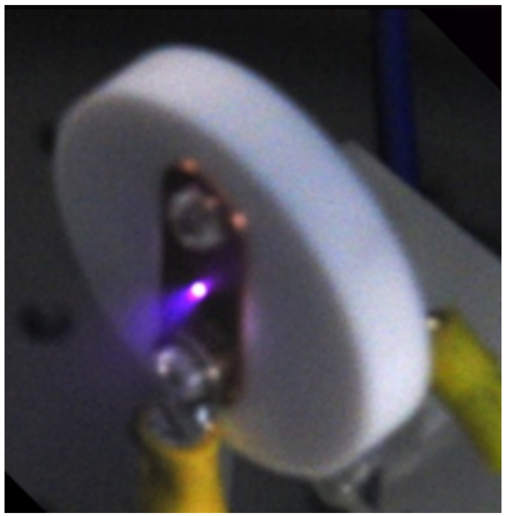
(3) Atomic processes in plasmas (UCD)

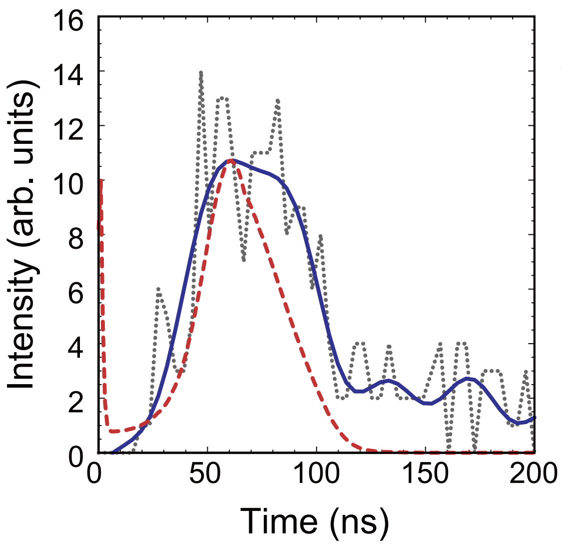


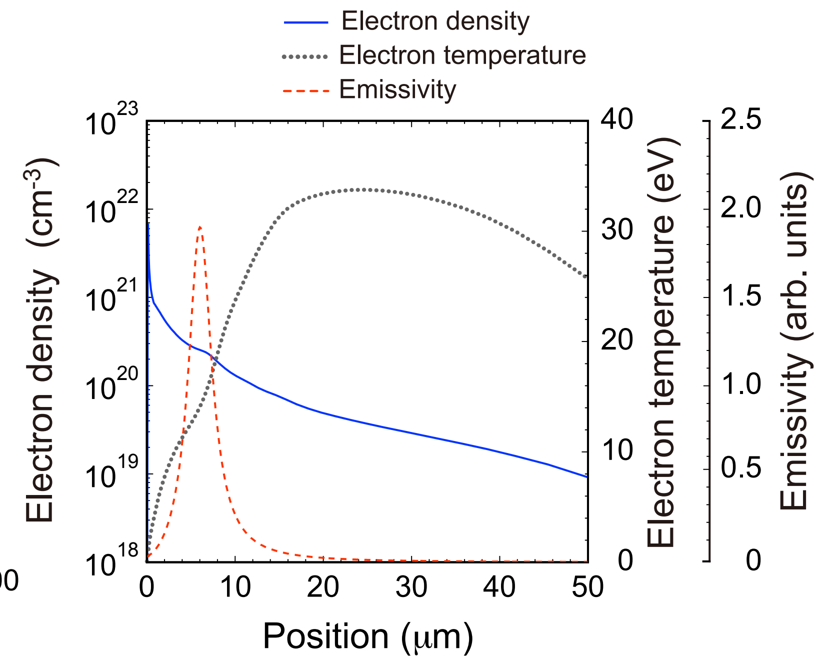


# *What's new*

- Observation of the spectra of a potassium plasma
- Evaluation of the multiple charge state ions
- Comparison between LPP and DPP





# *Why alkari metal XUV?*

(1) Low melting temperature [K (potassium: 63 $^{o}$C)]

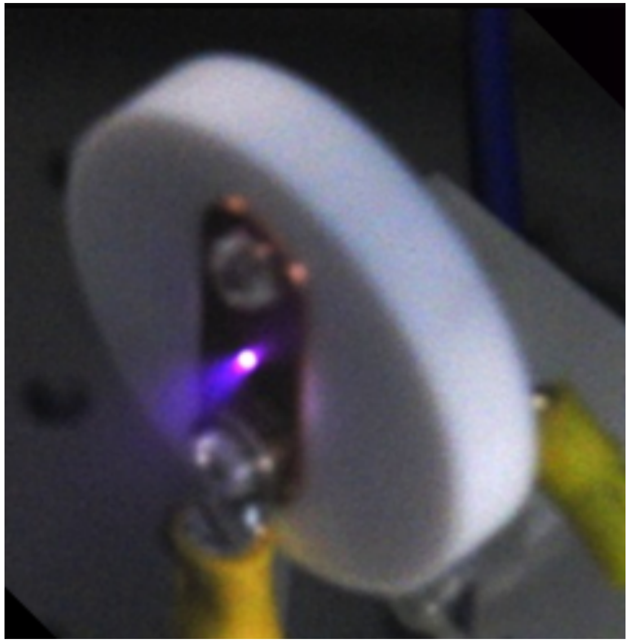
(easy vaporization by dsicharge)

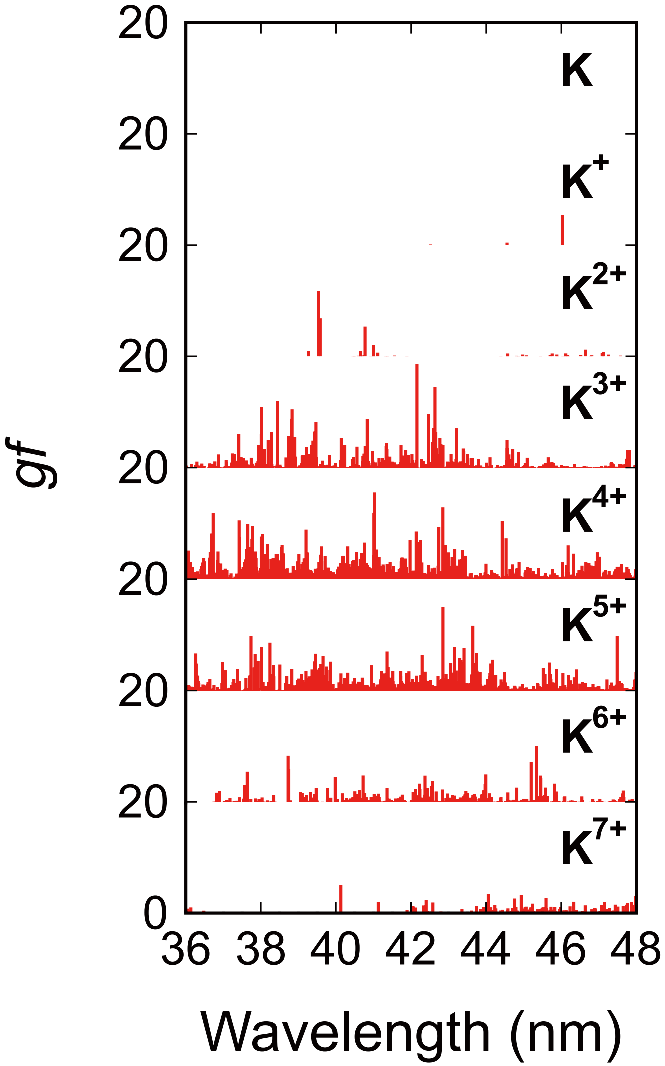
(2) Strong *gf* lines around XUV spectral region

(3) Little study of alkari metal XUV sources

(is equal to little academic paper)

# *Potassium source around 40 nm*





# Publication

APPLIED PHYSICS LETTERS **96**, 131505 (2010)

## Characteristics of extreme ultraviolet emission from a discharge-produced potassium plasma for surface morphology application

Takeshi Higashiguchi,[1,2,a)] Hiromitsu Terauchi,[1] Noboru Yugami,[1,2] Toyohiko Yatagai,[1] Wataru Sasaki,[3] Rebekah D'Arcy,[4] Padraig Dunne,[4] and Gerry O'Sullivan[4]
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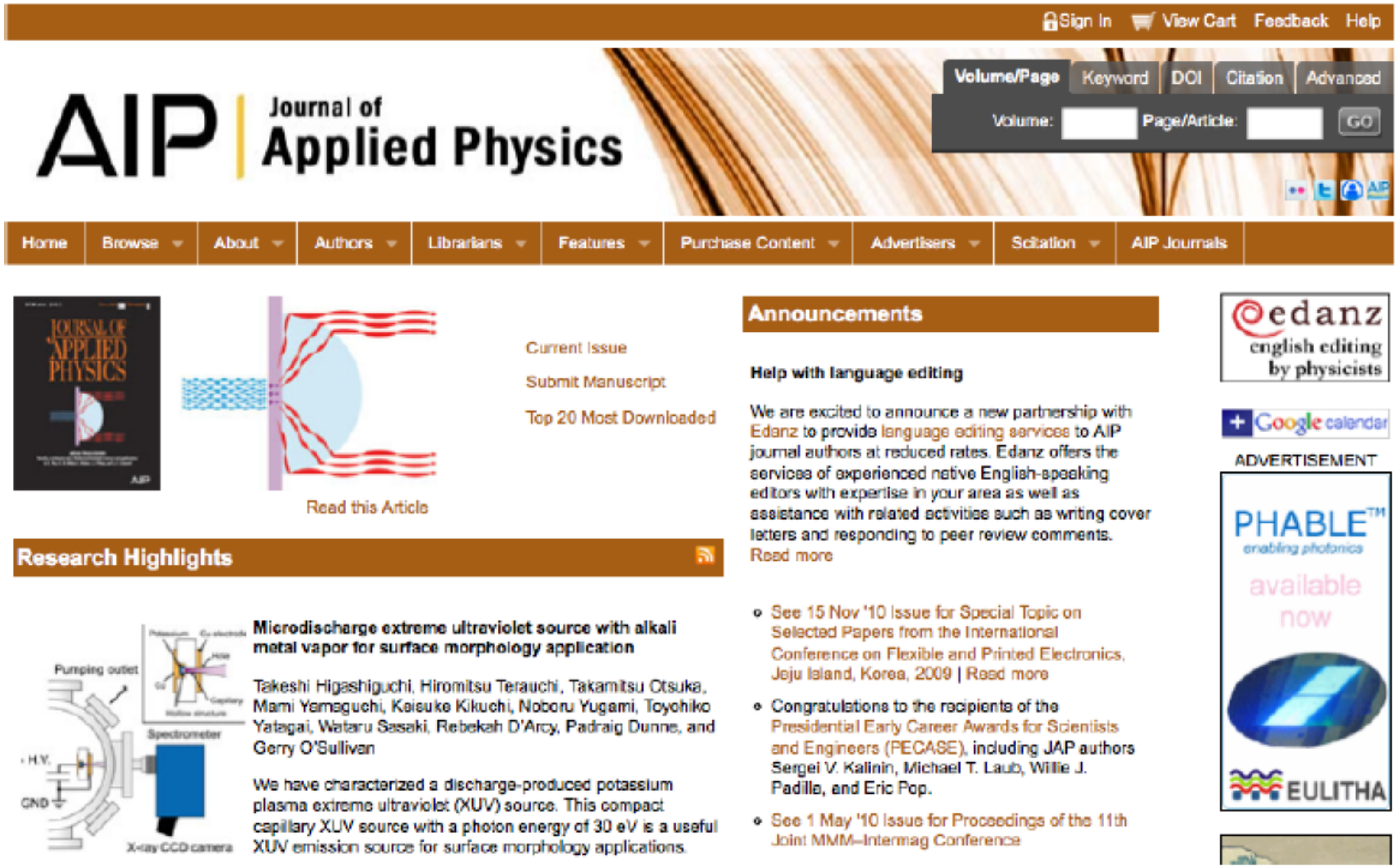
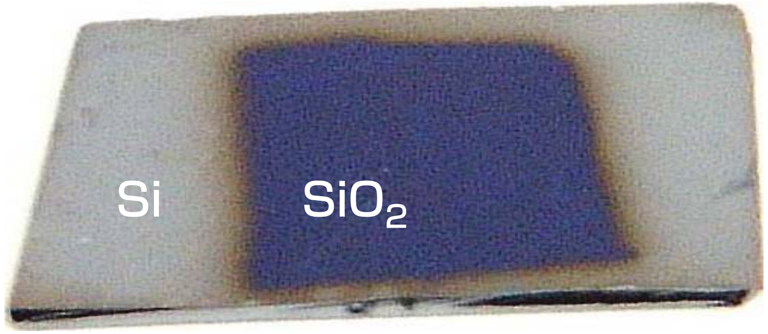
We have demonstrated a discharge-produced microplasma extreme ultraviolet source based on a pure potassium vapor. Potassium ions produced strong broadband emission around 40 nm with a bandwidth of 8 nm (full width at half-maximum). The current-voltage characteristics of microdischarge suggest that the source operates in a hollow cathode mode. By comparison with atomic structure calculations, the broadband emission is found to be primarily due to $3d-3p$ transitions in potassium ions ranging from $K^{2+}$ to $K^{4+}$. 

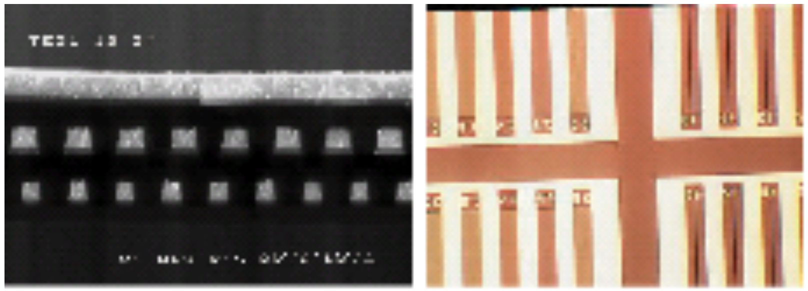
# One of JAP Highlights



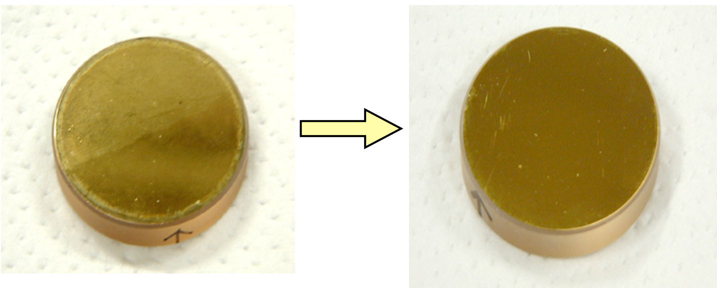
# *Applications by us*




Remove $SiO_2$ layer

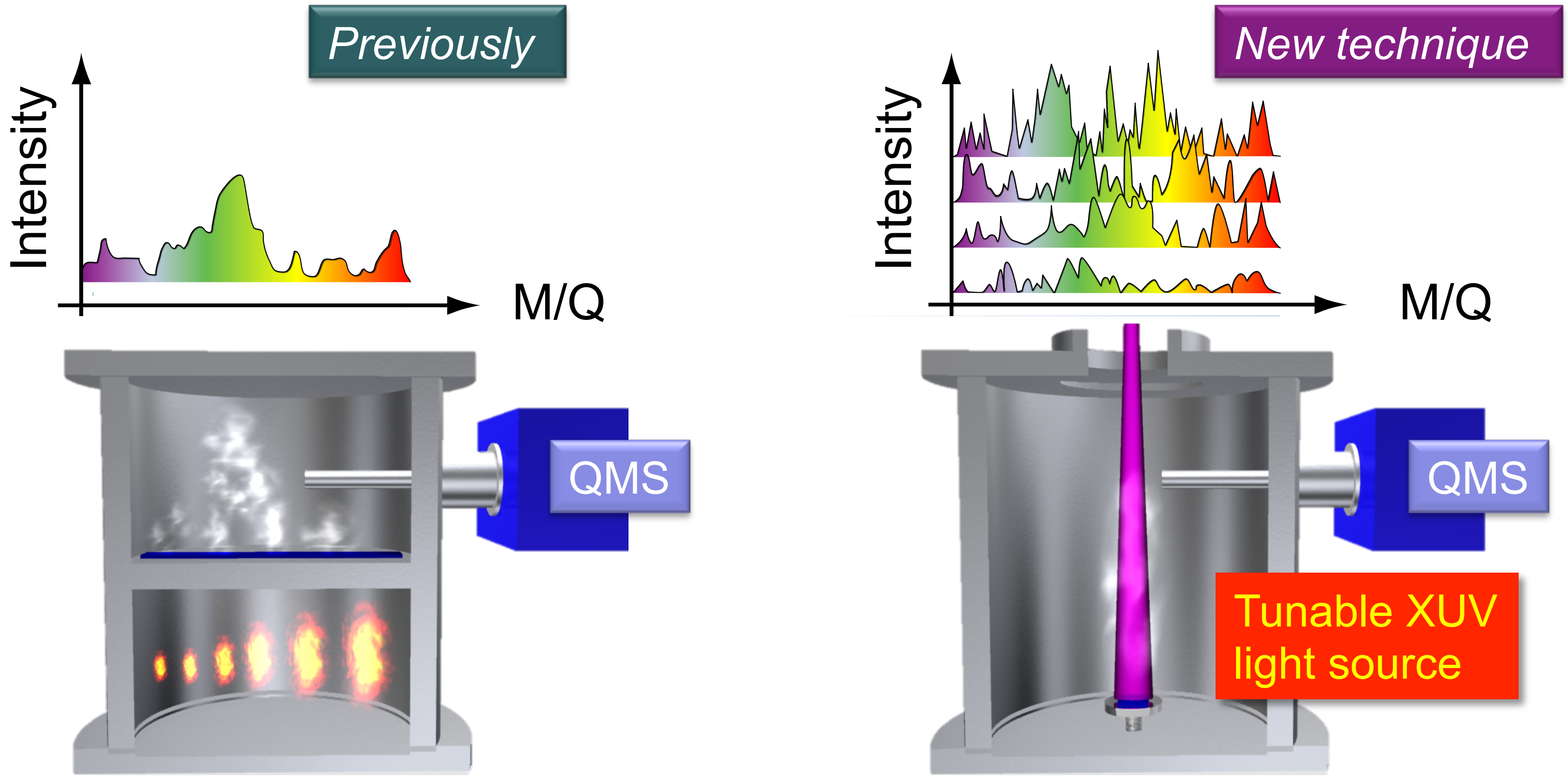


VUV CVD



Cleaning of the grating

# *Photo-stimulated desorption mass spectrometer using EUV emission*

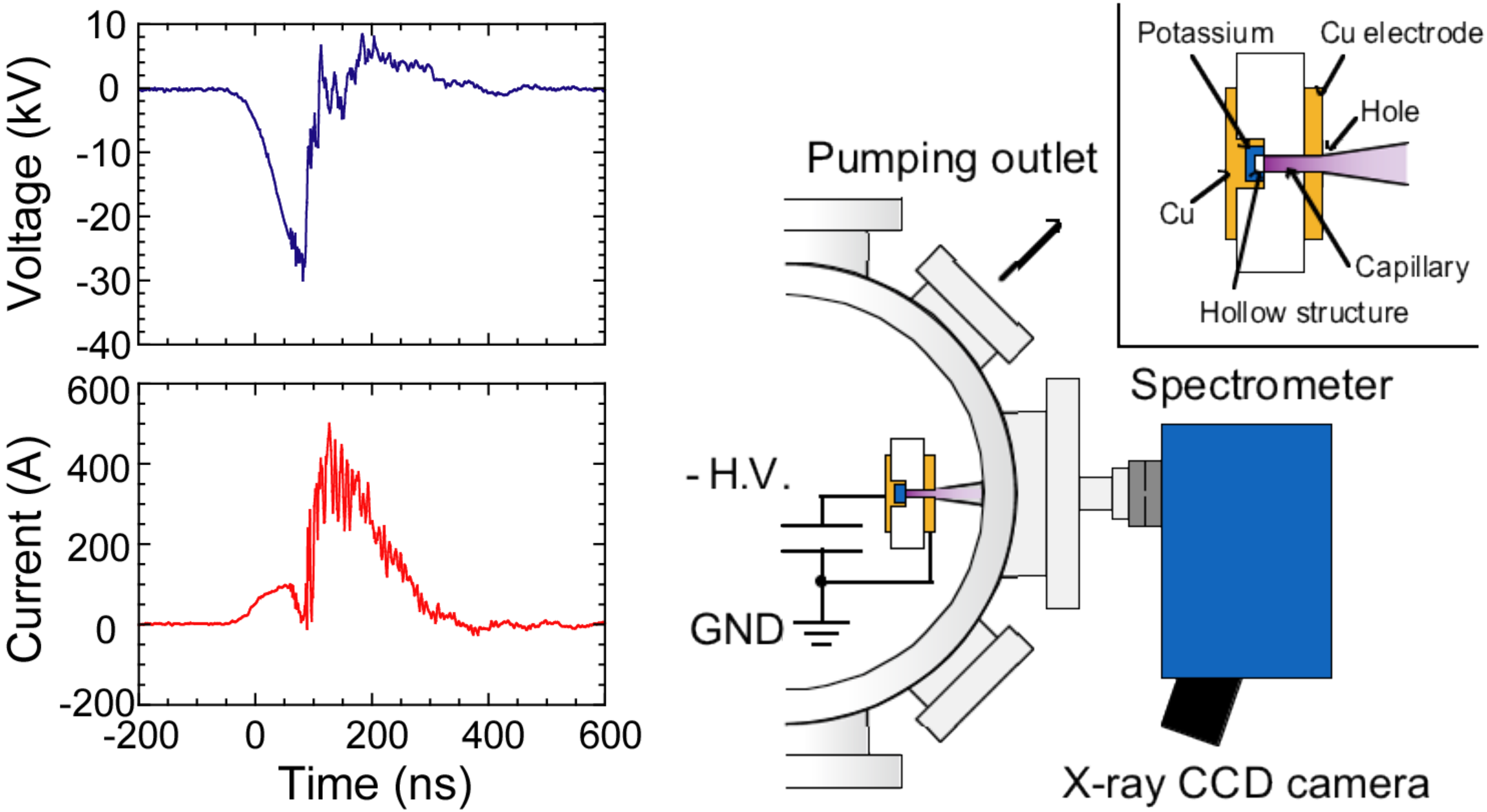



- Photodesorption → No damage
- Tunable XUV light source → Tunable material

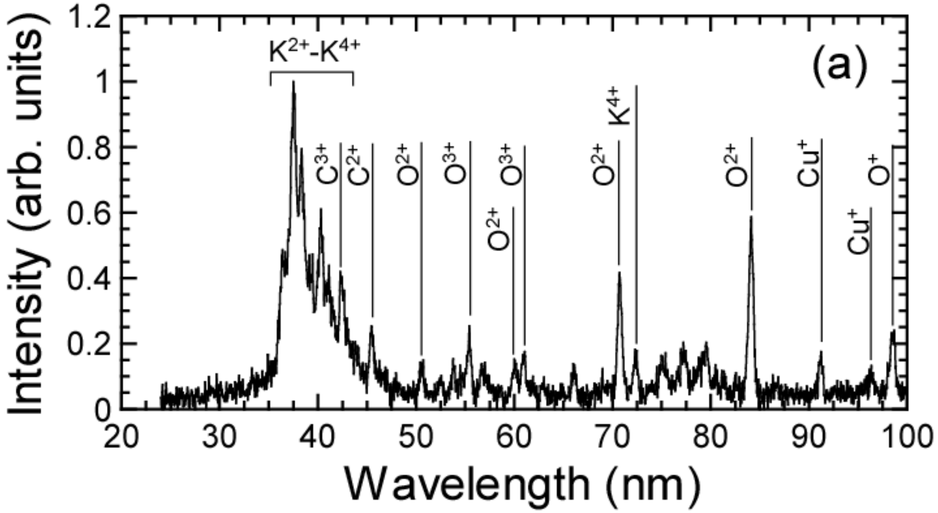
# *Objective*

**We characterize the capillary discharge-produced plasma XUV source by use of pure alkali metal vapor.**

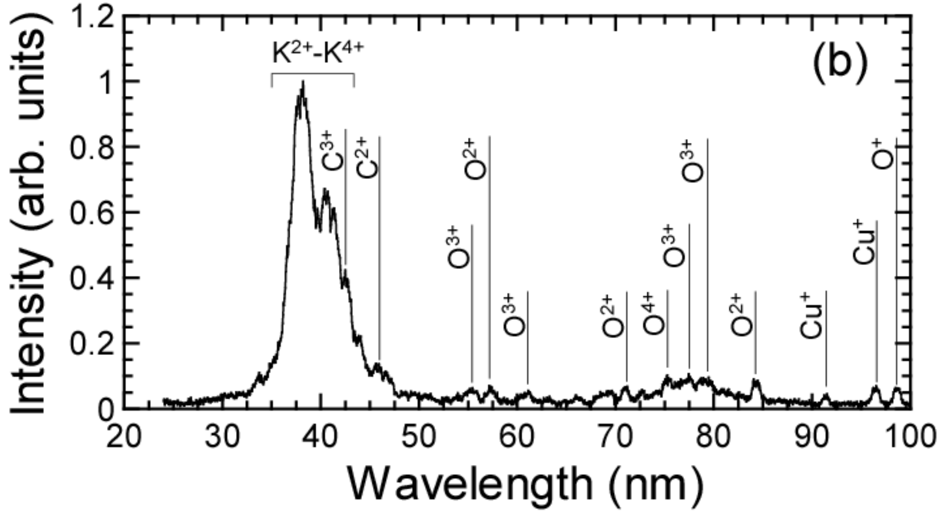
# *Schematic diagram of the experimental apparatus*



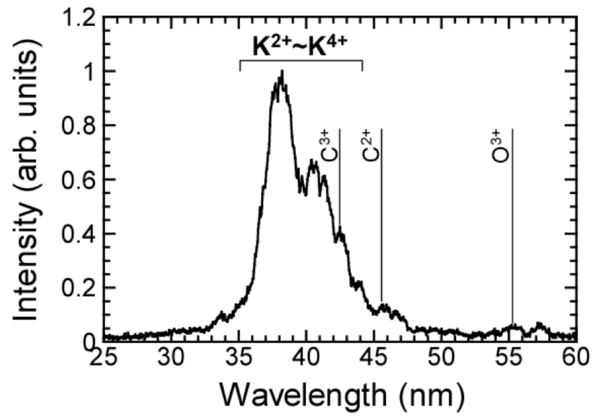
# *Emission spectra from the different capillary inner diameters*



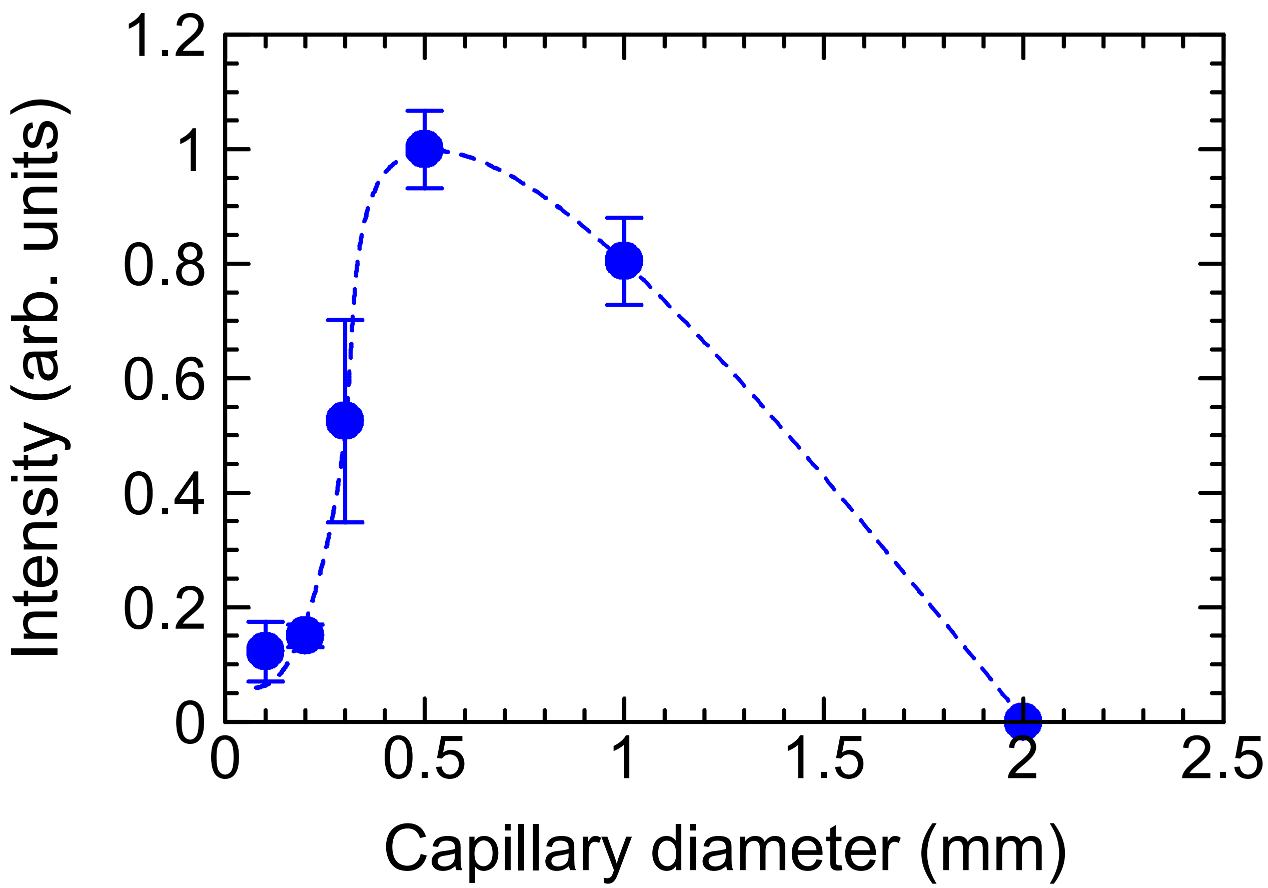

**(a) Inner diameter: 1 mm**



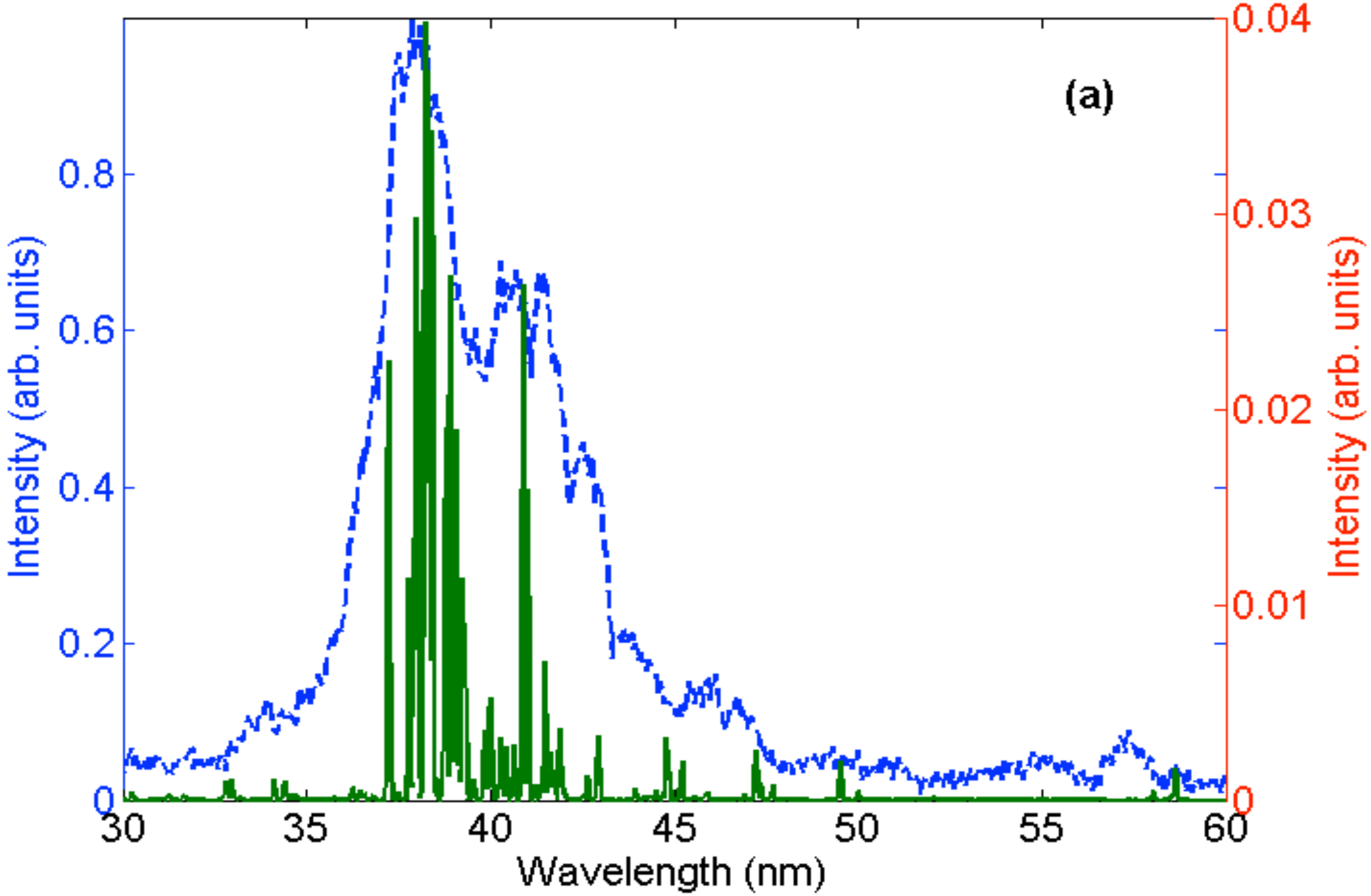

**(b) Inner diameter: 0.5 mm**



# *Capillary inner diameter dependence of the emission energy*

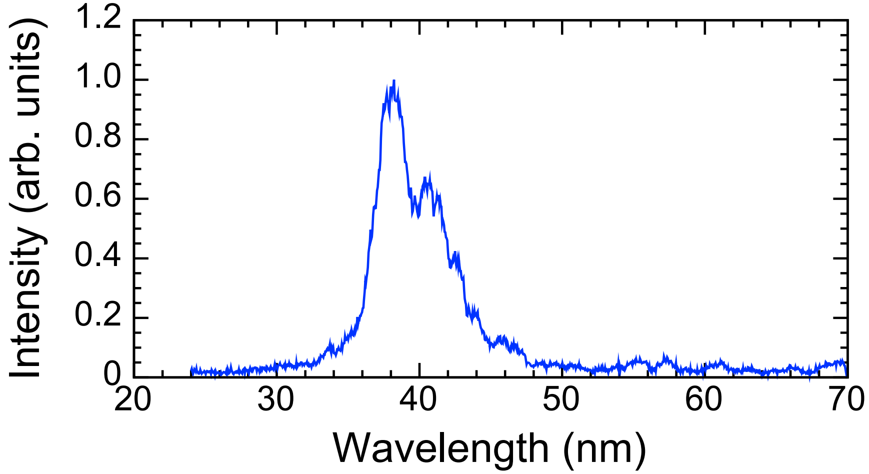


# *Comparison of experiments and gf spectral line calculation*

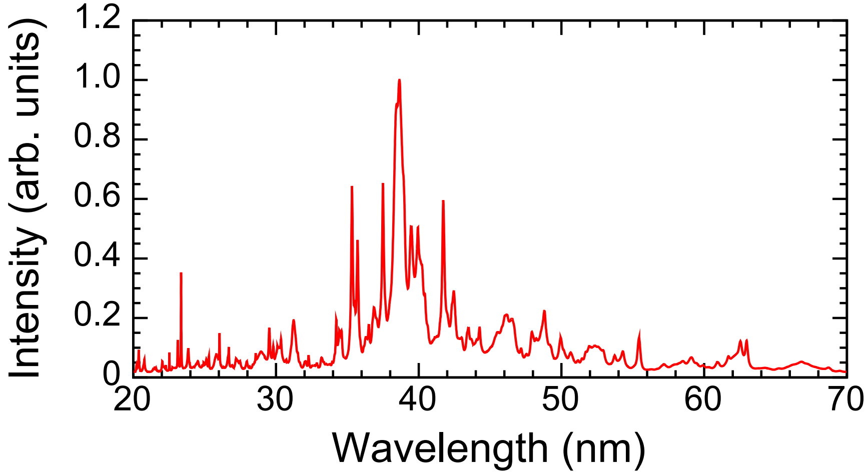


# *Comparison of experiments and numerical simulation*

**Experiments**




**Numerical simulation**

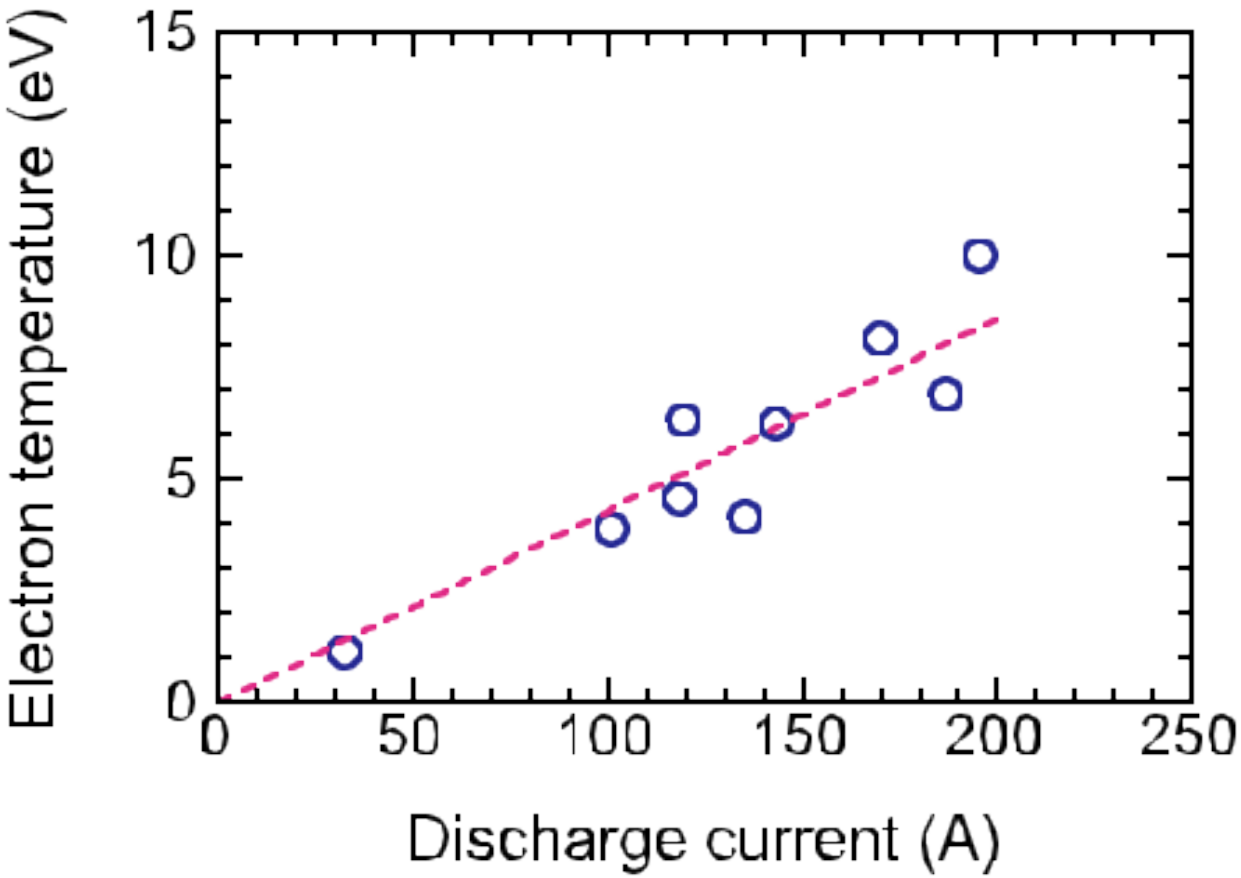



Time-integrated electron temperature: 12 eV

Electron density: 1 × $10^{20}$ $cm^{-3}$


T. Higashiguchi *et al*., Appl. Phys. Lett. **96**, 131505 (2010).

# Discharge current dependence of time-integrated electron temperature

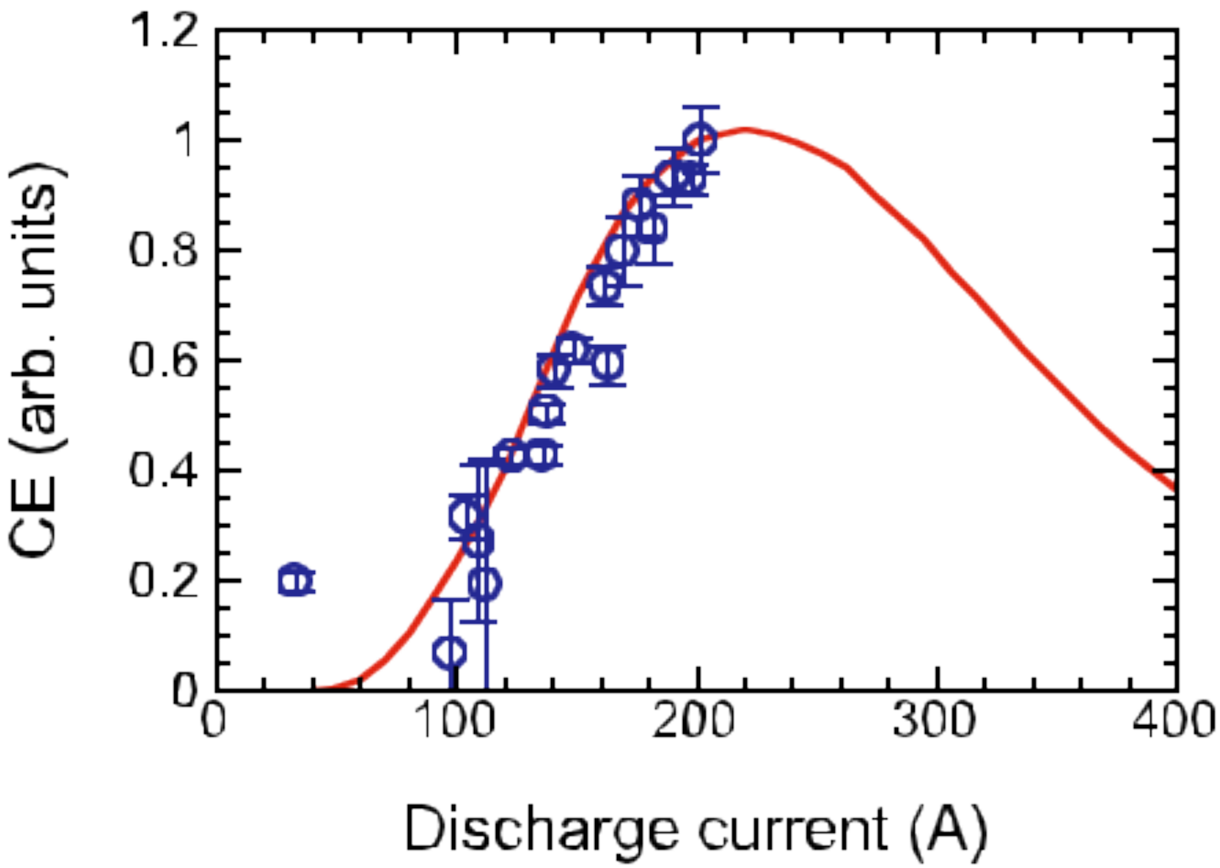



$$T_e \propto \frac{\Delta E}{\ln(I_1\lambda_1/I_2\lambda_2)}$$

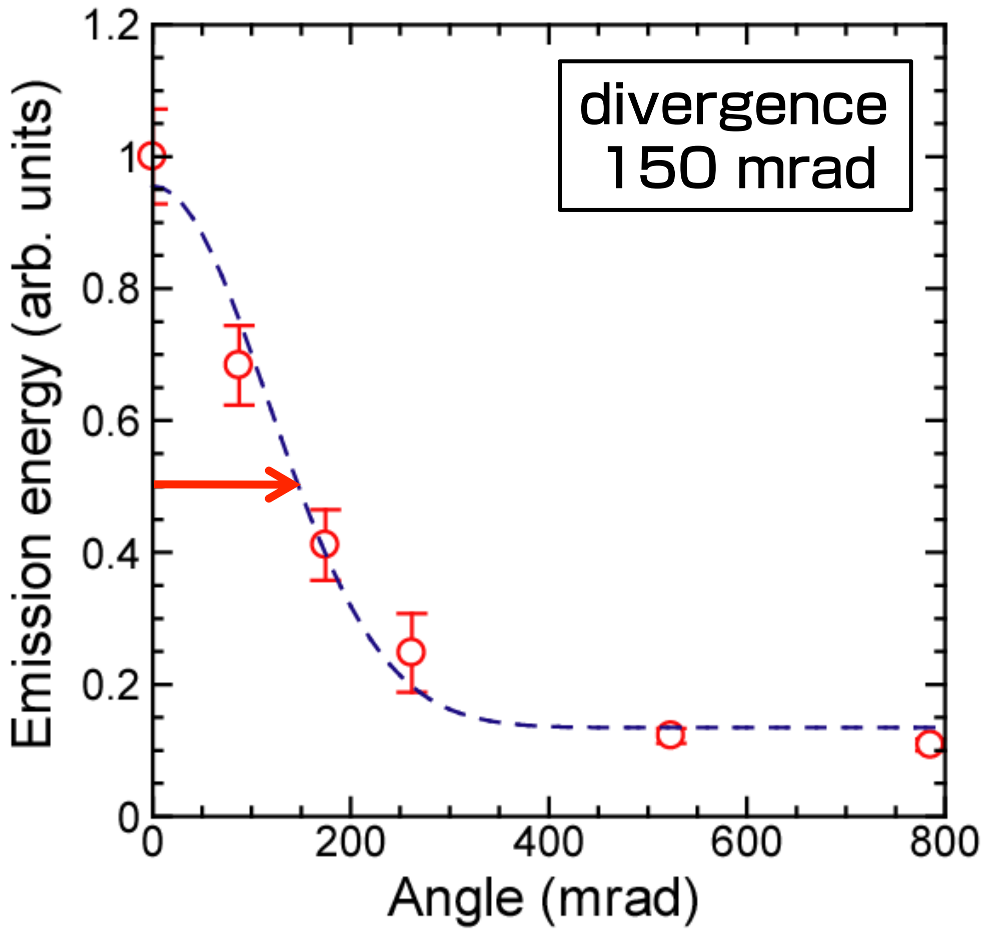
$O^{2+}$: $l_1$ = 70.4 nm
$O^{2+}$: $l_2$ = 83.4 nm

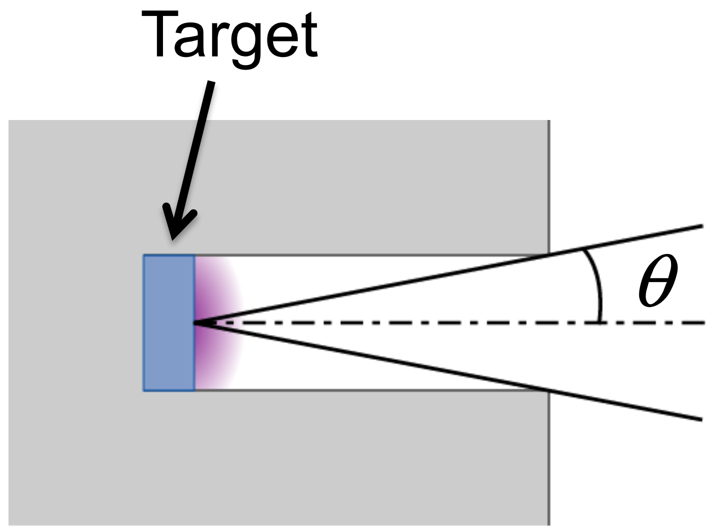
$O^{3+}$: $l_1$ = 55.4 nm
$O^{3+}$: $l_2$ = 61.7 nm

# *Discharge current dependence of the XUV conversion efficiency*



# *Angular distribution of the XUV emission energy*

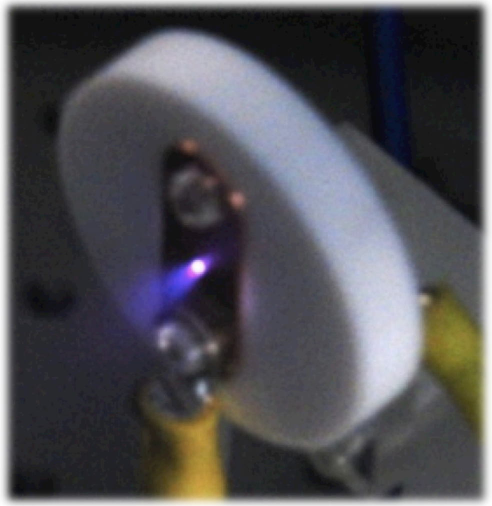


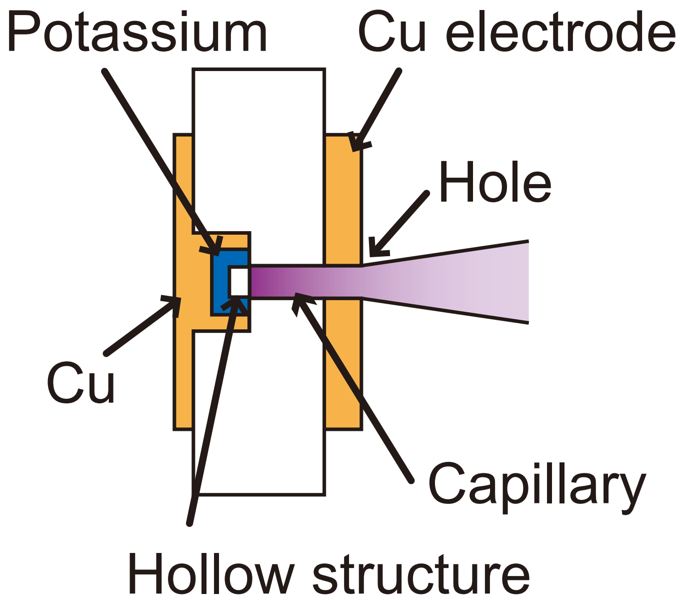




$$\theta = \tan^{-1}\frac{r}{l}$$

; 170 mrad

# Electrode structure

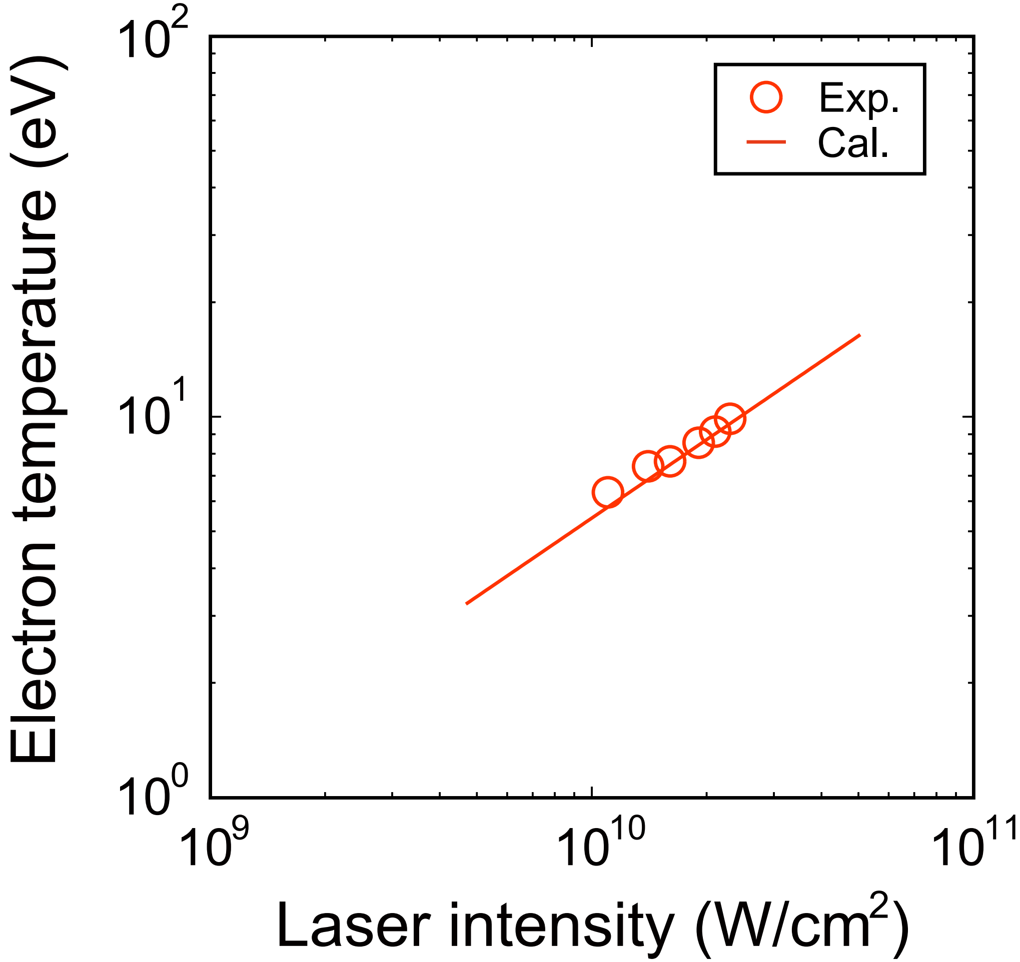




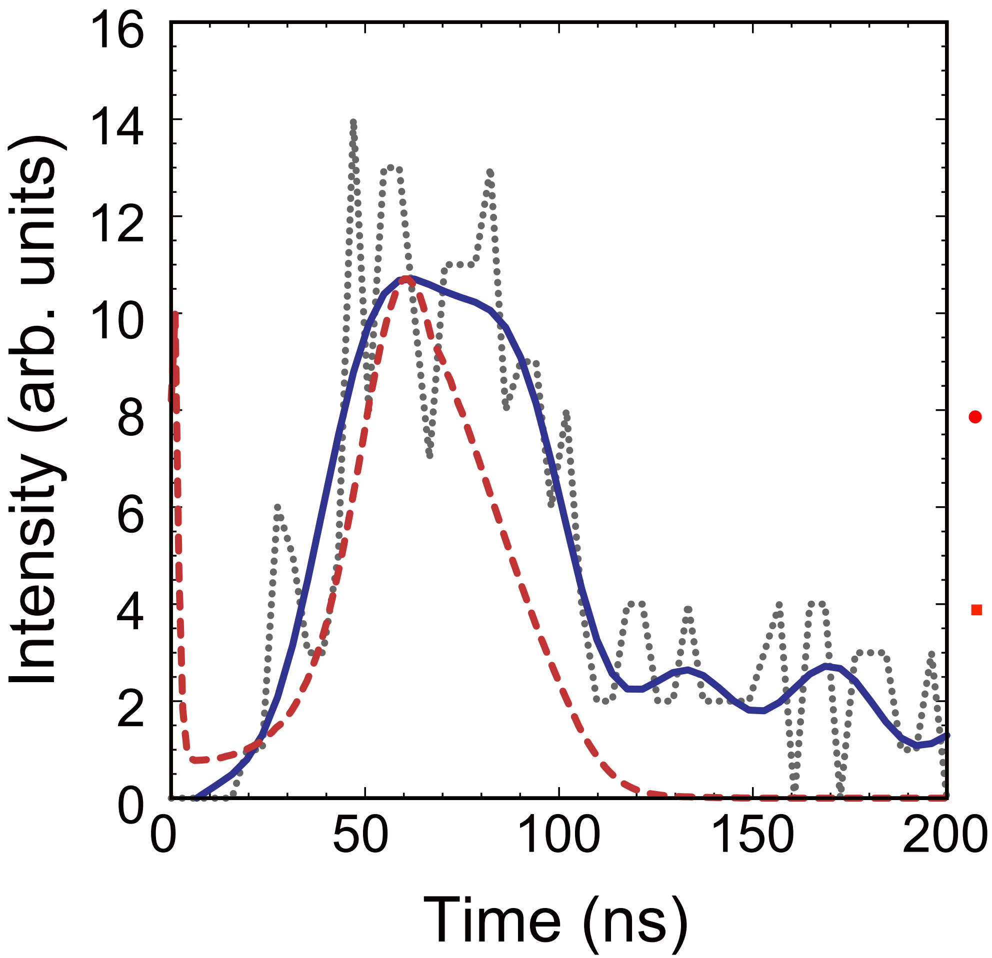

- Limited to the emission region
- Contamination emission spectra, together with the carbon due to a capillary material

T. Higashiguchi *et al*., Appl. Phys. Lett. **96**, 131505 (2010).

# *Electron temperature to turn 12 eV*



# *Temporal history of the emission at 39 nm*

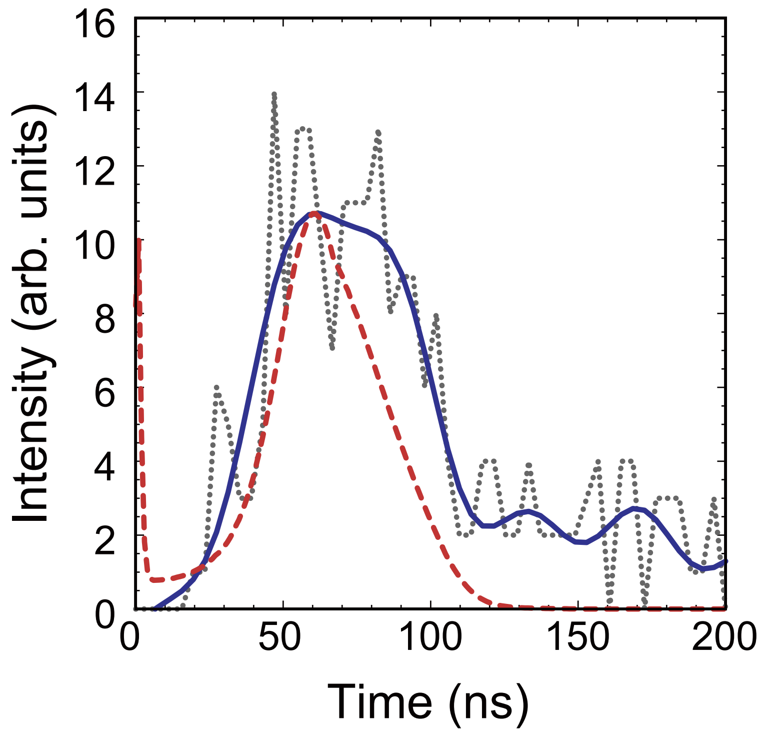


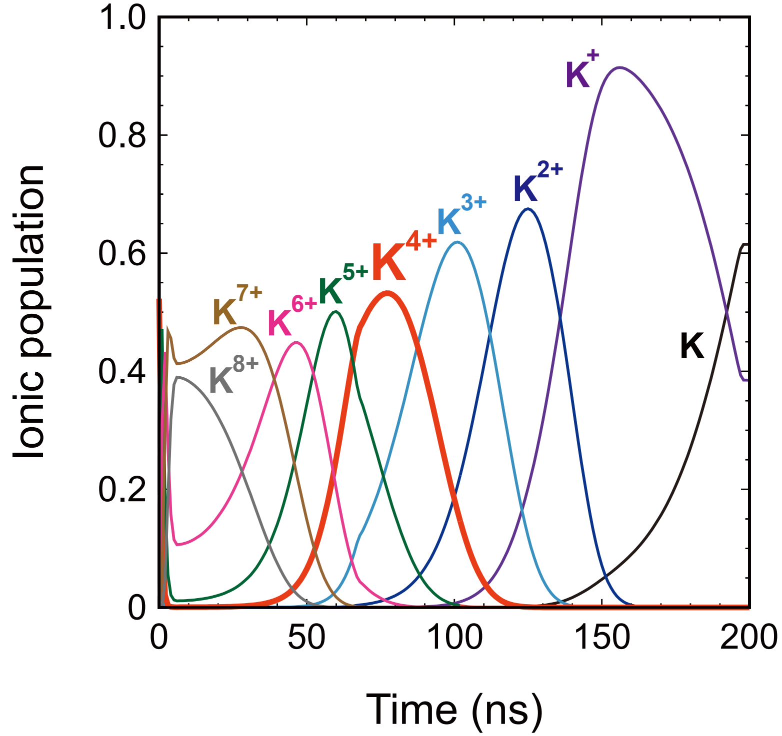

Wavelength: 1064 nm
Laser intensity: 2 × $10^{10}$ W/cm$^2$

- **The duration of the emission: 50 ns (FWHM)**
- **Recombination radiation**

# *Temporal history of the emission at 39 nm*

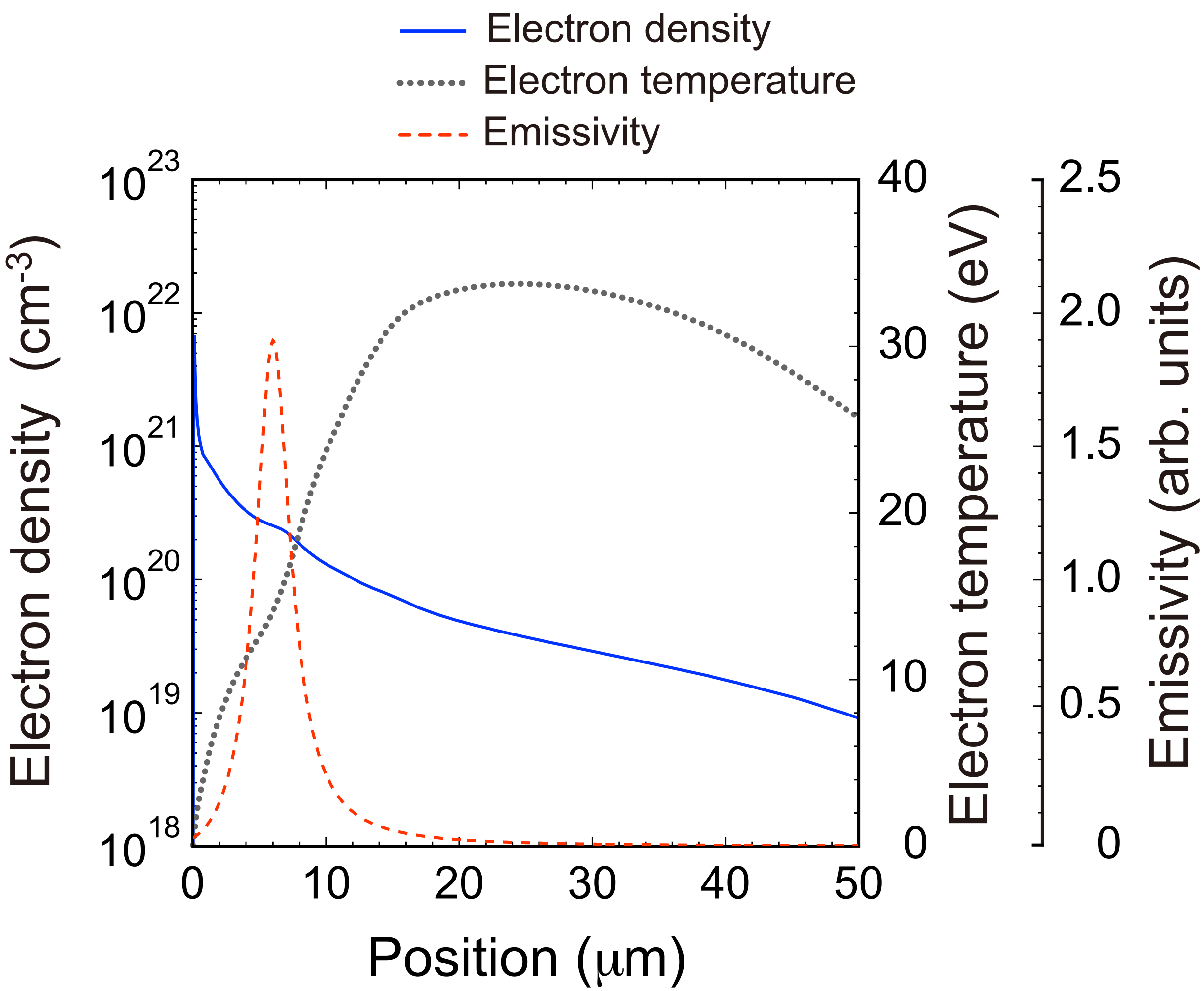
Wavelength: 1064 nm, Laser intensity: $2 \times 10^{10}$ W/cm$^2$




- **The duration of the emission: 50 ns (FWHM)**
- **Recombination radiation**

# *Emissivity of the 39-nm emission*



# *Summary*

**We characterized the emission spectra and temporal history of a pure potassium plasma.**

**[Microdischarge]**
T. Higashiguchi *et al*., Appl. Phys. Lett. **96**, 131505 (2010).
T. Higashiguchi *et al*., J. Appl. Phys. **109**, 013301 (2011).

**[Laser-produced plasma]**
T. Higashiguchi *et al*., Appl. Phys. Lett. **98**, 091503 (2011).