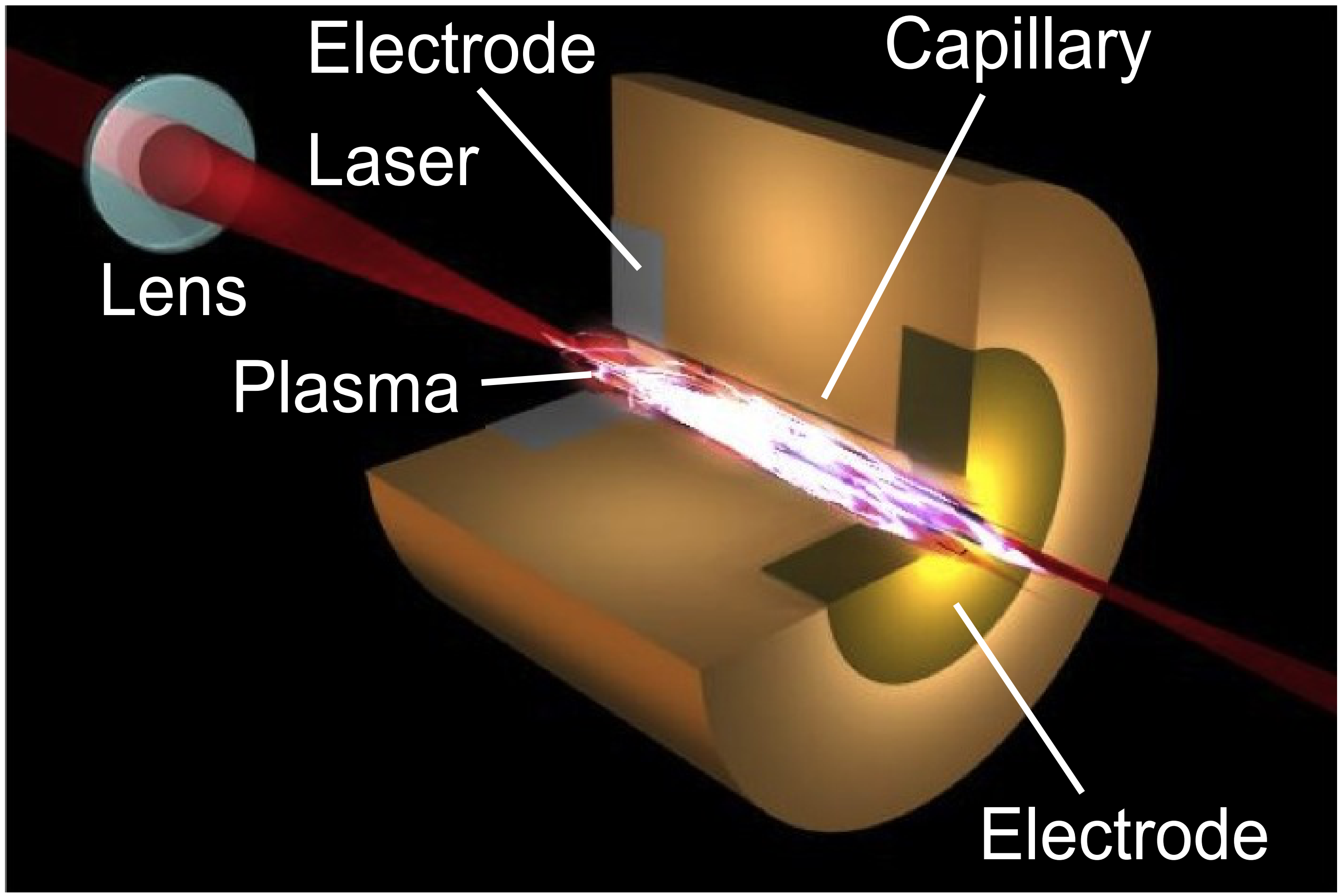
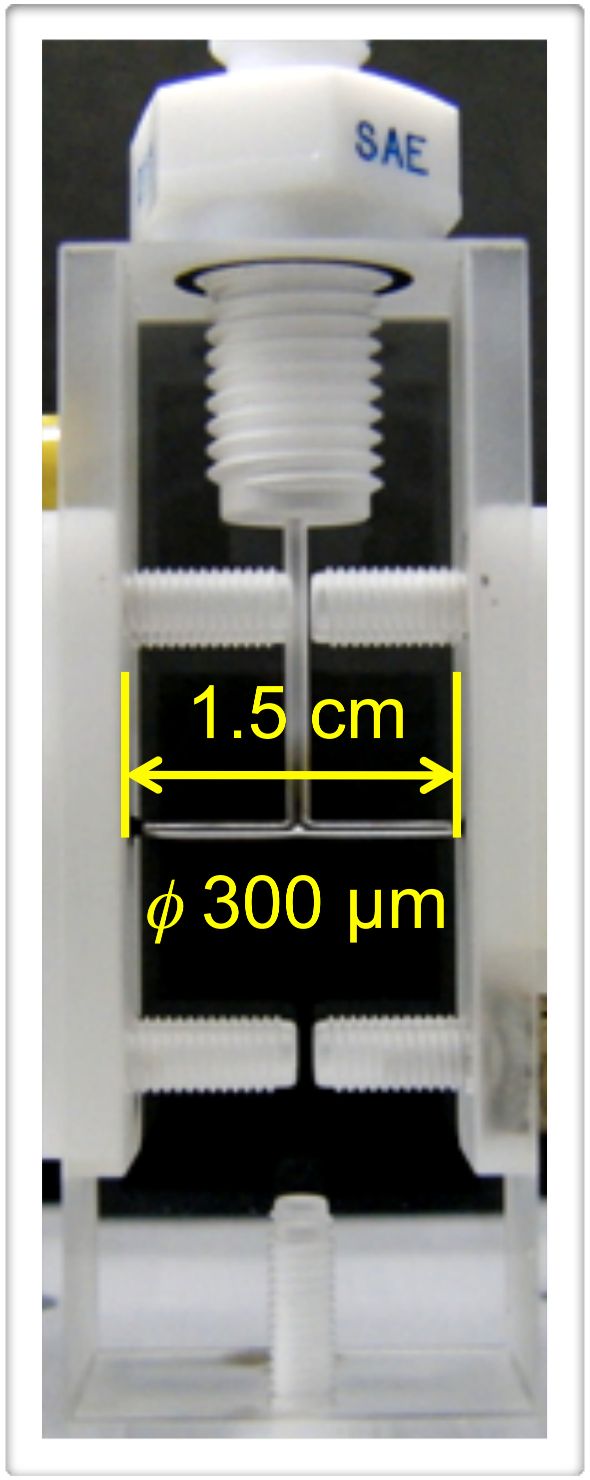
高原子番号物質プラズマによる

UTA EUV光源

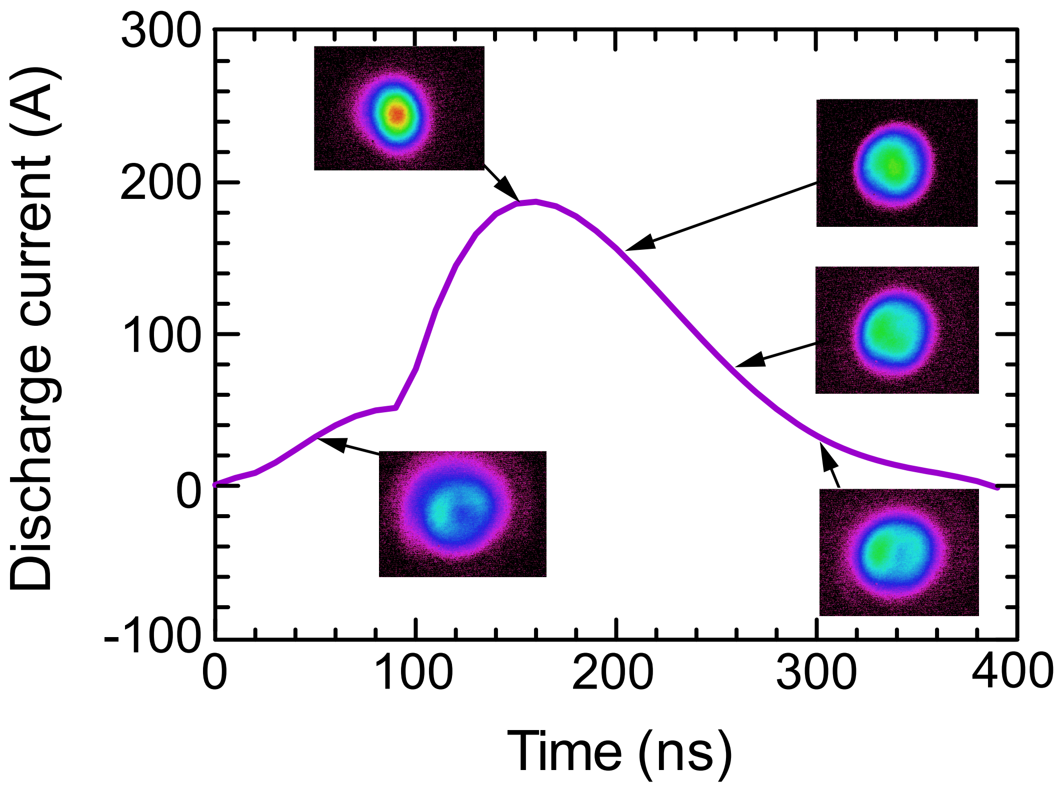
東口 武史

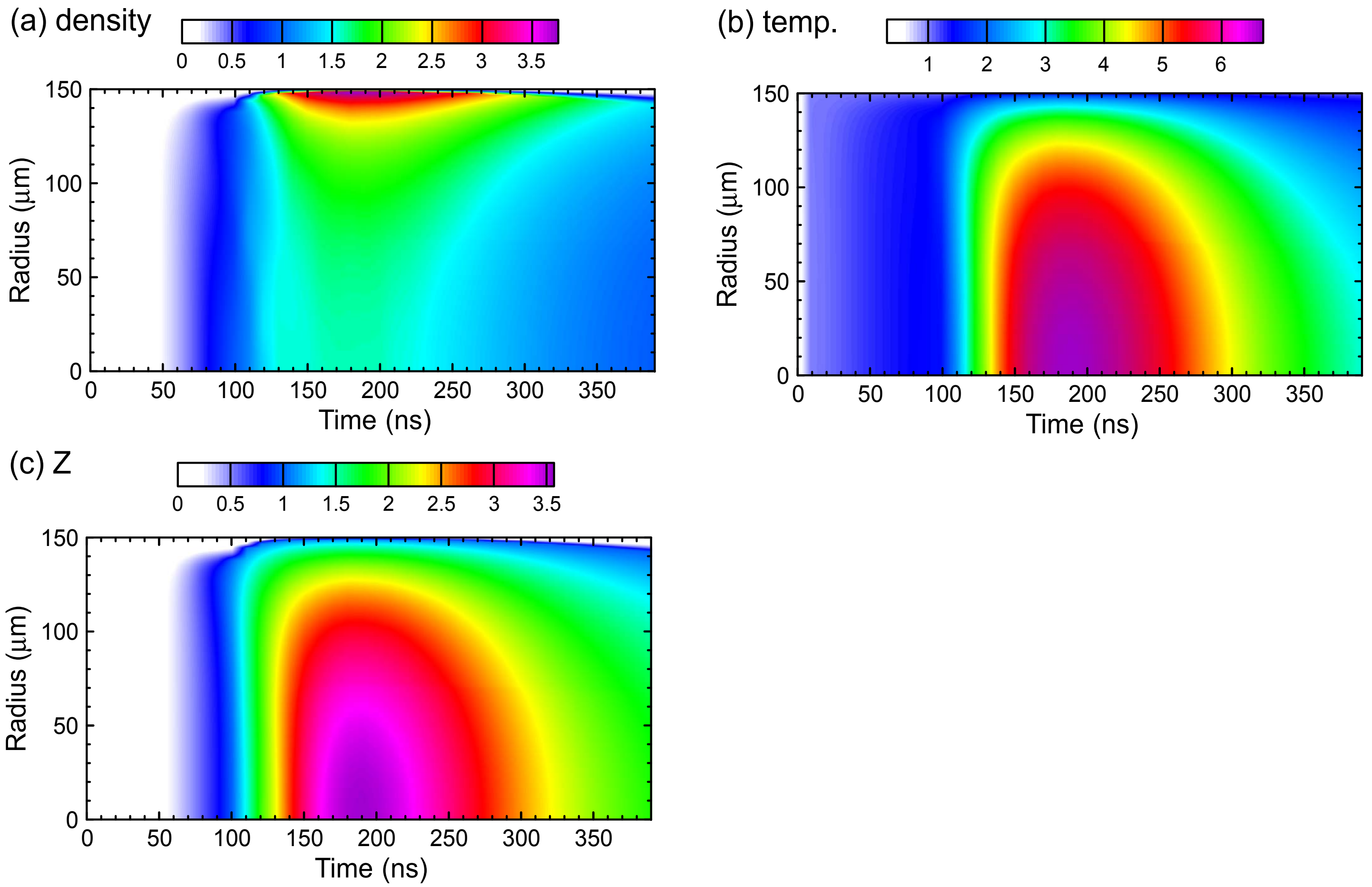
Recent Progress: Hydrogen & Argon Capillary for LWF & SXR





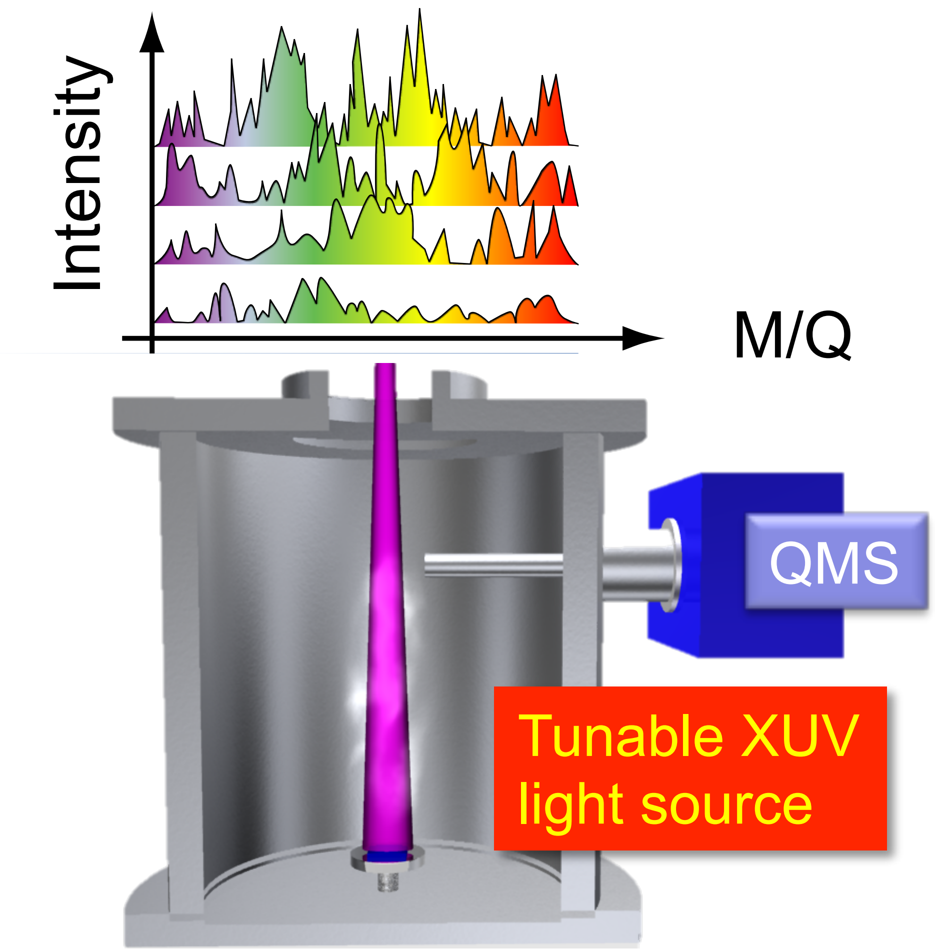
Recent Progress: Hydrogen & Argon Capillary for LWF & SXR

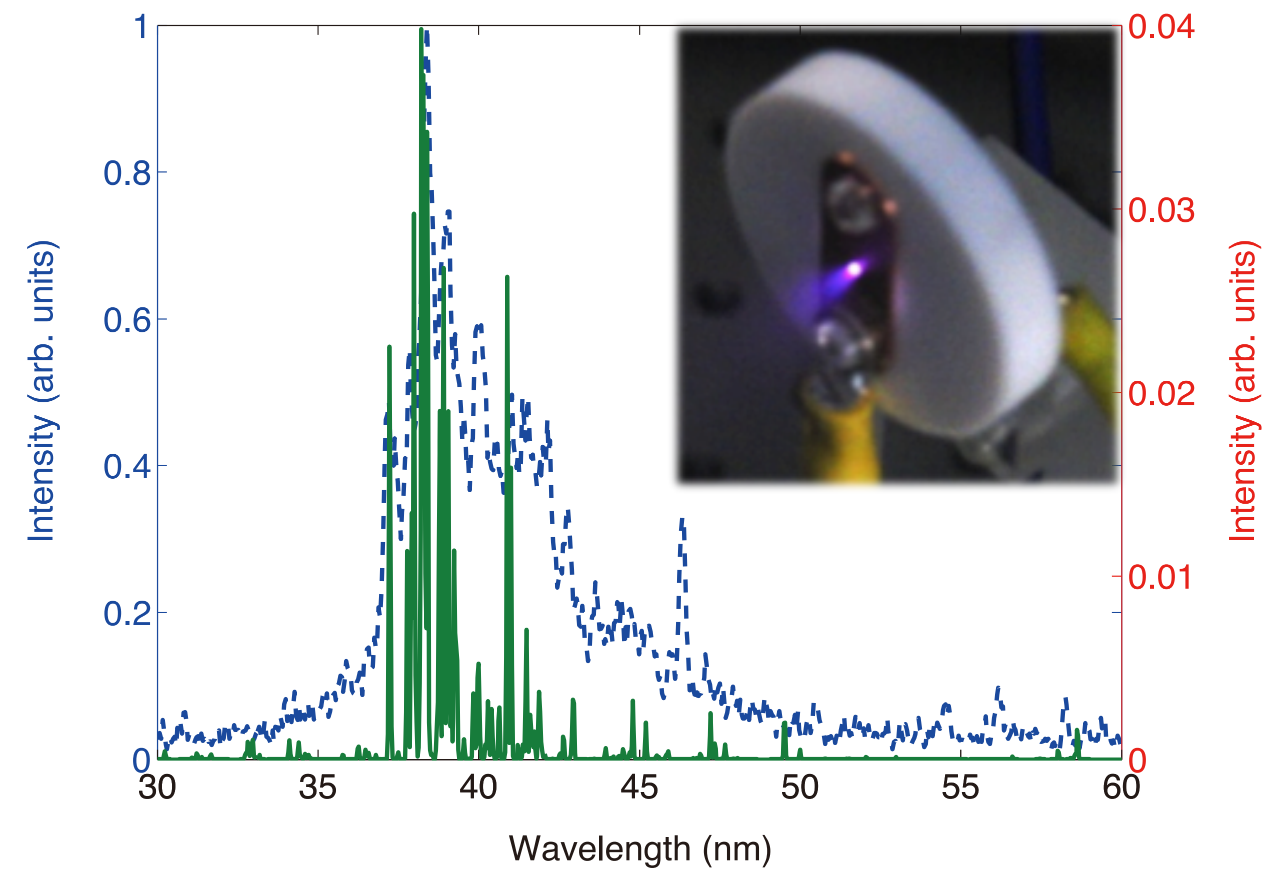




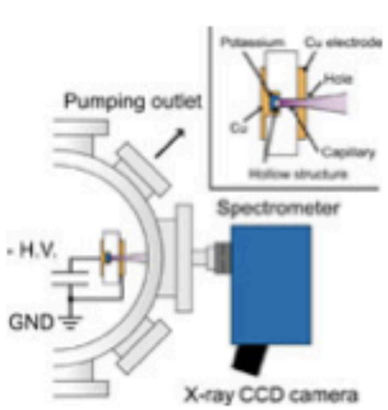
[1] T. Higashiguchi *et al*., Rev. Sci. Instrum. **81**, 046109 (2010).
[2] H. Terauchi *et al*., J. Appl. Phys. **109**, 053304 (2011).
[3] S. Sakai *et al*., Rev. Sci. Instrum. **82**, 103509 (2011).
[4] T. Higashiguchi *et al*., J. Appl. Phys. **111**, 093302 (2012).

Recent Progress: 40-nm source for mass spectroscopy





Research Highlights



Microdischarge extreme ultraviolet source with alkali metal vapor for surface morphology application

Takeshi Higashiguchi, Hiromitsu Terauchi, Takamitsu Otsuka, Mami Yamaguchi, Keisuke Kikuchi, Noboru Yugami, Toyohiko Yatagai, Wataru Sasaki, Rebekah D'Arcy, Padraig Dunne, and Gerry O'Sullivan

We have characterized a discharge-produced potassium plasma extreme ultraviolet (XUV) source. This compact capillary XUV source with a photon energy of 30 eV is a useful XUV emission source for surface morphology applications.

[Compact discharge source]

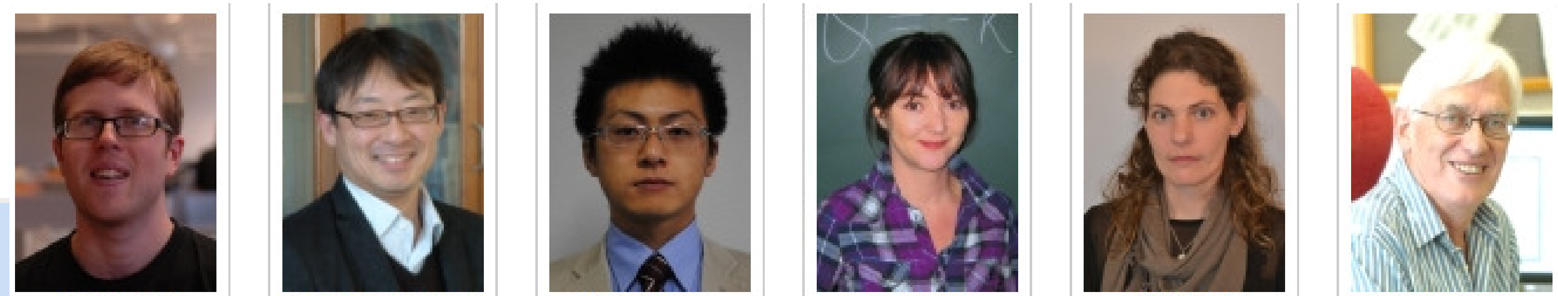
T. Higashiguchi *et al*., Appl. Phys. Lett. **96**, 131505 (2010).
T. Higashiguchi *et al*., J. Appl. Phys. **109**, 013301 (2011).

[Temporal hehavior]

T. Higashiguchi *et al*., Appl. Phys. Lett. **98**, 091503 (2011).
T. Higashiguchi *et al*., J. Appl. Phys. (submitted in 2012).

Recent Progress: **W** plasma spectroscopy in **LabTalk, IOP/JPB**

IOPscience Journals Login



Journal of Physics B: Atomic, Molecular and Optical Physics

Tungsten spectroscopy for magnetic fusion

Understanding the radiative properties of tungsten is vital for the success of ITER.

The first ITER plasma is due in 2019 and this plasma, like every future one, will contain tungsten as an intrinsic impurity since tungsten has been chosen as a plasma facing component due to its high melting point and low erosion properties. The presence of tungsten in a hot plasma may present a problem in terms of radiation losses in the EUV region but studying this emitted light will provide crucial plasma diagnostic information. However, the EUV radiation emitted from moderately ionized tungsten (W^{12+}–W^{37+}) is complex and does not usually take the form of isolated lines but of transition arrays and a lack of definitive data makes interpretation of spectra quite challenging.

Laser produced plasma at UCD.

C. S. Harte *et al.*, J. Phys. B **45**, 245004 (2012).

Requirement in high-Z plasma UTA **with high CE**

Low density, high temperature plasma

Optically thin plasmas for reducing self-absorption effects

Suppression of satellite emission & higher spectral purity

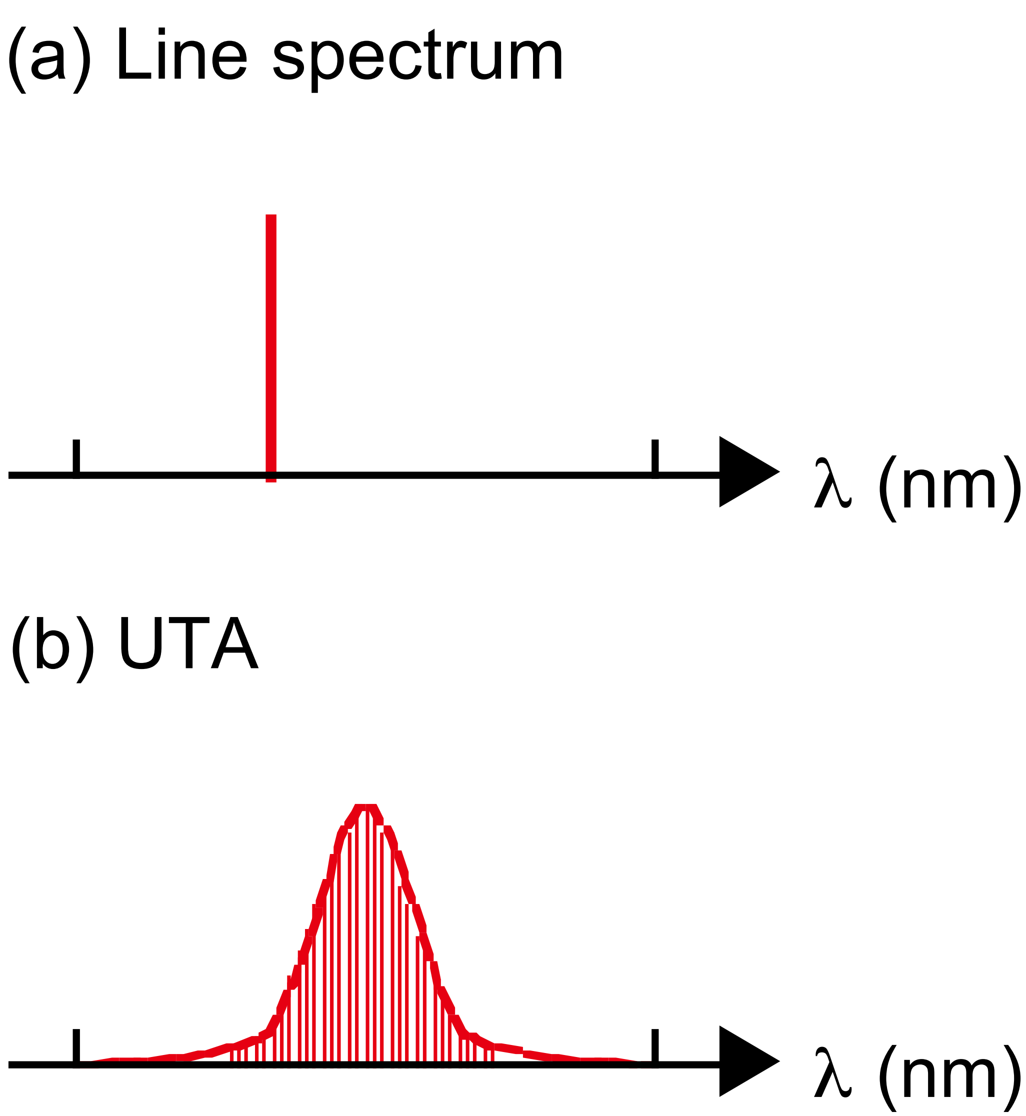
Long wavelength (low critical density): **CO_2 laser**@10^{19} /cc

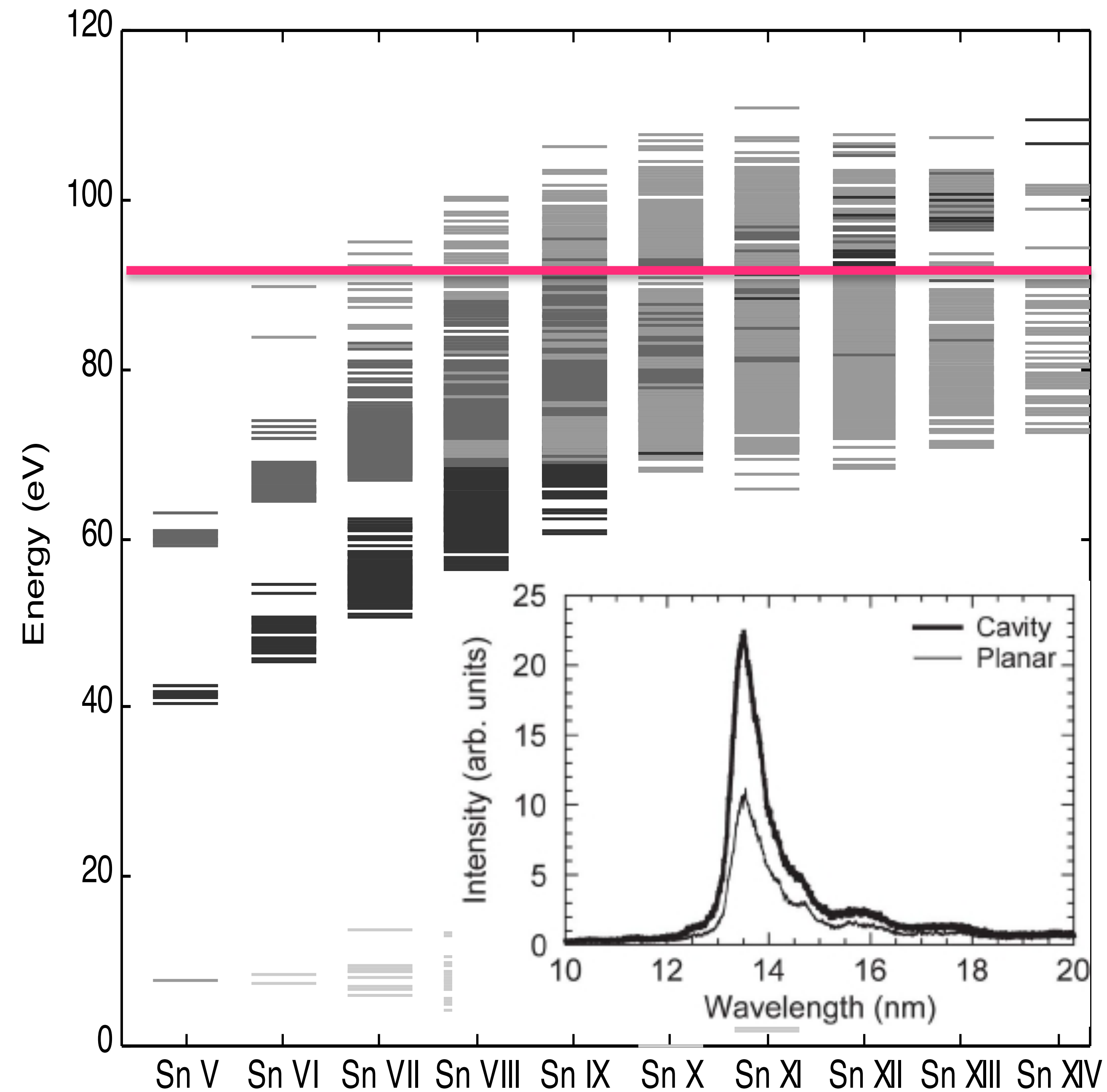
Short laser pulse duration: ~1-2 ns@YAG laser (1064 nm)

Low density targets

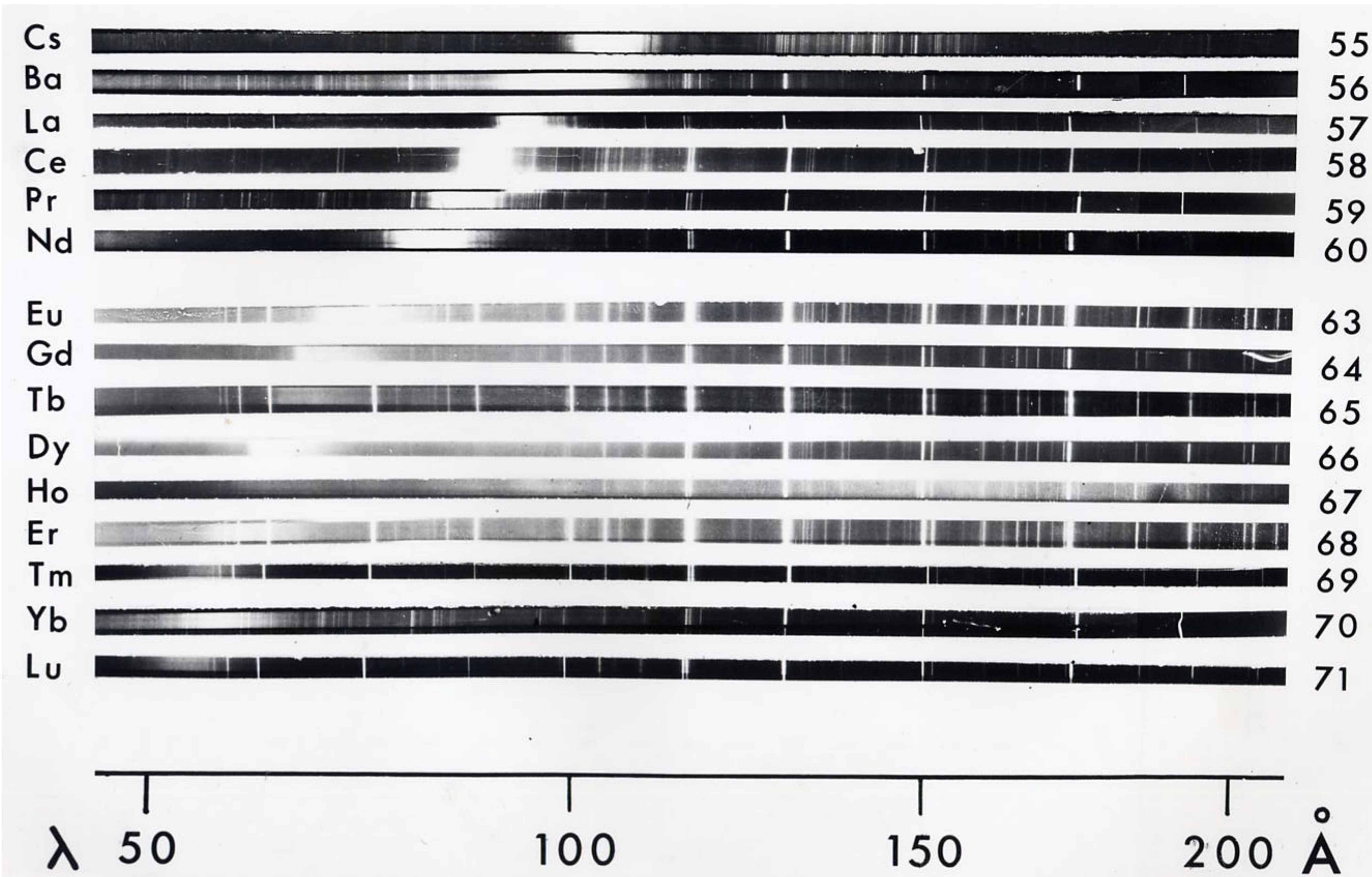
Discharge plasmas (low density plasmas)

Scheme for high-energy emission: **unresolved transition array**

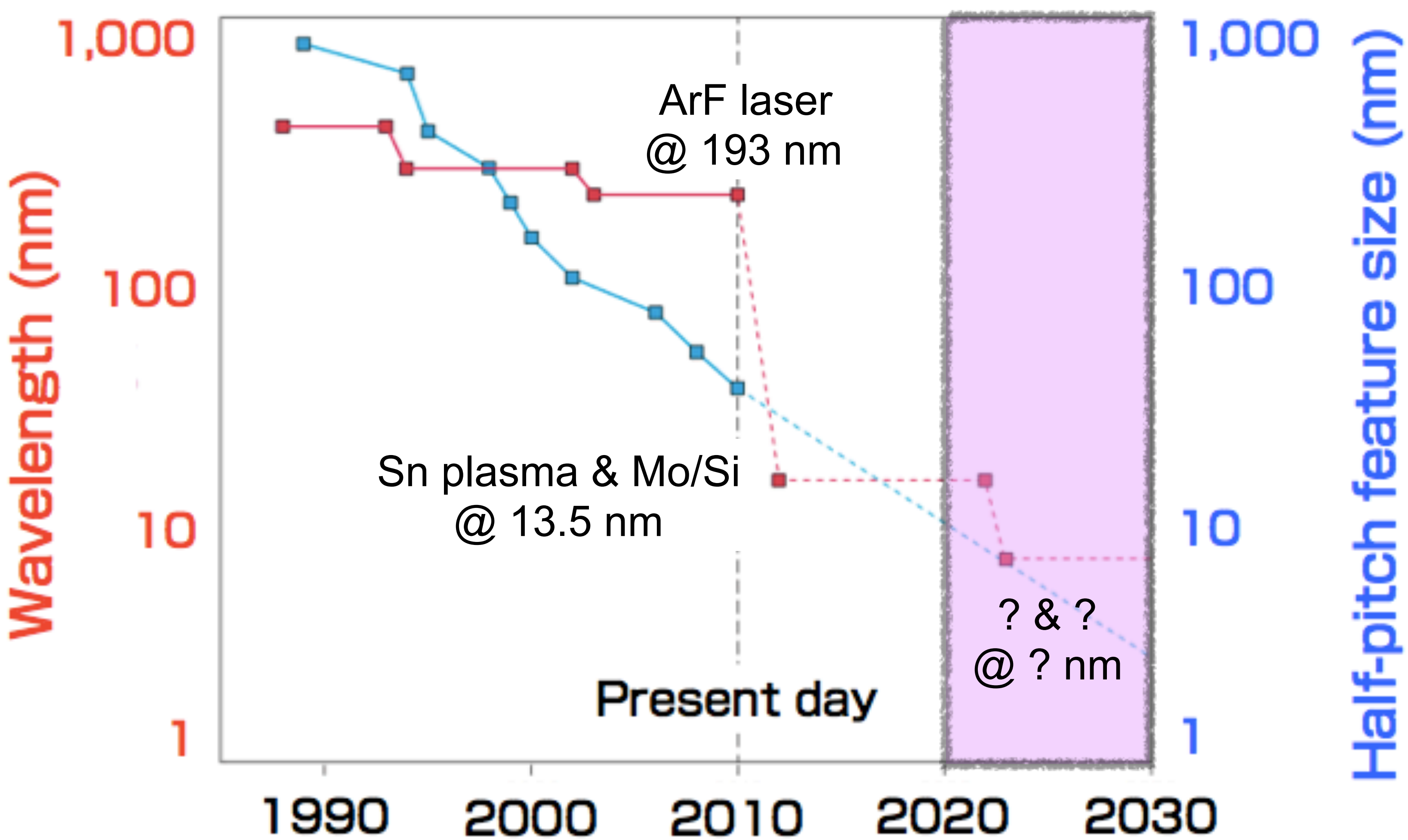




Shorter wavelength emissions: **Atomic number dependence**

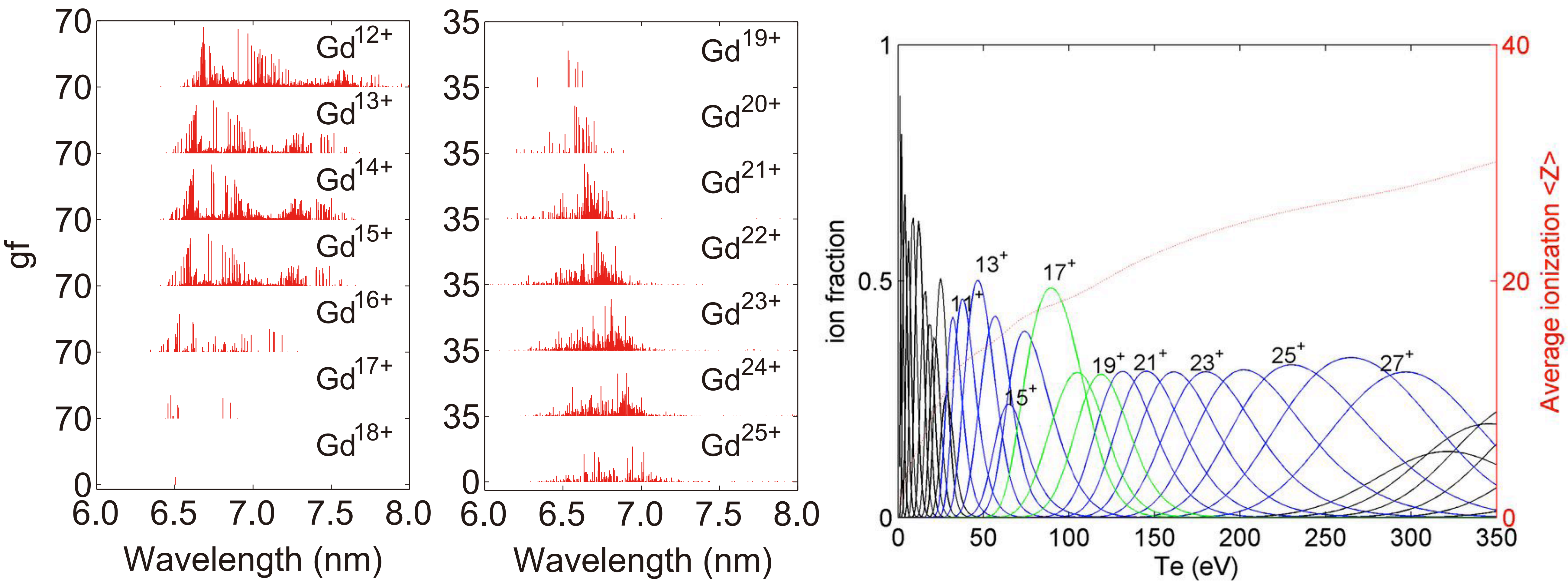


Possibility of wavelength switching



G. Tallents *et al.*, Nature Photonics **4**, 809 (2010).

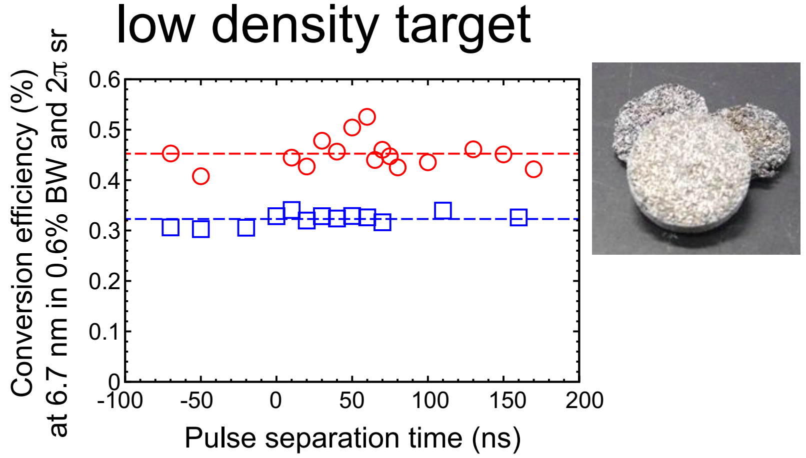
Gd/Tb plasmas for 6.X-nm Beyond EUV (**BEUV**) sources



T. Otsuka *et al*., Appl. Phys. Lett. **97**, 111503 (2010).
B. Li *et al*. Appl. Phys. Lett. **99**, 231502 (2010).

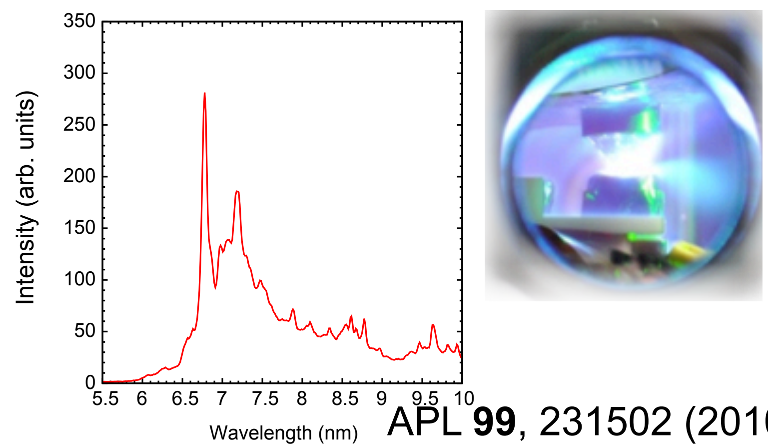
Recent Progress: 6.X-nm Beyond EUV sources

low density target



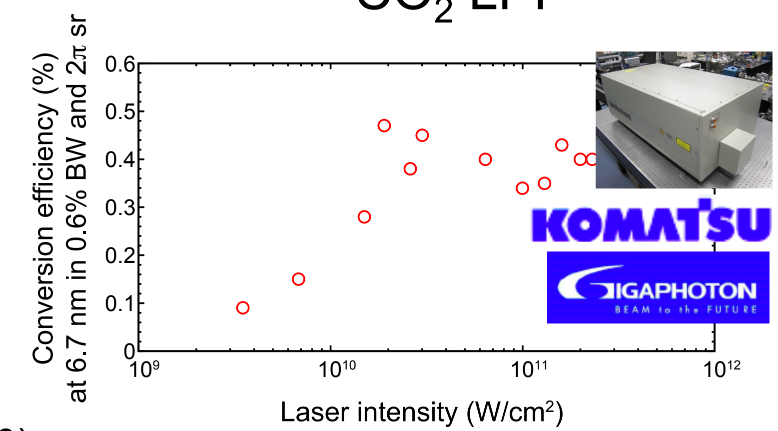
APL **99**, 191502 (2011).

DPP



APL **99**, 231502 (2010).

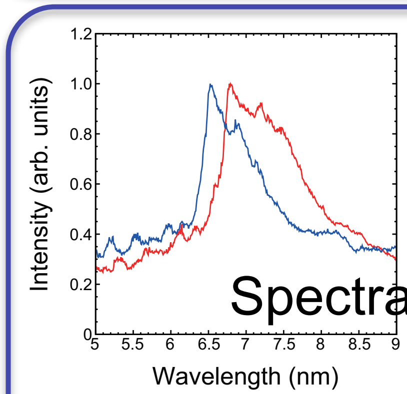
CO_2 LPP



$$I(\lambda) = I_0(\lambda)e^{-\sigma n \ell}$$

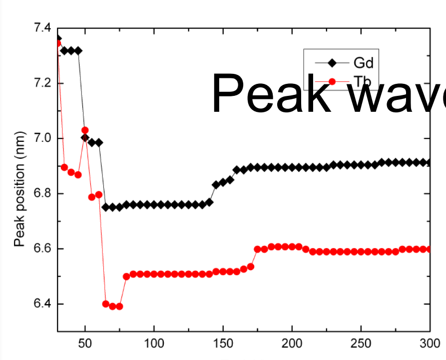
$$\ell \approx c_S \tau_L$$

Spectral structure



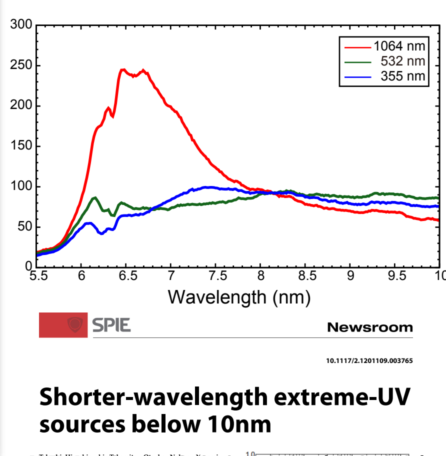
APL **97**, 111503 (2010).

Peak wavelength

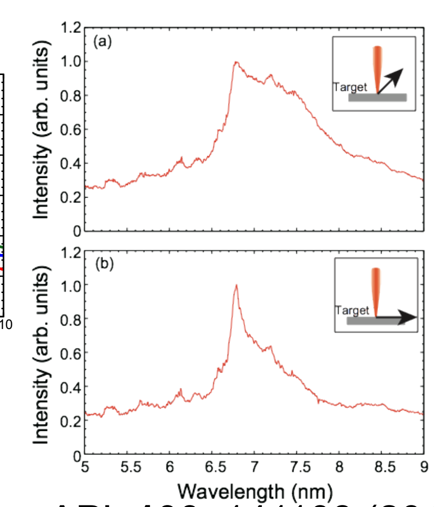


APL **101**, 013112 (2012).

Self-absorption

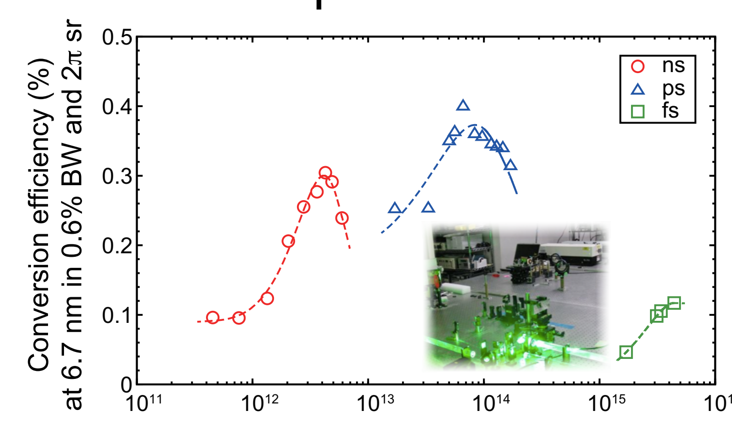


APL **97**, 231503 (2010).



APL **100**, 141108 (2012).

ps LPP

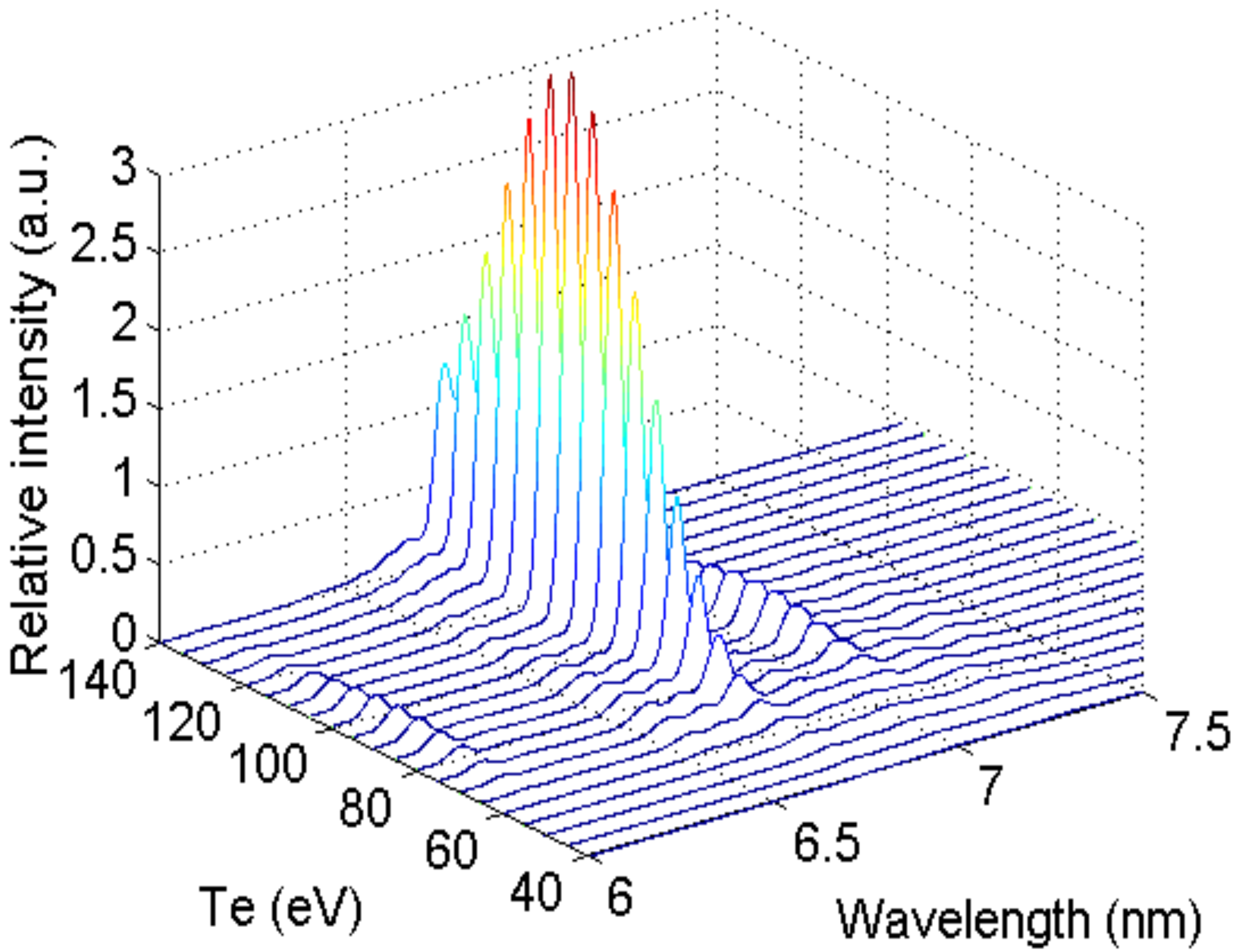


APL **100**, 061118 (2012).

BEUV Activity

Kumamoto University
UCD DUBLIN
Speclab
ILT Institute for Laser Technology
JAEA
NIFS
Nikon
Canon
NTT AT
SAMSUNG
USHIO
GIGAPHOTON
宇都宮大学
UTSUNOMIYA UNIVERSITY

Optimum condition for 6.X nm

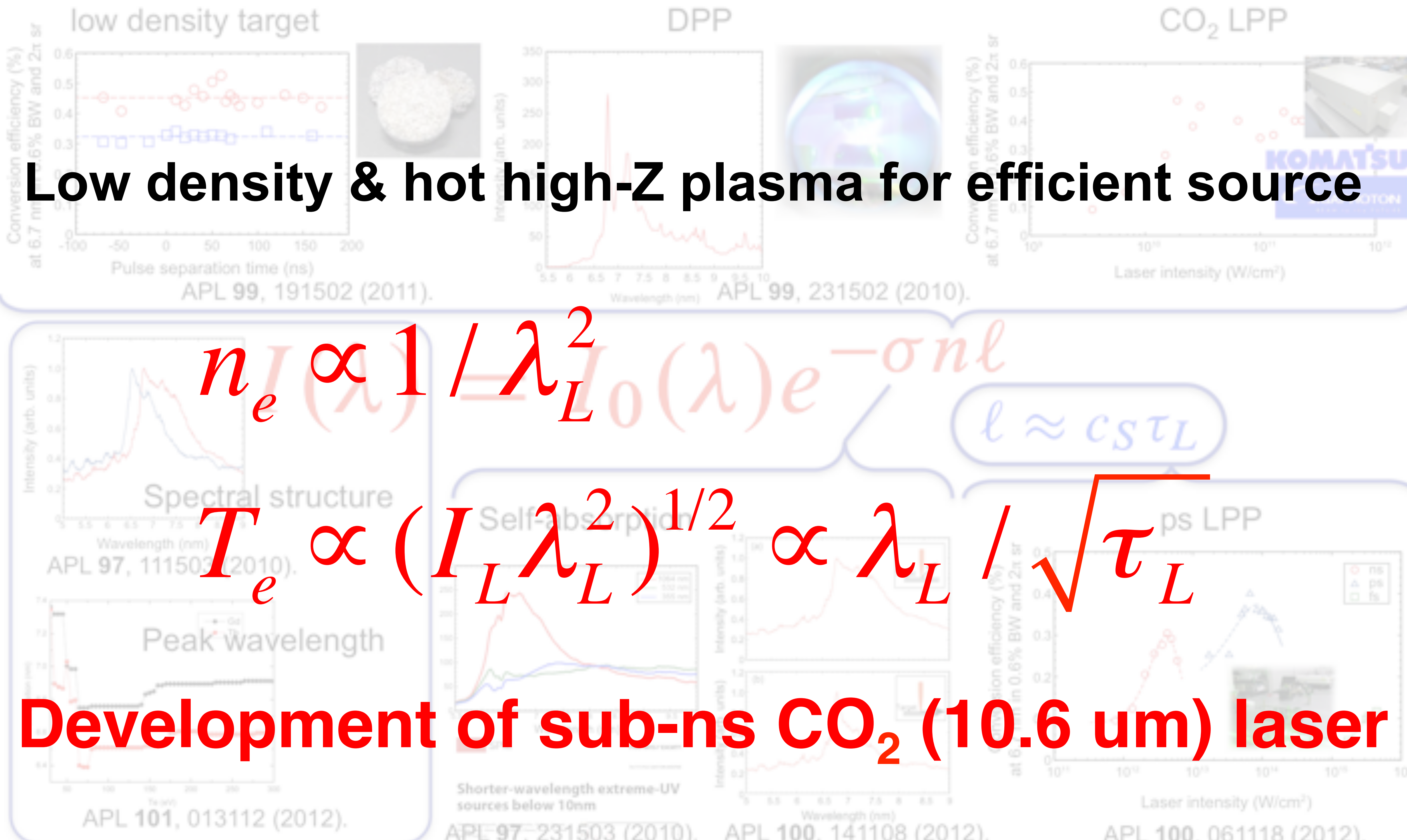


CO_2 laser intensity:

2.4×10^{11} W/cm^2

B. Li *et al*. Appl. Phys. Lett. **99**, 231502 (2010).

Why sub-ns CO_2?



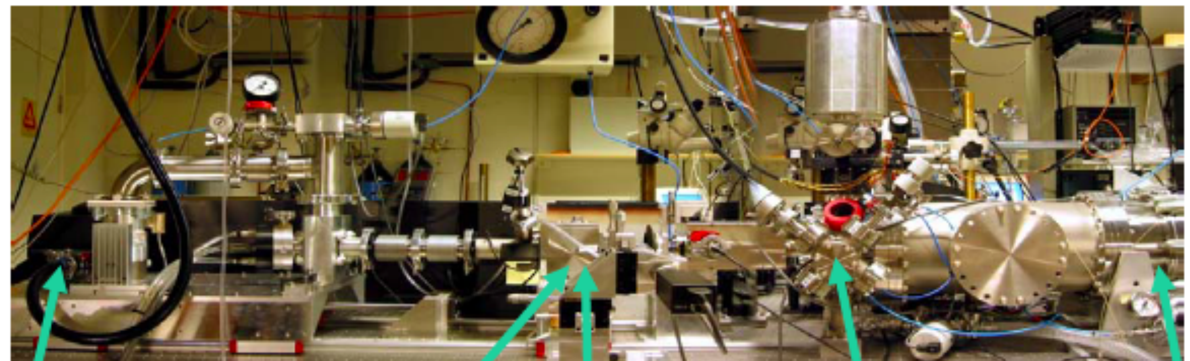
Low density & hot high-Z plasma for efficient source

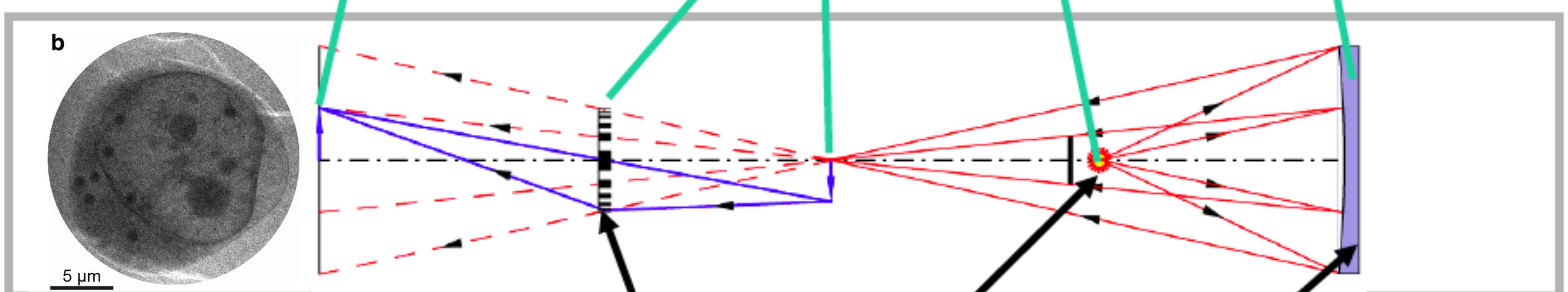
$$n_e \propto 1/\lambda_L^2$$

$$T_e \propto (I_L \lambda_L^2)^{1/2} \propto \lambda_L / \sqrt{\tau_L}$$

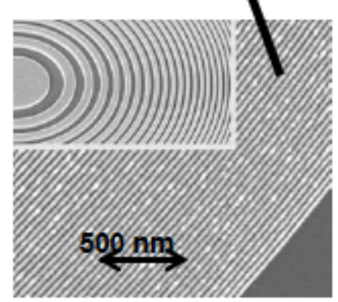
Development of sub-ns CO_2 (10.6 um) laser

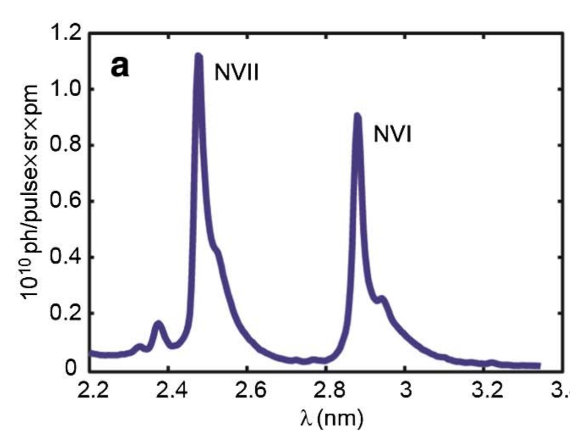
Low CE N-plasma & Low Reflectivity, resulting in **MANY SHOTS**

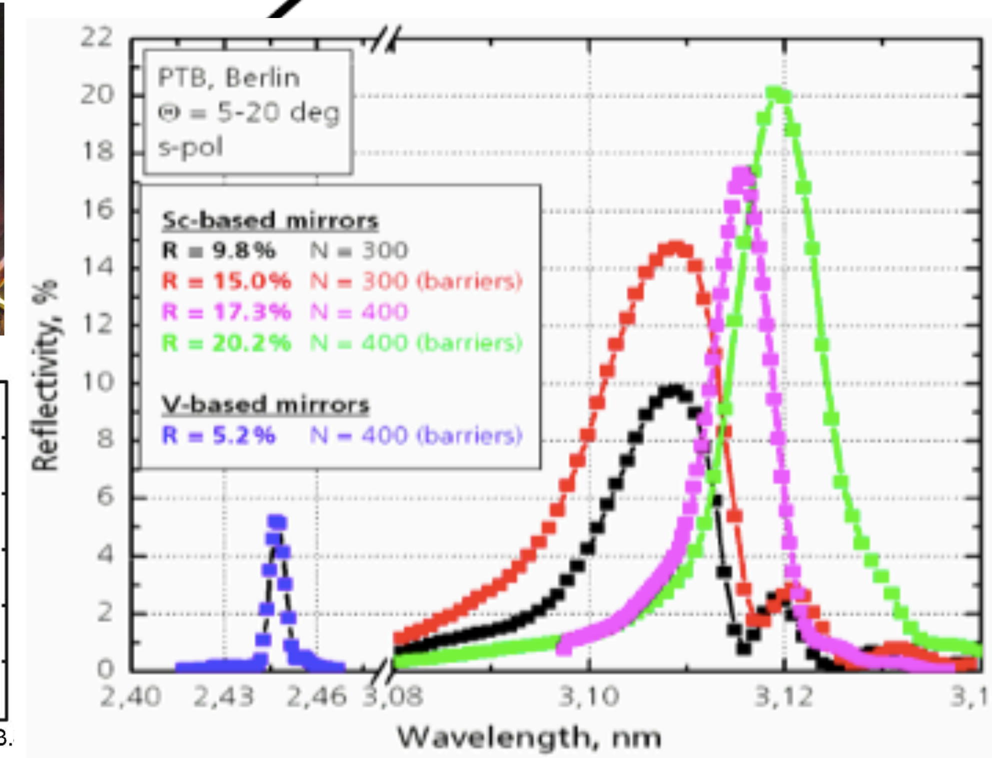




Micro zone plates for high-resolution imaging



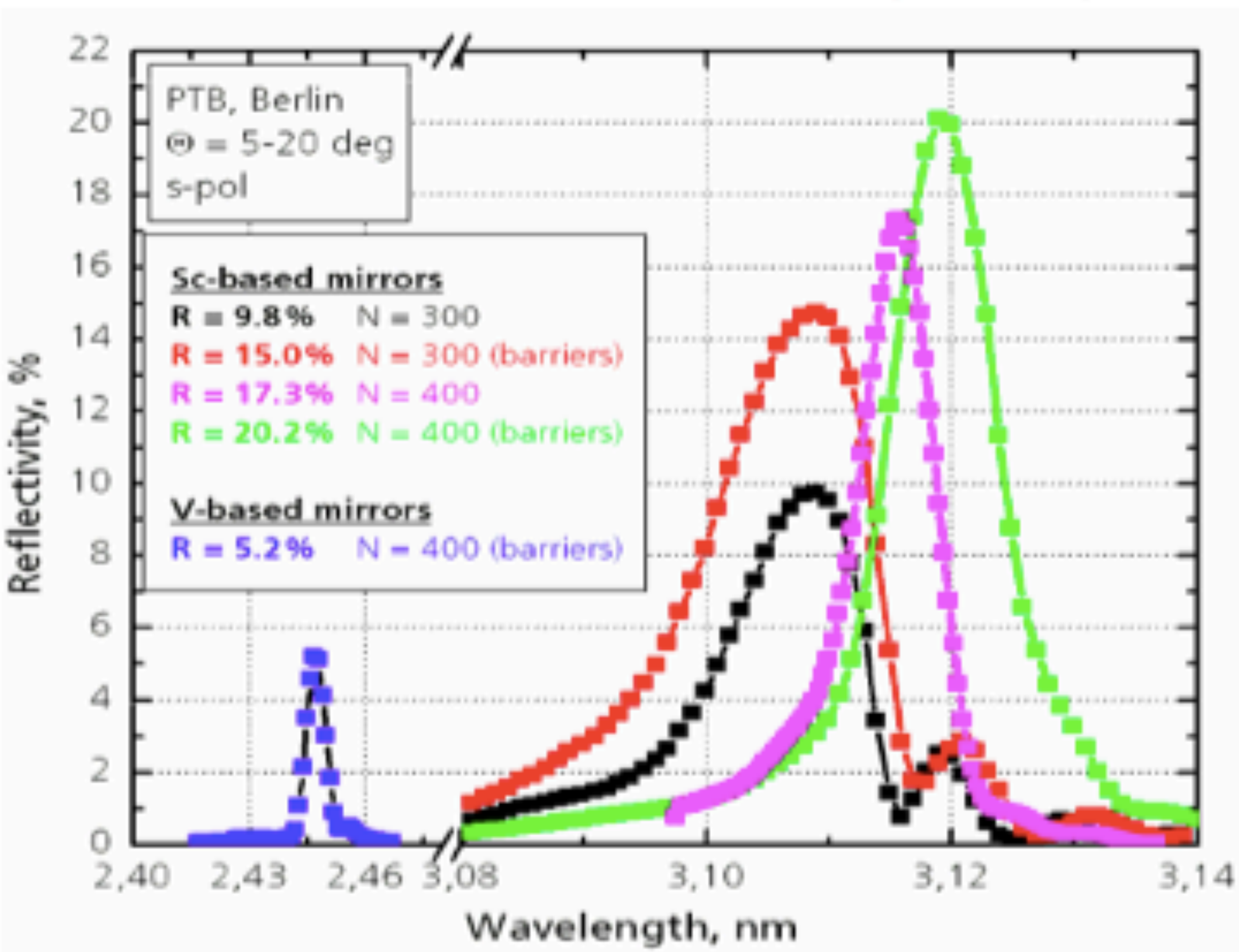




Multilayer Mirrors in Water Window

Spectral range from 2 to 5 nm

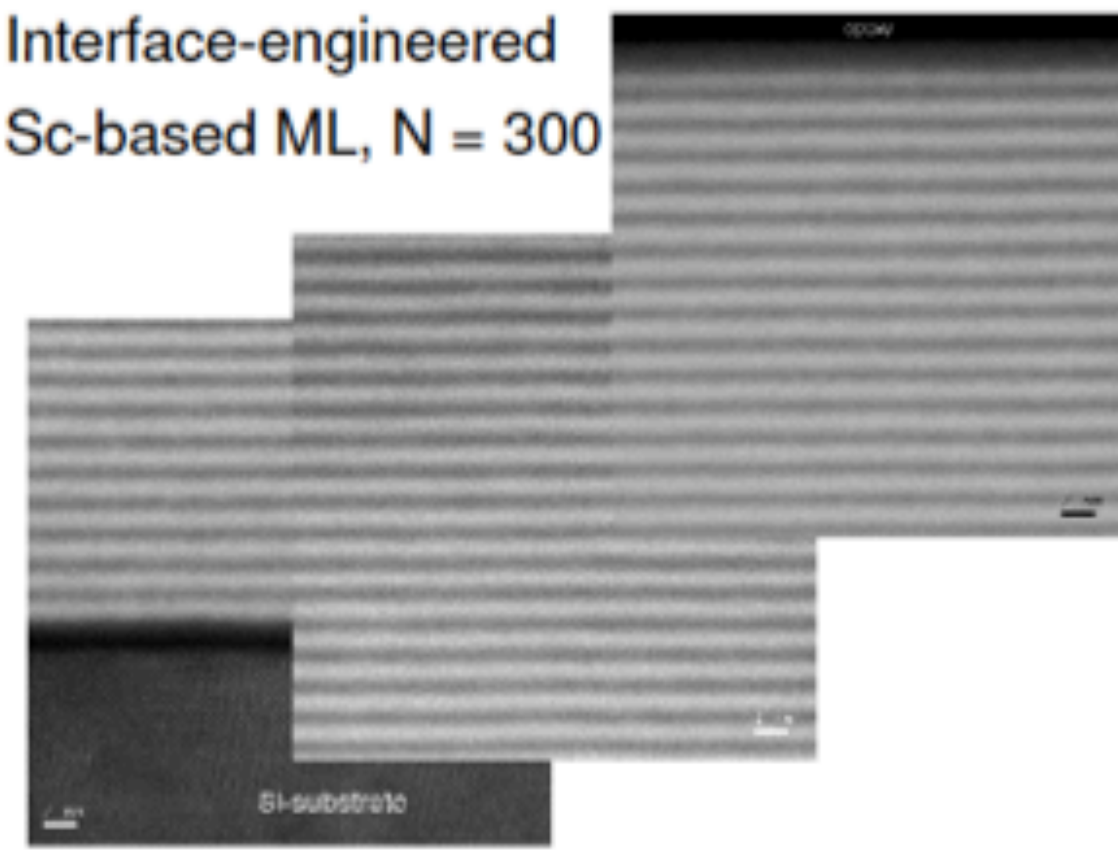
Enhanced reflectance of Sc- and V-based multilayer mirrors with interface-engineering



S. Yulin et al., "Hochreflektierende EUV/Röntgen-Mehschichtspiegel", Photonik 2, 2008

Multilayer	λ	N	R	FWHM
Sc - based	4.4 nm 3.1 nm	300 400	7.1 % 20.2 %	0.021 nm 0.008 nm
V - based	2.5 nm	400	5.2 %	0.006 nm

Interface-engineered Sc-based ML, N = 300

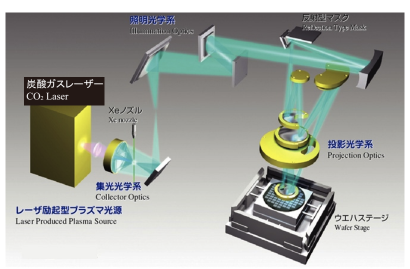


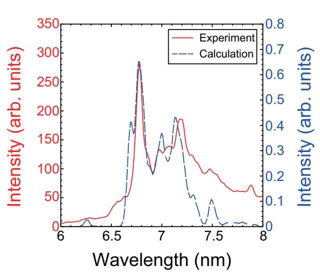
Single shot flash source in WW for Bio Photo **in LAB**

Our objective is a demonstration of high-brightness, high energy EUV/soft x-ray source in water window (3.2 nm) for the first time in the world!!!

Lithography

EUV & BEUV source study
Wavelength: 13.5 & 6.x nm






半導体 容量10倍へ
回路描く光 微細化成功
宇都宮大など

MEXT

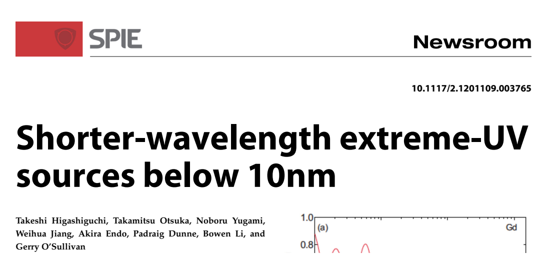
キヤノン財団
The Canon Foundation

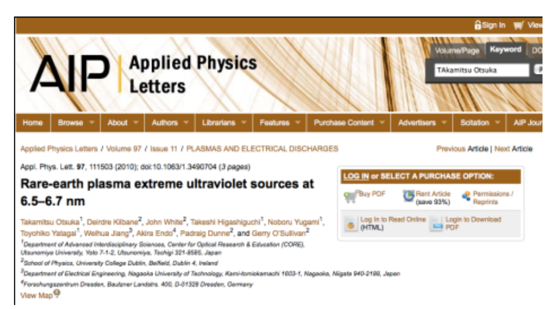
NEDO

宇都宮大学

APL x 7
(2010-2012)

Shorter wavelength



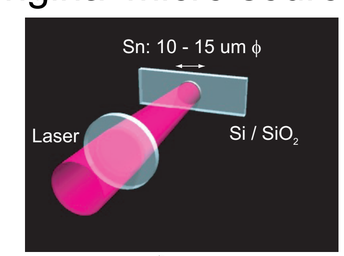


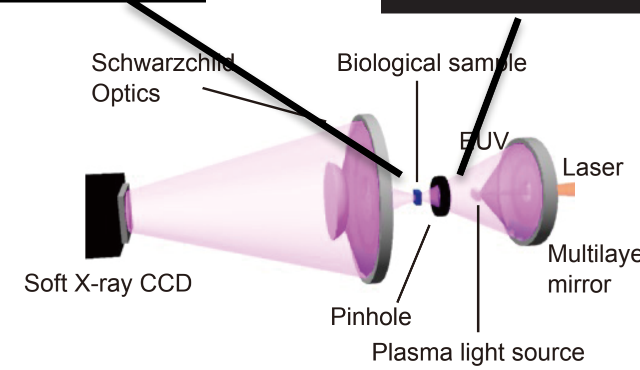
Life Innovation

Compact source development for Bio.
Wavelength: 2-4 nm

In vivo cell observation

Original micro source

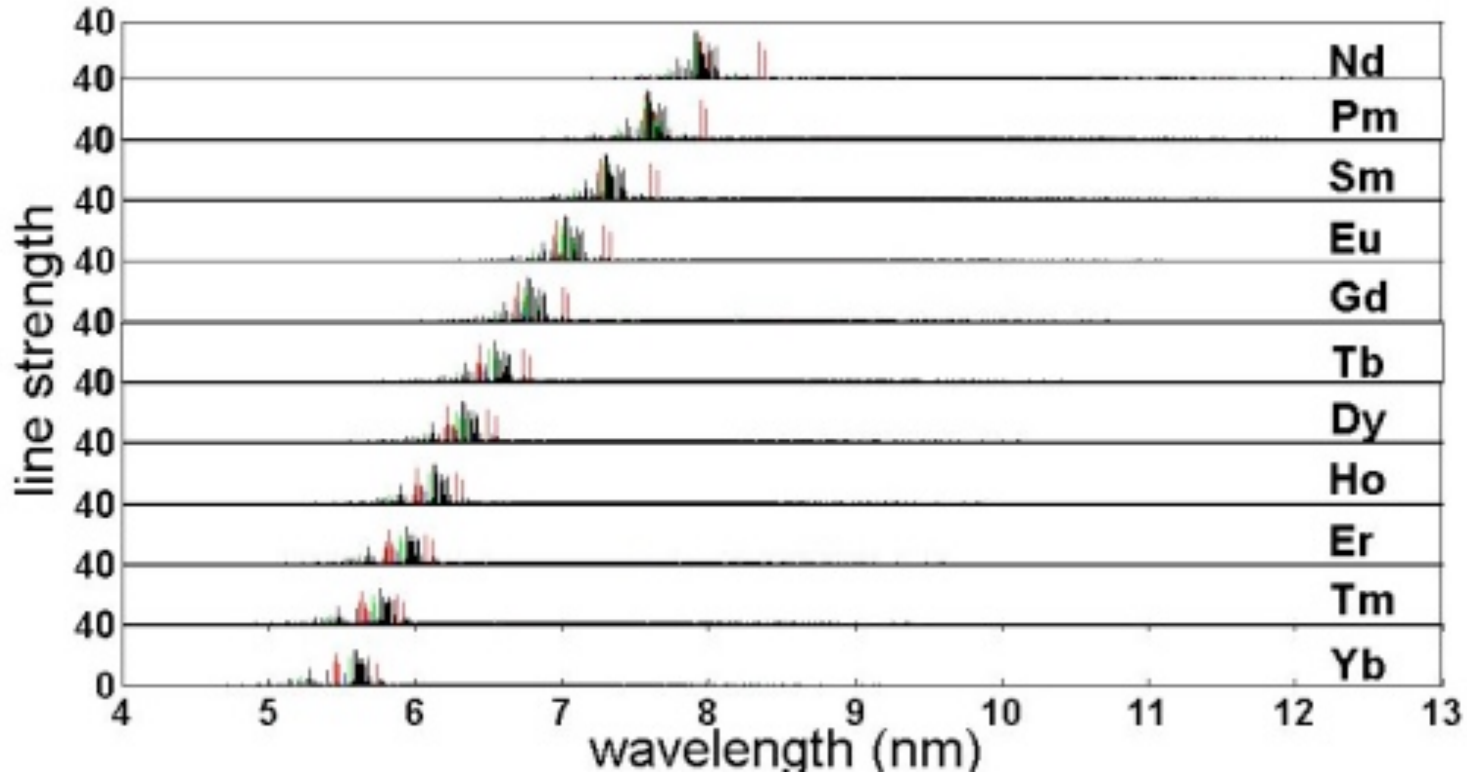


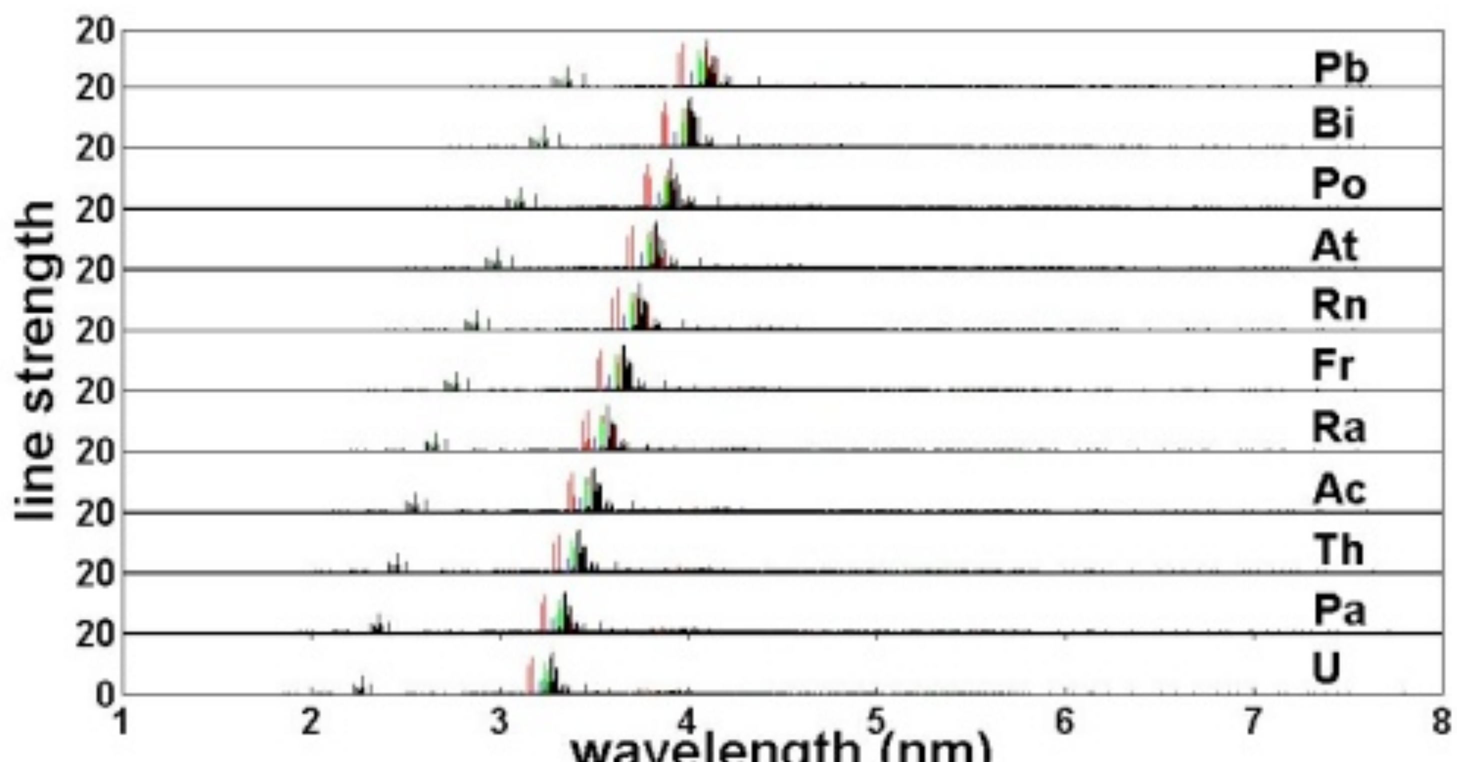


Single shot, flash biological imaging

Proposal (APL x 1)

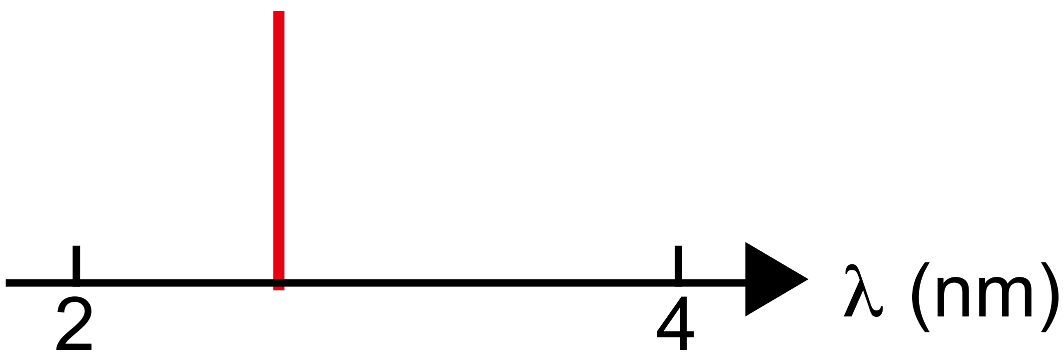
Quasi-Moseley's law...



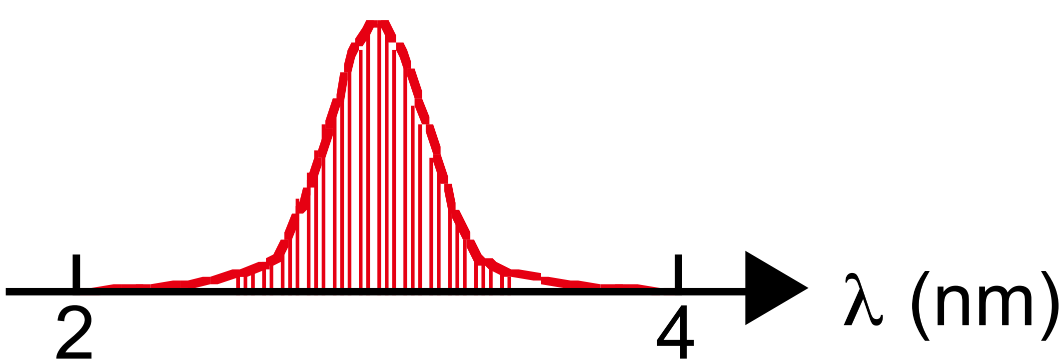


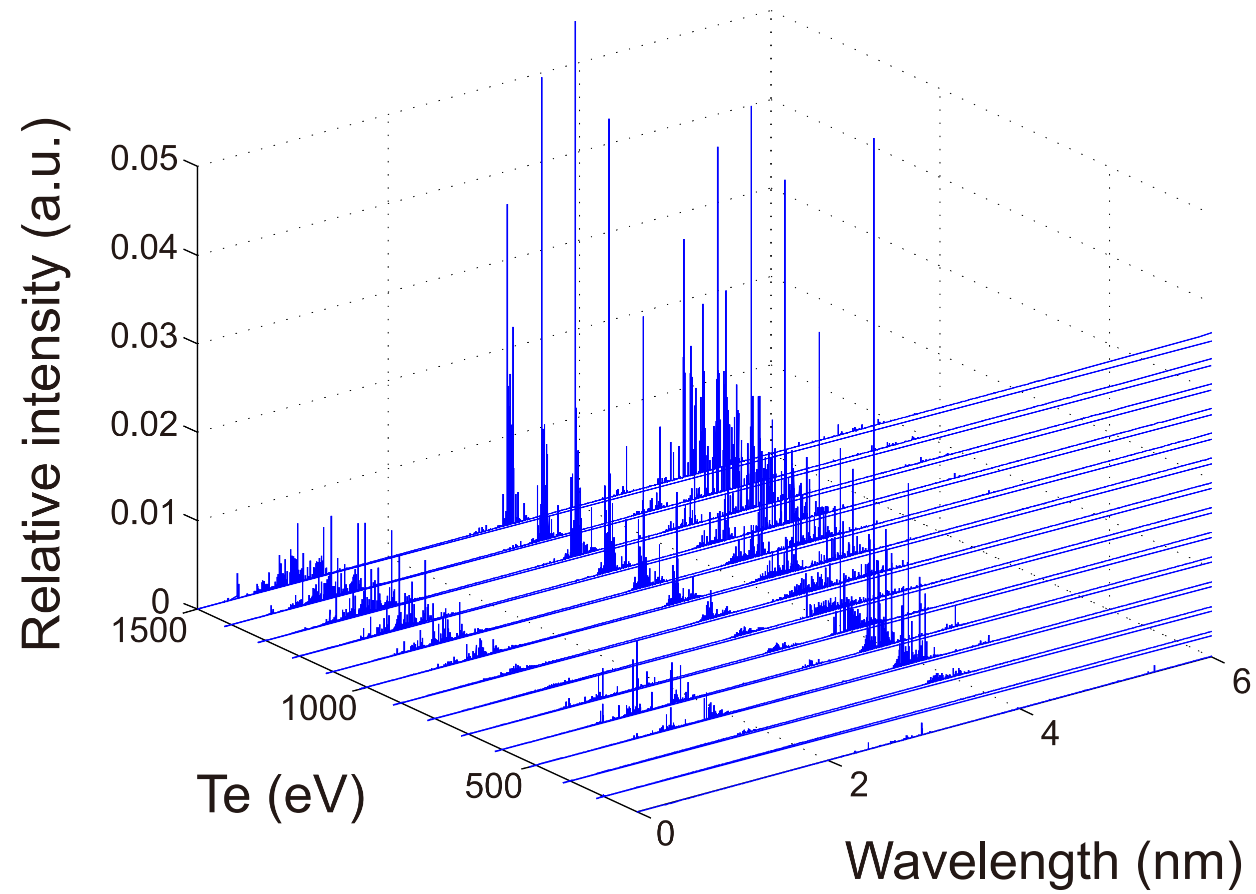
Concept for high CE WW flash source

(a) Line spectrum

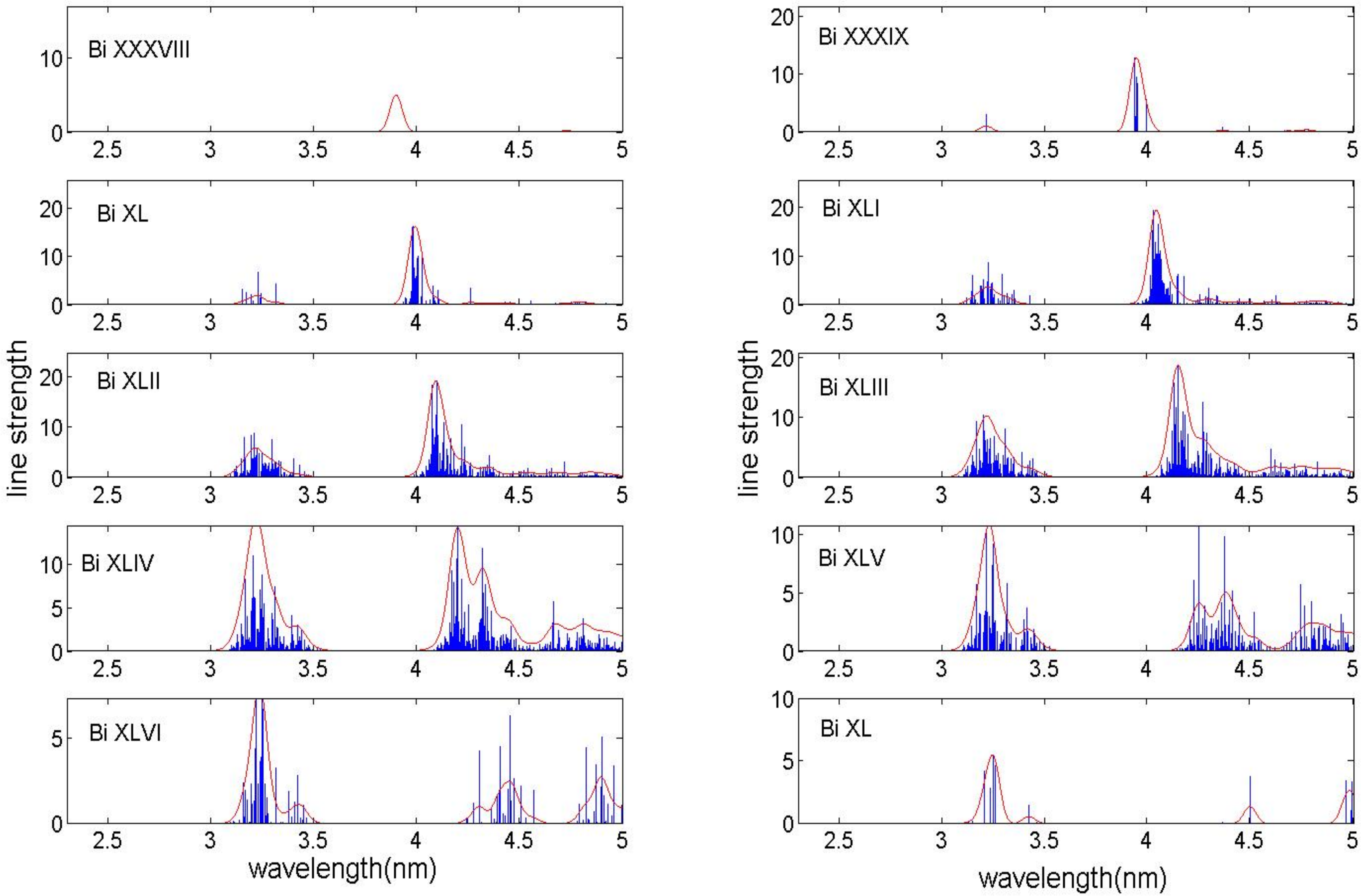


(b) UTA

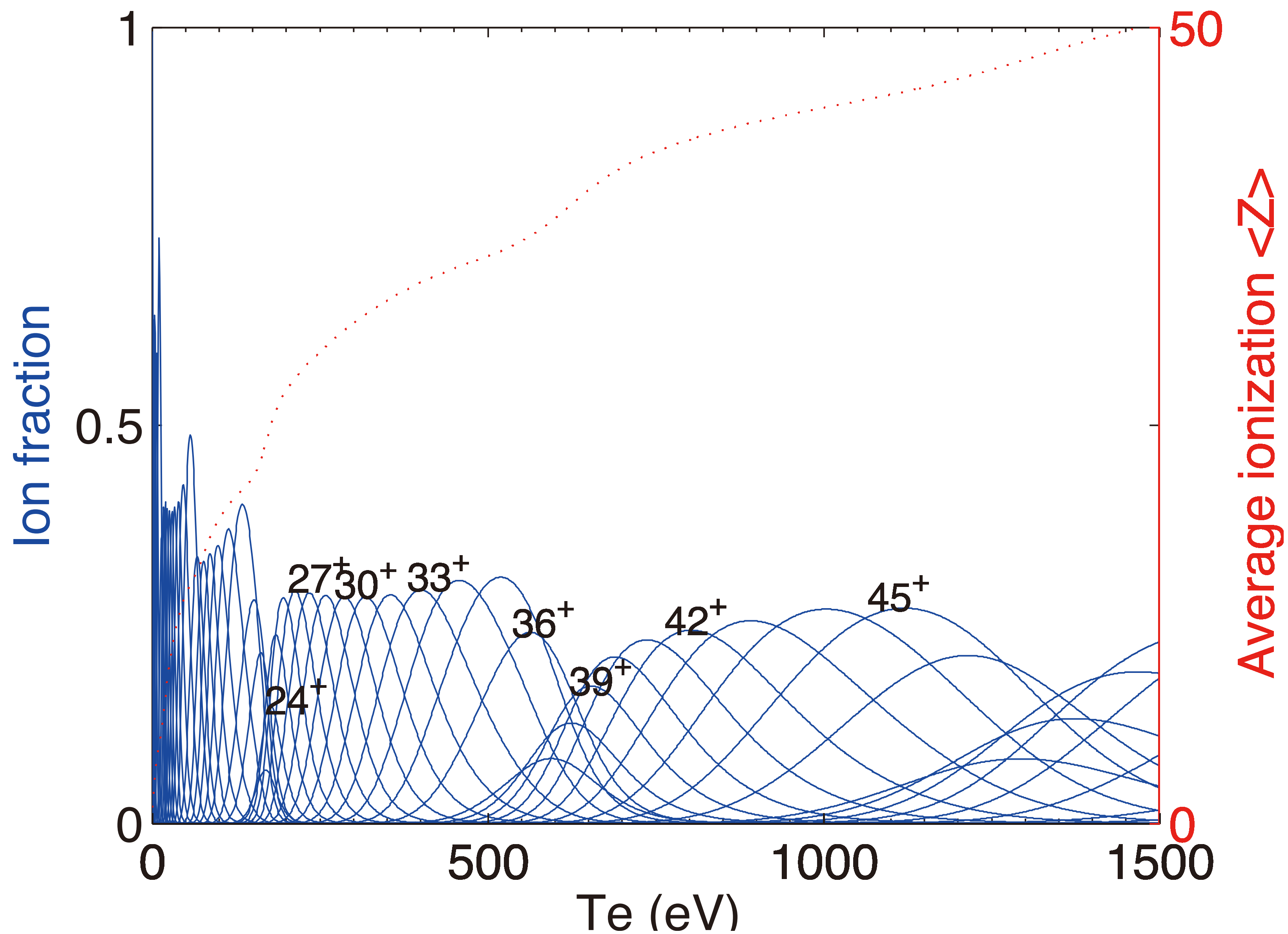




Ionic charge state in **Bi**

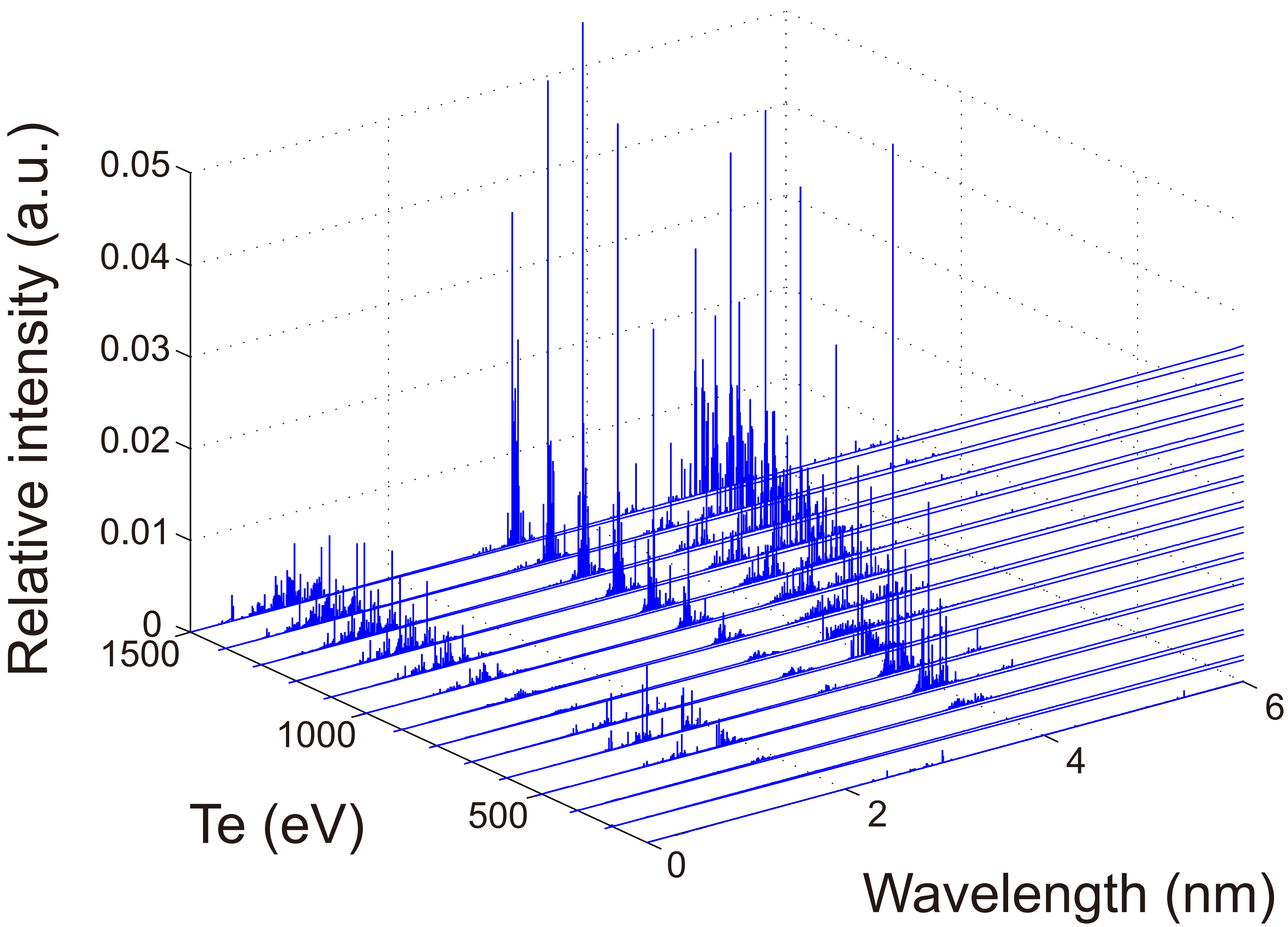


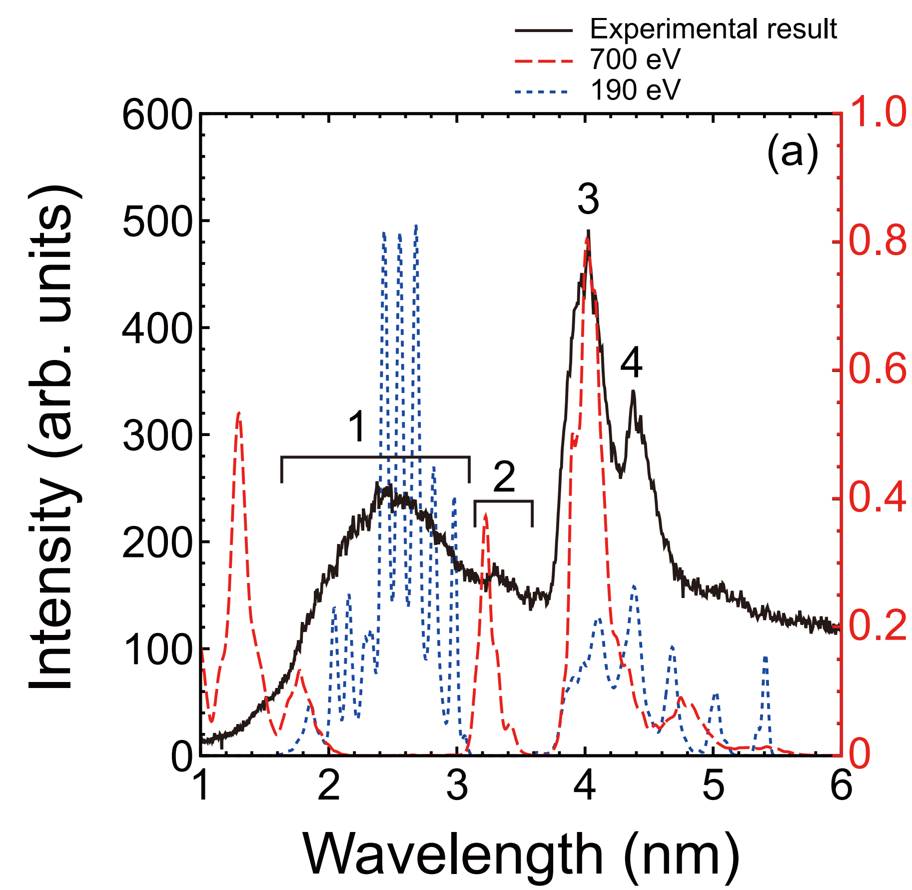
Optimum plasma temperature in Bi plasma: **1 keV**



T. Higashiguchi *et al.*, Appl. Phys. Lett. **100**, 014103 (2012).

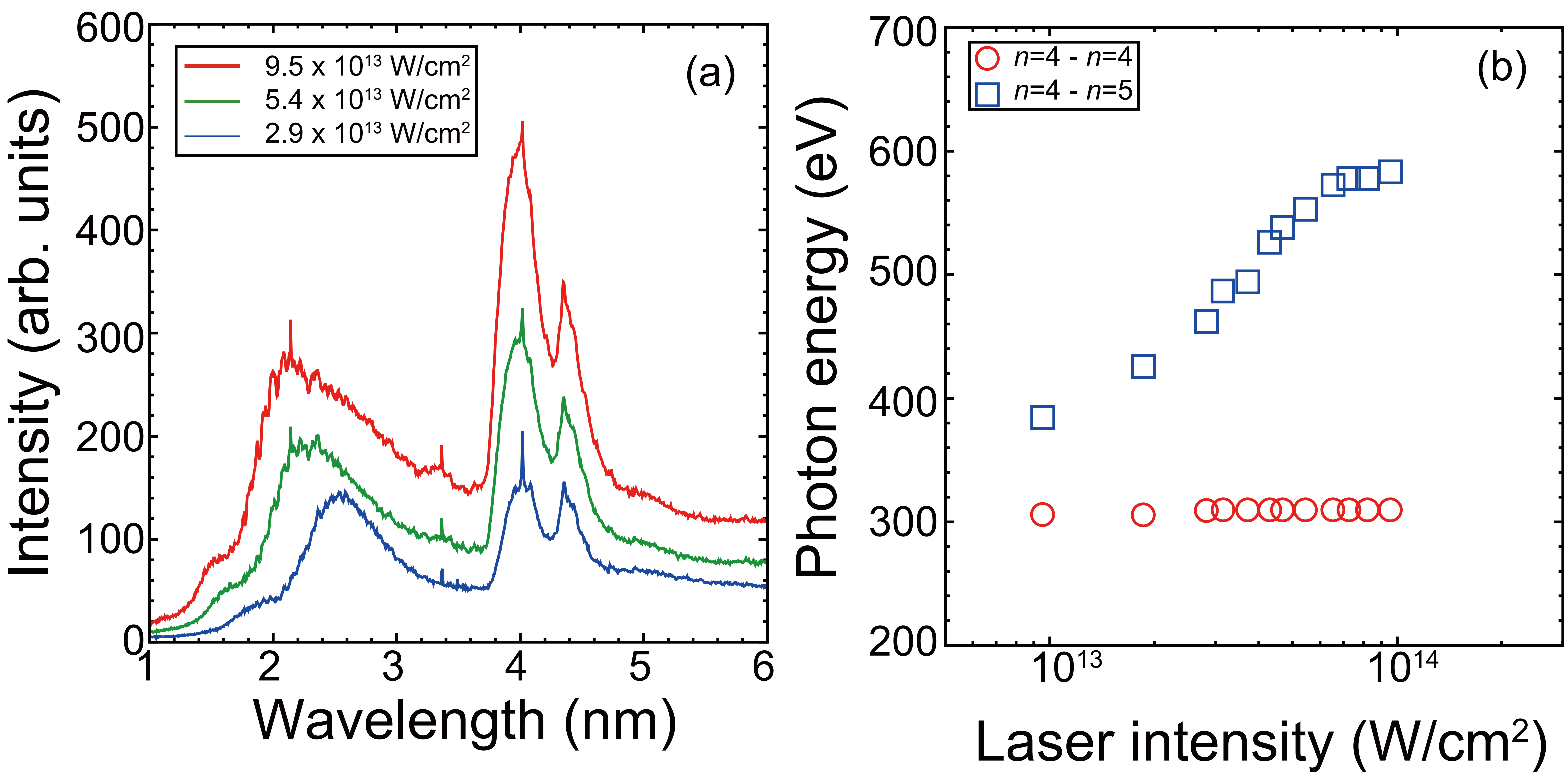
3-nm at high Temp. *v.s* **4-nm at low Temp.**





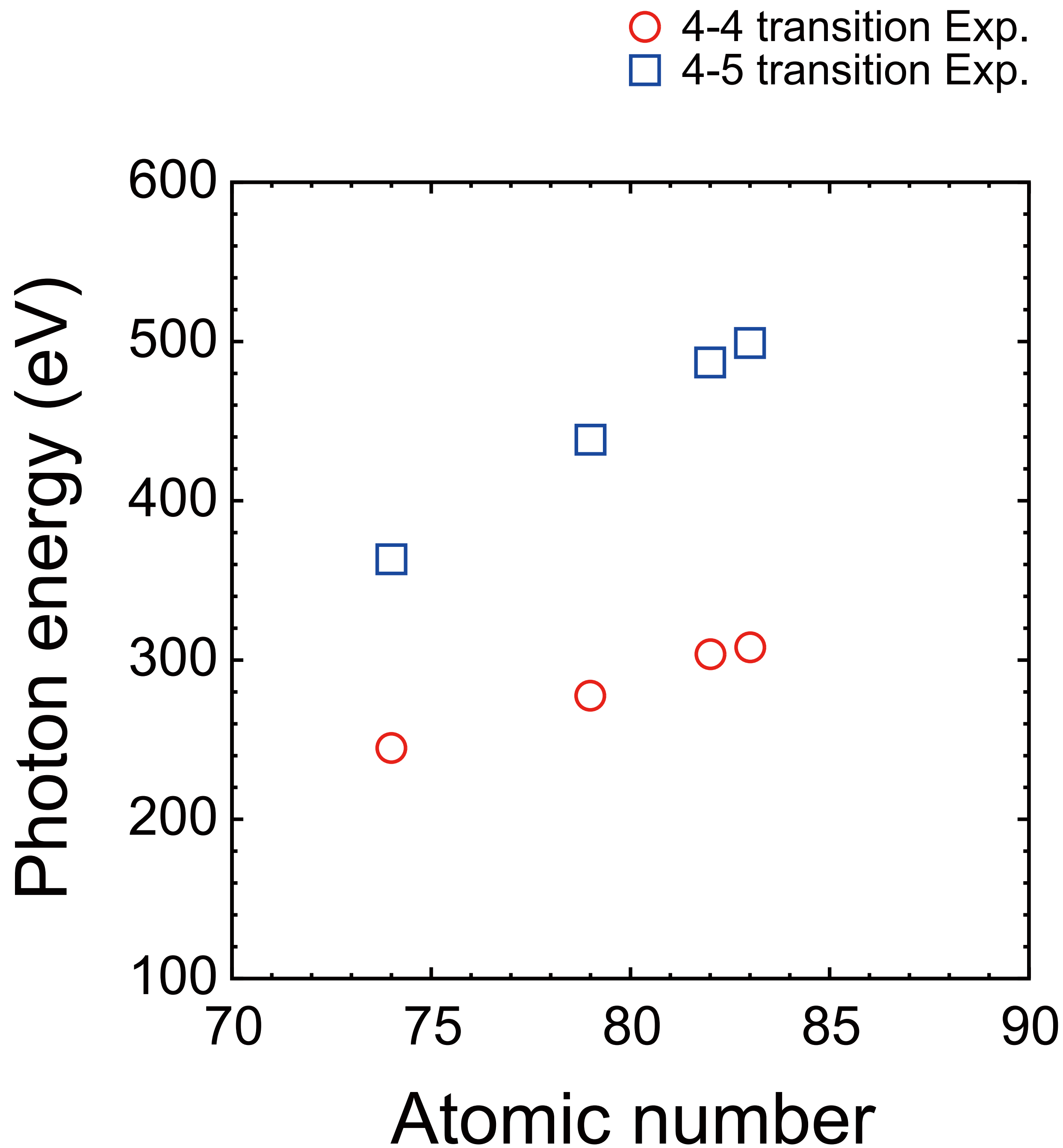
T. Higashiguchi *et al.*, Appl. Phys. Lett. **100**, 014103 (2012).

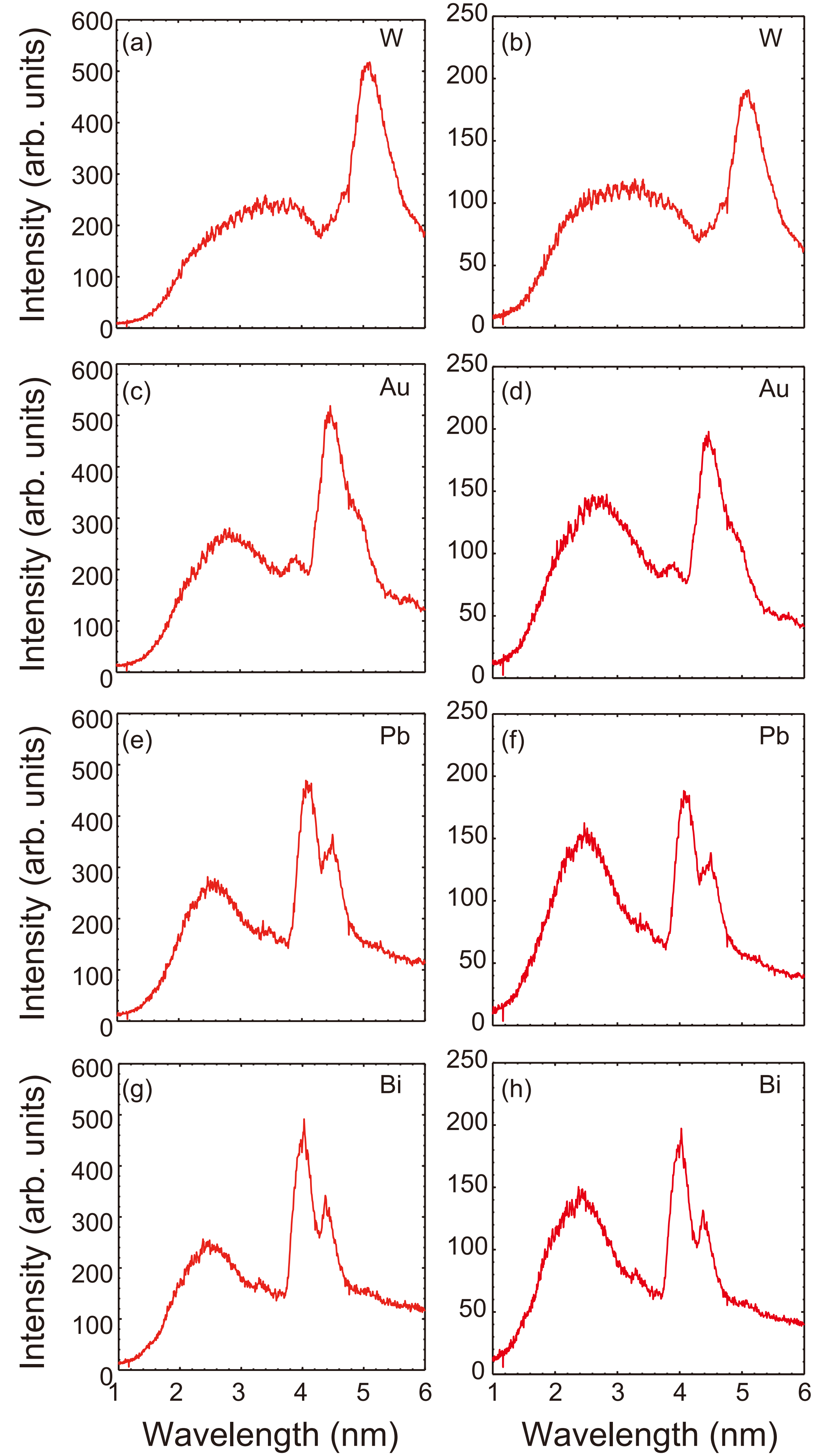
Laser intensity dependence in Bi



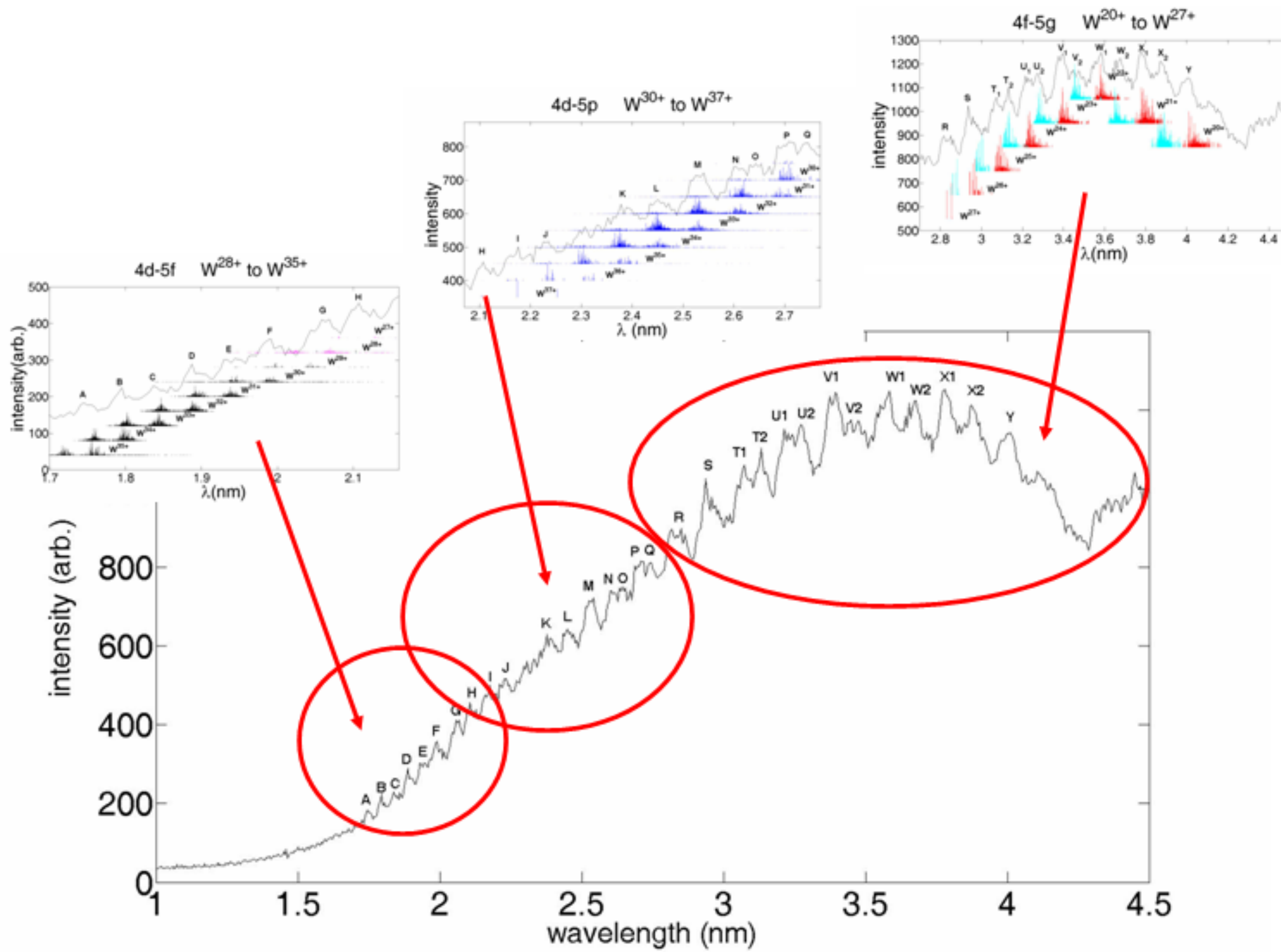
T. Higashiguchi *et al.*, Appl. Phys. Lett. **100**, 014103 (2012).

n = 4-4, 4-5 transitions

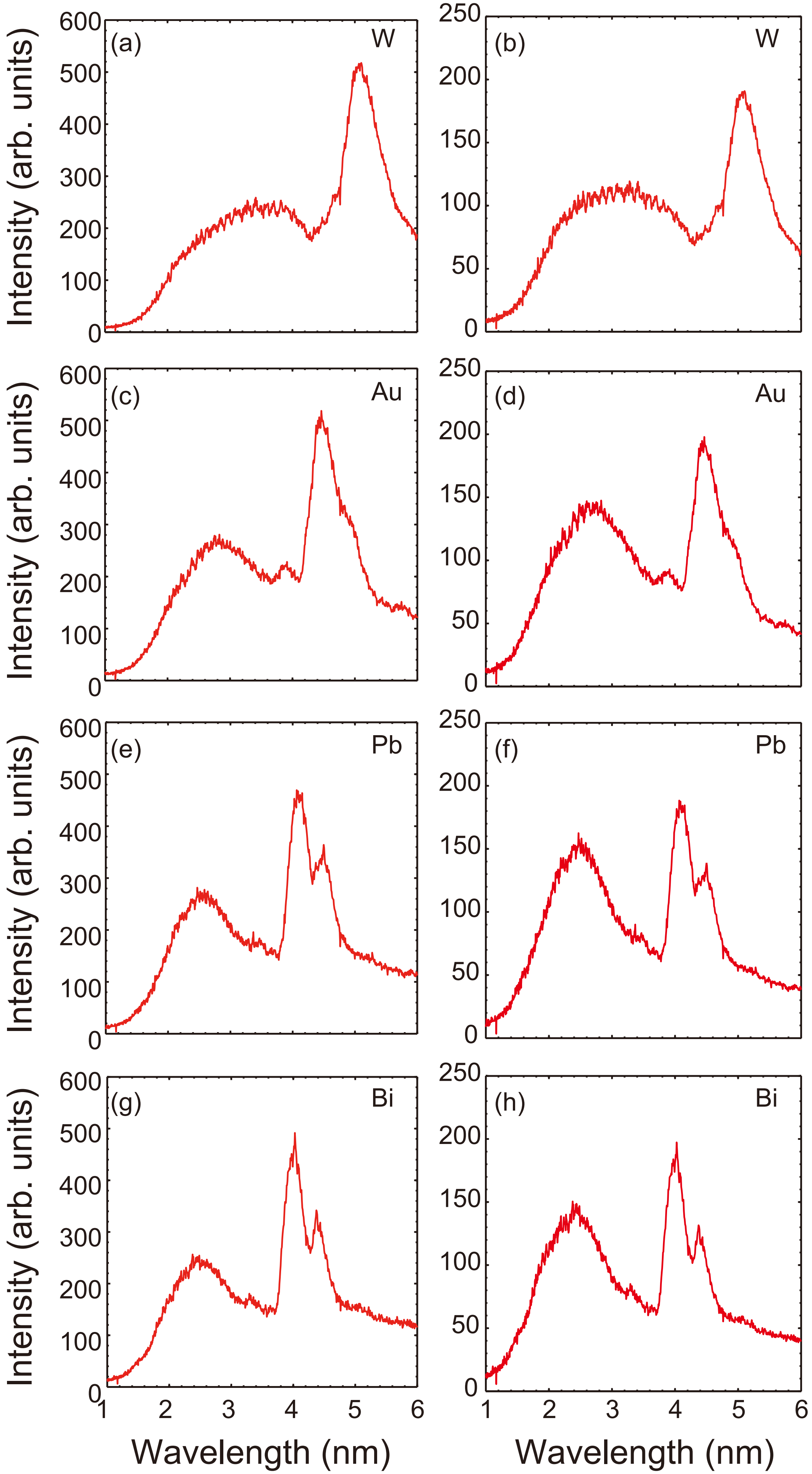




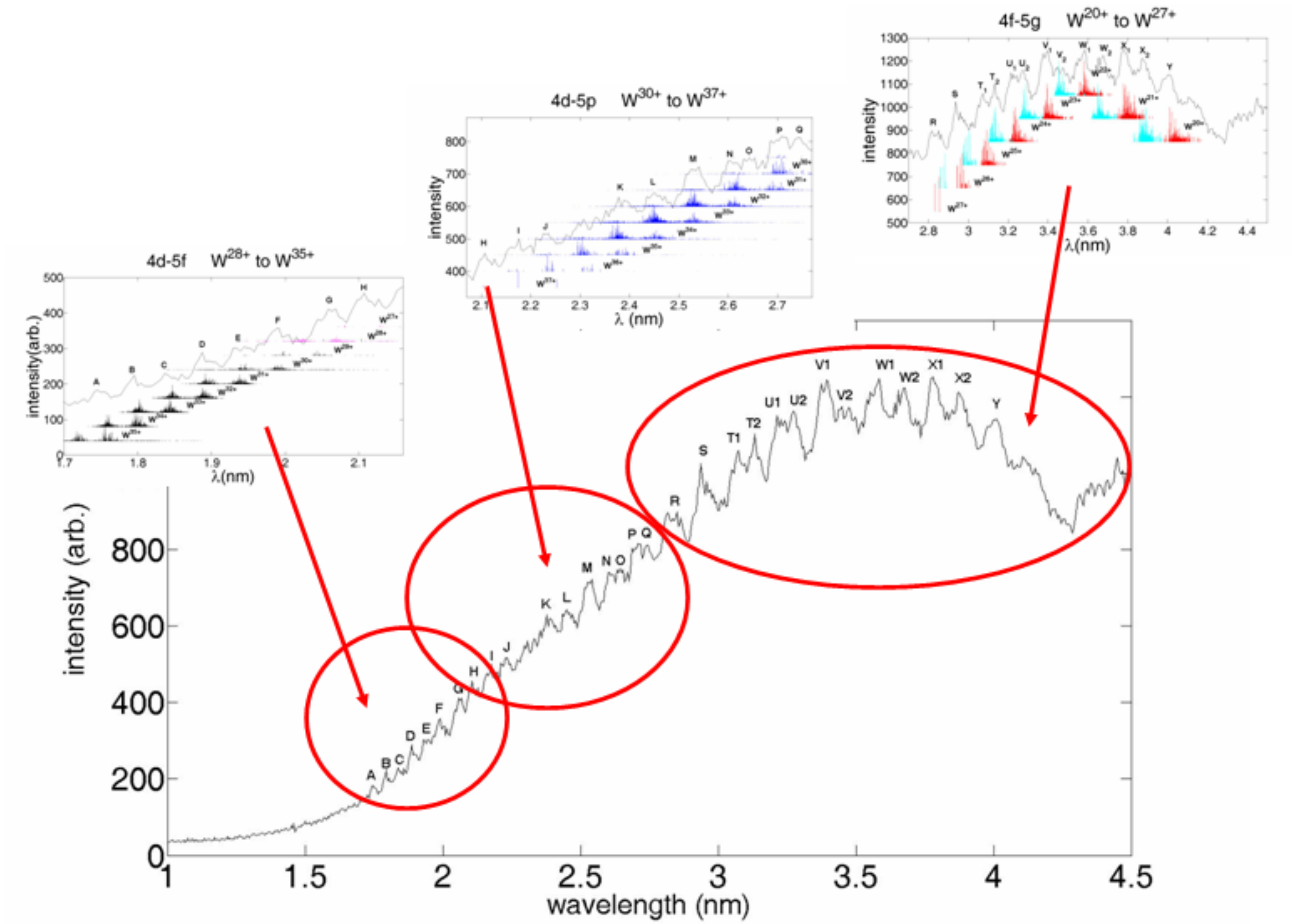
Water Window Spectrum from laser-produced **W plasma**



C. S. Harte *et al.*, J. Phys. B **45**, 245004 (2012).

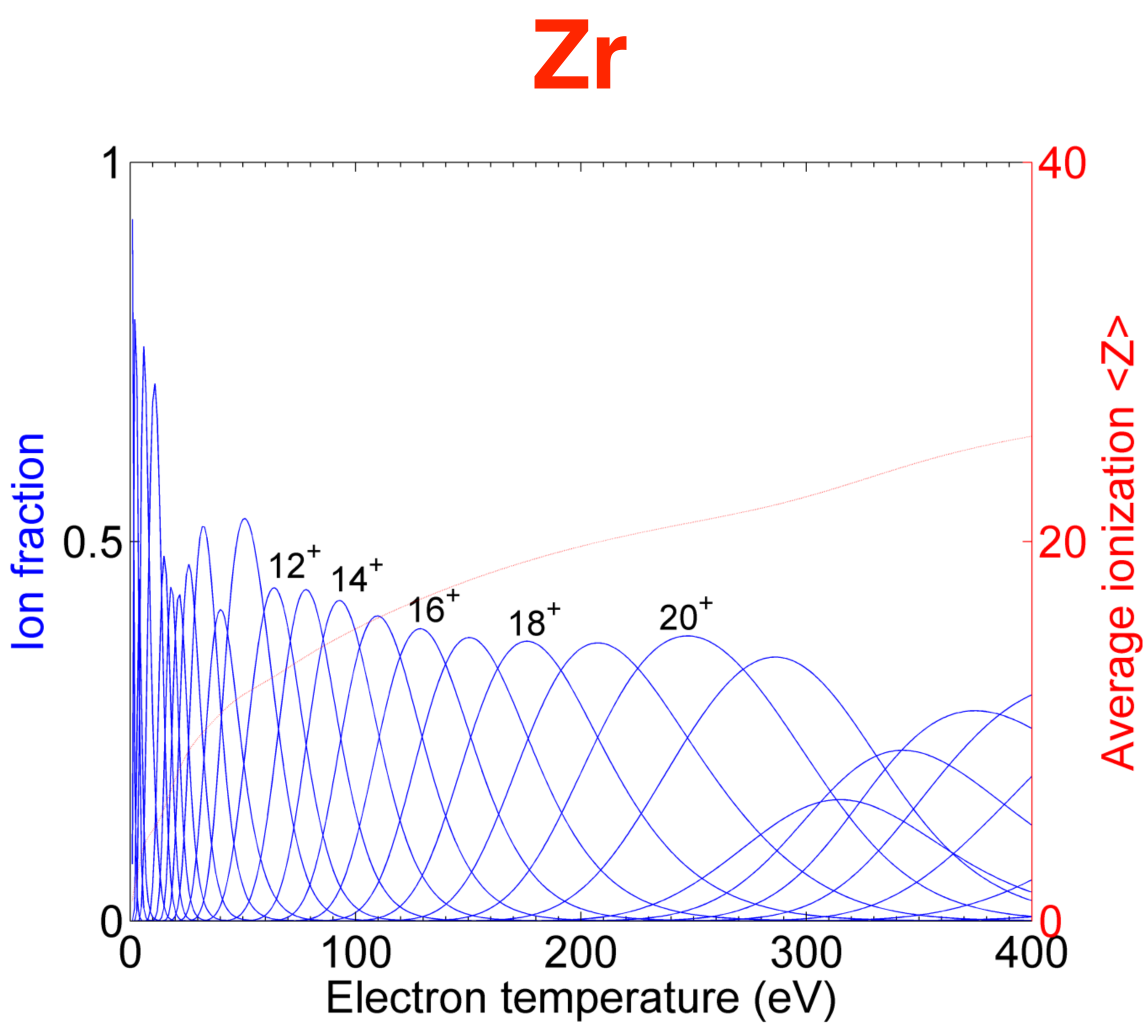


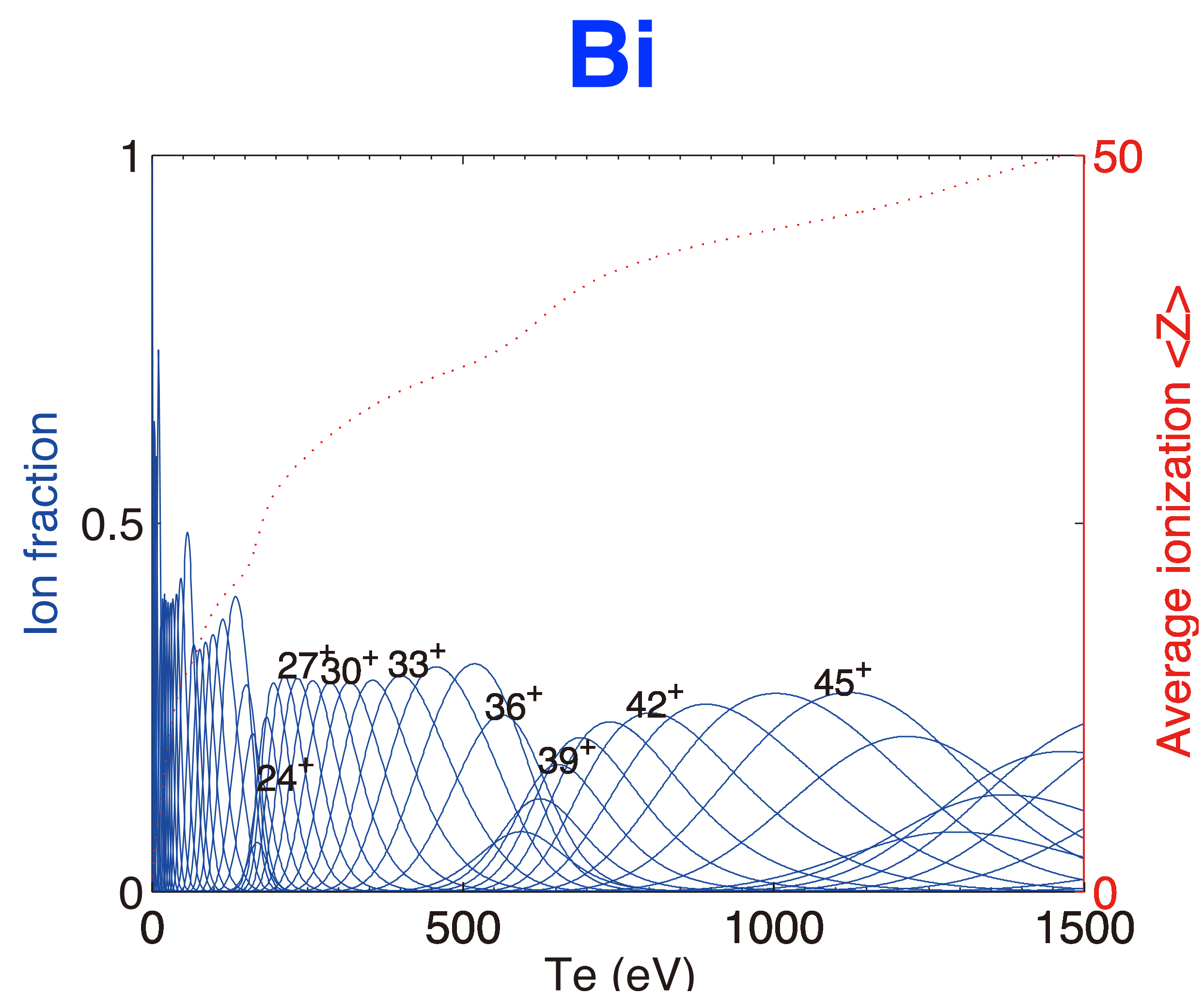
(a) W
(b) W
(c) Au
(d) Au
(e) Pb
(f) Pb
(g) Bi
(h) Bi
Intensity (arb. units)
Wavelength (nm)



4d-5f W^{28+} to W^{35+}
4d-5p W^{30+} to W^{37+}
4f-5g W^{20+} to W^{27+}
intensity(arb.)
intensity
λ(nm)
λ (nm)
intensity (arb.)
wavelength (nm)
A B C D E F G H I J K L M N O P Q R S T1 T2 U1 U2 V1 V2 W1 W2 X1 X2 Y

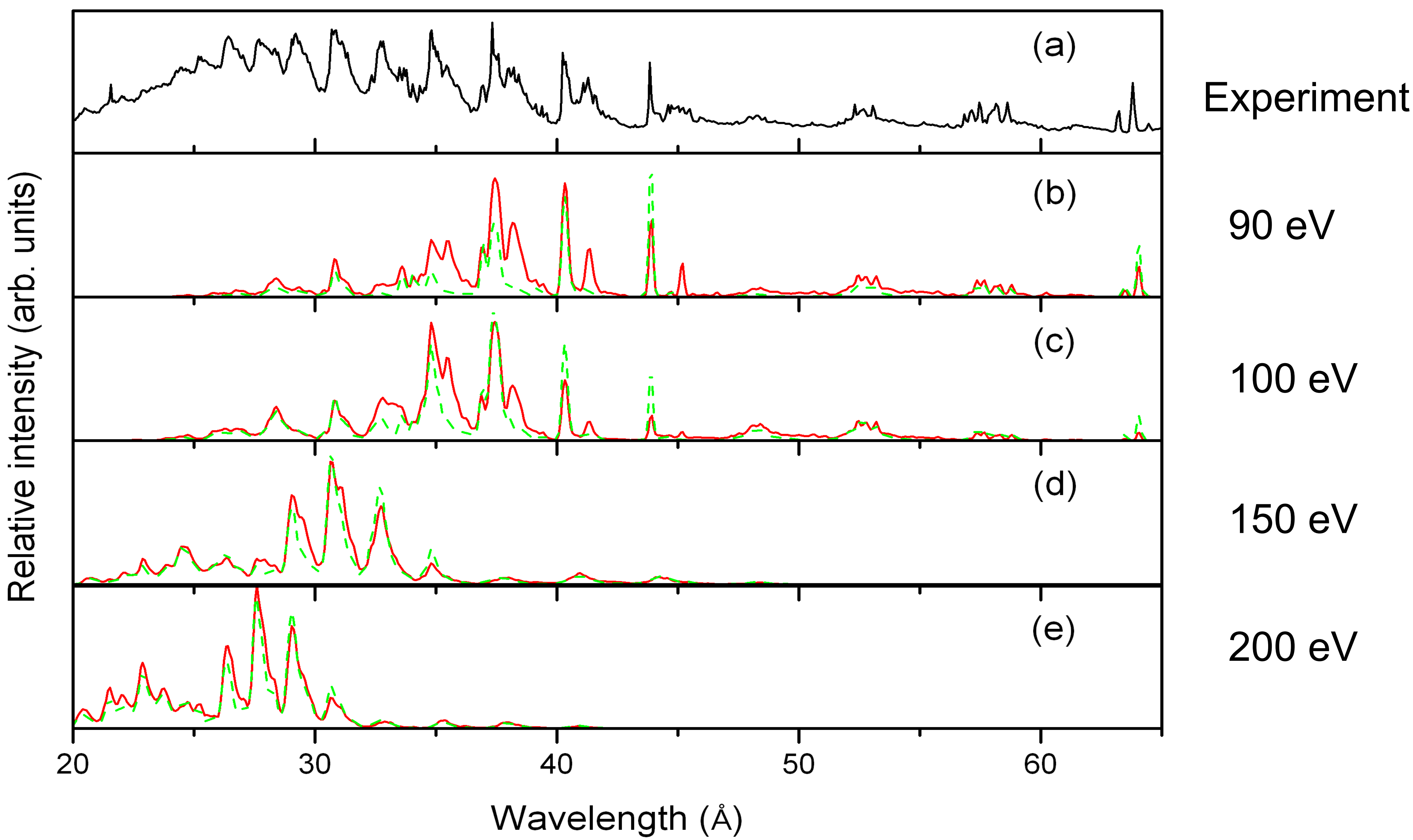
Lower temperature ~**0.2** keV vs 1 keV





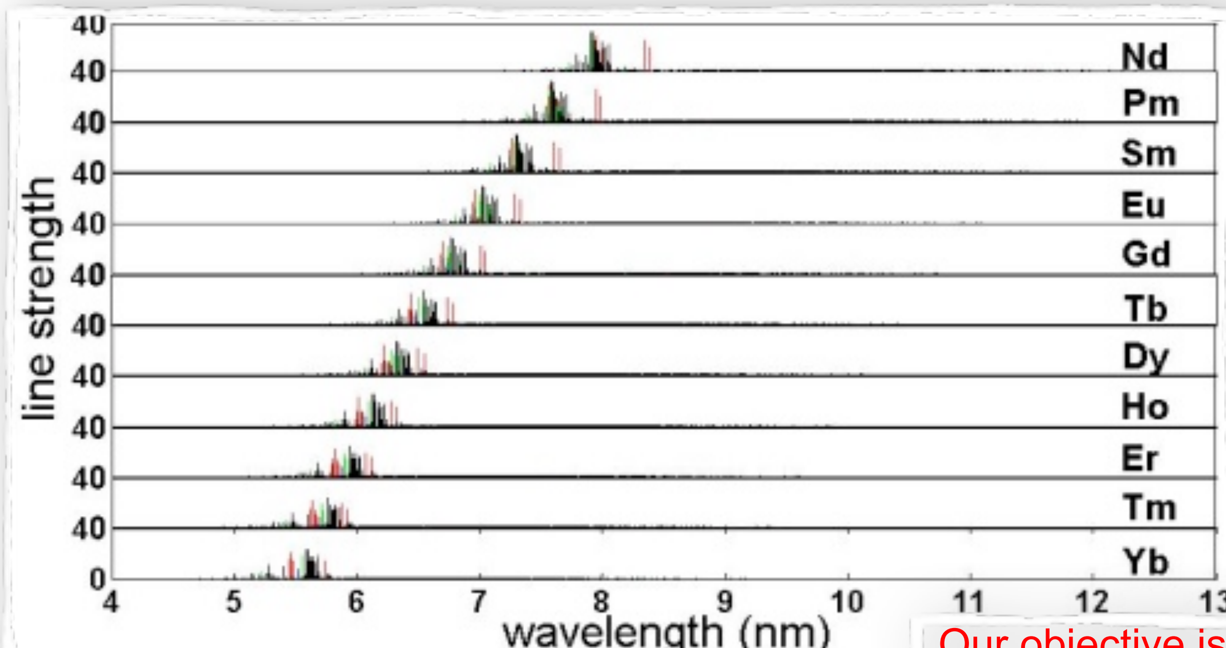
B. Li *et al*., J. Phys. B **45**, 245004 (2012).
B. Li *et al*., (submitted)

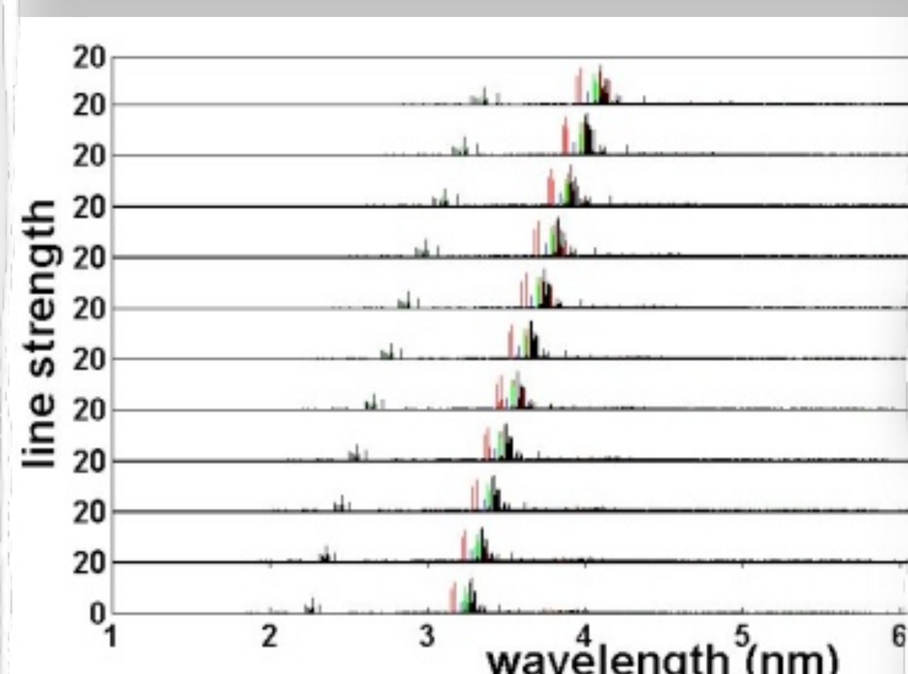
Recent Progress: **Zr** plasma WW source



B. Li *et al*., J. Phys. B **45**, 245004 (2012).
B. Li *et al*., (submitted)

Summary





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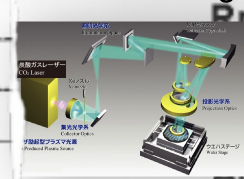
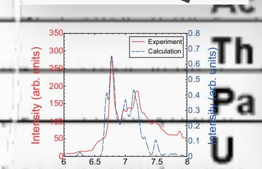
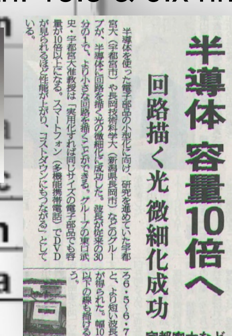
Lithography

EUV & BEUV source study
Wavelength: 13.5 & 6.x nm







MEXT

キヤノン財団
The Canon Foundation

NEDO

宇都宮大学

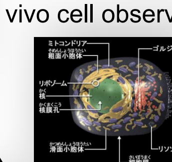
APL x 7
(2010-2012)

Shorter wavelength

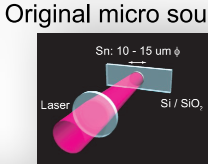
Life Innovation

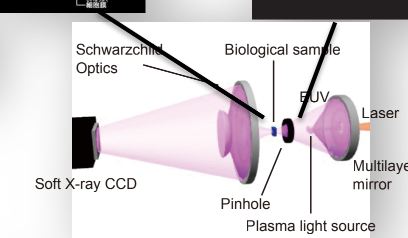
Compact source development for Bio.
Wavelength: 2-4 nm

In vivo cell observation



Original micro source





Single shot, flash biological imaging

Proposal (APL x 1)