Hydrothermal method grown ZnO crystal as a fast EUV scintillator and EUV laser imaging device

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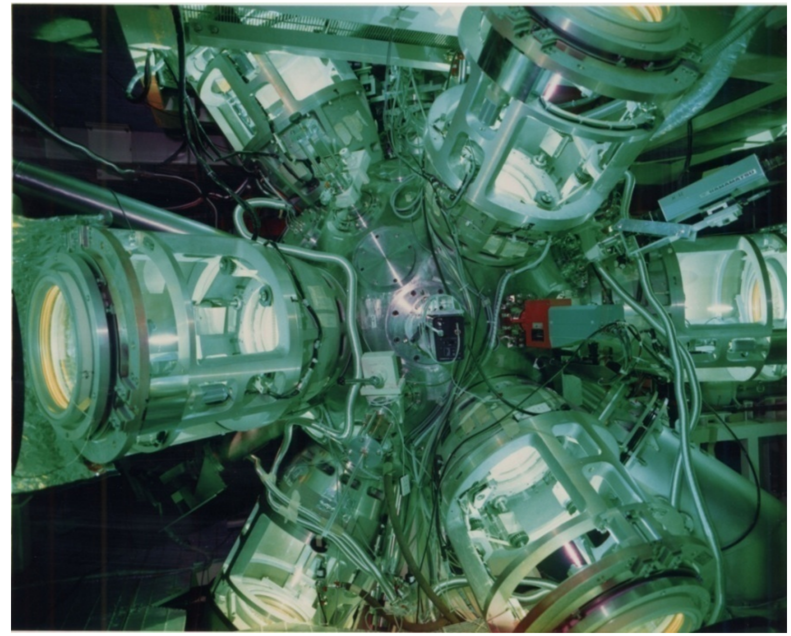
[4]RIKEN XFEL Project Head Office
[5]Japan Synchrotron Radiation Research Institute

Gekko XII laser for laser fusion

Amplifier chain

12 beams, 30 kJ (w)

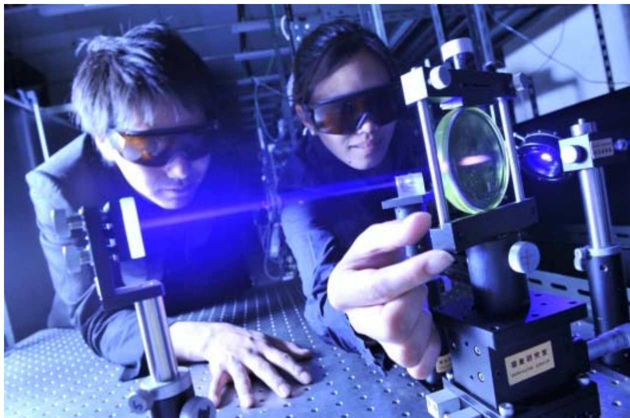


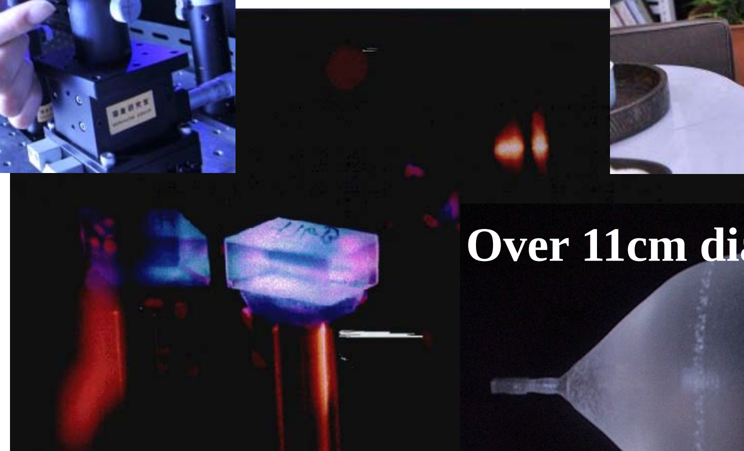
Target chamber

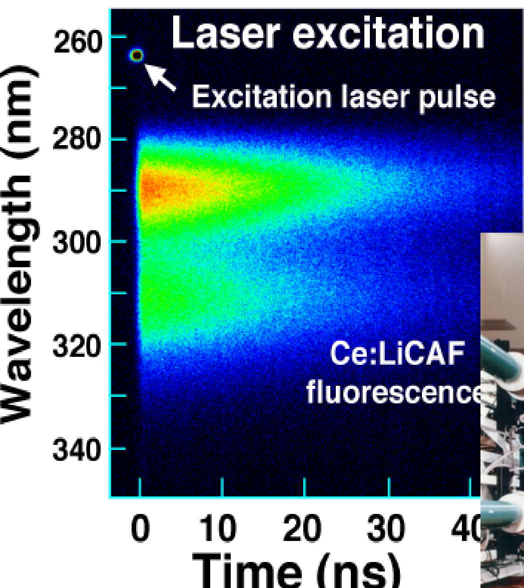
Sarukura Lab.

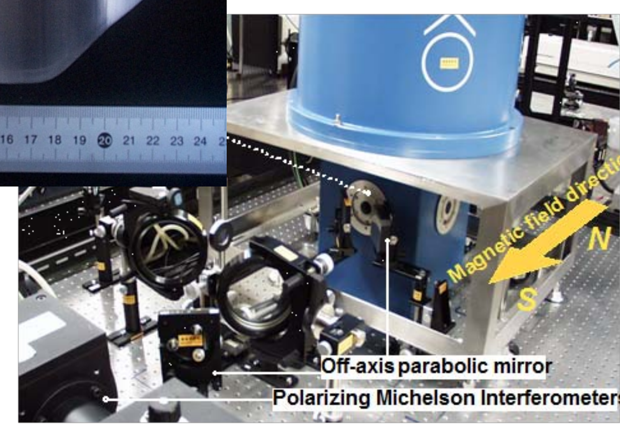
Institute of Laser Engineering, Osaka Univ.,

Characterization of optical material and laser system









Outline

1. ZnO as EUV scintillator
2. focal image of EUV laser
3. XFEL timing measurements
   with response time improved ZnO

Motivation

100 W EUV light source should have some other applications?

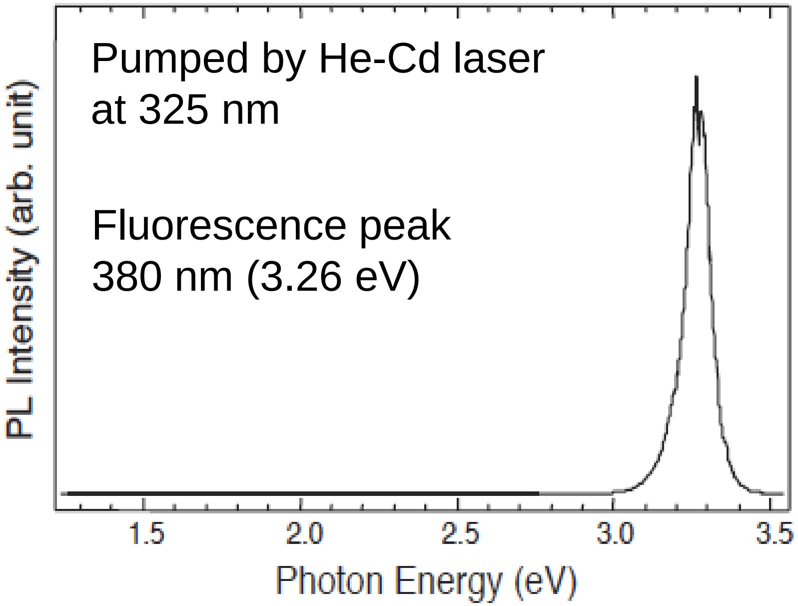
Even 1 W EUV would be nice for spectroscopy of wide-gap material

EUV material science

Hydrothermal method grown ZnO crystal

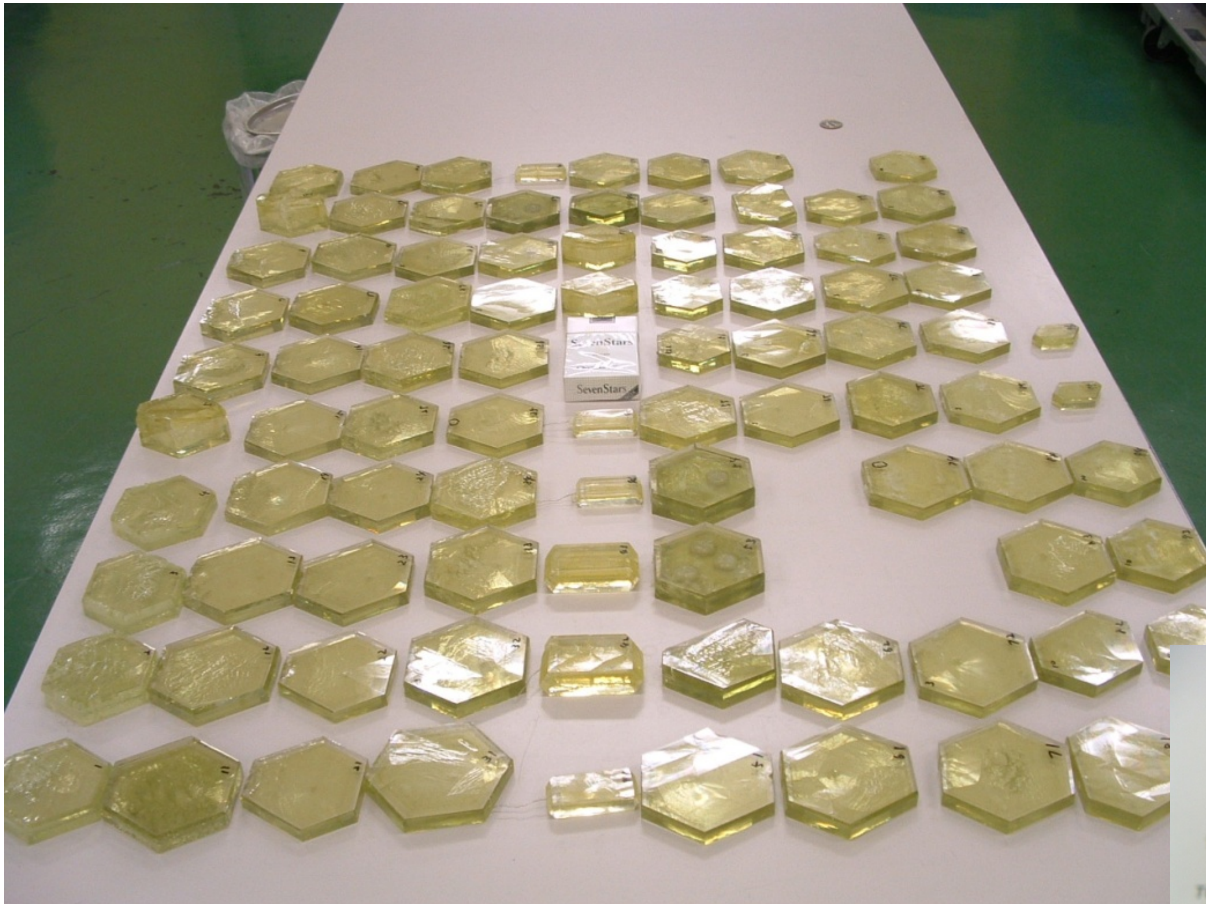
Short fluorescence decay time of ~1 ns.
Useful emission wavelength (Transparent for glass).
Large sized single crystal of up to 3 inch-diameter can be grown.

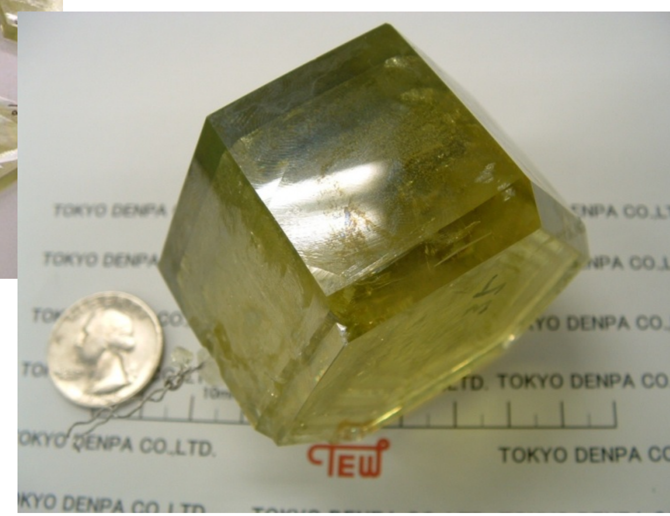
ZnO Crystal grown by hydrothermal method



E. Ohshima, et.al. J. Crystal Growth **260** (2004) 166

ZnO crystal





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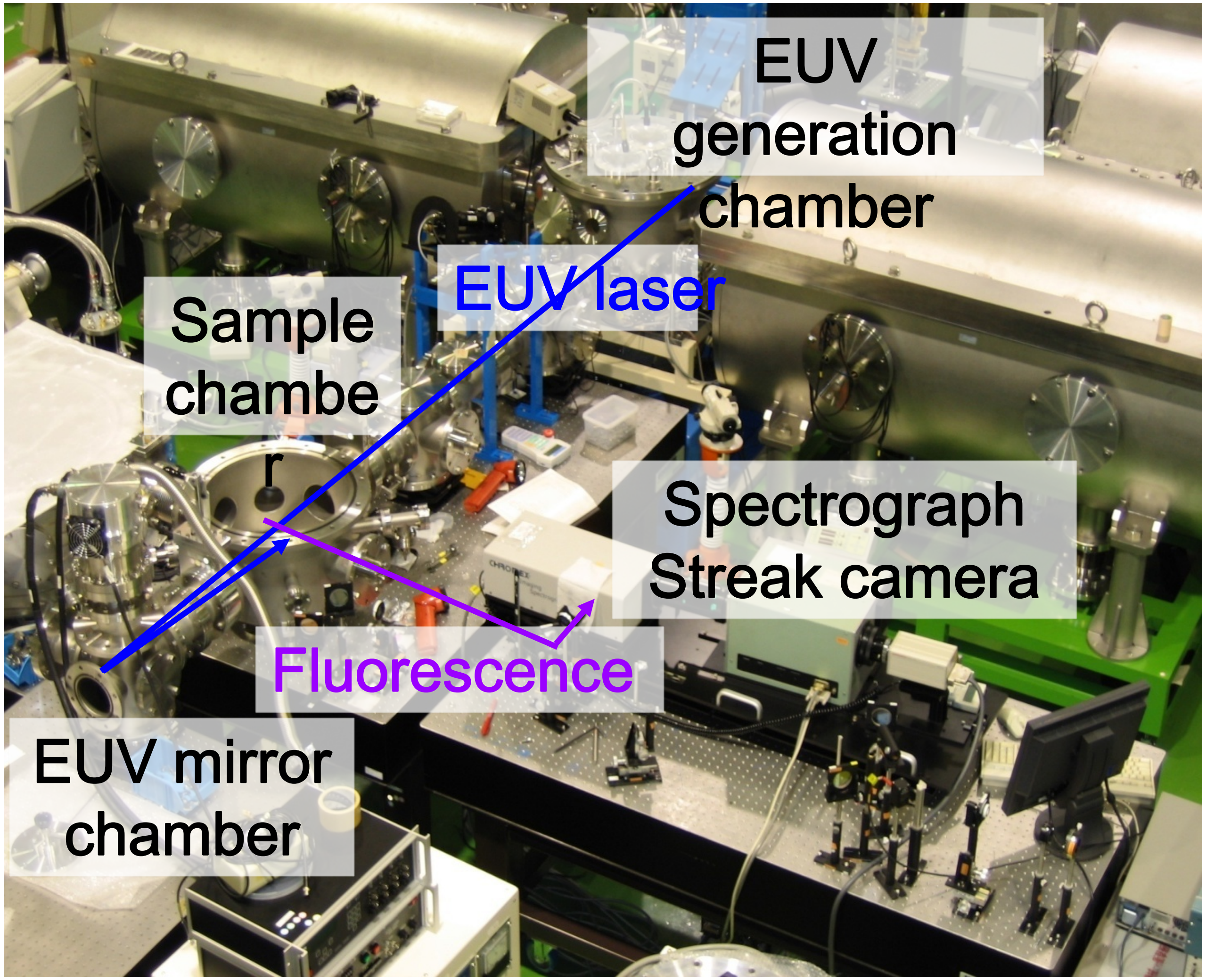
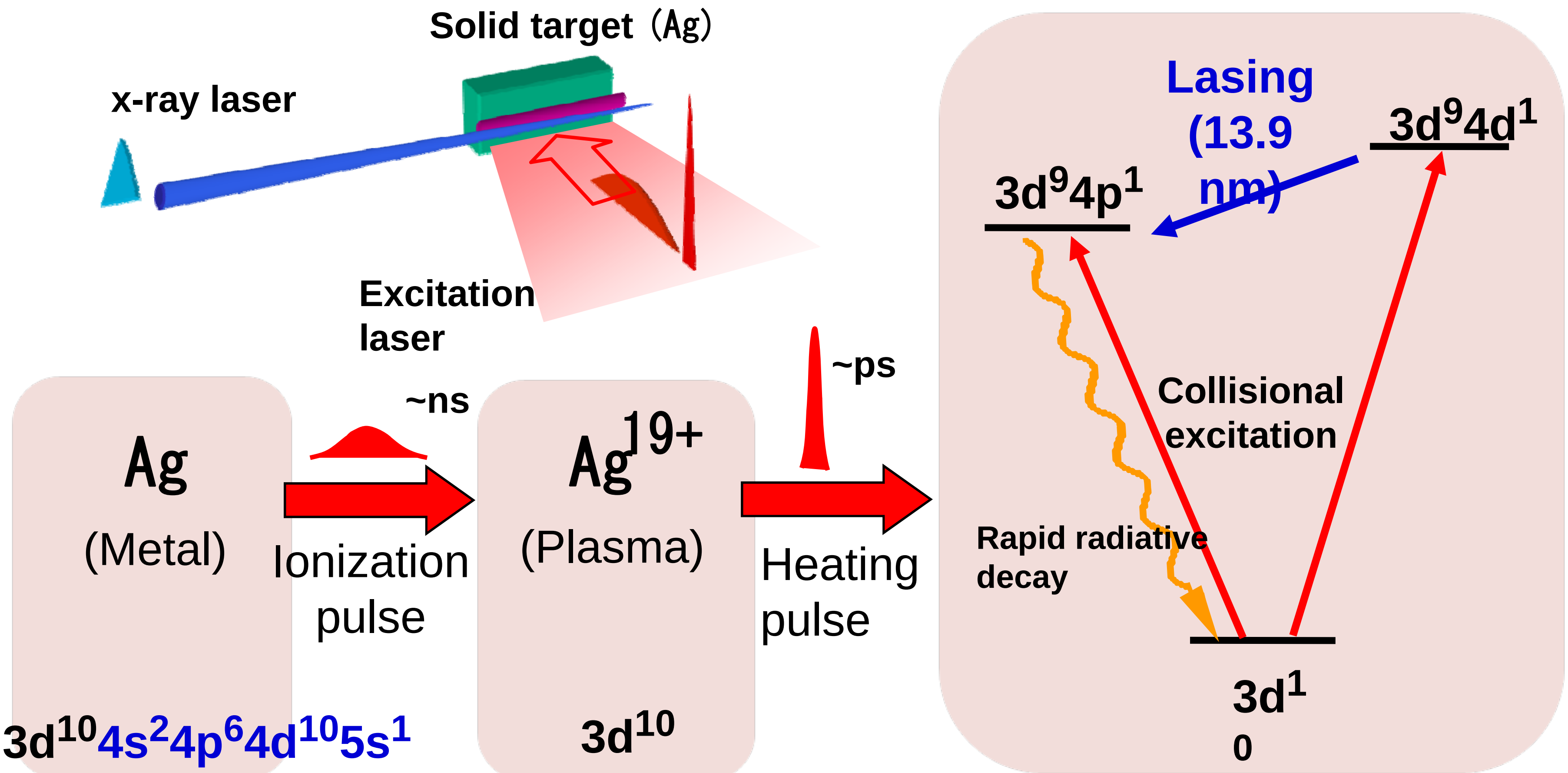
Photograph of Experimental Setup (X-ray laser, JAEA)



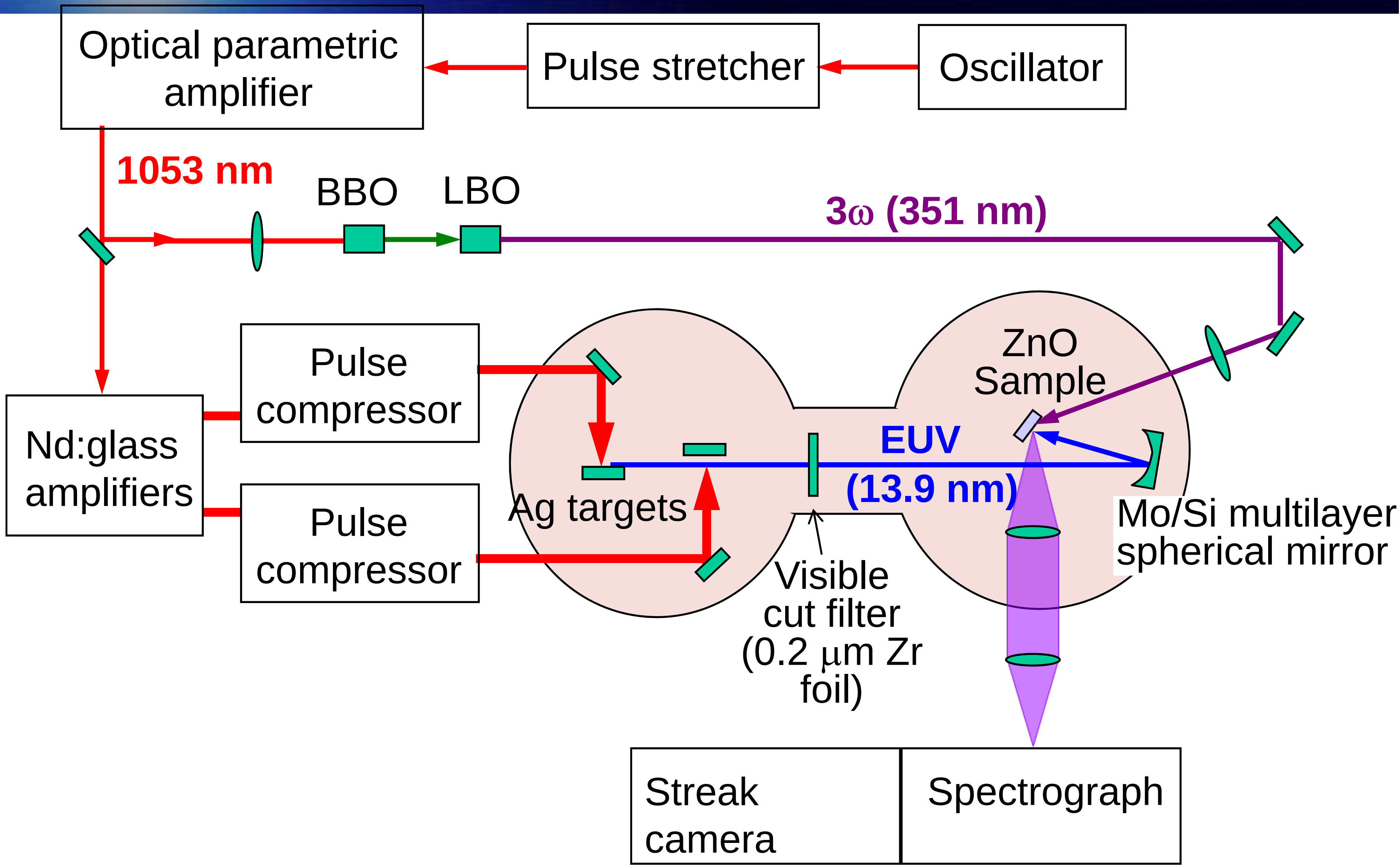
Ni-like Ag x-ray laser



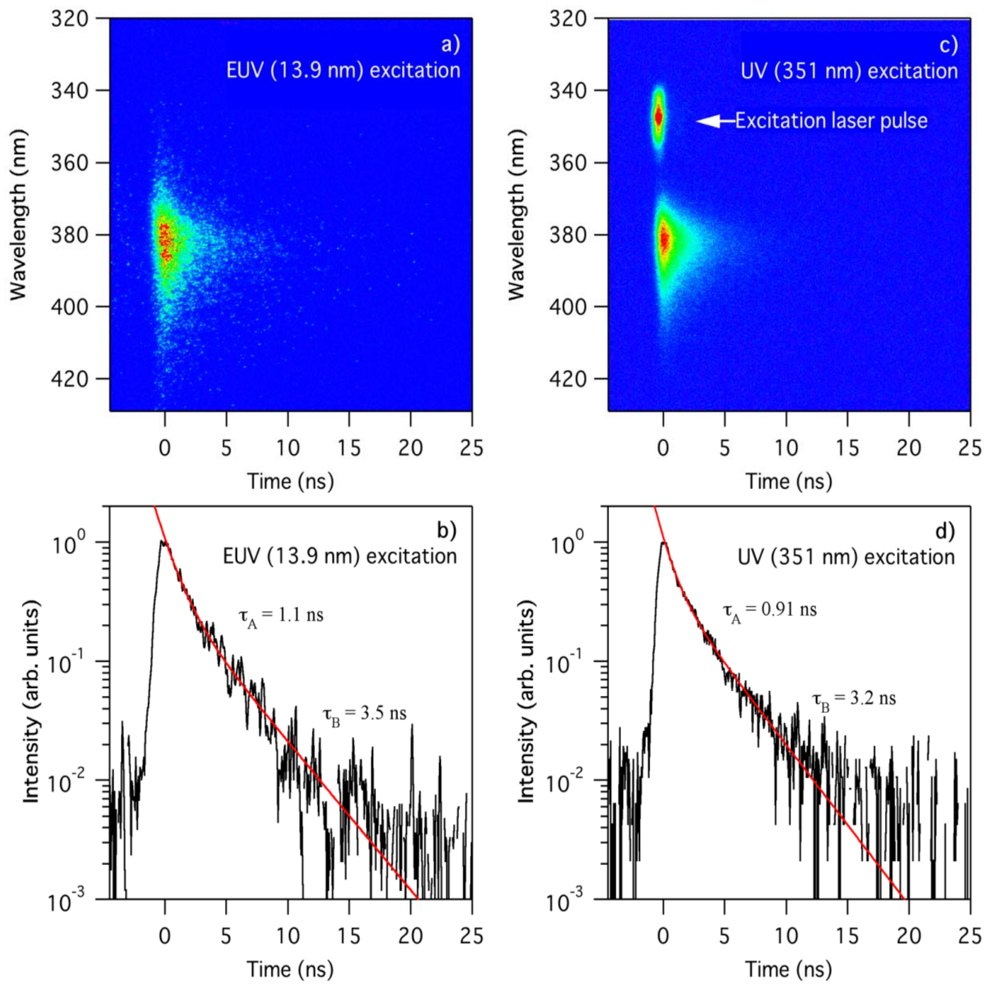
Tanaka et.al. Opt. Lett. 28 (2003) 1680.

The 13.9 nm x-ray laser is generated with transient collisional excitation scheme.

Experimental setup of UV excitation



Comparison of EUV and UV excitations



Double exponential decay $\tau_A = 1$ ns, $\tau_B = 3$ ns

The fluorescence behavior is similar in both cases.

ZnO crystal promises to be a feasible scintillation material.

Tanaka et.al., APL. 91, 231117 (2007)

ZnO as EUV scintillator

3-inch single crystal wafer is available

Sufficiently fast response time

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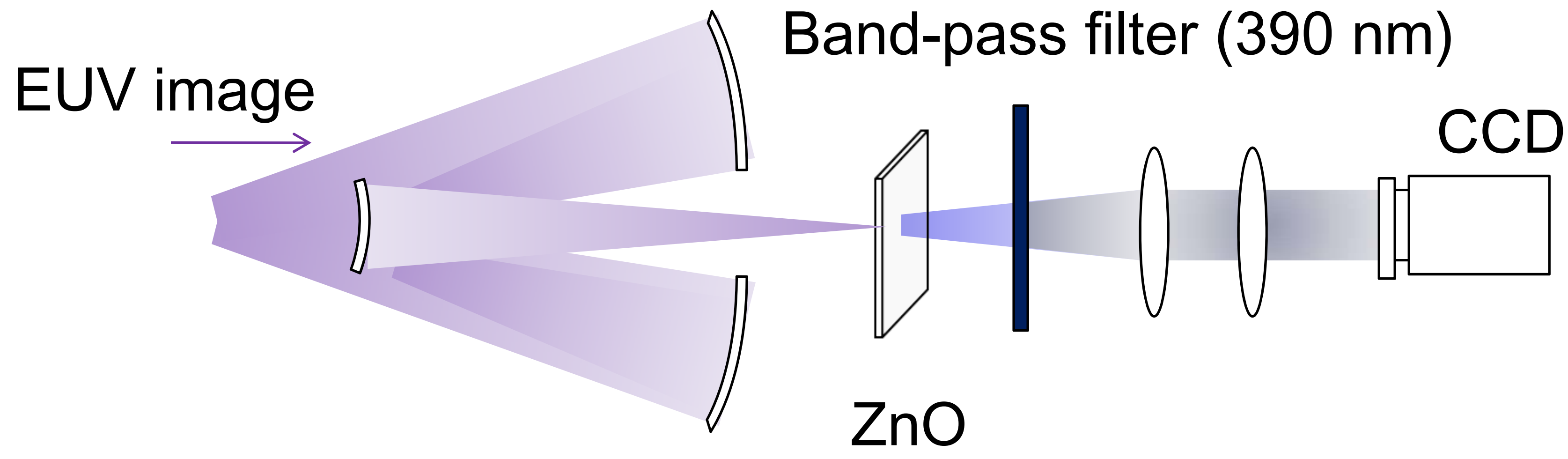
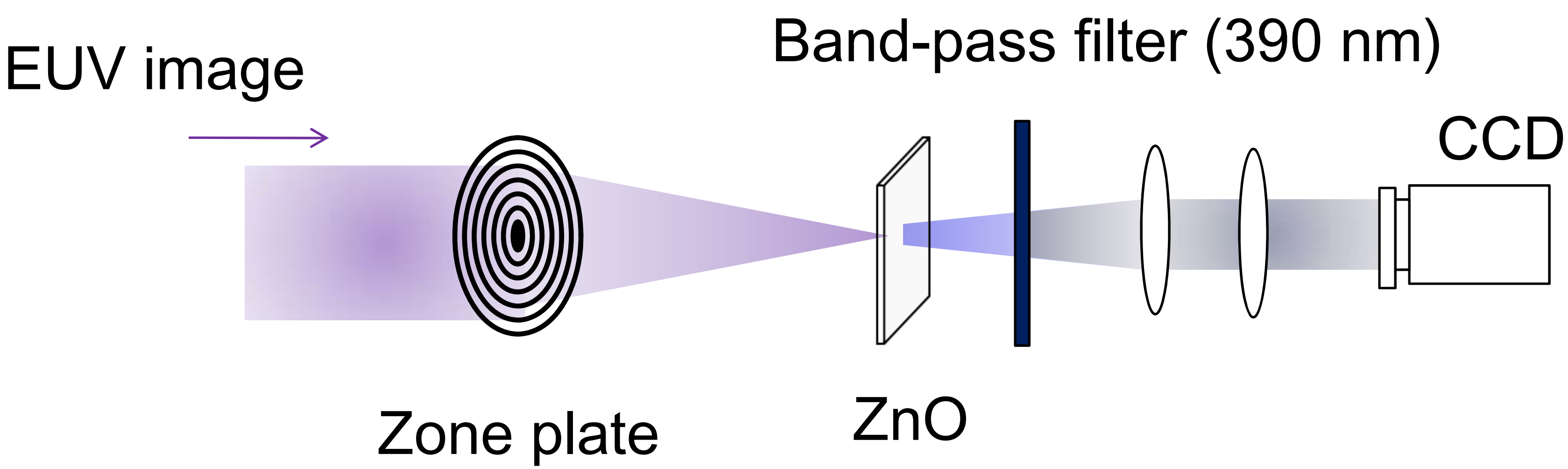
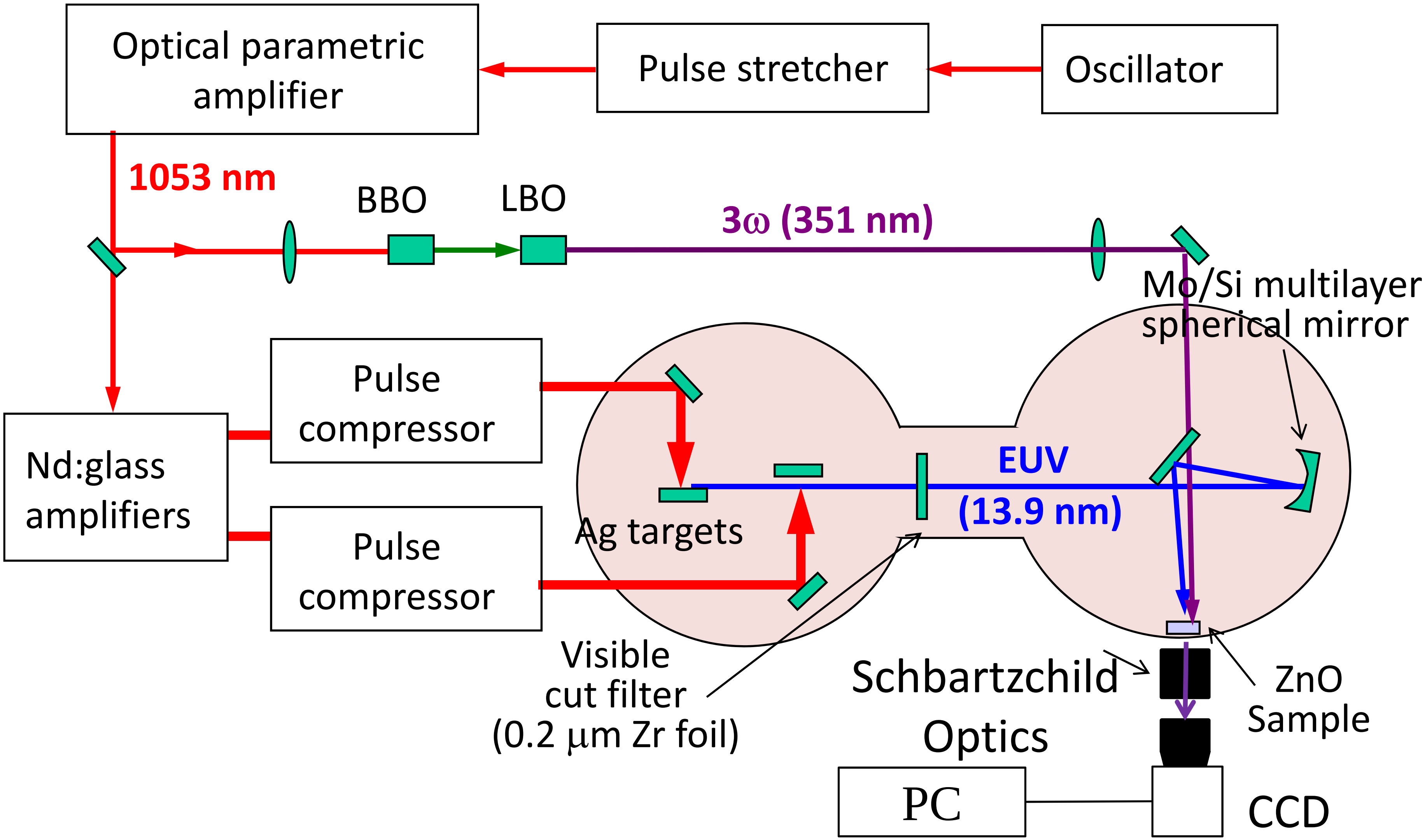
Next step; EUV-visible image converter

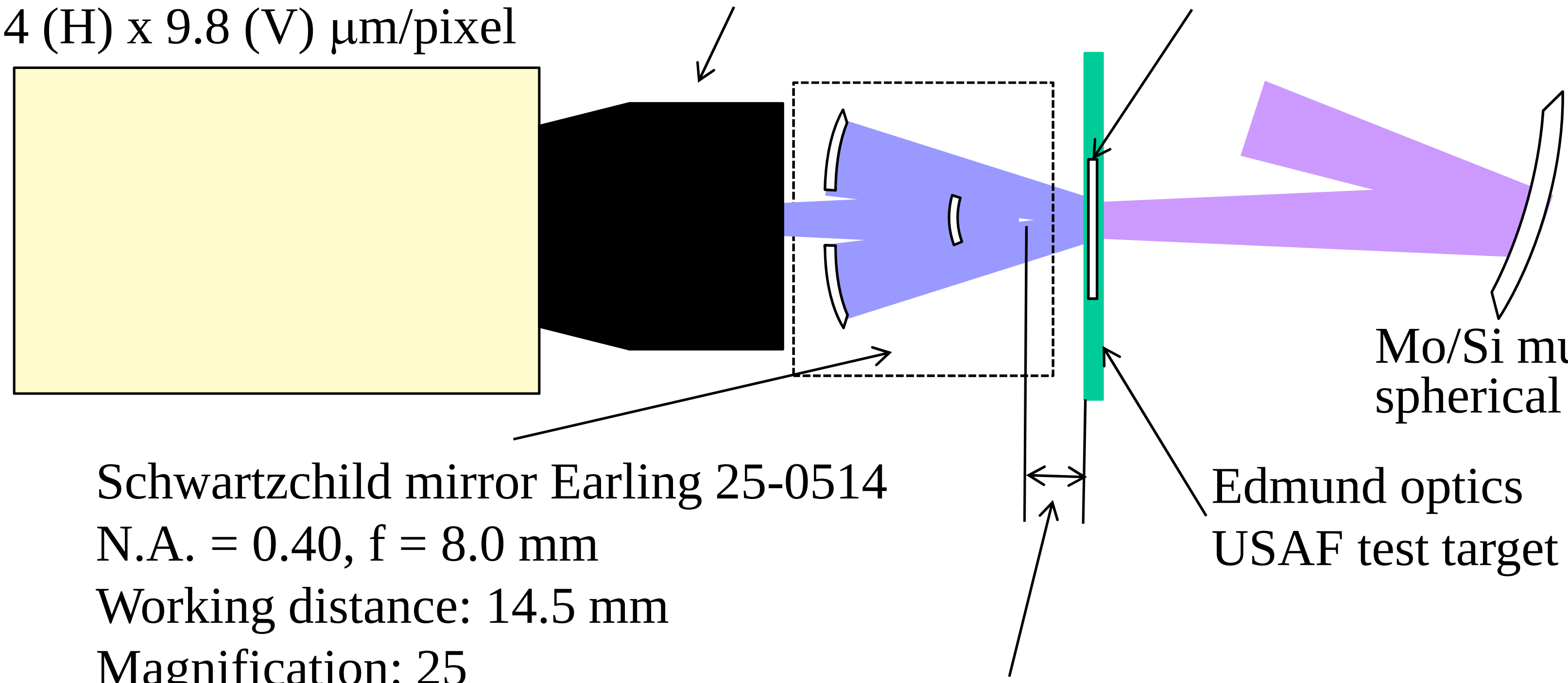




Experimental set-up for imaging

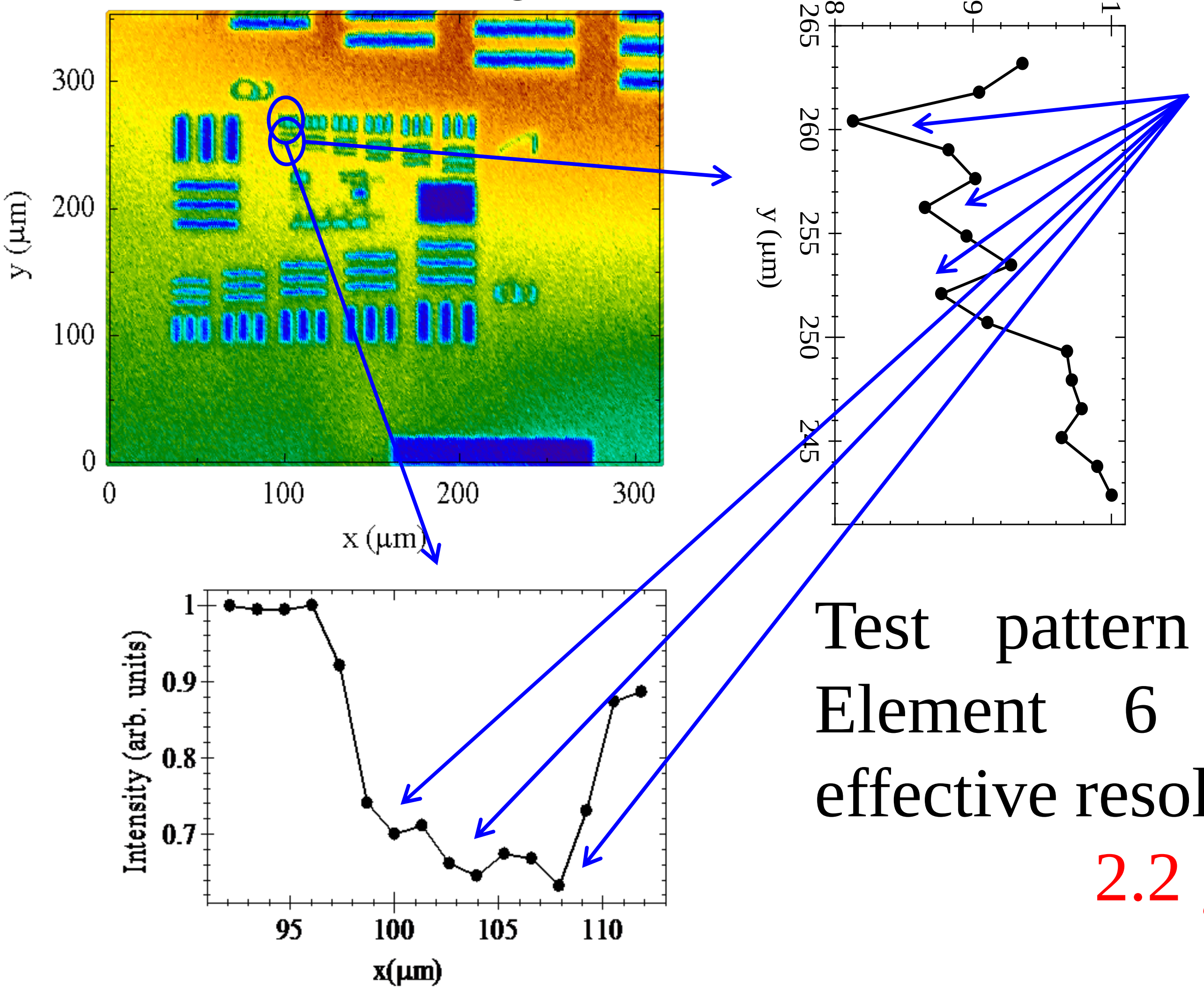


Spatial resolution
-experimental setup-



Spatial resolution

Edmund optics
1951 USAF test target

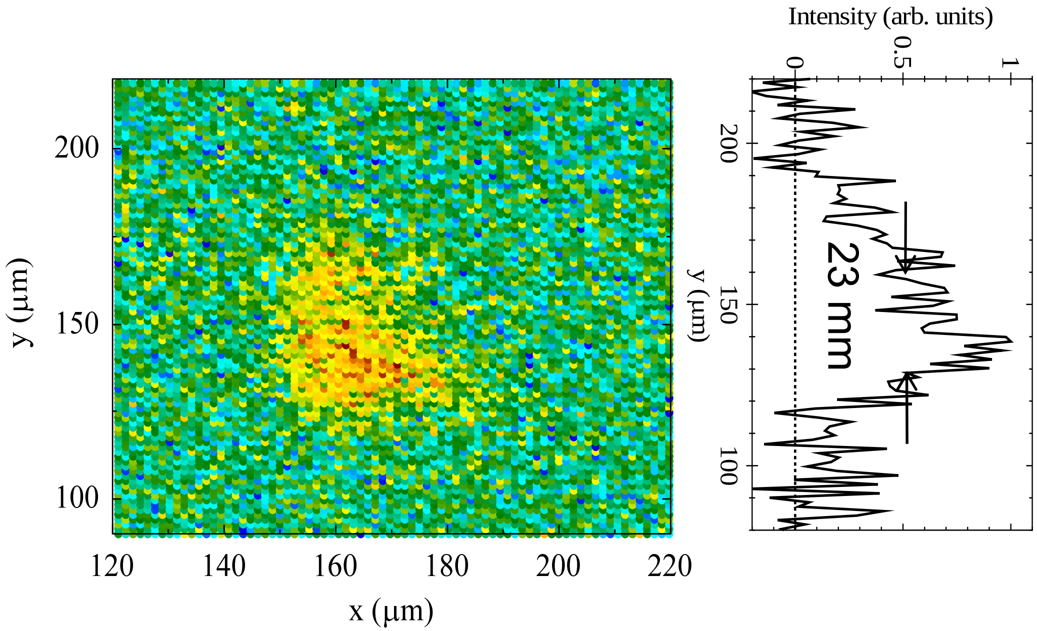


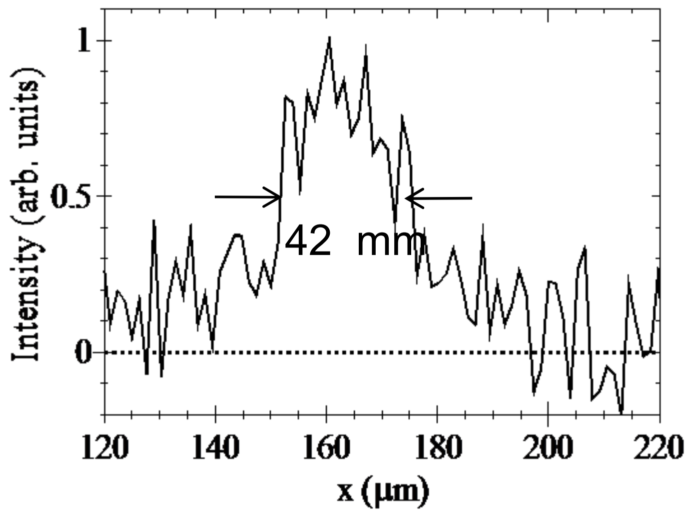
Test pattern can be resolved.

Test pattern in Group 7 Element 6 revealed an effective resolution of:

2.2 µm

EUV laser focal image





(FWHM/ e^{-1})
Horizontal : 23 / 26 mm
Vertical : 42 / 50 mm

3-inch single crystal wafer is available

Sub-micron spatial resolution demonstration is on going.

Outline

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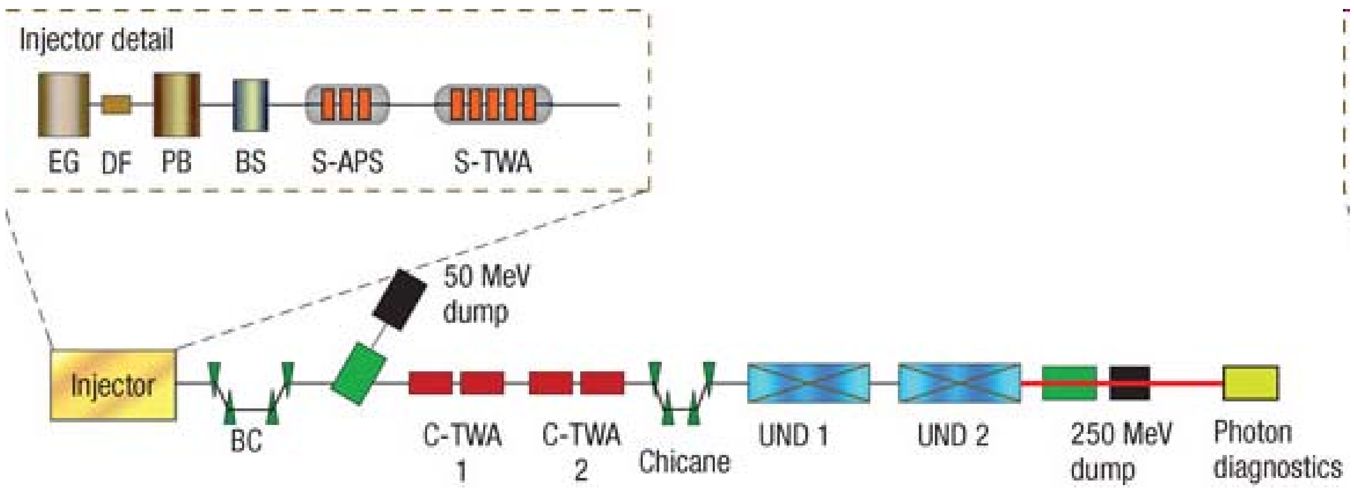
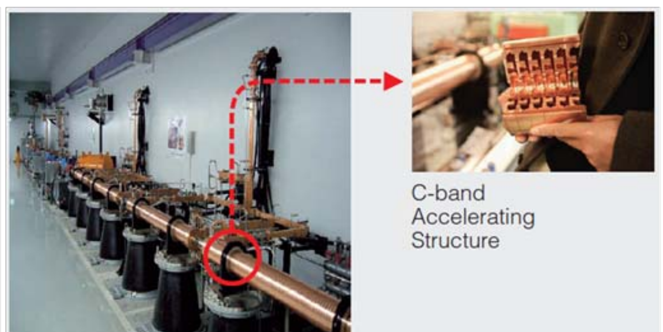
SCSS (SPring-8 Compact SASE Source) test accelerator



T. Shintake, et al., Nature Photonics **2**, 555 (2008)

A high-quality electron beam is launched from a CeB_6 electron gun.



The C-band accelerator swiftly increases the electron energy.

The in-vacuum undulator generates strong XFEL radiation.

from the pamphlet of XFEL at SPring-8 (2008)

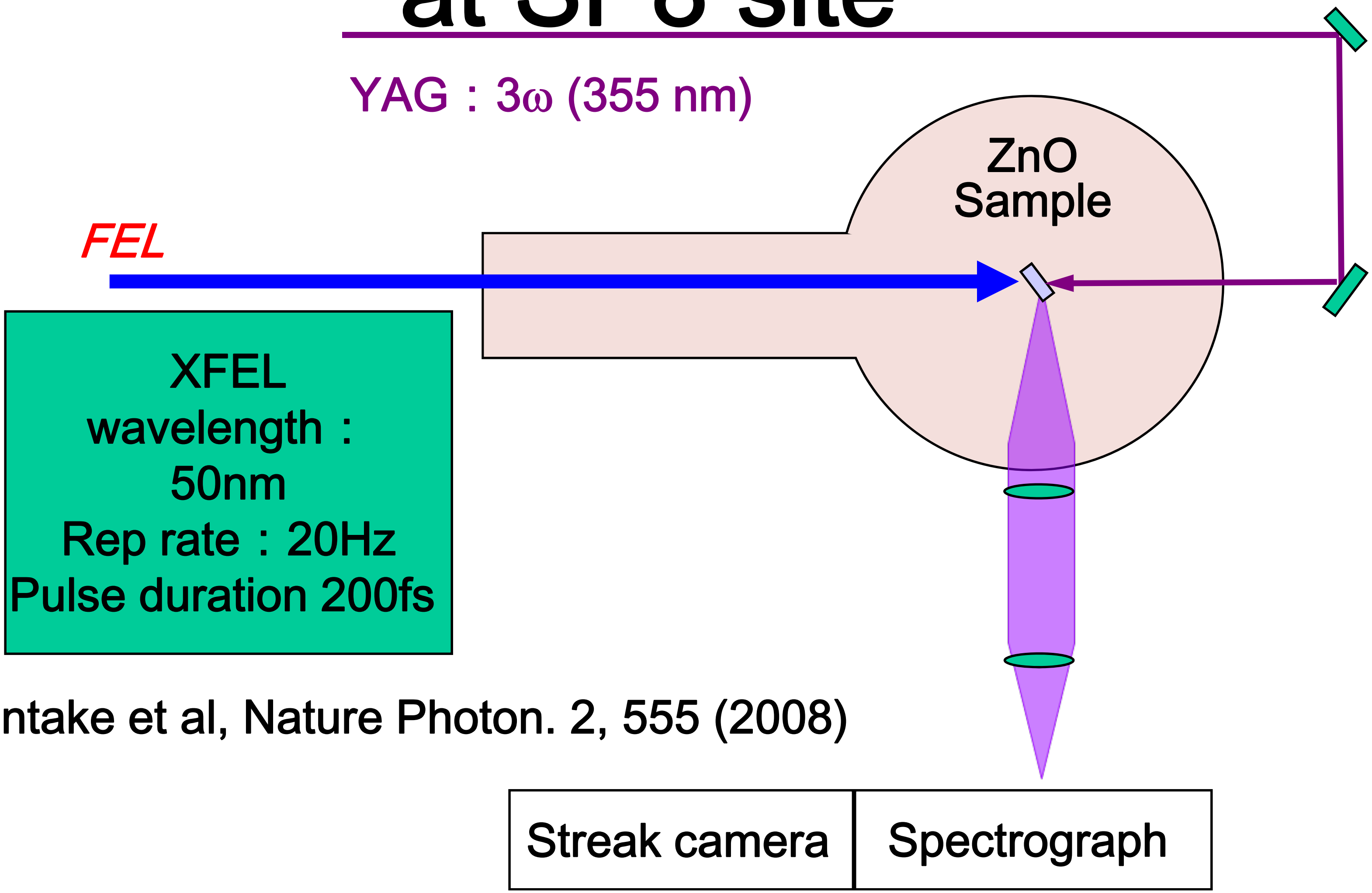
Experimental set up
FEL at SP8 site

Why fast scintillator is needed for XFEL facilities?

High accuracy temporal overlap with optical pulse is required for the pump and probe experiment

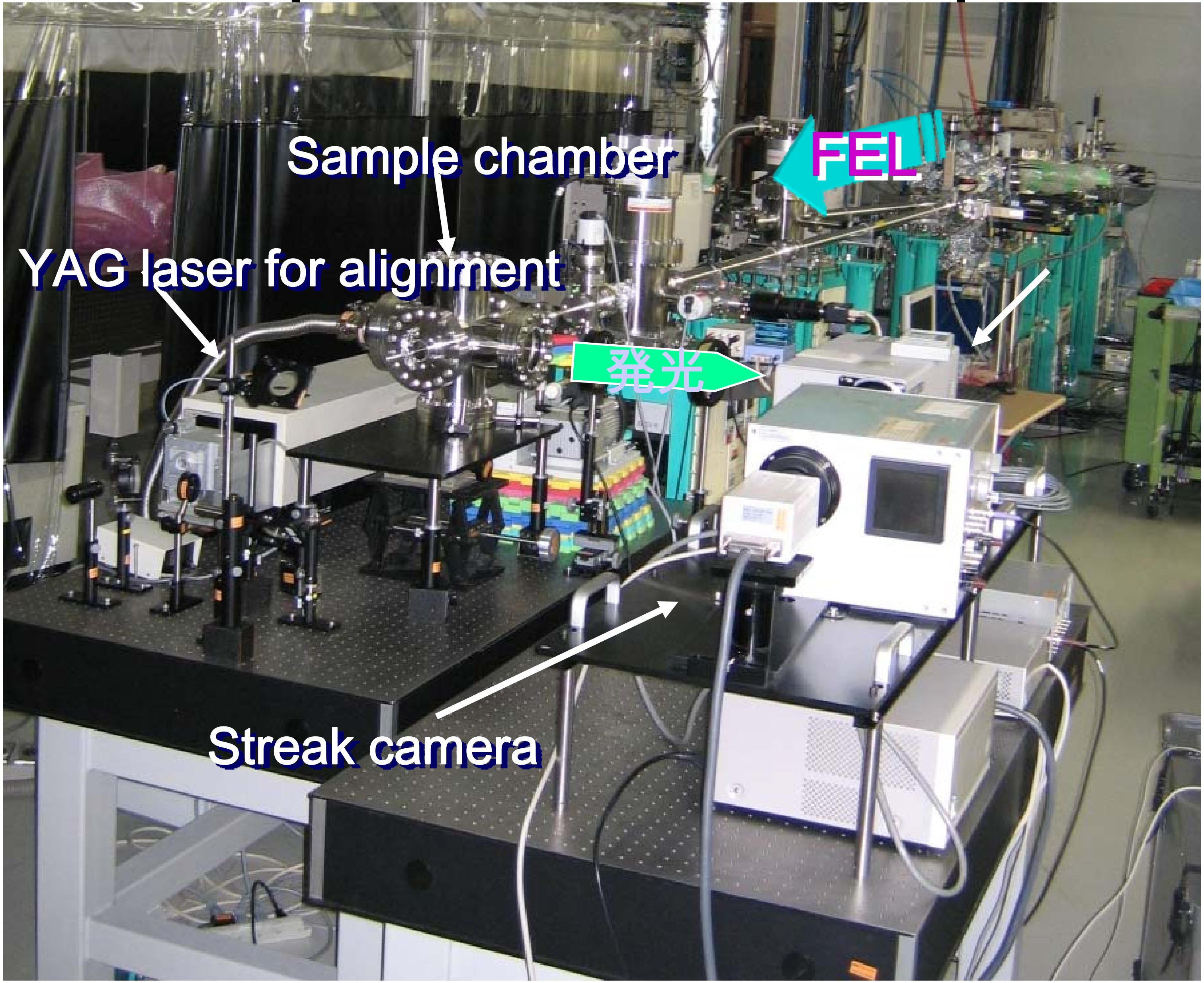
EUV and optical pulse should be synchronized within 0.1 psec accuracy.

XFEL scintillation experiment at SP8 site



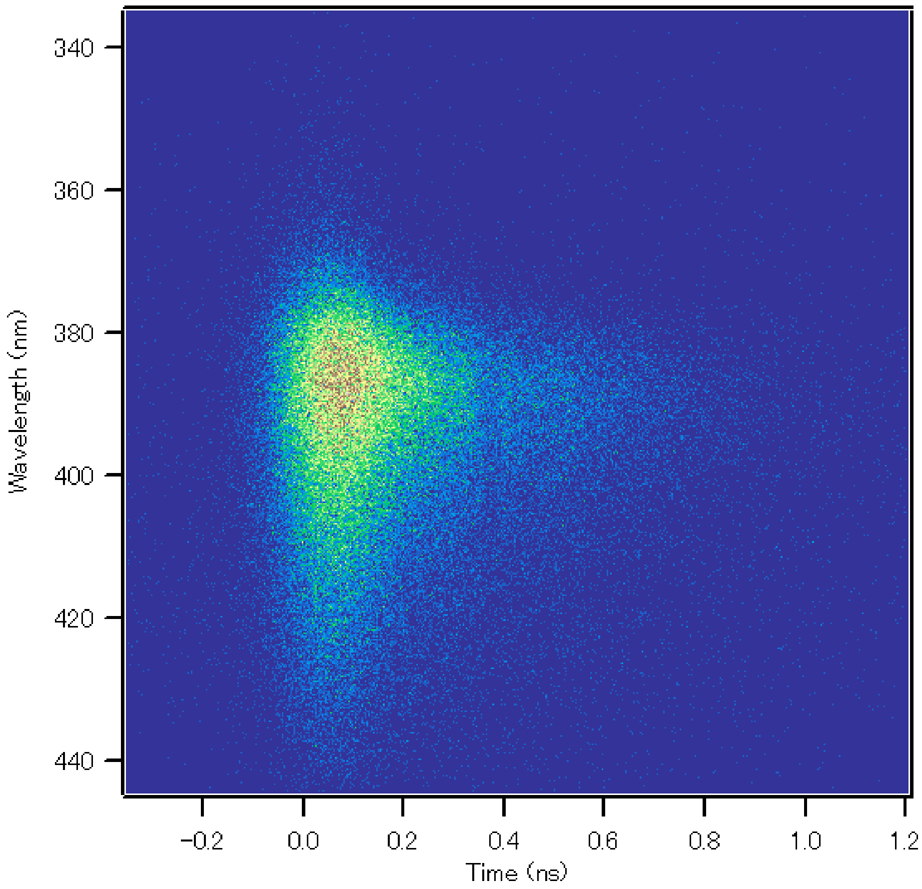
T. Shintake et al, Nature Photon. 2, 555 (2008)

Experimental set up



Streak image

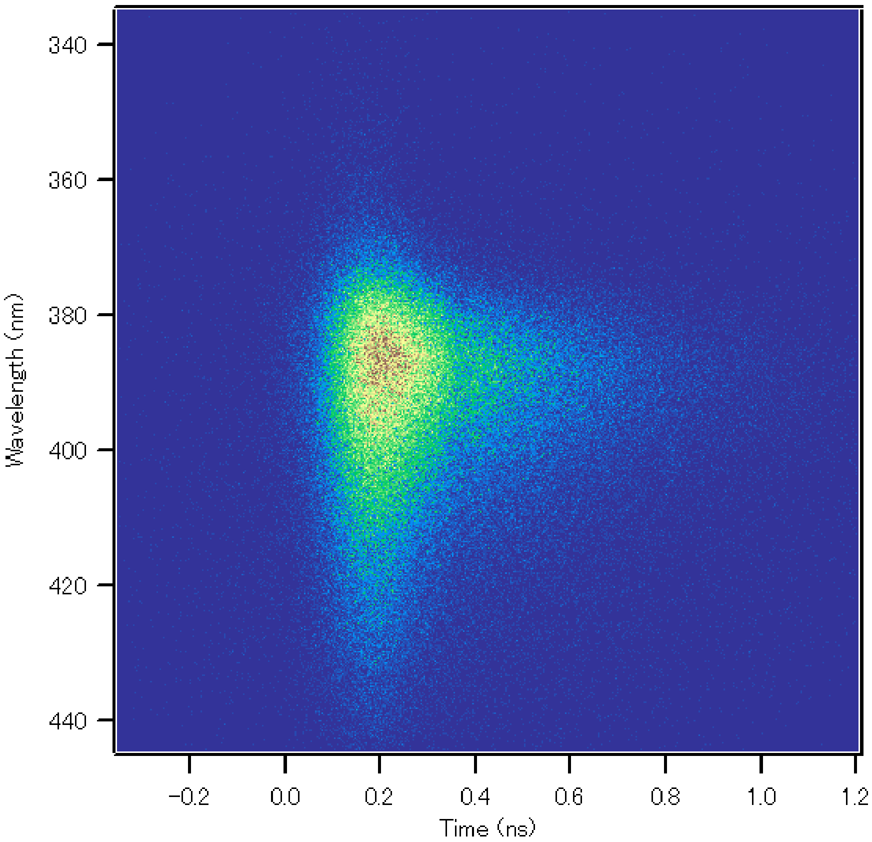
Resolution of wavelength = 3nm



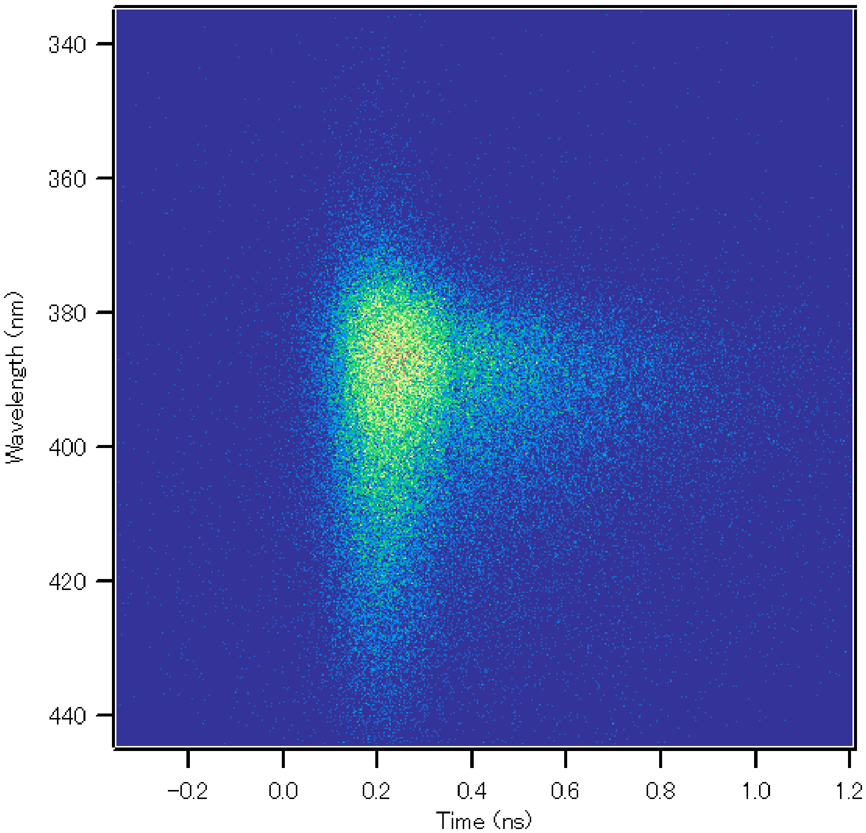
51nm excitation
50000shot

Dependence of excitation wavelength

56nm excitation



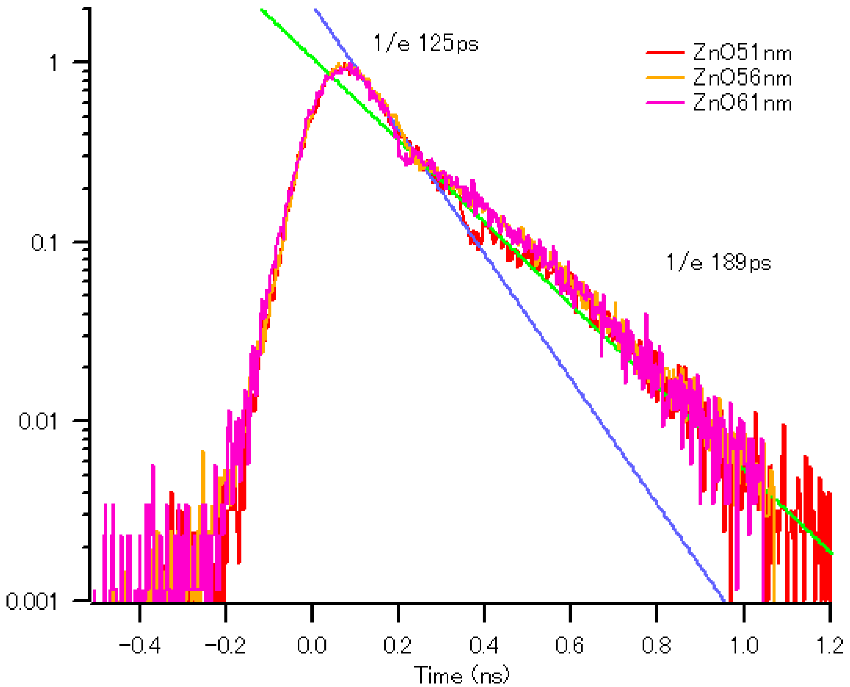
61nm excitation



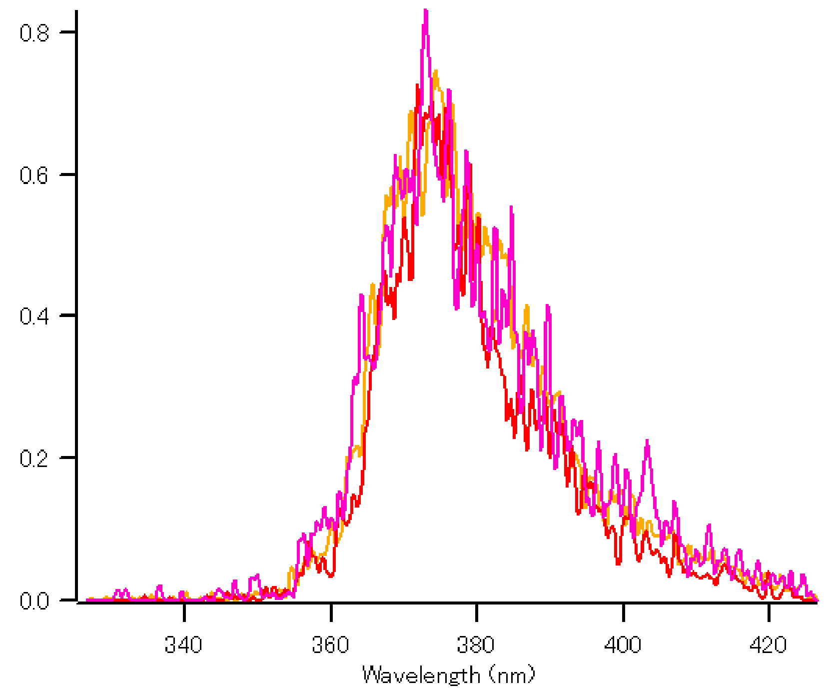
50000shot

Dependence of excitation wavelength

Time profile

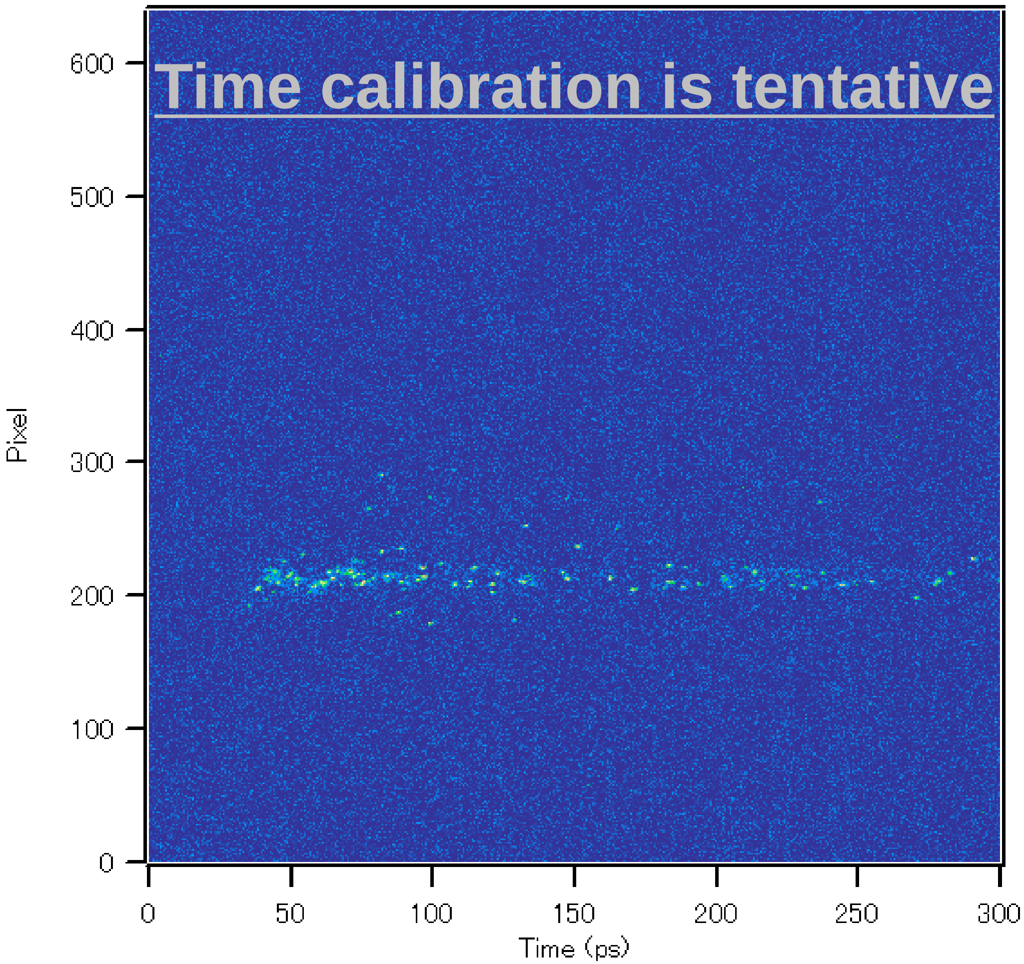


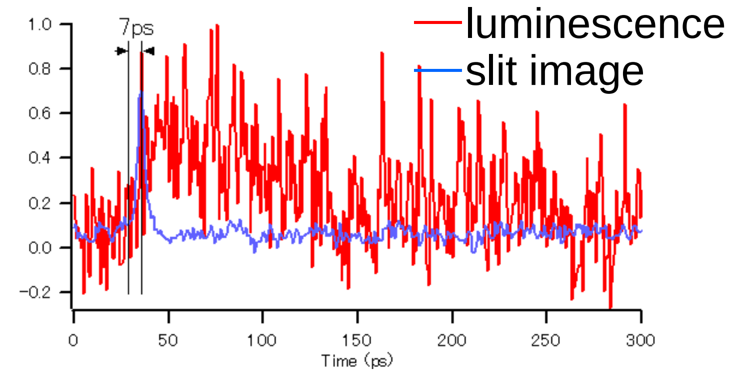
Spectrum



No dependence of excitation wavelength

Measurement of rise time



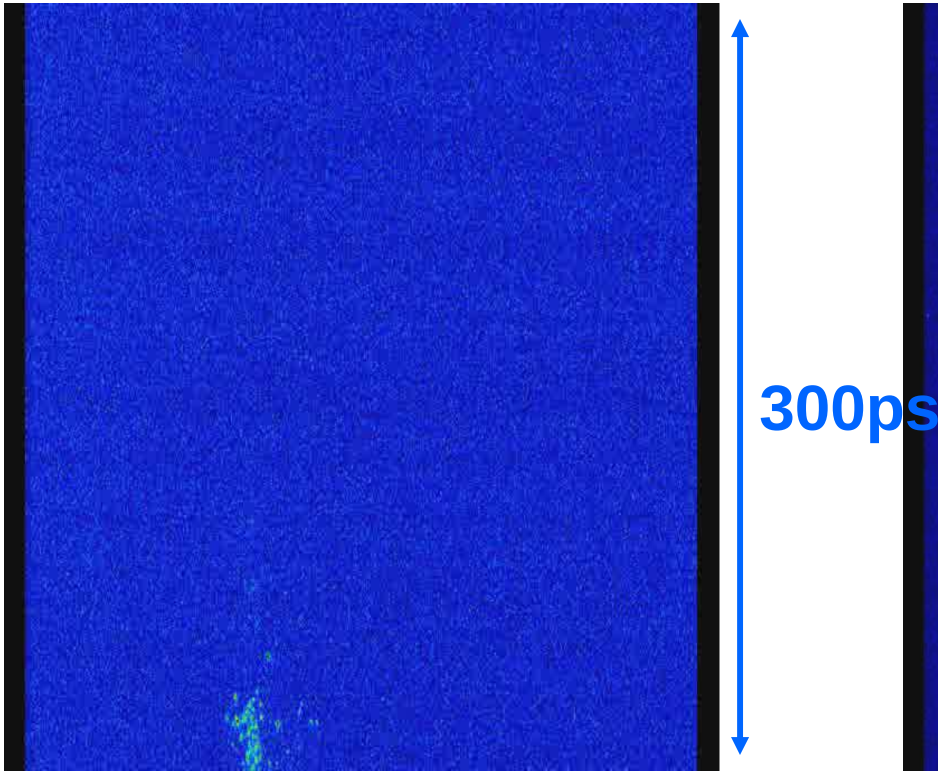


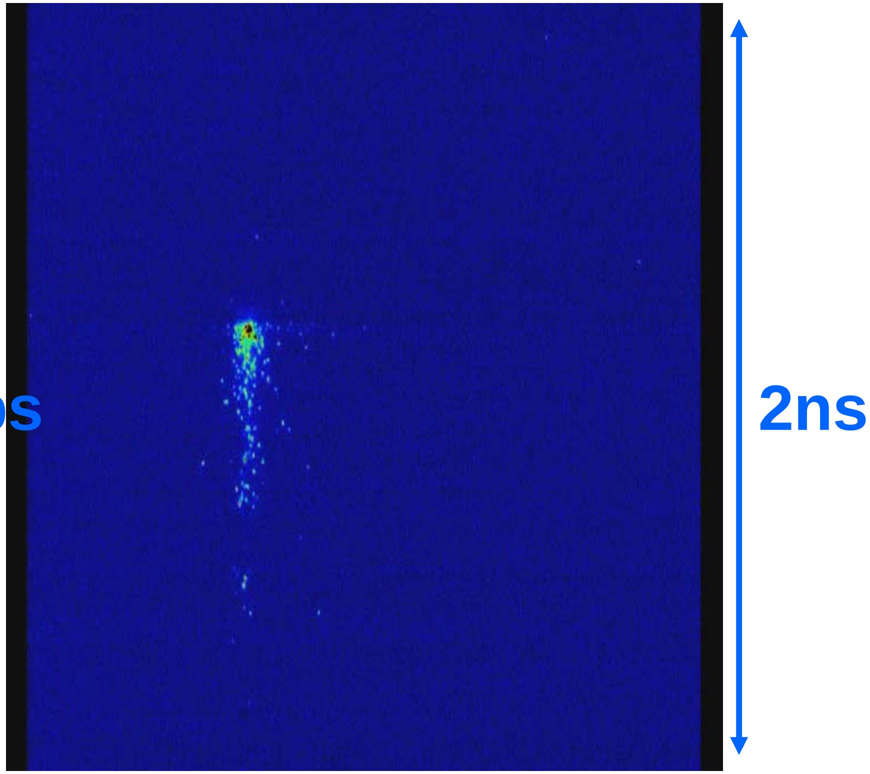
Single shot experiment

→**rise time < 7ps**

limit of slit width

Time variation of the jitter





Response time is controlled
by intentional doing

Rise time of the FL is less than 10-psec

Timing observation beyond the jitter of
electronics for XFEL was demonstrated

Summary

Demonstrated the excellent properties of ZnO as a scintillation material for the EUV region (13.9 nm)

High spatial resolution imaging is under going

ZnO improved response time was demonstrated using XFEL

Tanaka et al APL 91, 231117 (2007)
Furukawa JOSA B 25, B118 (2008)

N. Sarukura Group Jun 2009

Nobuhiko Sarukura (Ph.D.)   18 Jun. 1963

Education
Ph.D. in Physics, 1998, University of Tokyo,
(Prof. S. Watanabe)
M.S. in Physics, 1989, University of Tokyo,
B.S. in Physics, 1987, University of Tokyo,
(Prof. Soji TANAKA)

Professional Experience

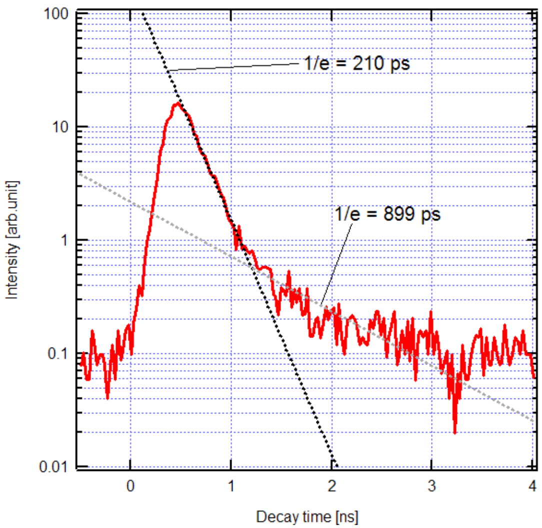
2006 ~ Present,
Institute of Laser Engineering,
Osaka University, Professor,

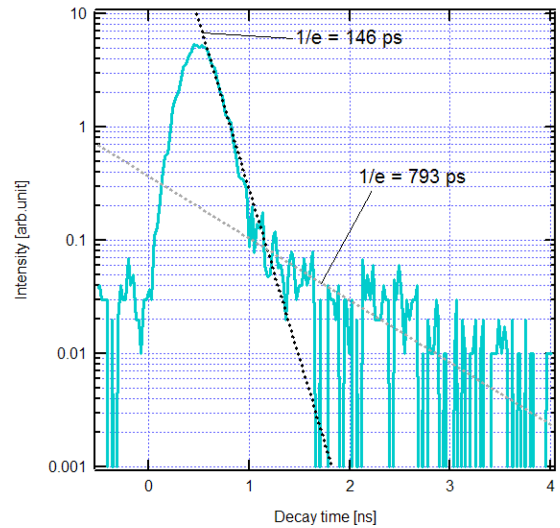
1996 ~ 2005, Institute for Molecular Science (IMS),
Associate Professor,
1992 ~ 1996, Institute of Physical and Chemical Research,
1989 ~ 1992, NTT corporation, Japan (Yamamoto and Uesugi Group)

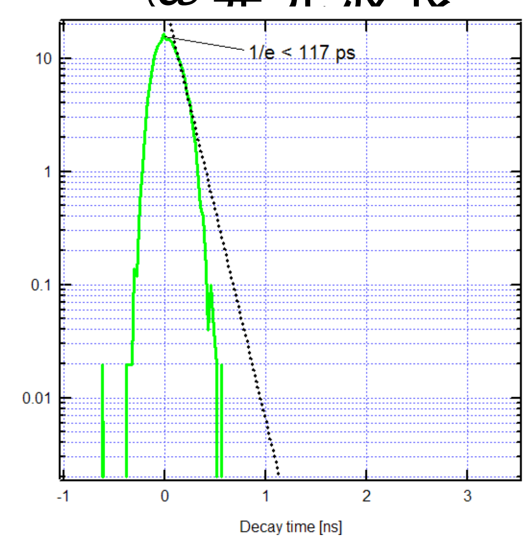
Major Professional Service
1. Program committee, Ultrafast Phenomena 1998-2002
2. Program committee, Advanced Solid-State Lasers topical meetings 2000-2002
3. Head Editor for the *Japanese Journal of Applied Physic*s. 2000-
4. Editor, JJAP, 1999~.
5. Advisory committee, Gordon conference, 1998~1999.
6. Visiting Editor, JSTQE of IEEE, 2000~2001.

FEL　比較

0 order　　@発光波長周辺　　TiS 3ω @発光波長







Ti:S 3ω(290nm)励起よりも長寿命
50nmの光源を用いているため
より高エネルギーの準位の励起が起こり、
それが影響を及ぼしている可能性がある

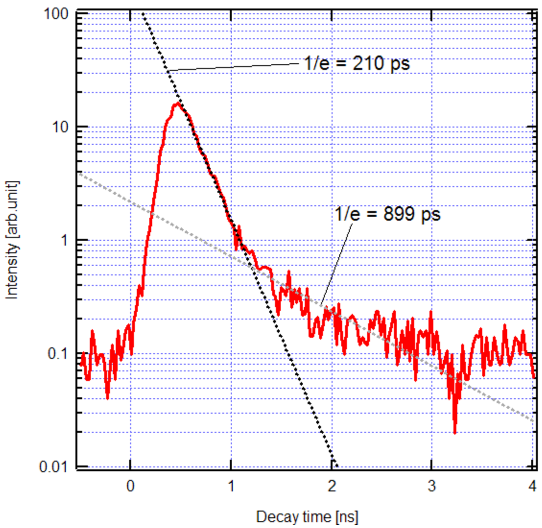
その他FELの計測時は
・励起光非集光(スポット〜6mmϕ)
・ストリークカメラのスリットが数倍広い(100μm)
・分光器のスリットもかなり広い(2mm)
などより寿命が長めにでたと考えられる
低速成分もそれら由来か

従来型のサンプル(発光寿命1ns)での実験では
13.9nmと351nm励起の違いによる影響は見られなかった。
・短寿命サンプルの特性
・高分解能光源を用いたことによる影響　　であるかもしれない

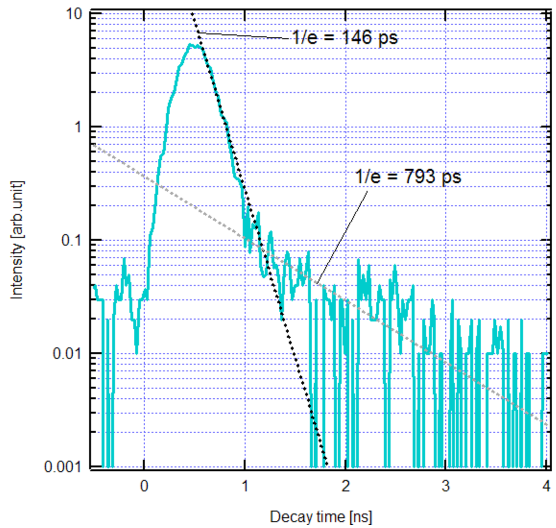
比較

FEL

0 order

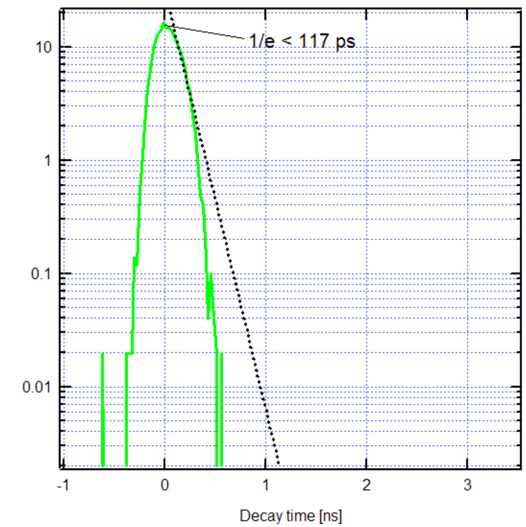


@発光波長周辺



TiS 3ω

@発光波長



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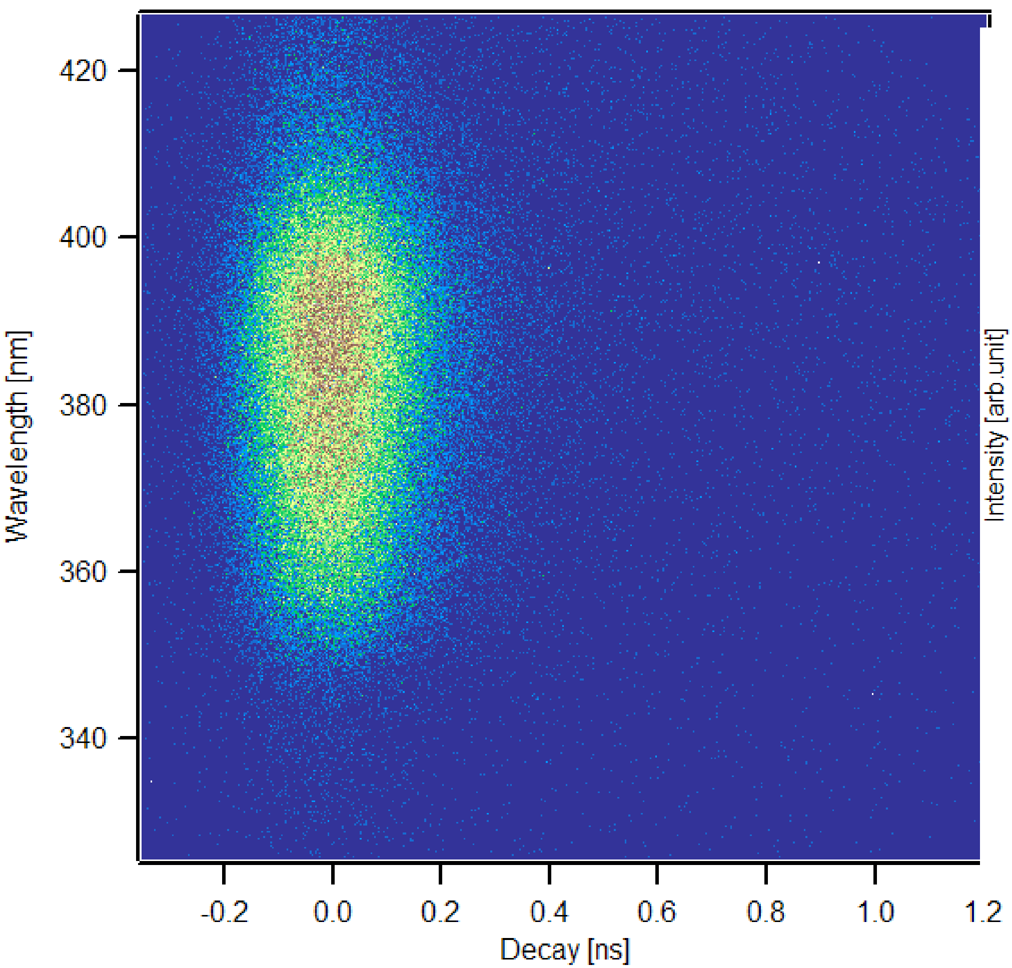
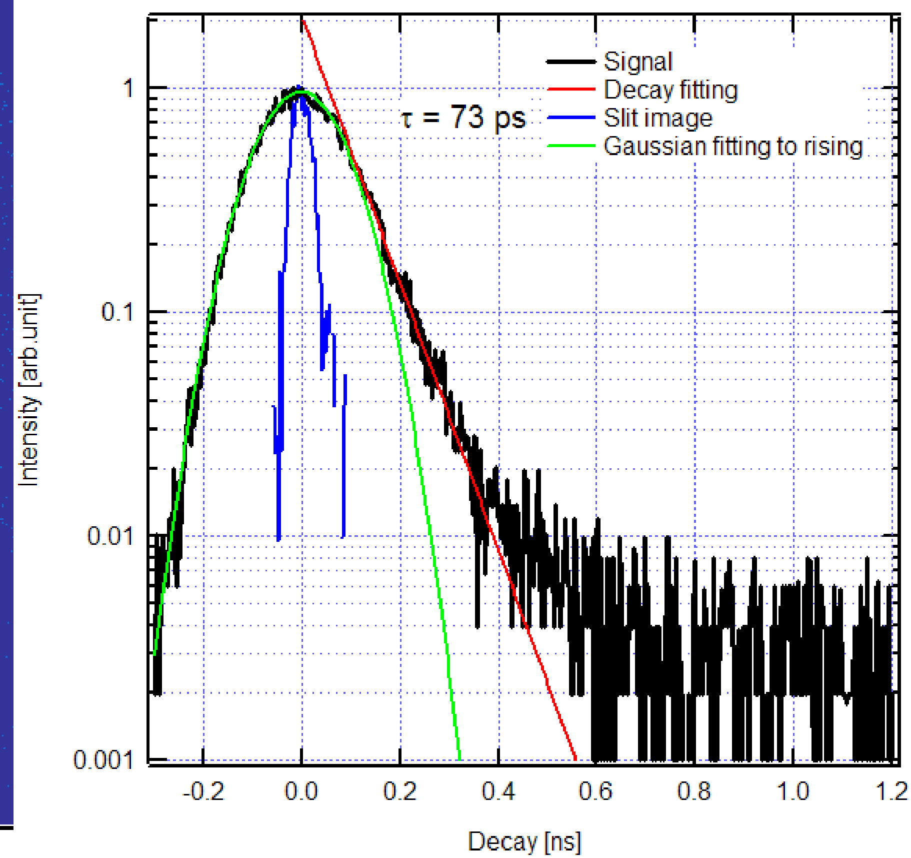
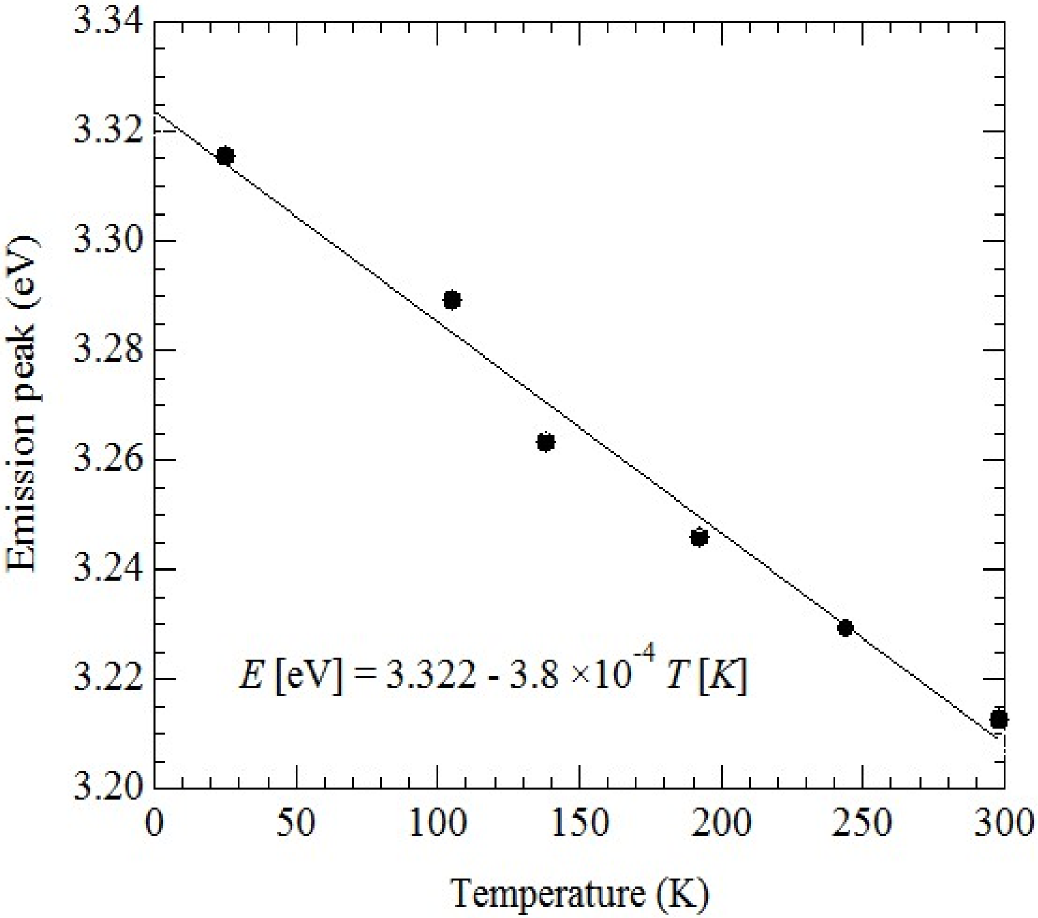
Response time improved ZnO demonstrated XFEL at SP8 site





Peak position vs. Temperature

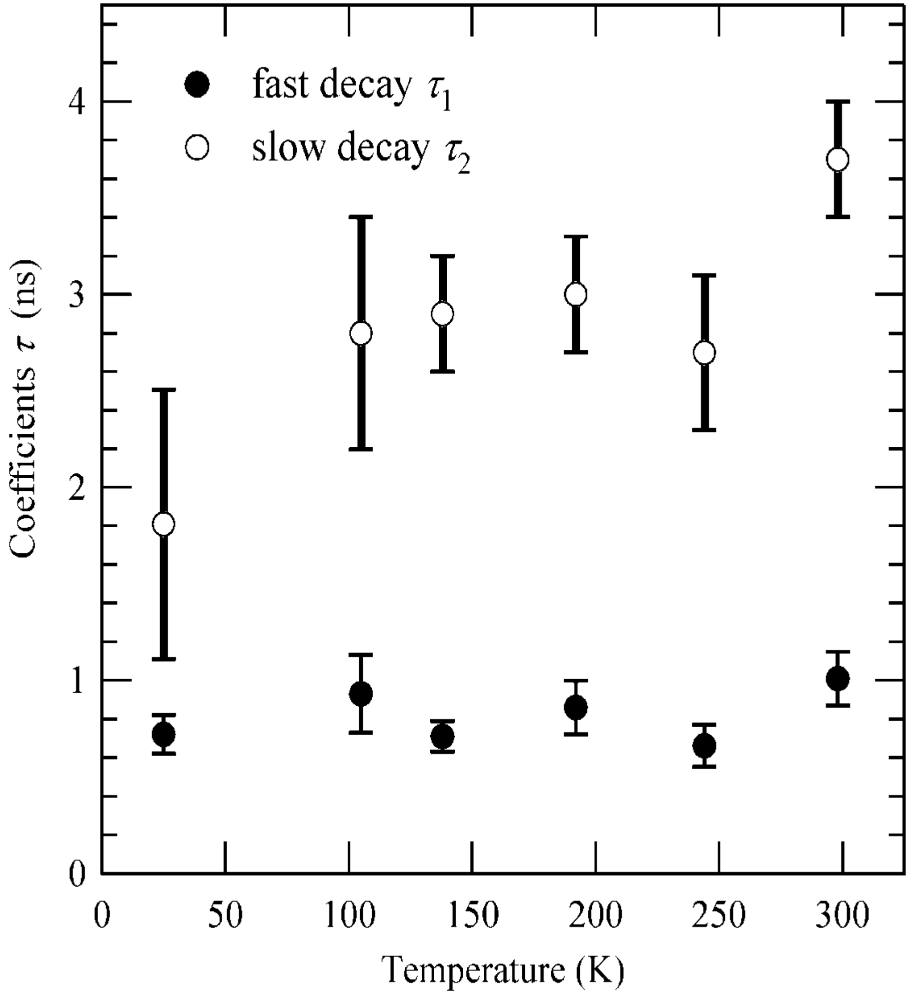


Peak position linearly depends on temperature

This peak shift is similar to the work on band-gap shift of ZnO [Houschild et al. phys.stat.sol. 3,976(2006).]

Furukawa et.al., JOSA B. 25, B118 (2008)

Two decay constants



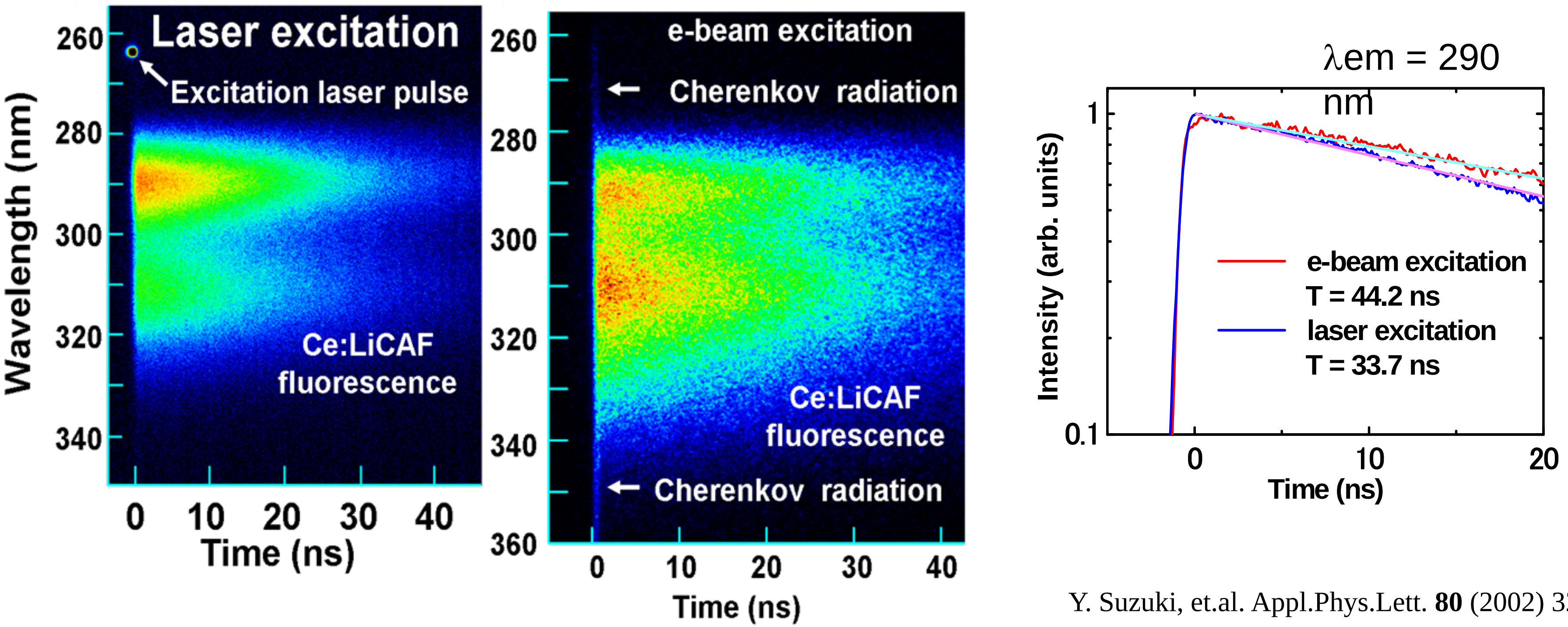
Two exponential decay

fast decay time (τ_1)
- free exciton emission

slow decay time (τ_2)
- trapped carriers

Furukawa et.al., JOSA B. 25, B1

Optical property in high energy excitation case (Ce:LiCAF)



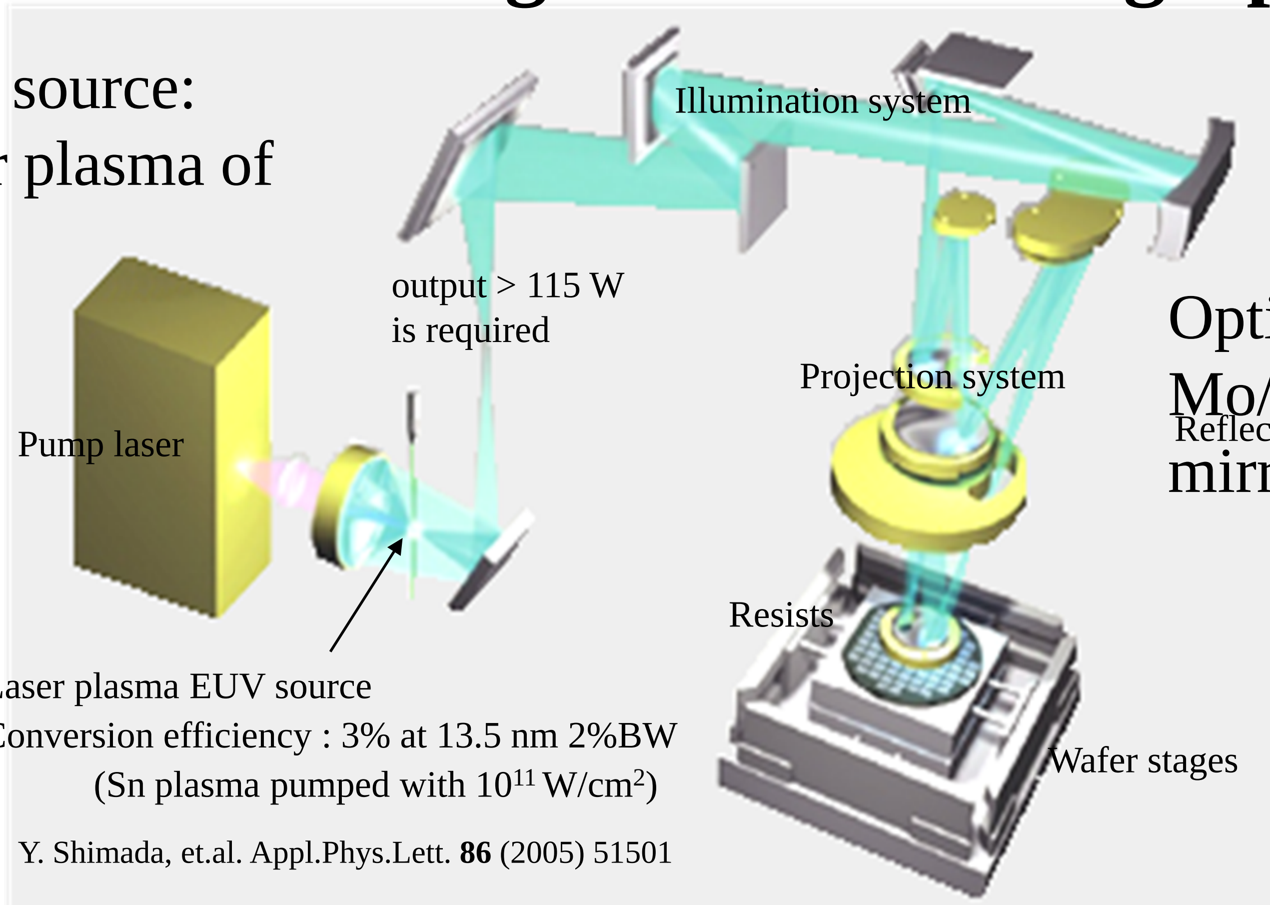
Y. Suzuki, et.al. Appl.Phys.Lett. **80** (2002) 3280.

In the case of e-beam excitation of Ce:LiCAF, fluorescence lifetime became longer.

→ For a scintillator, fluorescence property is required to be identical in different excitation condition.

Base technologies of EUV lithography

EUV source:
Laser plasma of Tin



Optics:
Mo/Si multilayer mirror
Reflectance : 70% at 13.5 nm

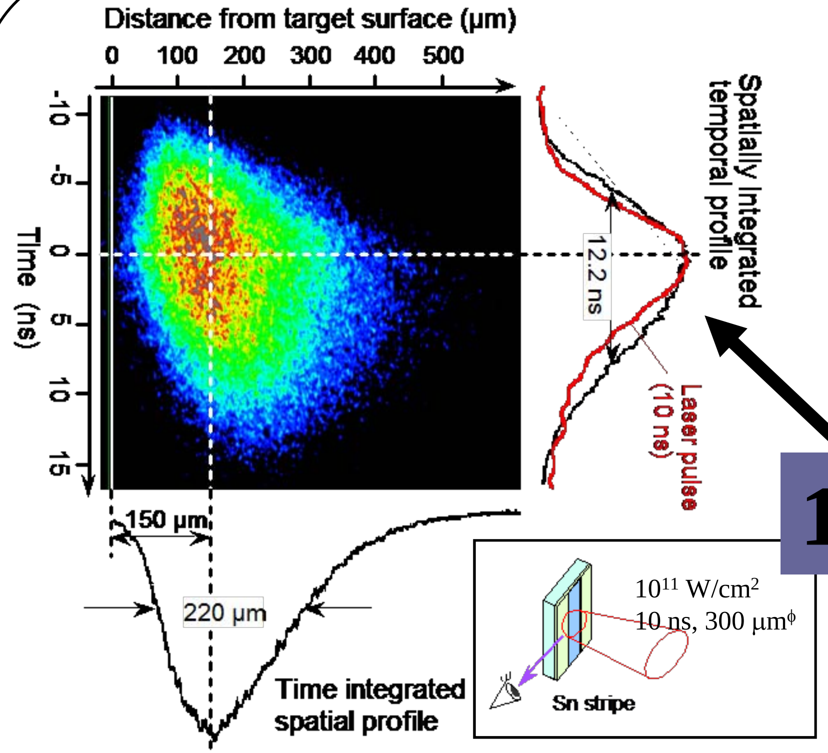
H. Nishimura (ILE Osaka)

One of the indispensable devices for EUV lithographic applications

→ An efficient imaging device for 13.5 nm with sufficient size

EUV source for lithography

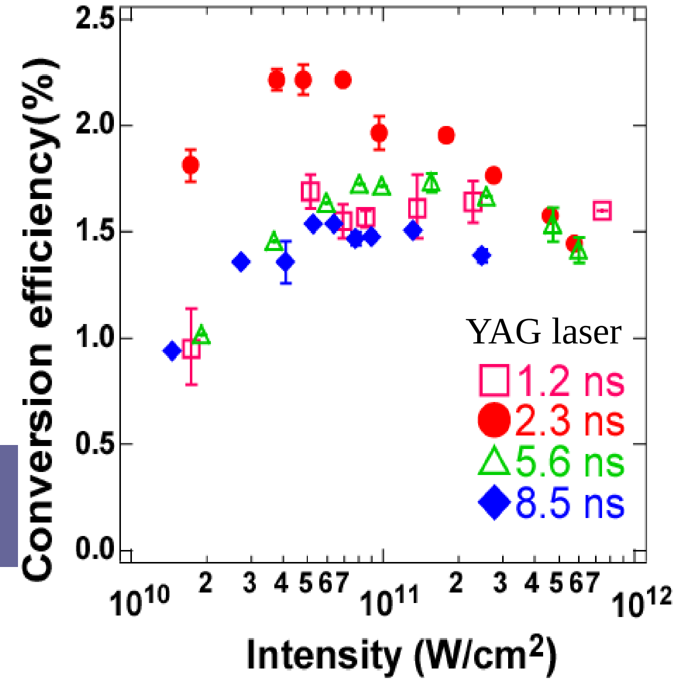
Pumping laser for EUV source : YAG, CO_2, etc.



Temporal and spatial profile of EUV emitting region

Y.Tao, et al., APL. **86**,(2005) 201501

12 ns



Shorter pumping pulse supplies higher conversion efficiency

T. Ando, et al., APL **89** (2006) 151501

Time resolution of an imaging device for EUV lithography :

nanosecond resolution is required

H. Nishimura (ILE Osaka)