# LASER-WAVELENGTH DEPENDENCE OF LASER-PRODUCED-PLASMA EUV EMISSION

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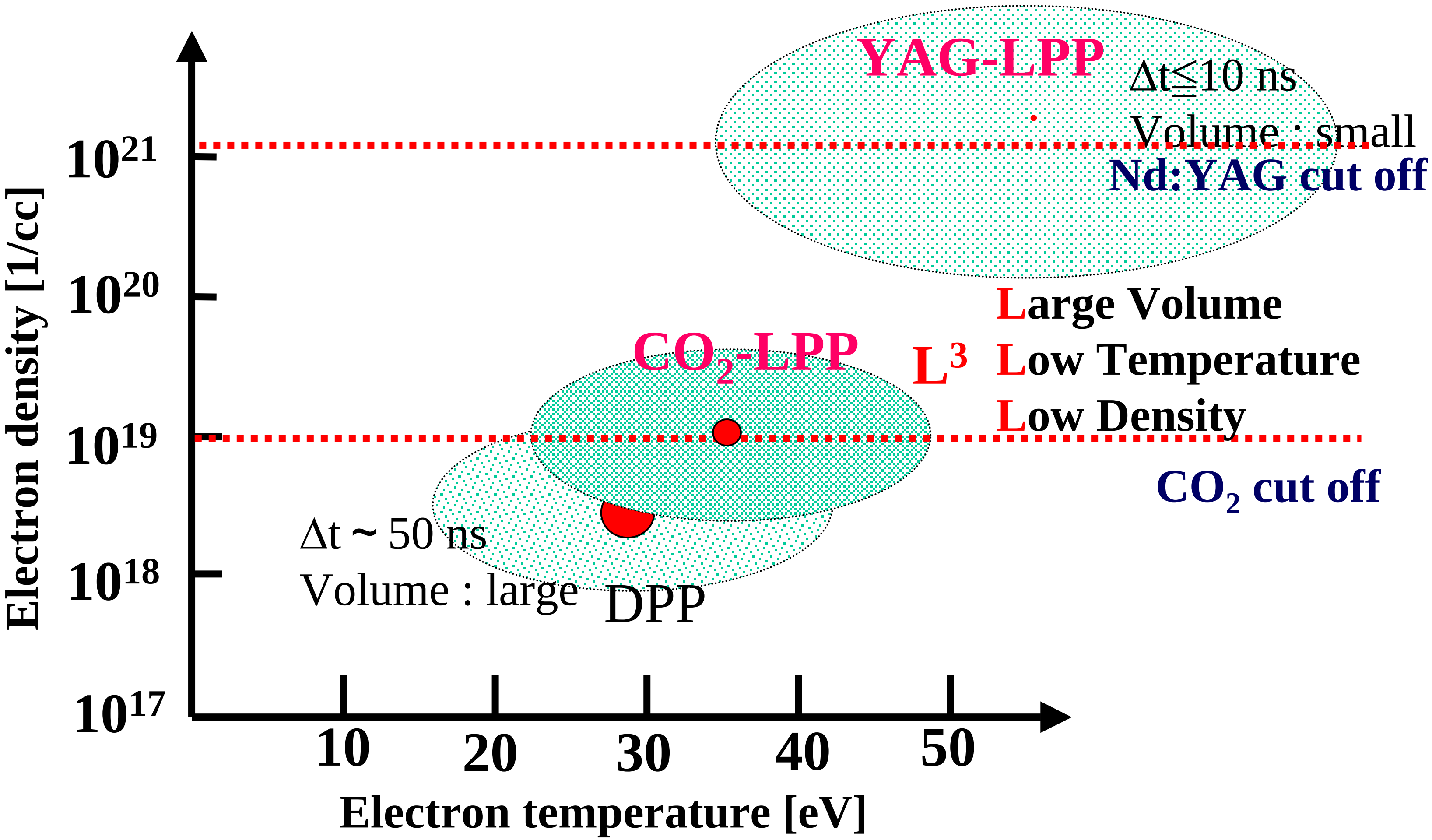
# Abstract

In the development of extreme ultra-violet (EUV) lithography source using laser-produced-plasma (LPP), it is important to investigate the optimum wavelength of the driver laser to obtain the high conversion efficiency. We have proposed the EUV generation pumped by $CO_2$ laser-produced plasma. The $CO_2$ laser beam (4 J, 50 ns FWHM) was focused on a Xe gas target and a Xe cryogenic target, and the EUV energy was measured by a Flying Circus II detecting system. The EUV energy was 3 mJ/pulse and the conversion efficiency of 0.2 % per 2π sr at 13.5 nm (2% B.W.) in maximum for Xe targets. This value is comparable to that of YAG laser-produced Xe plasma, indicating the potential scalability of the EUV light source using a $CO_2$ laser produced plasma. During this conference, we will present the emission characteristics from YAG- laser produced plasma under the same experimental setup to investigate the laser-wavelength dependence of the EUV emission in detail.

# EUV Light Generation from $CO_2$-LPP
## --comparison between YAG and $CO_2$--

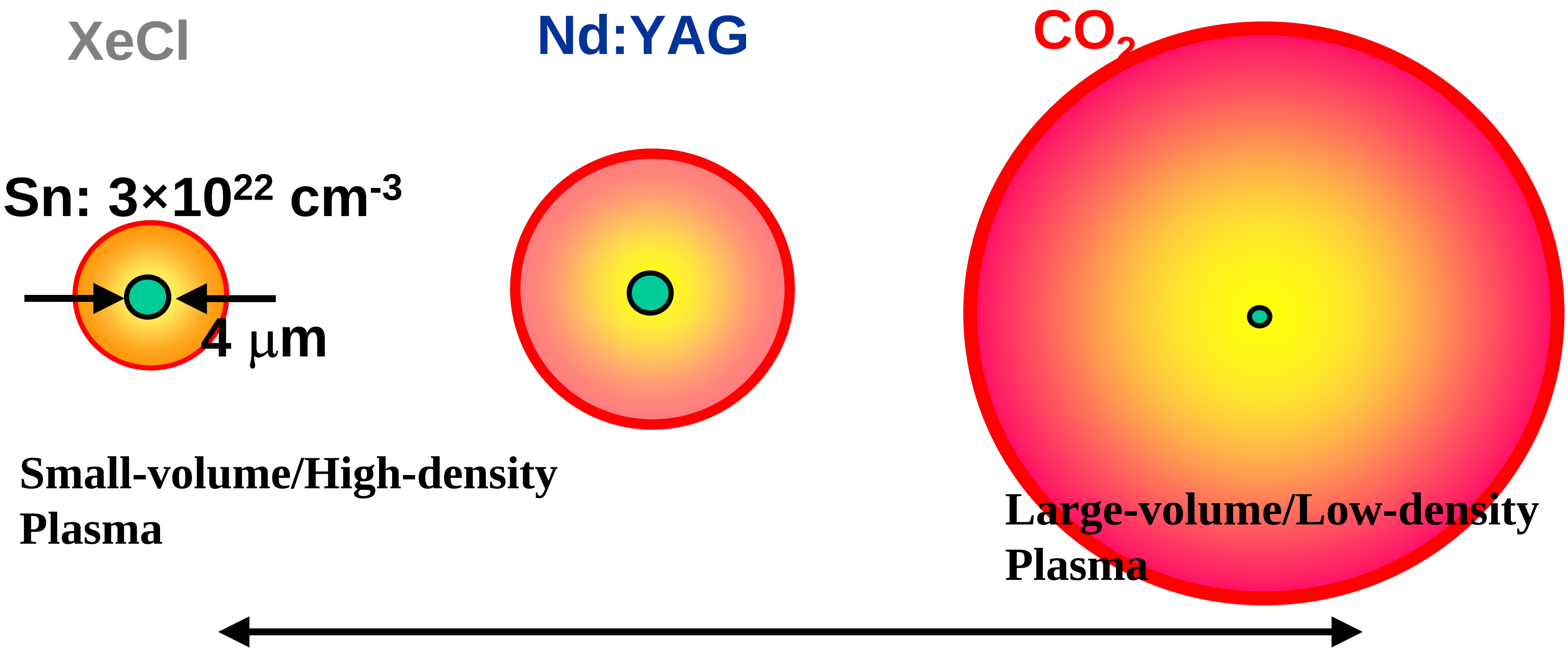
*Kyushu University*



# Plasma Size and Wavelength

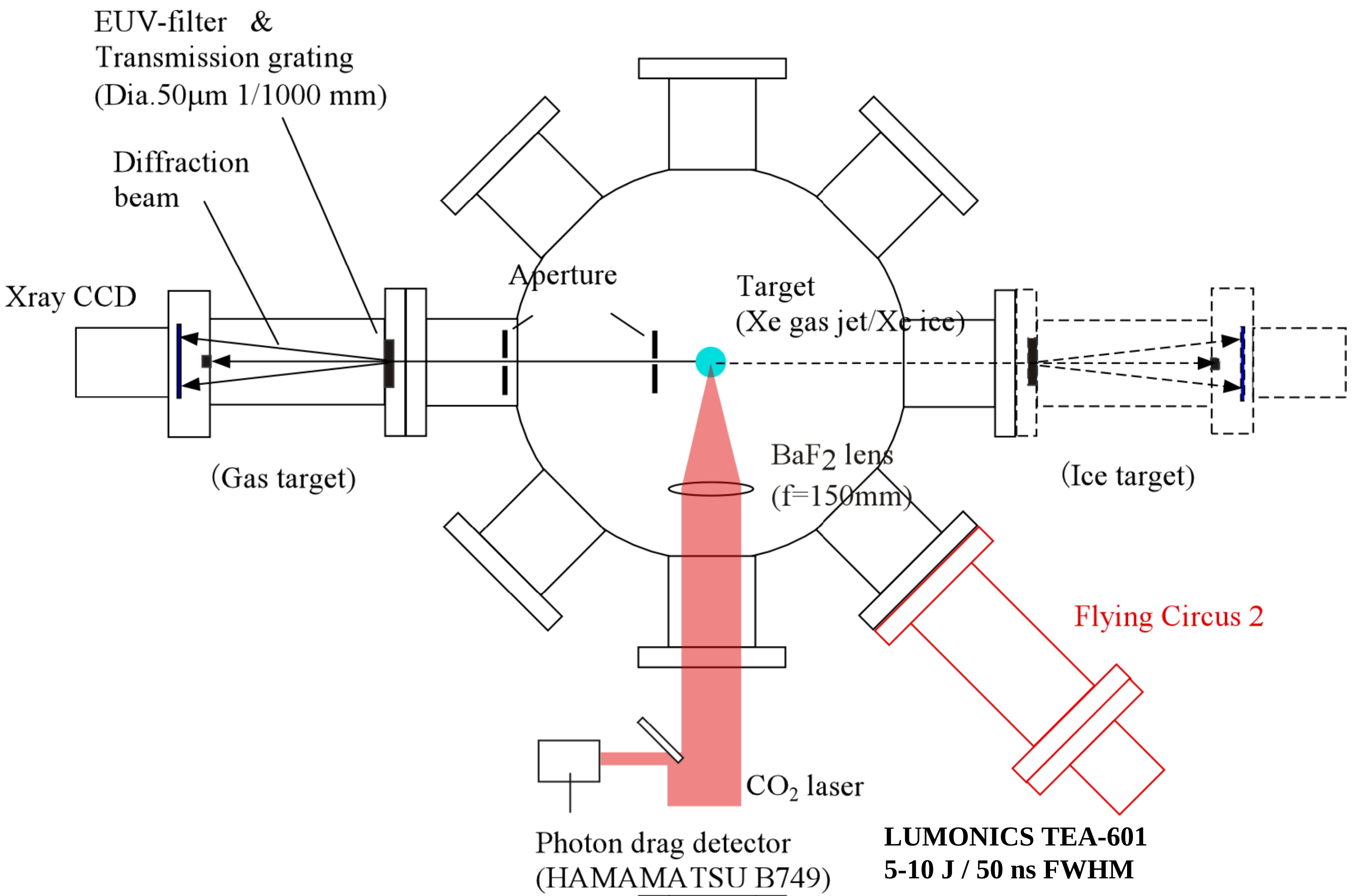
## Mass limited target :debris-free

Provided that 3.3 $\times 10^{11}$ excited atoms @ 1 %

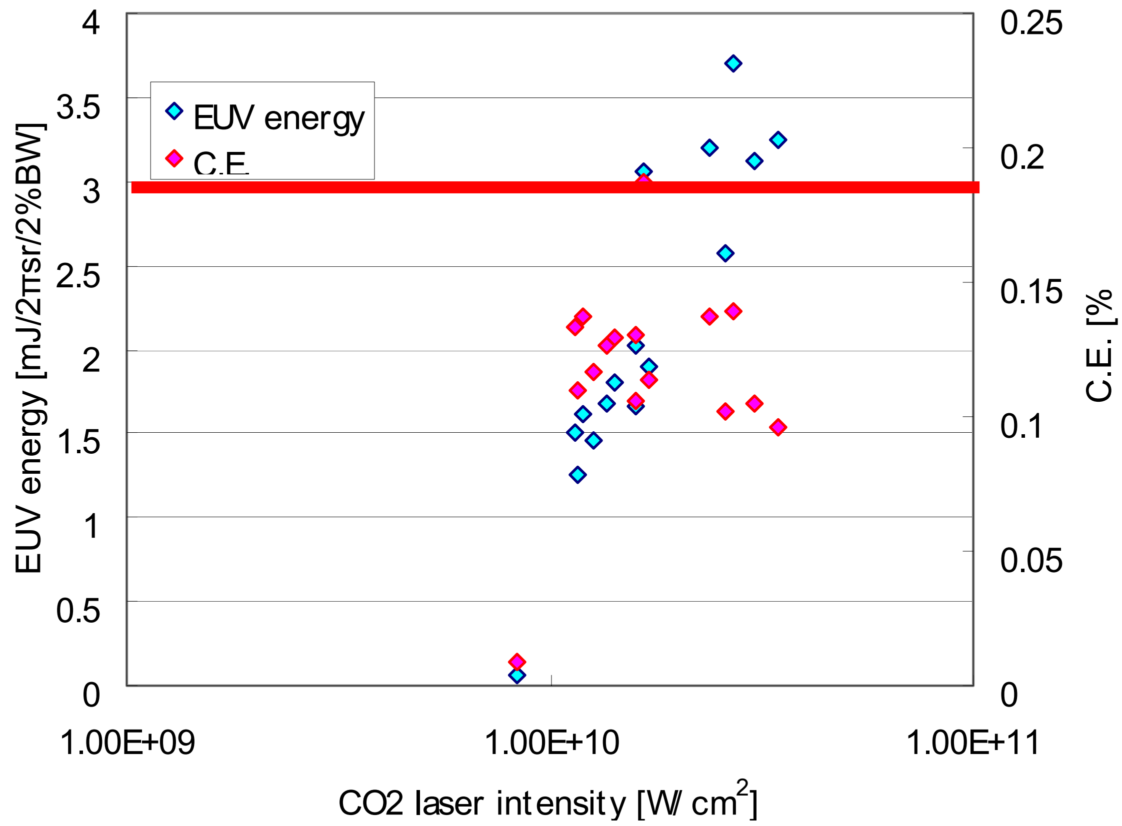



**Short-pulse pumping** **Long-pulse pumping**

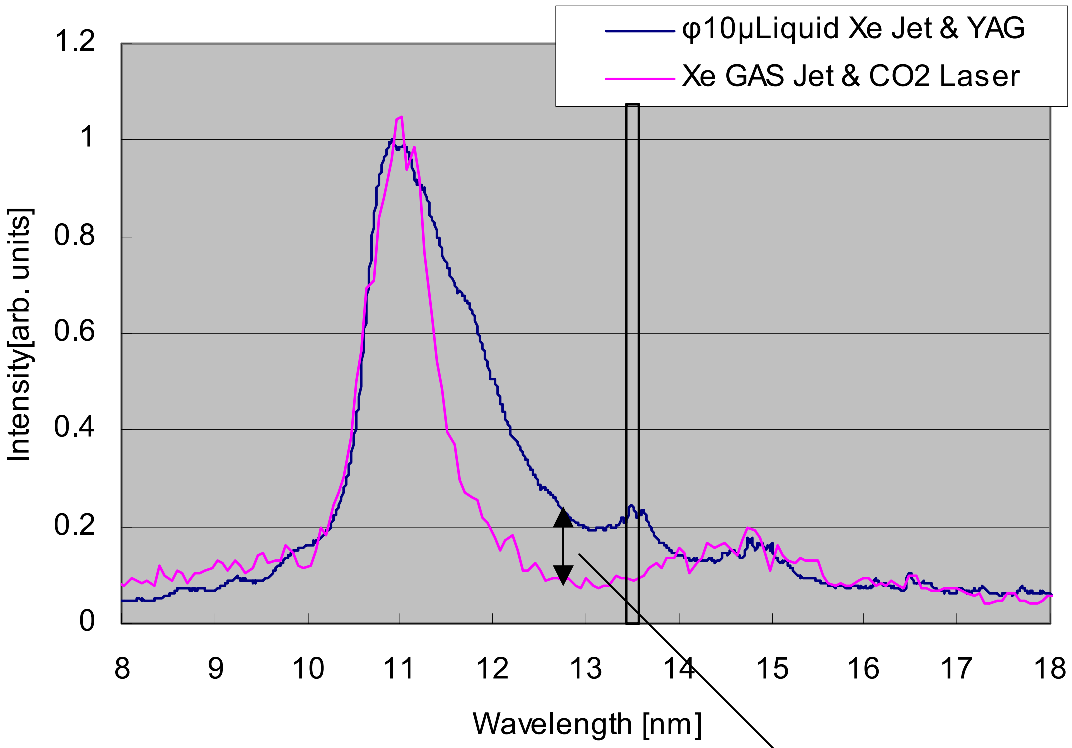
# EUV Generation from Xe Target : Experimental Setup



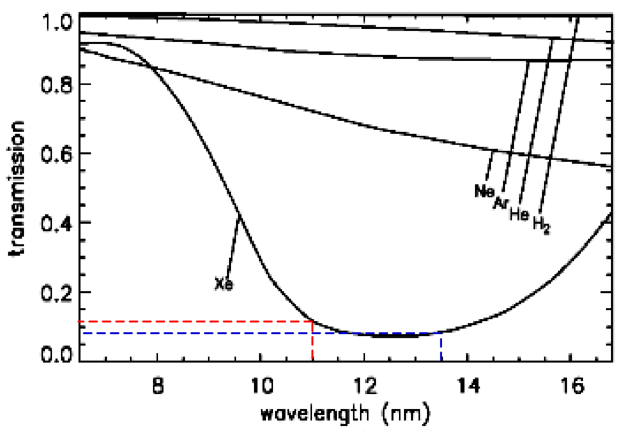
# Xe Gas Target - EUV In-band Energy & C.E. -



# EUV Spectrum from Xe Gas-jet Target

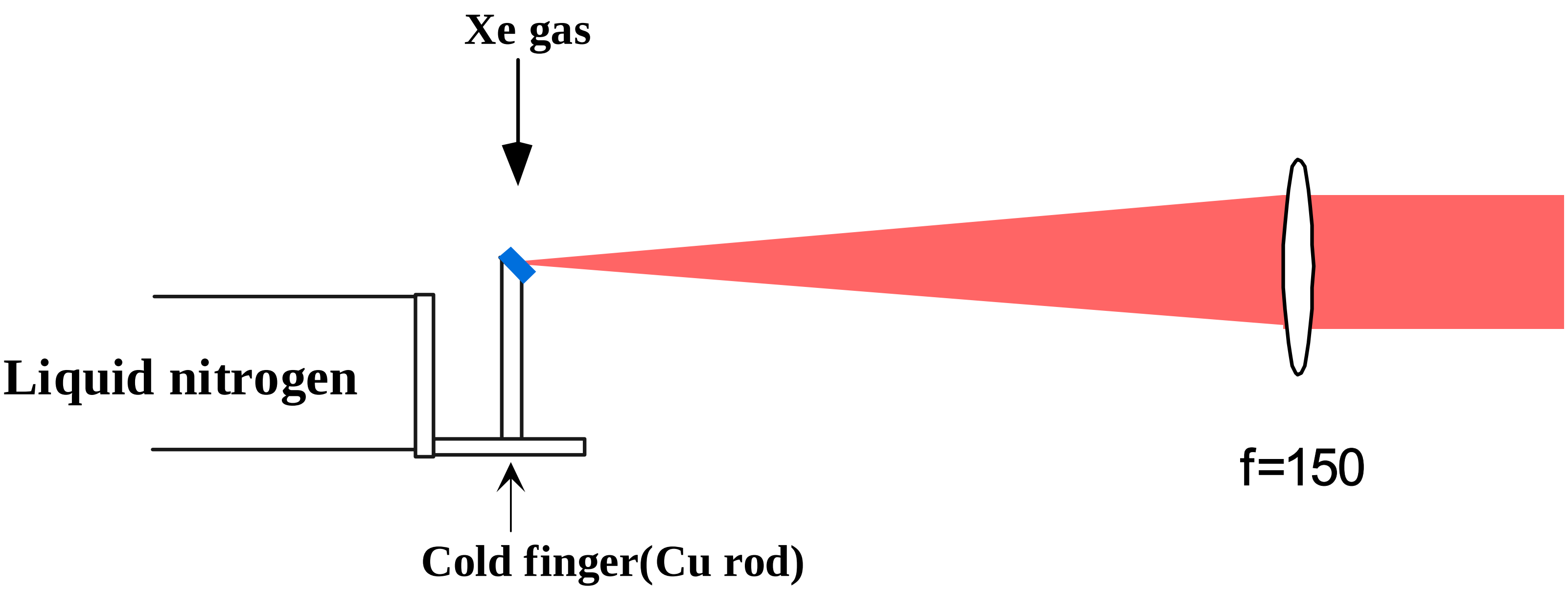



**Transmission curves of Xe, $H_2$, He, Ar, and Ne**

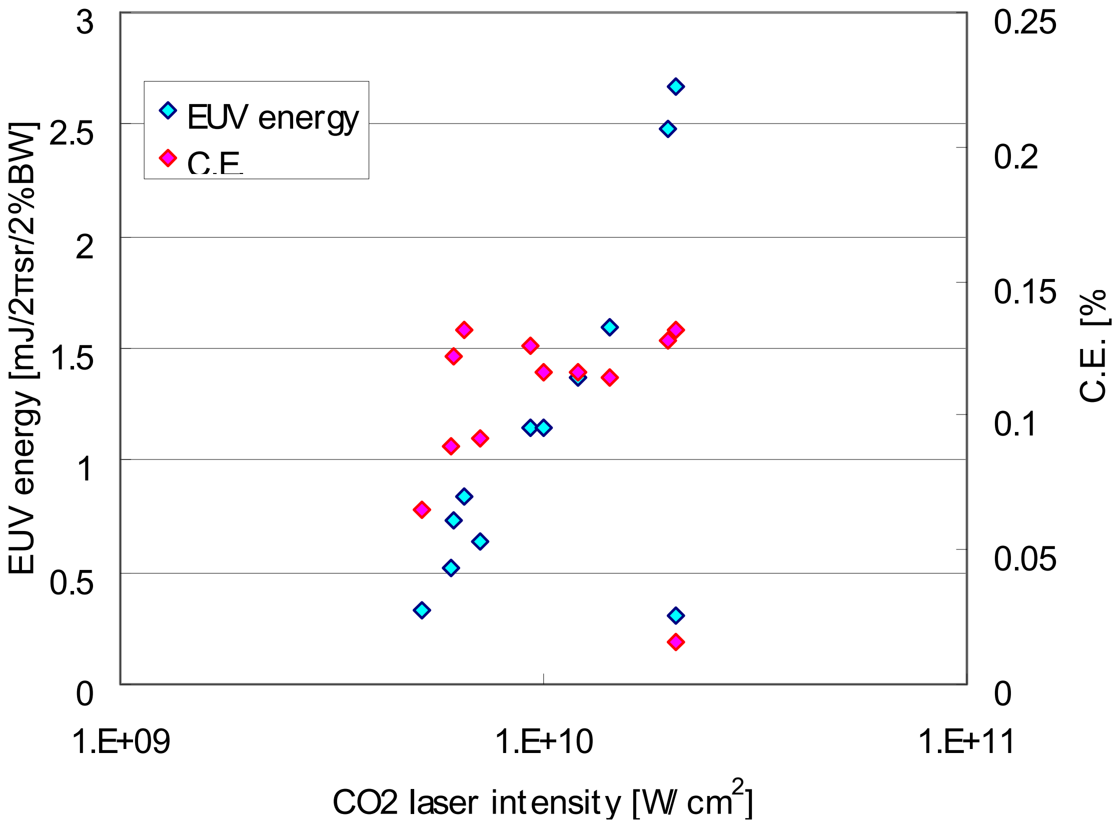



Absorption by Xe atoms

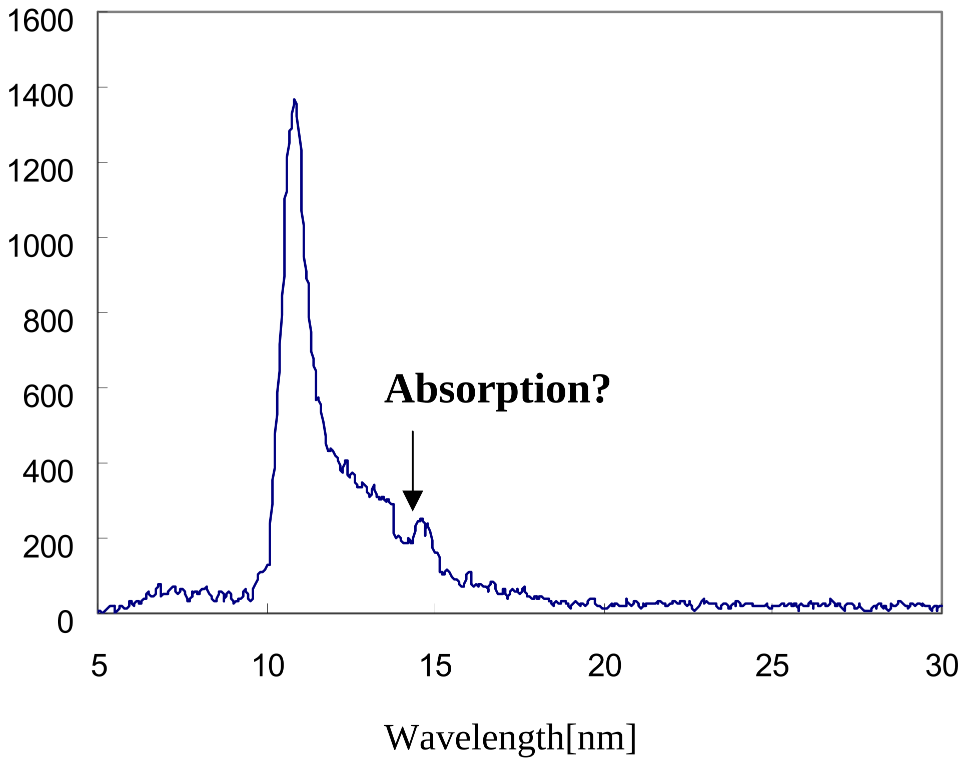
# Xe Ice Target



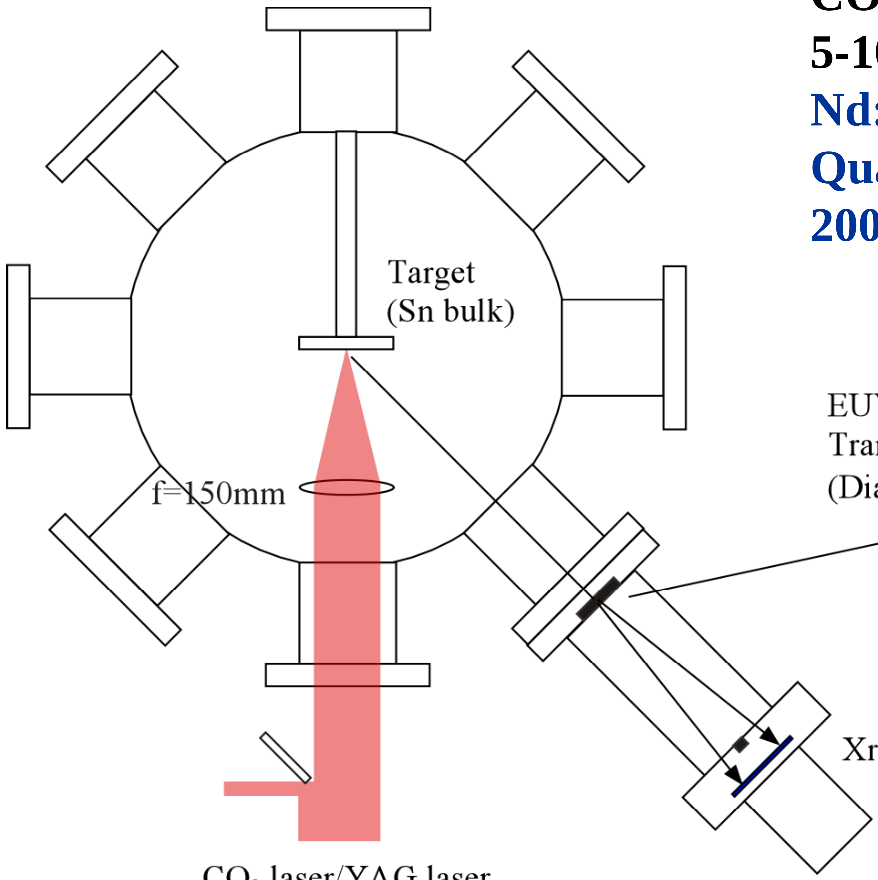
# Xe Ice Target - EUV In-band energy & C.E. -



# EUV Spectrum from Xe Ice Target

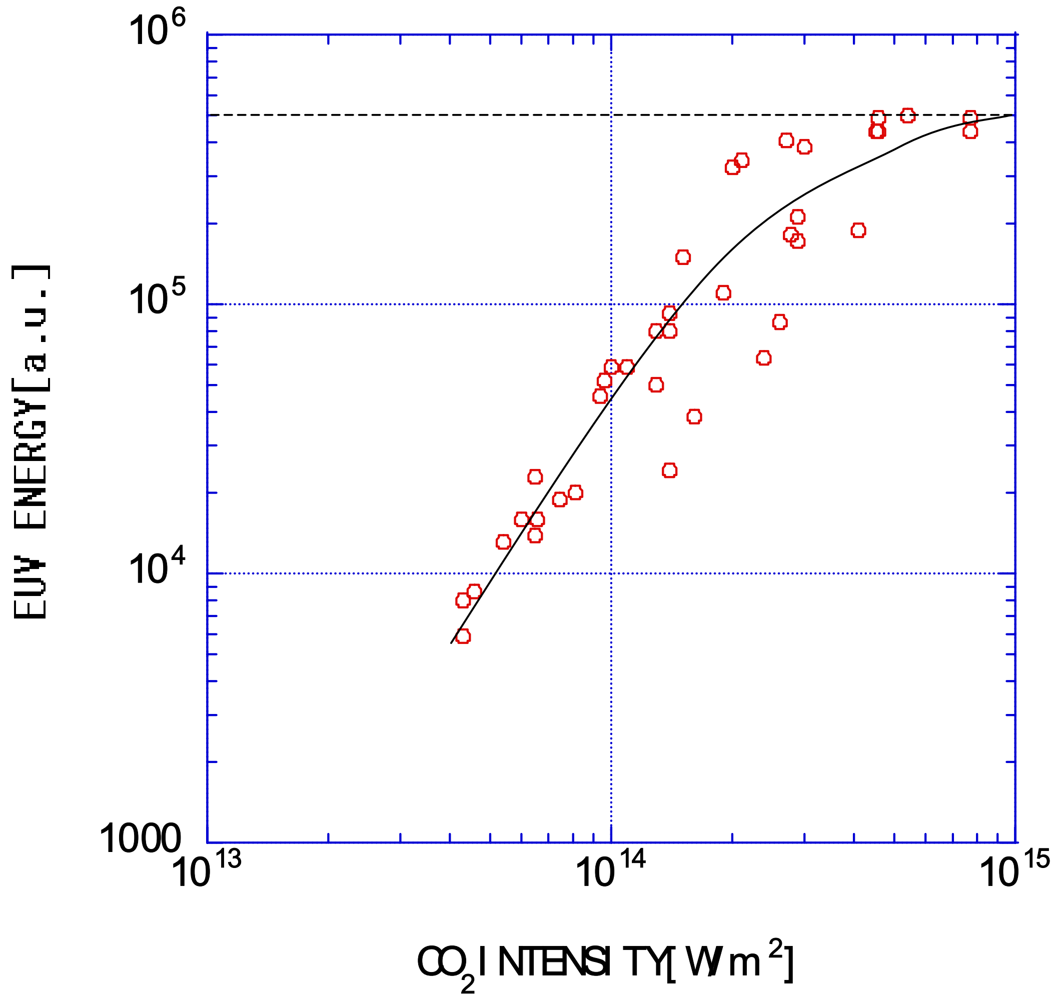


# EUV Generation from Sn Target Pumped by $CO_2$/YAG Laser



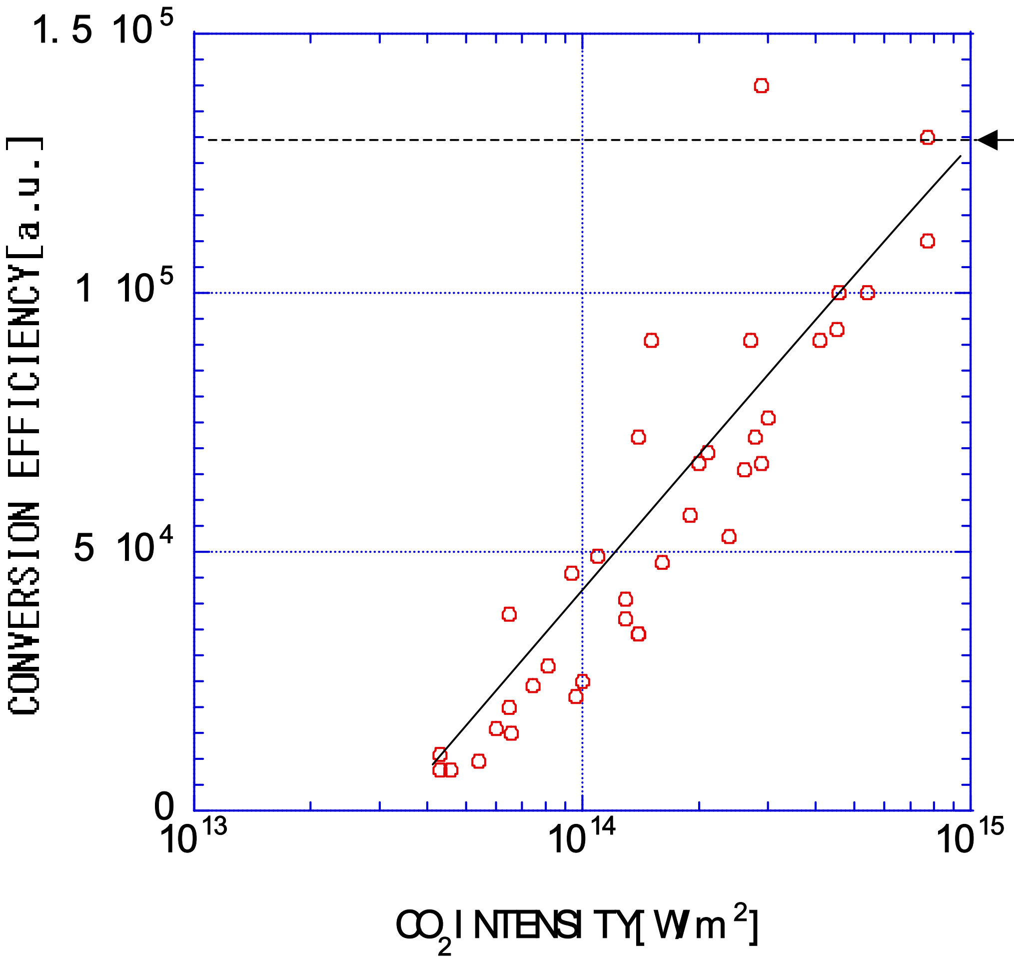

**$CO_2$: LUMONICS TEA-601**
**5-10 J / 50 ns FWHM**
**Nd:YAG: SPECTRA-PHYSICS**
**Quanta-Ray PRO**
**200-1200 mJ /8 ns FWHM**

# EUV (@13.5 nm) Energy by $CO_2$ Laser



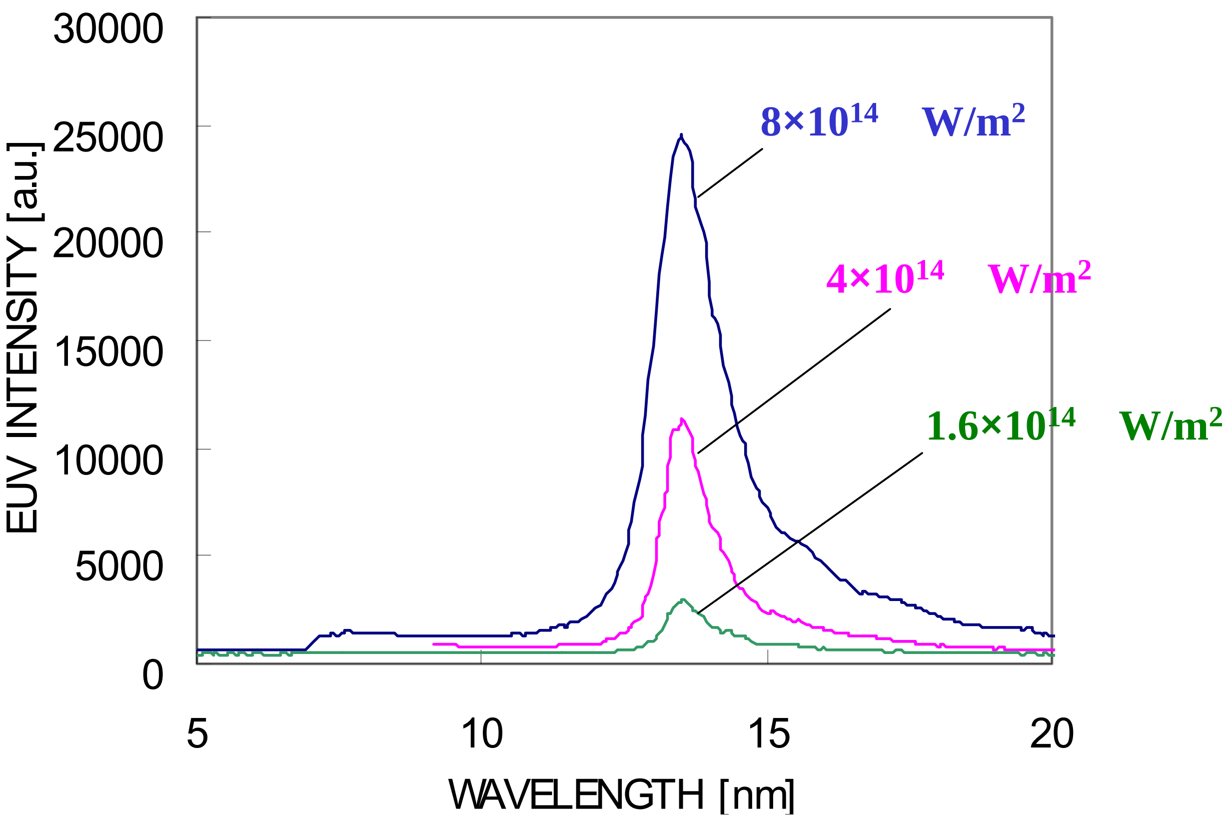

**30 mJ , provided that the EUV energy is 10 times larger than that of Xe target.**

# Conversion Efficiency by $CO_2$ Laser



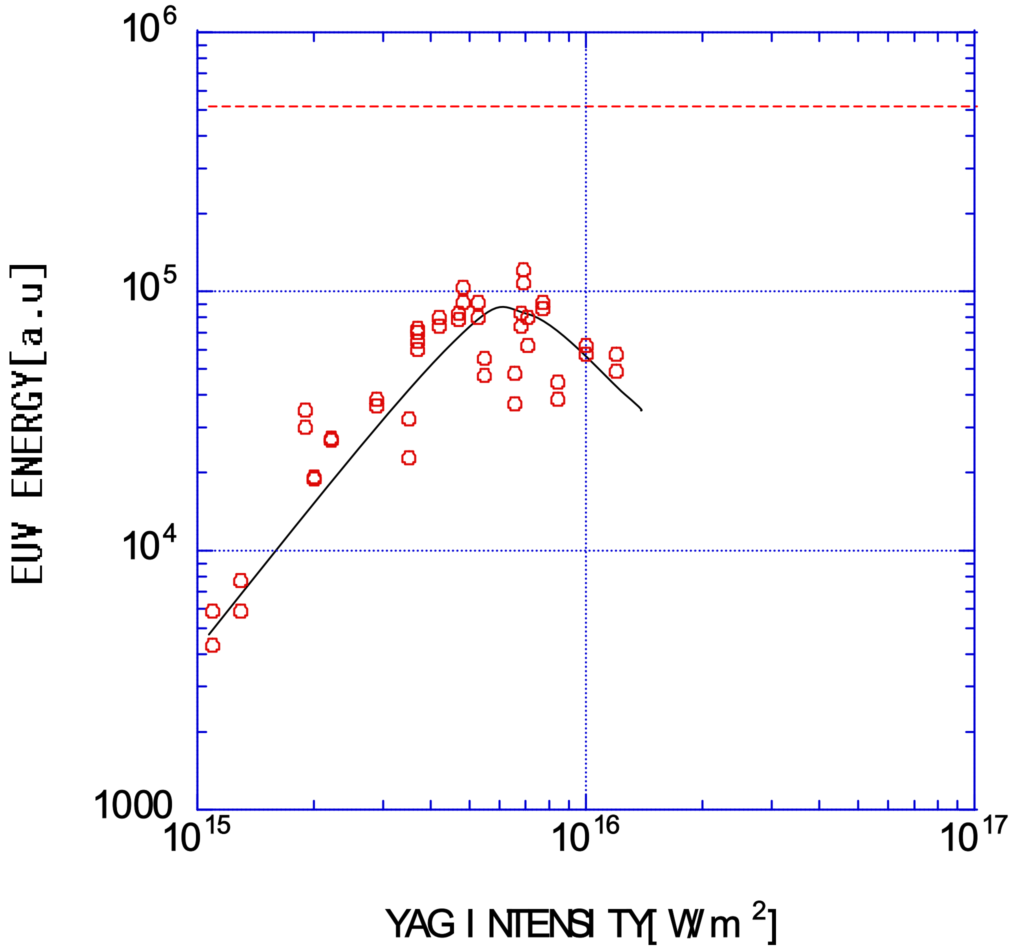

**0.8 %** provided that the energy is 30 mJ

# EUV Spectra of $CO_2$-LPP



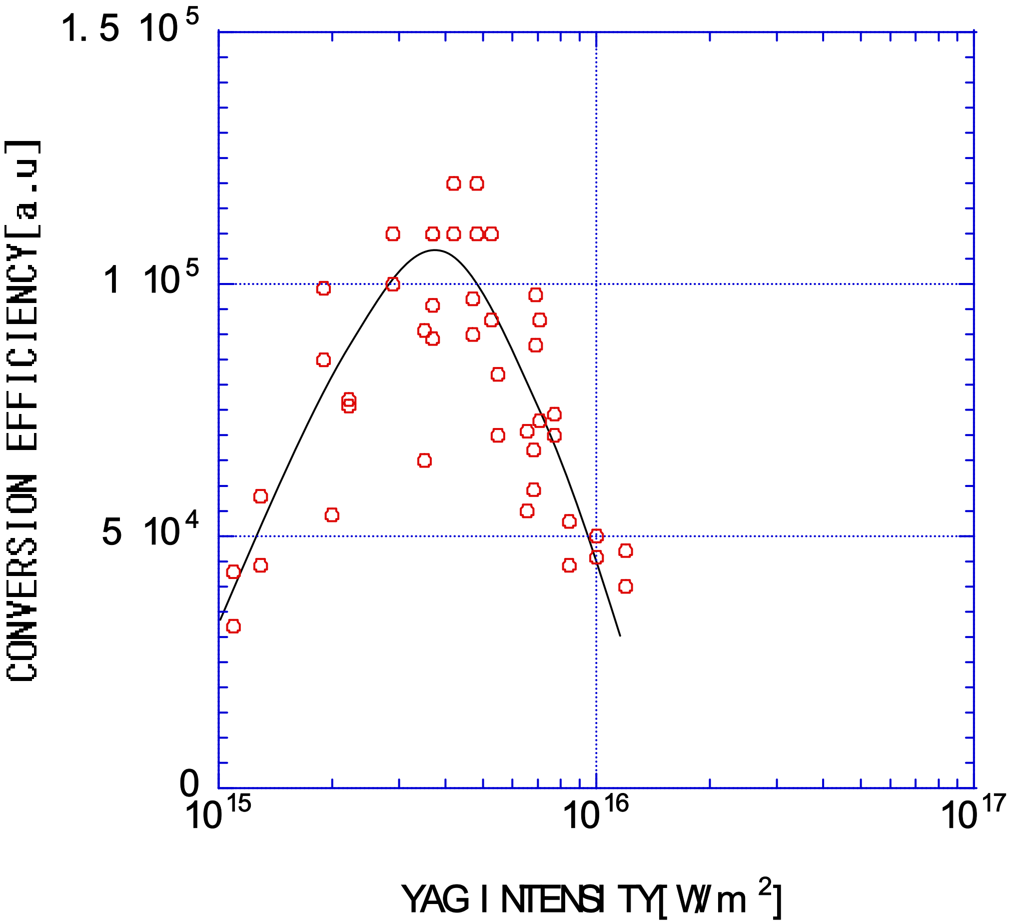
# EUV (@13.5 nm) Energy by YAG Laser





# Conversion Efficiency by YAG Laser



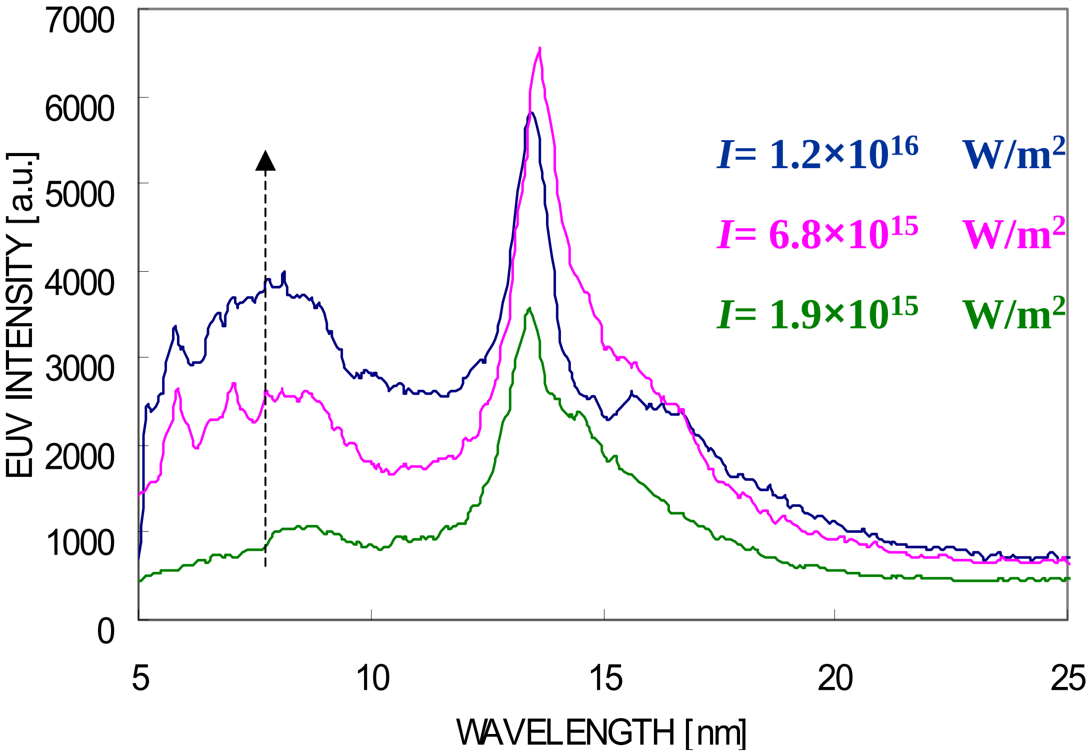



**Conversion efficiency decreases in the input intensity more than $5x10^{15}$ W/$m^2$**

# EUV Spectra of YAG-LPP

**Intensity at shorter wavelength increases with increase in the input intensity.**

**Input energy is transferred to higher excited levels?**



# Summary

## For Xe target (gas-jet & ice)

We adopted a TEA-$CO_2$ laser as a driver laser.
An EUV output energy of more than 3 mJ and a conversion efficiency (C.E.) of 0.1-0.15 % per 2π sr at 13.5 nm.

## For Sn (tin-bulk) target

A Nd:YAG laser and the TEA-$CO_2$ laser were used as the driver laser under the same experimental setup. In this experiment, the maximum C.E. of $CO_2$-LPP was almost same as that of YAG-LPP(~0.8%).
However, the characteristics of C.E. for the input power were quite different.
The C.E. of $CO_2$-LPP might increase in the higher input power than that in this experiment.

# Acknowledgement

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