Development of low-density target for high efficient EUV Generation

Keiji Nagai, Takayoshi Norimatsu, Shinsuke Fujioka, Hiroaki Nishimura, Katsunobu Nishihara, Masahiro Nakatsuka, Noriaki Miyanaga Yasukazu Izawa, Kunioki Mima

Institute of Laser Engineering(ILE),

Osaka University

Outline

1. **Tin is the highest conversion material from laser to EUV light.**

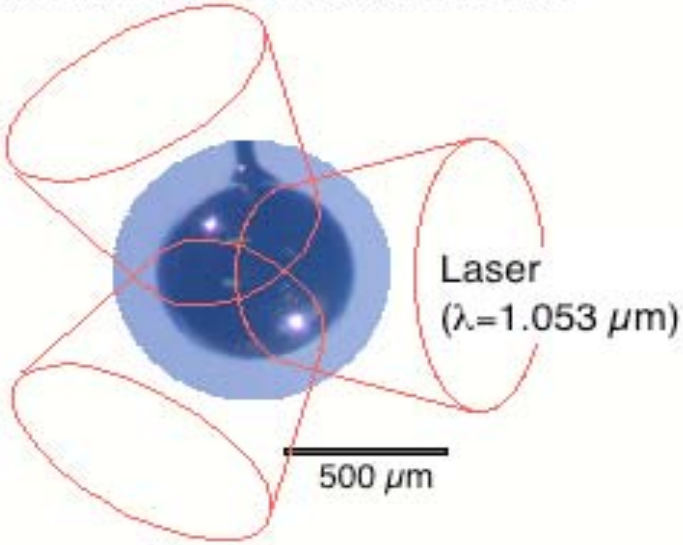
2. **Low-density Sn shows higher efficiency for long pulse (10 ns) with low debris, high brightness.**

3. **Various low-density Sn targets have been fabricated.**

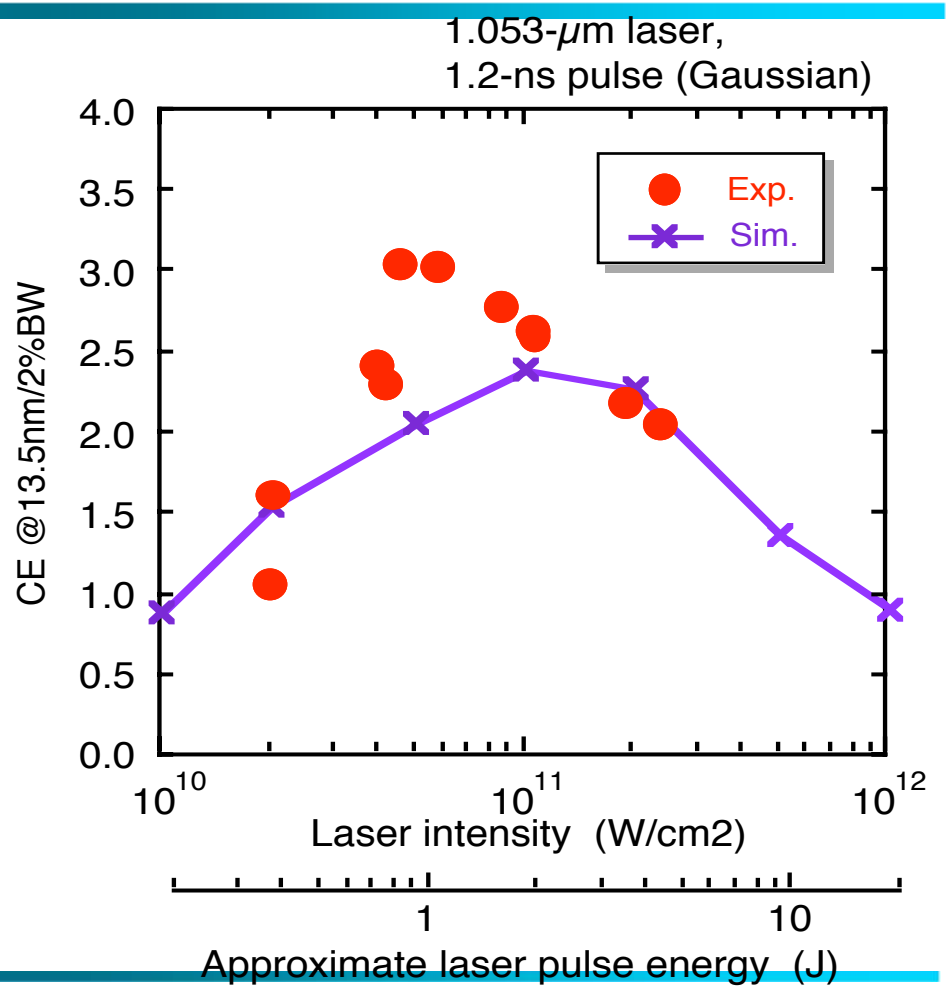
A part of this work was performed under the auspices of Ministry of Education, Culture, Science and Technology, Japan (MEXT) under contract subject “Leading Project for EUV lithography source development”.

Tin (Sn) is one of attractive materials for creating highly efficient 13.5 nm radiator.

Uniform irradiation with 12 beams



Sn (or SnO_2) coated plastic shell



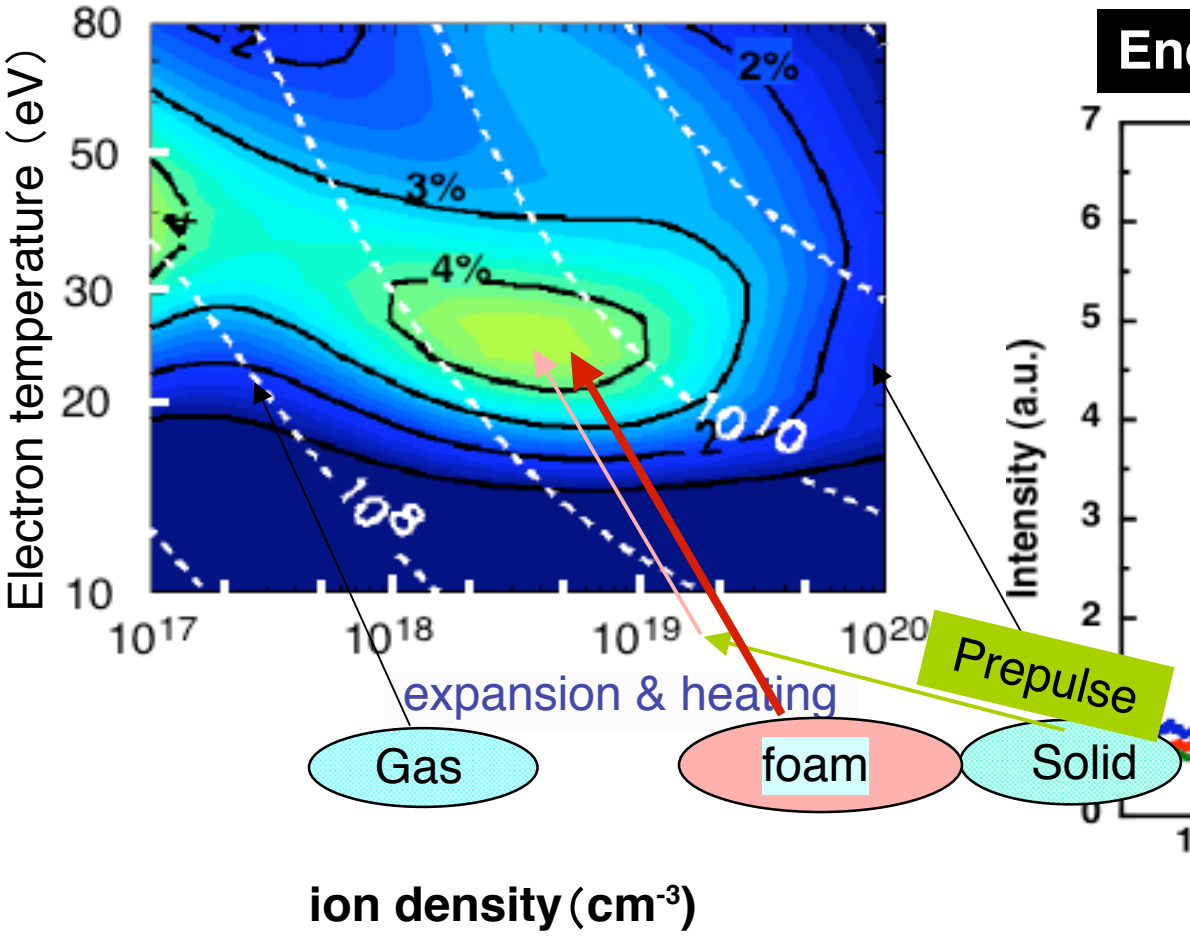
Y. Shimada *et al.*, APL Vol.86, 051501 (2005).

Theoretical analysis gave a mapping of conversion efficiency.

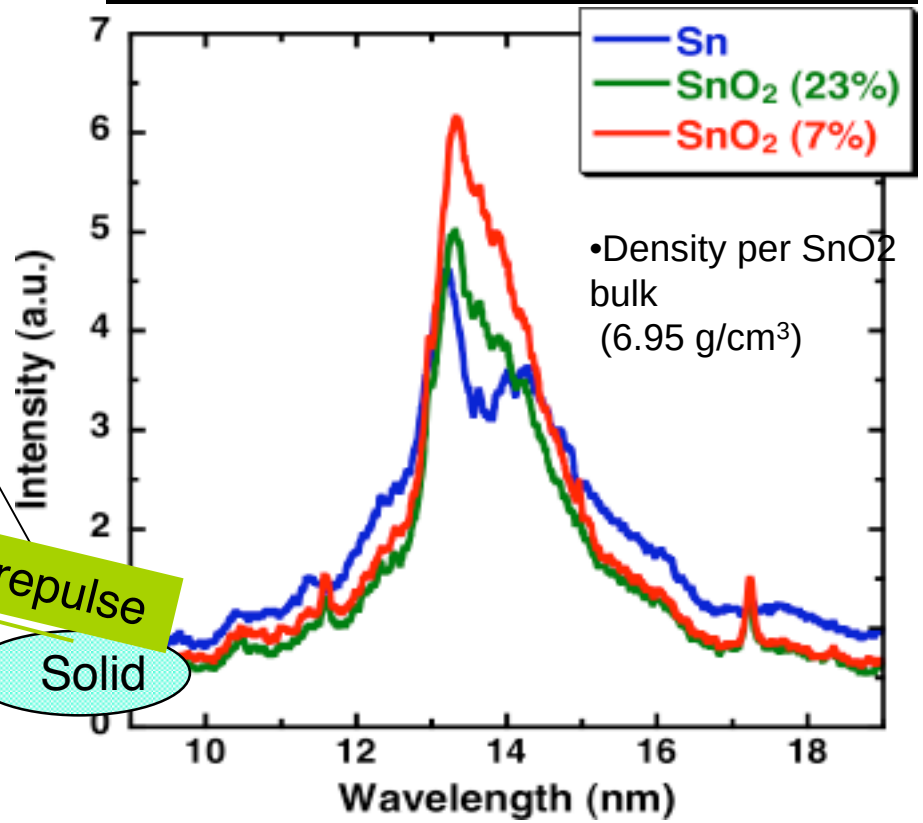
High efficiency is obtained from the plasma to be 30 eV, 10^{18} ~ 10^{19} cm^{3}

Conversion efficiency for EUV emission

(Nishihara et al.)



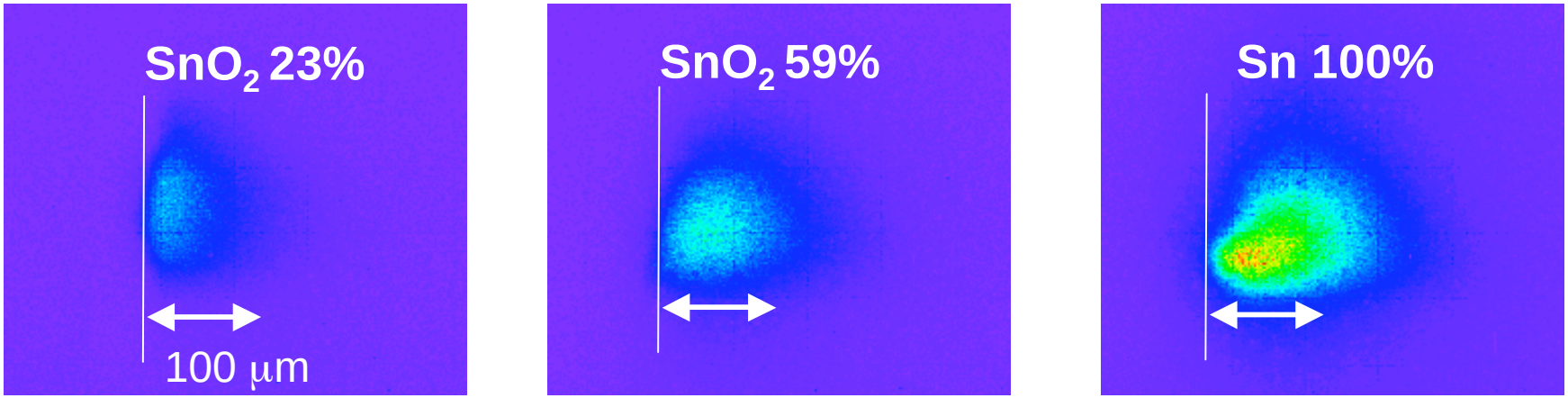
Energy normalized EUV spectra

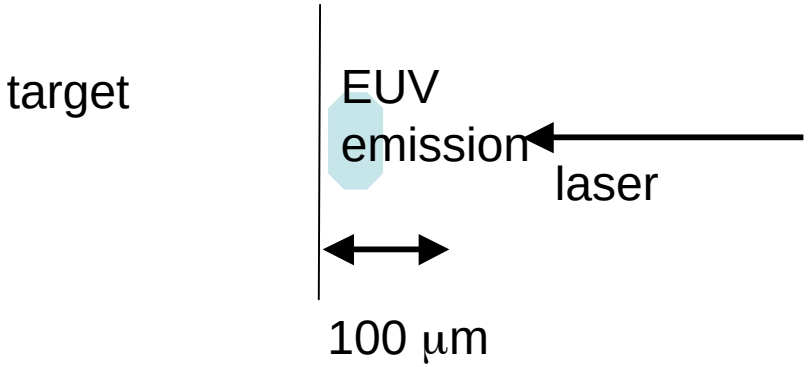


10 ns, 1064 nm

T. Okuno et al., *Appl. Phys. Lett.*, **88** (16), 161501 (2006).

Nanoporous tin oxide showed higher brightness than tin oxide powder and bulk tin.



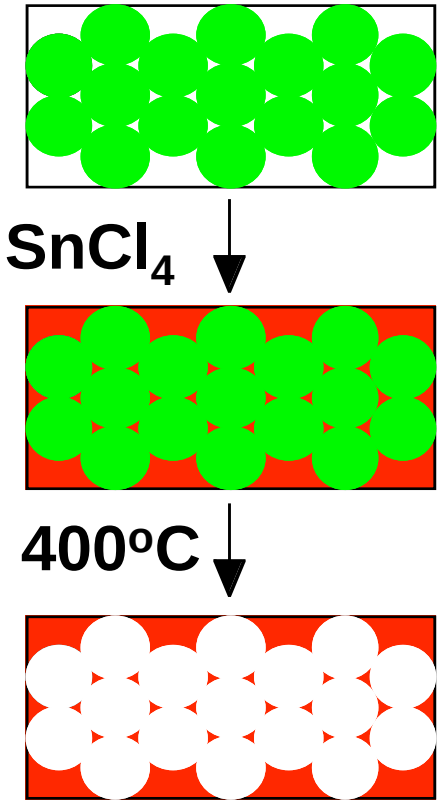


Small emission region means high brightness, when the intensity is constant.

Y. Tao et al., *Appl. Phys. Lett.*, **85**, 1919, (2004).

Low density tin oxide (d=1.5g/cm^3) using nanotemplate

(23 % of bulk crystal)

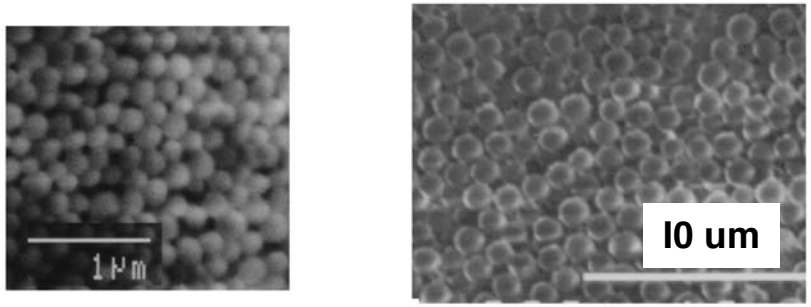


Polystyrene particles were aligned to be closed packing.

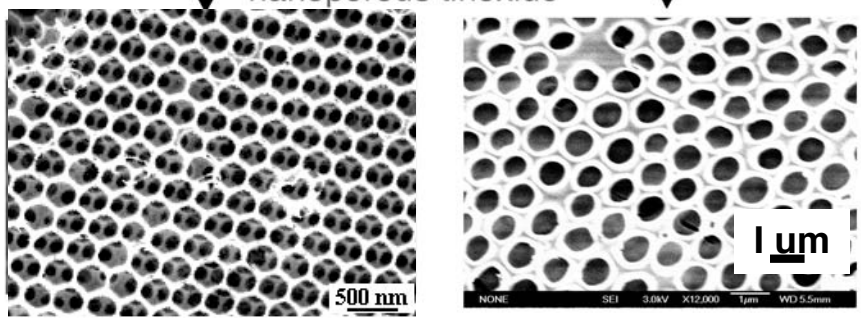
PS particles were immersed in liquid tin chloride. Tin chloride was hydrolyzed to be tin oxide.

PS particles were decomposed by heating. Porous tin oxide film was obtained.

Polystyrene nanoparticles



nanoporous tinoxide

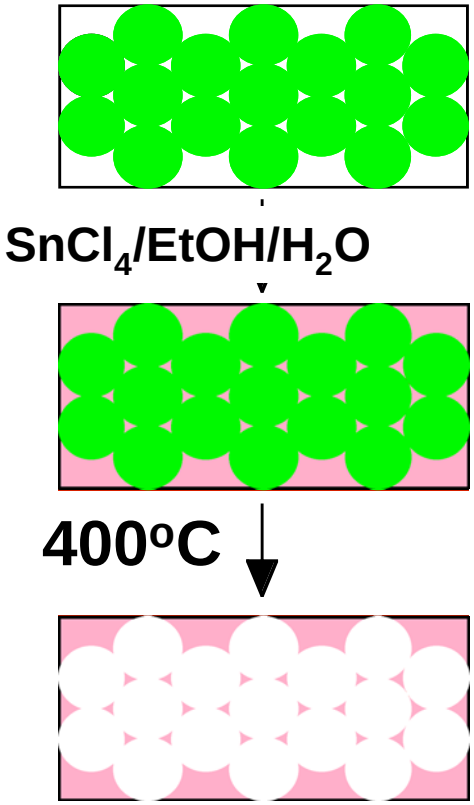


Pore size was well controlled by the template spheres.

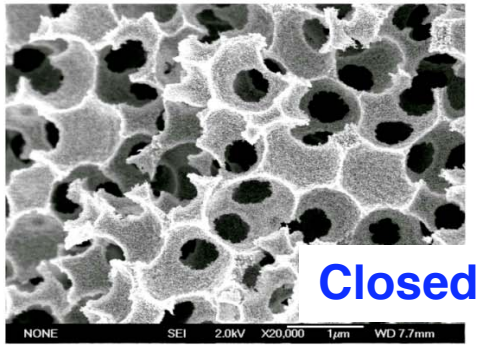
K. Nagai et al., Trans. Mater. Res. Soc. Jpn., 29 (3) 943 (2004)

Low density tin oxide (d=0.5g/cm^3) using nanotemplate

(7 % of bulk crystal)

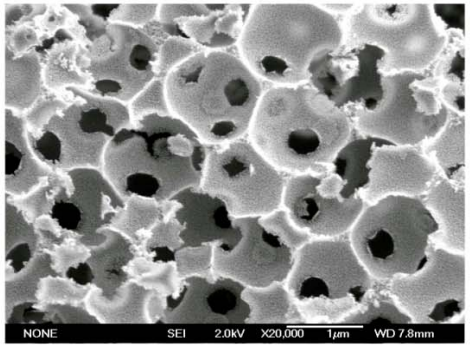


$n = EtOH_{mol} / SnCl_{4\ mol}$

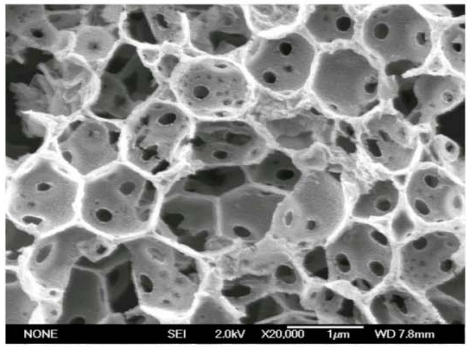


n=2

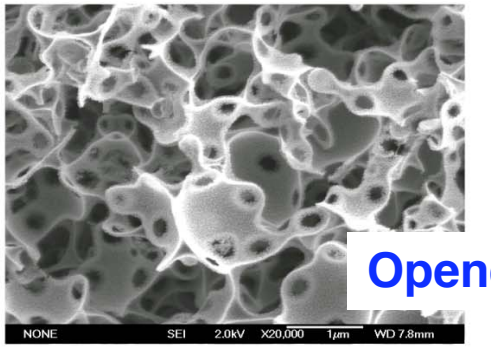
Closed cell



n=4



n=6



n=10

Opened cell

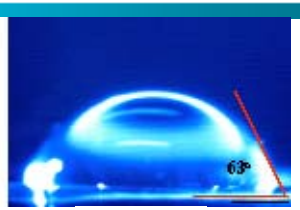
There were various morphologies.

Q.C.Gu et al., Chem. Mater., **17** (5), 1115-1122, (2005).

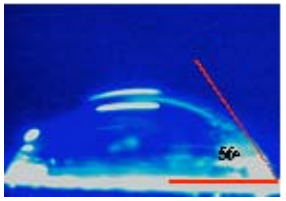
Volume template vs. Surface template

Contact angle on polystyrene film

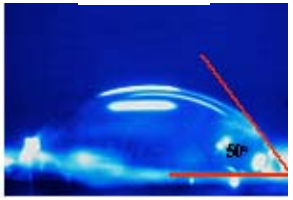
n=2



n=4



n=6



n=10

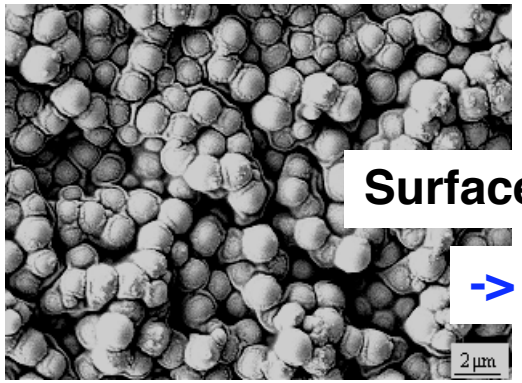
More EtOH (n), lower contact angle (higher affinity for PS)

SEM images before heating at 400 °C

n=2

Volume template

-> Closed cell



n=10

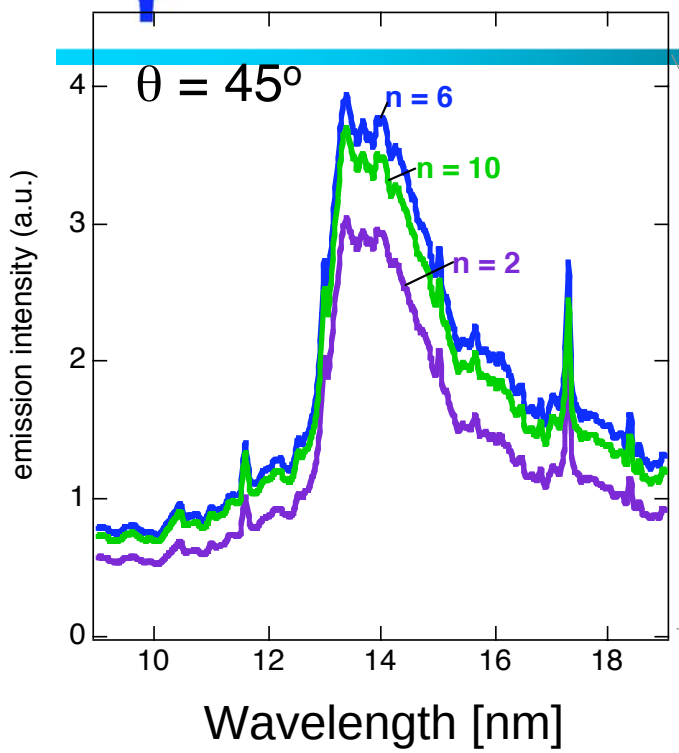
Surface template

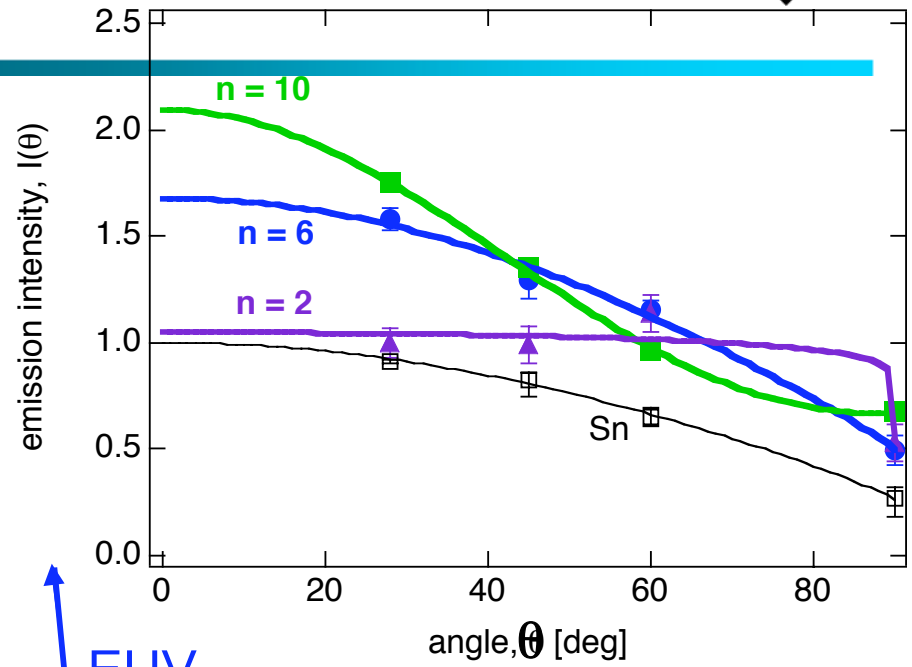
-> Opened cell

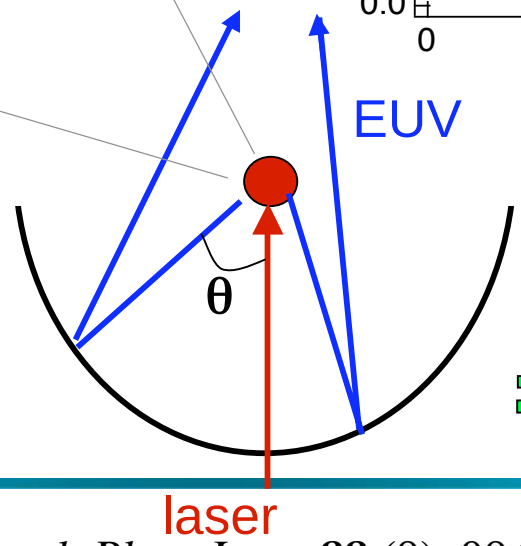
$n = EtOH_{mol} / SnCl_{4\ mol}$

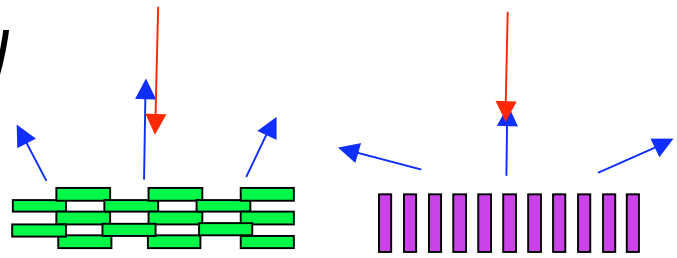
Q.C.Gu et al., Chem. Mater., **17** (5), 1115-1122, (2005).

Control of angular distribution depending on target surface morphology









K. Nagai et al., *Appl. Phys. Lett.*, **88** (9), 094102, (2006).

Specification of EUV Light source

EUV wavelength 13.5 nm with 2% band width

EUV power 115 W

Etendue 1~3.3 mm2sr

*etendue:source area x solid angle

Frequency 7~10 kHz

Stability of the power ± 0.3% (average for 50 pulses)

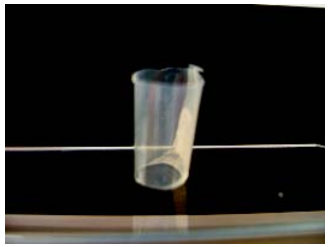
Solid angle 0.03 ~ 0.2 sr

Lifetime of apparatus > 30, 000 hours （3.4 year）

Cost of Ownership

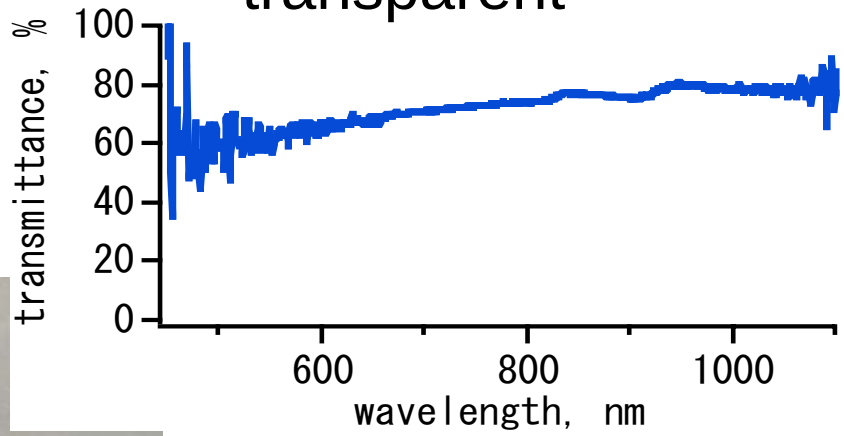
Target with low content tin for high rep. irradiation

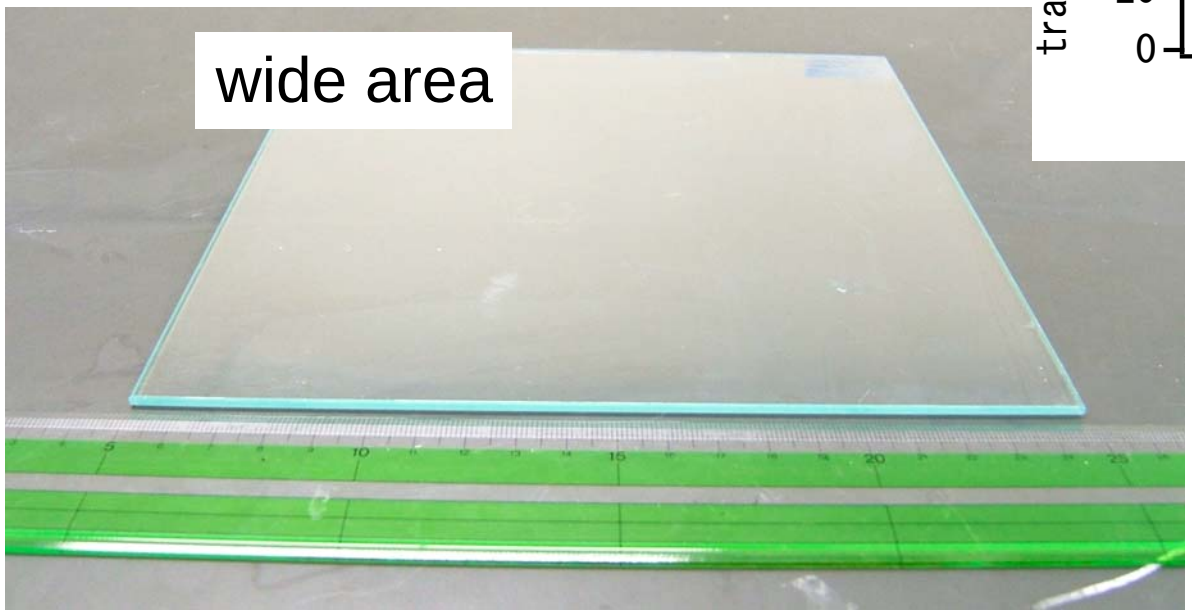
Transparent film with 0.1 ~ 100 μm thickness or bulk



flexible

transparent





wide area

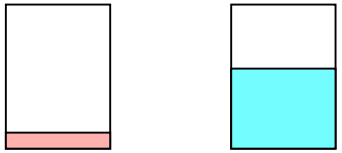
bulk

Osaka U., Kansai TLO co.ltd. Patent

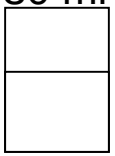
Preparation of thin film containing Sn

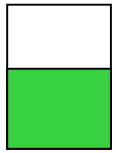
$Sn(t\text{-}BuO)_4$
$SnCl_4$

Ethanol

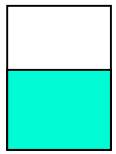


water
30 ml



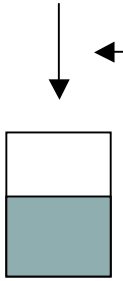


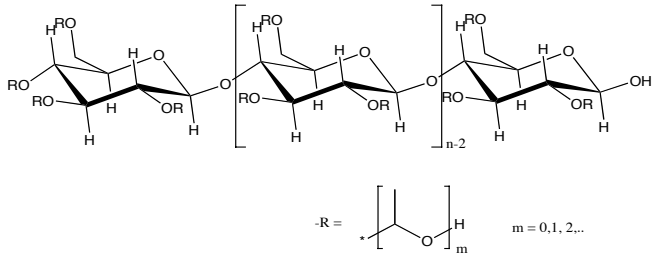
Sn / ethanol
＝1／3（a）10 ml

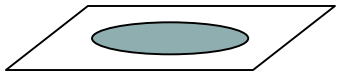


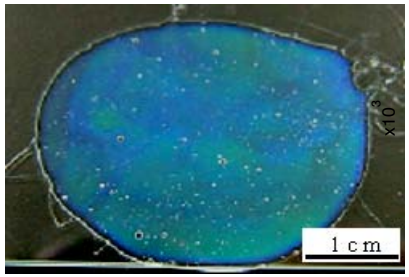
Sn solution (b)

HPC20 ~75 wt %

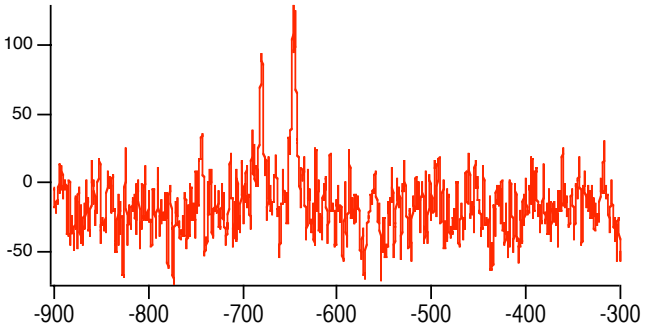








^{118}Sn NMR



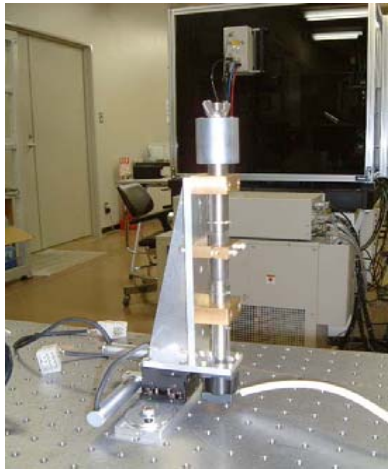
Different from SnO_2, $SnCl_4$

Application for 10 Hz rotation target

diameter　3.3 cm、　height3cm

3000 times irradiation（0.1rps, 5 min）

Before and after irradiation



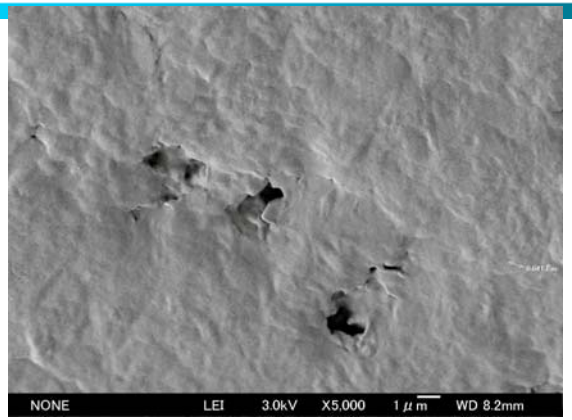
rotor

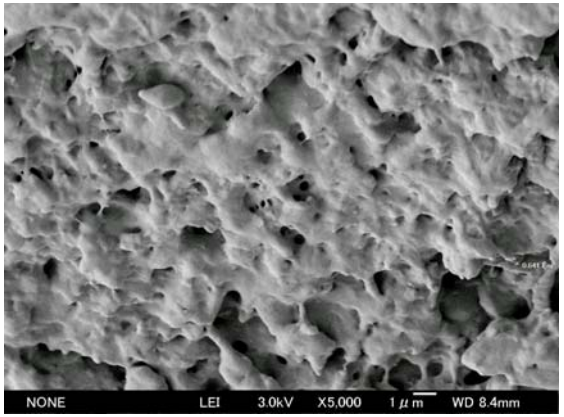
Y. Yasuda et al., *Fusion Sci. Technol.*, **49** (4), 691-694, (2006).

Ordered wavy nanocrystal was obtained by heating at 400°C

surface

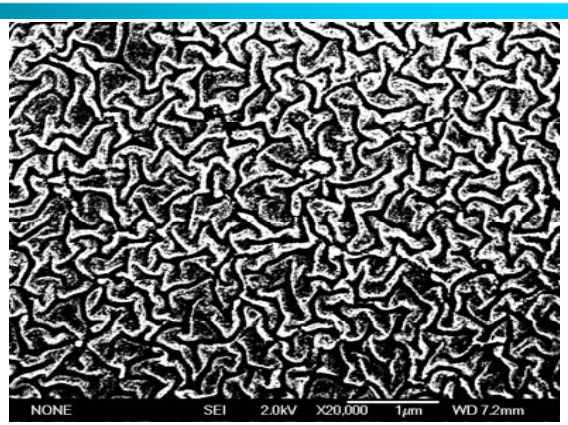
cross section

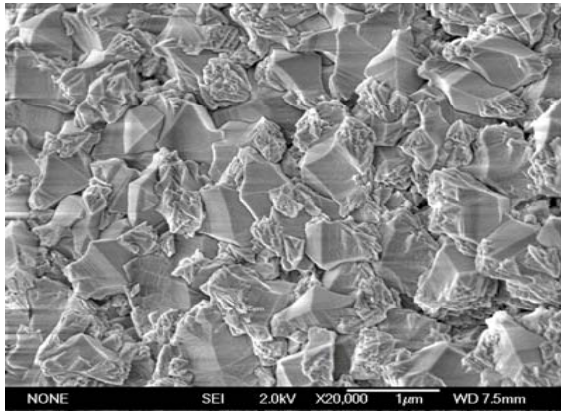




film x 5000

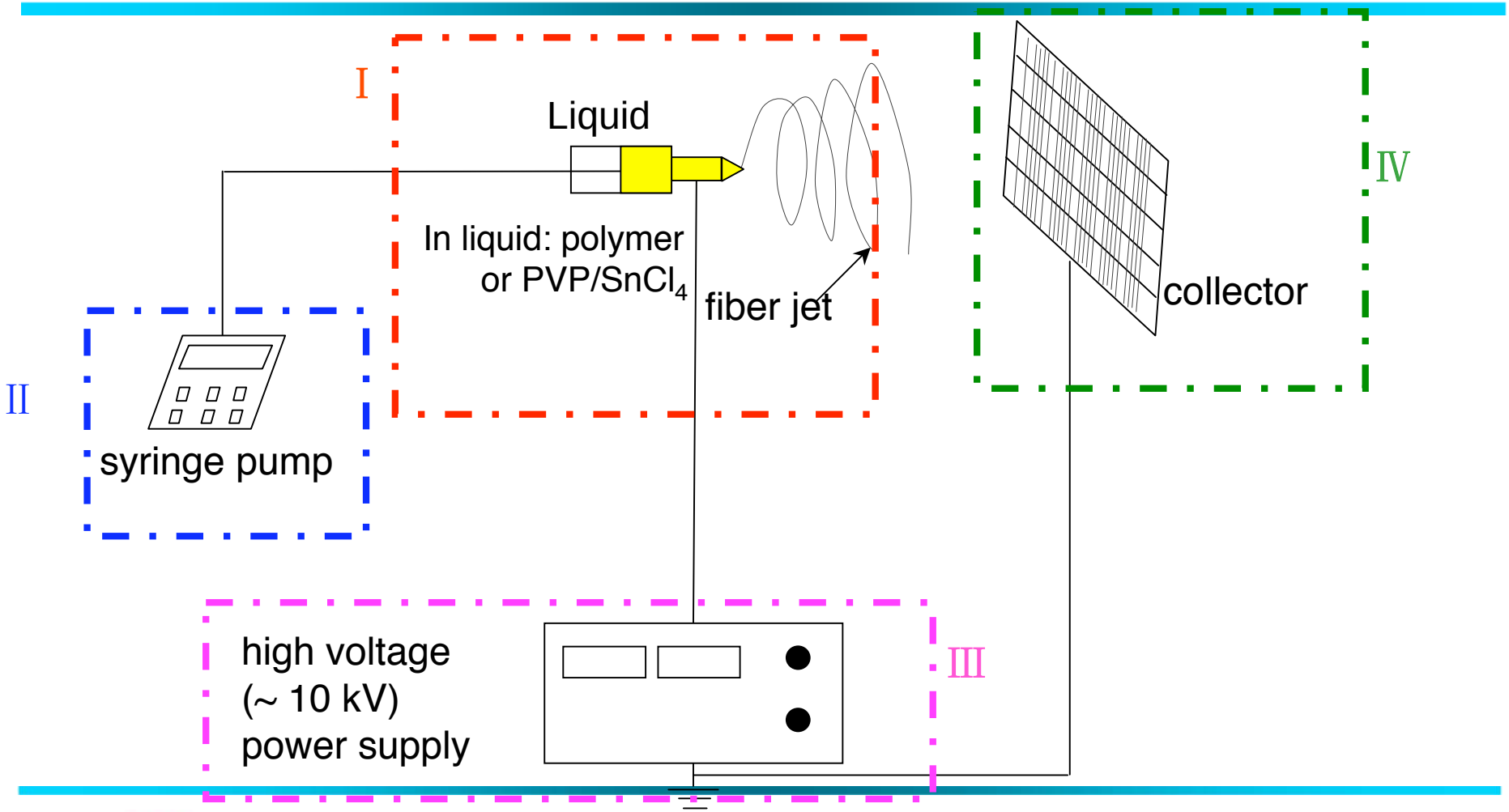
400°C



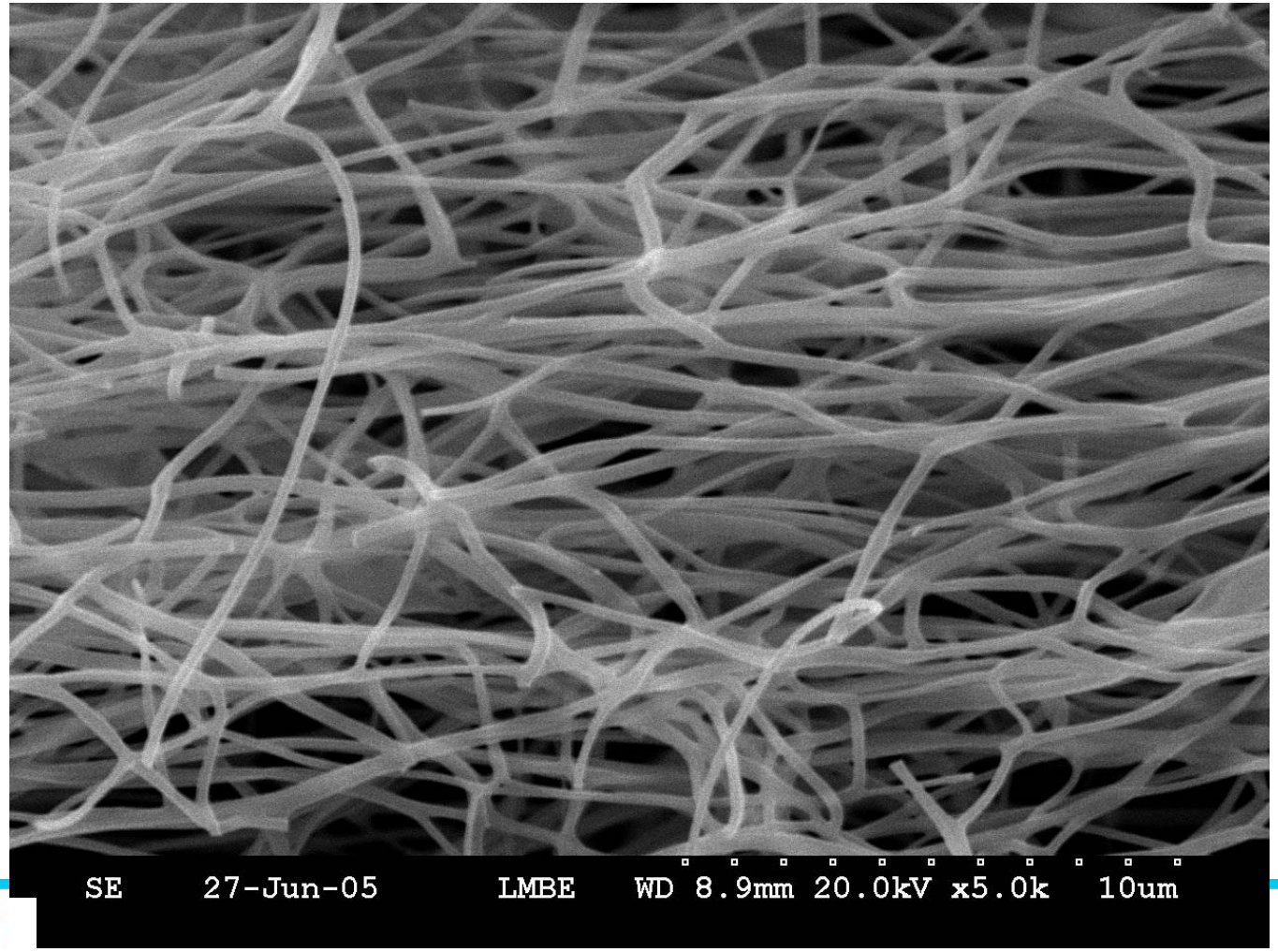


SnO_2 x 20000

Oriented low density materials : electrospinning nanofiber

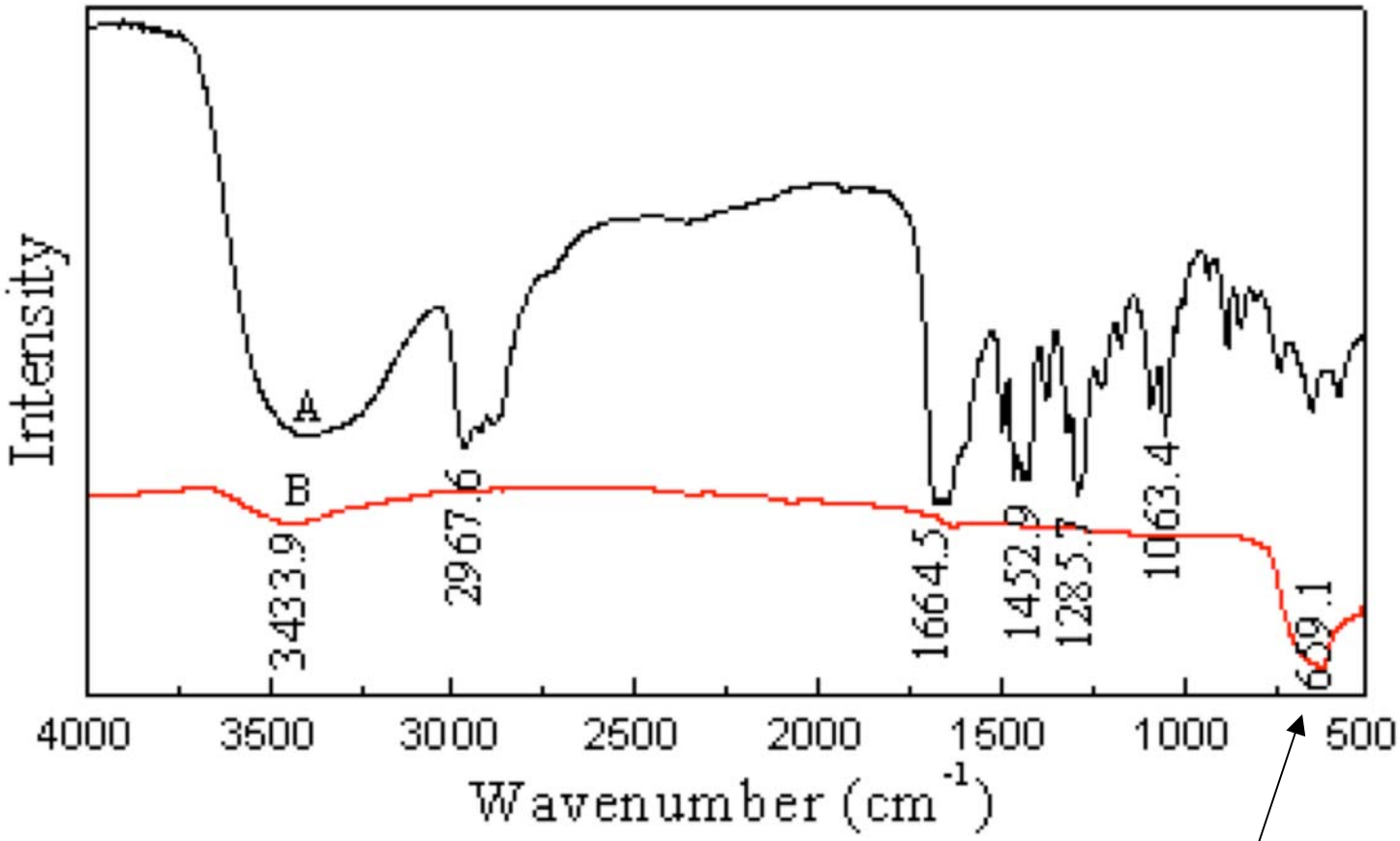


SnO_2 fibers



C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

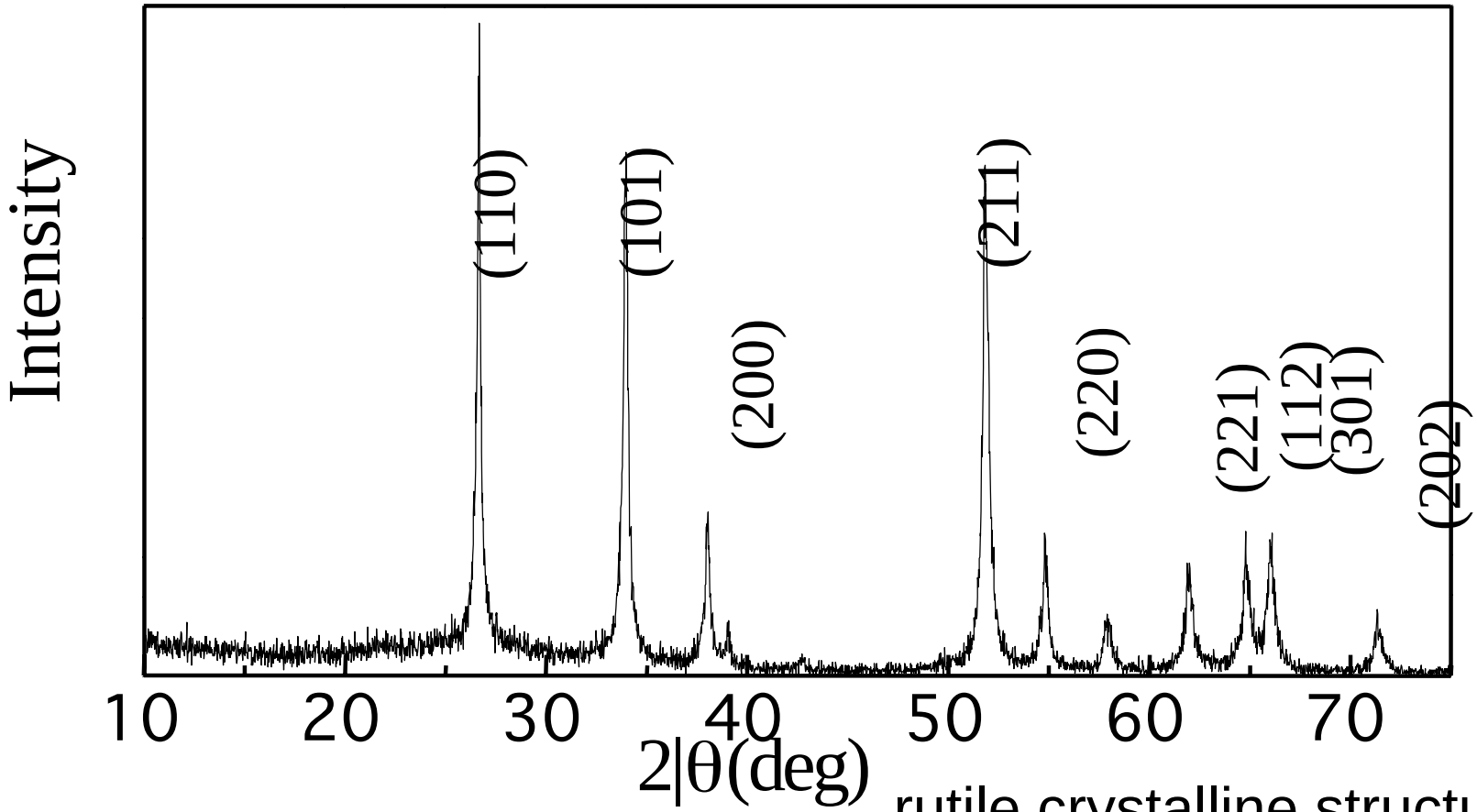
IR spectra before and after calcination at 500°C



νSn-O of tin dioxide (SnO2)

C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

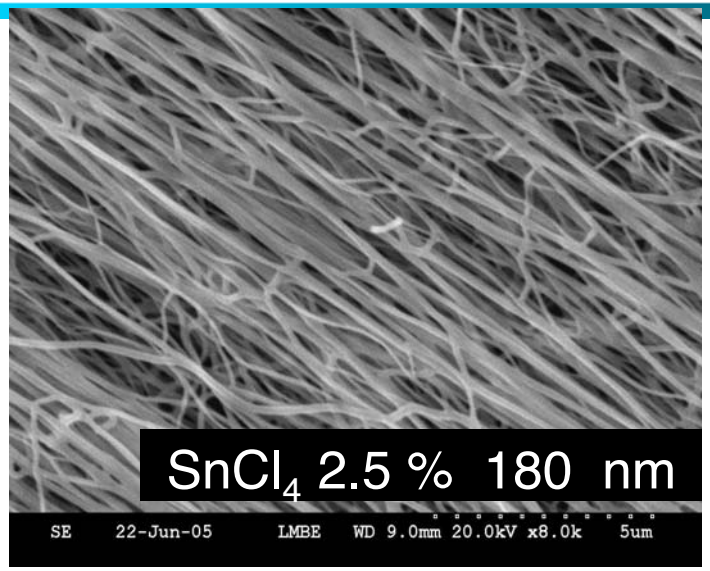
XRD of SnO_2 film

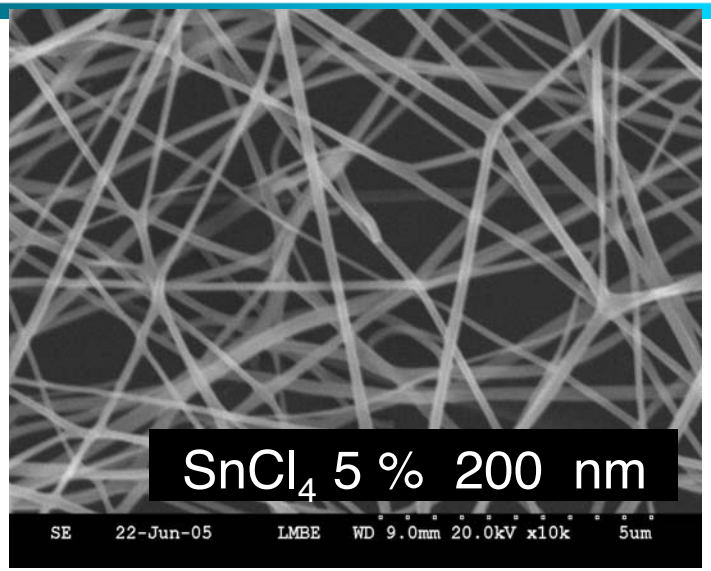


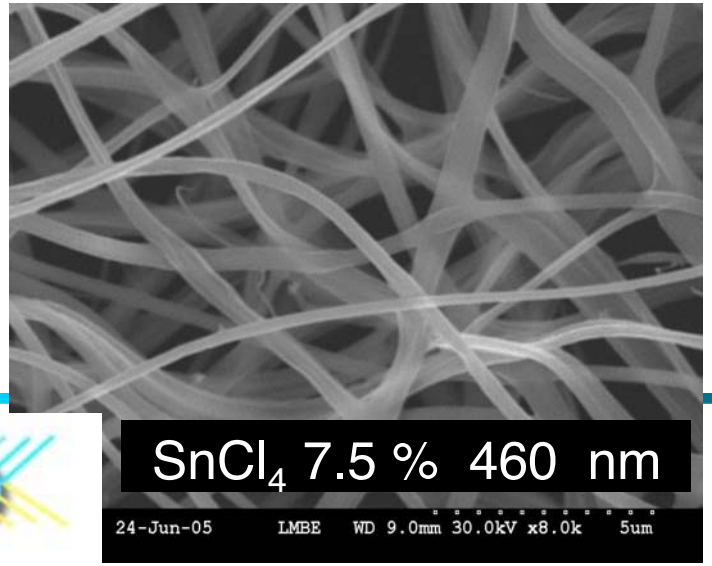
rutile crystalline structure

C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

SnO2 fibriformic film with controllable morphology

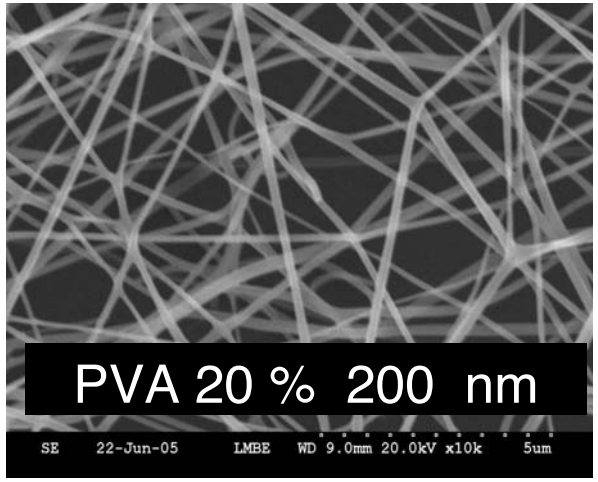


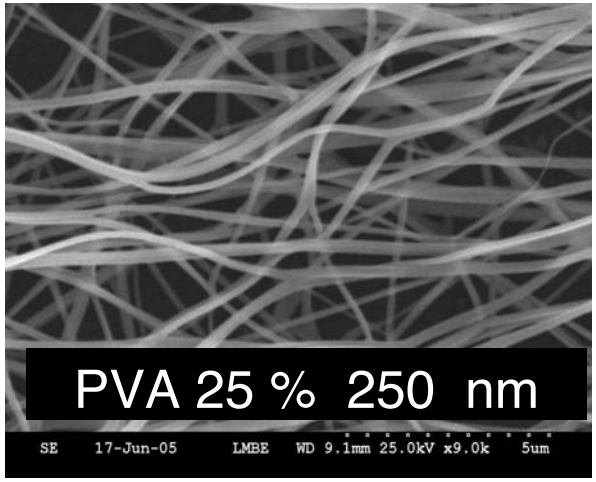


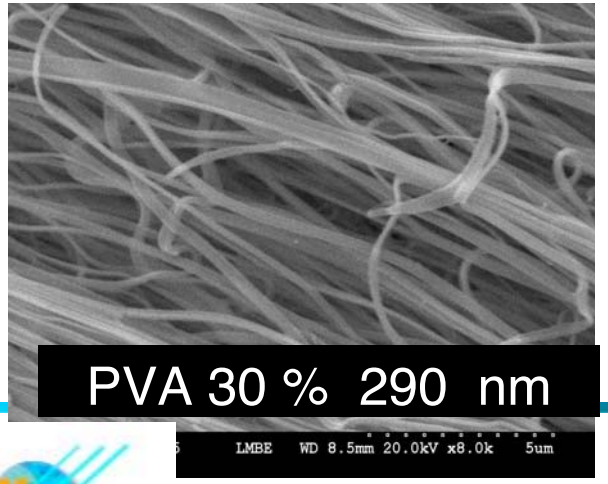


C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

the dependence of nanofiber diameter on concentration of PVP



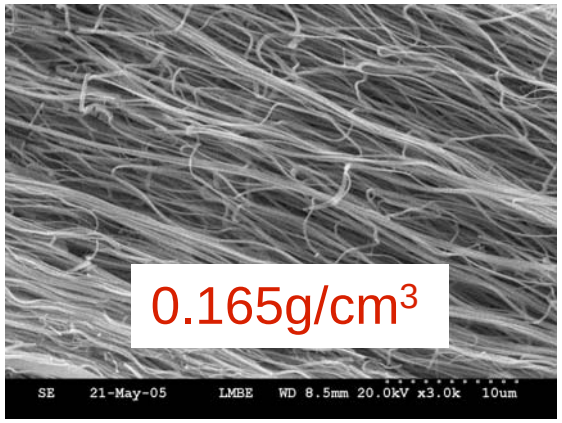


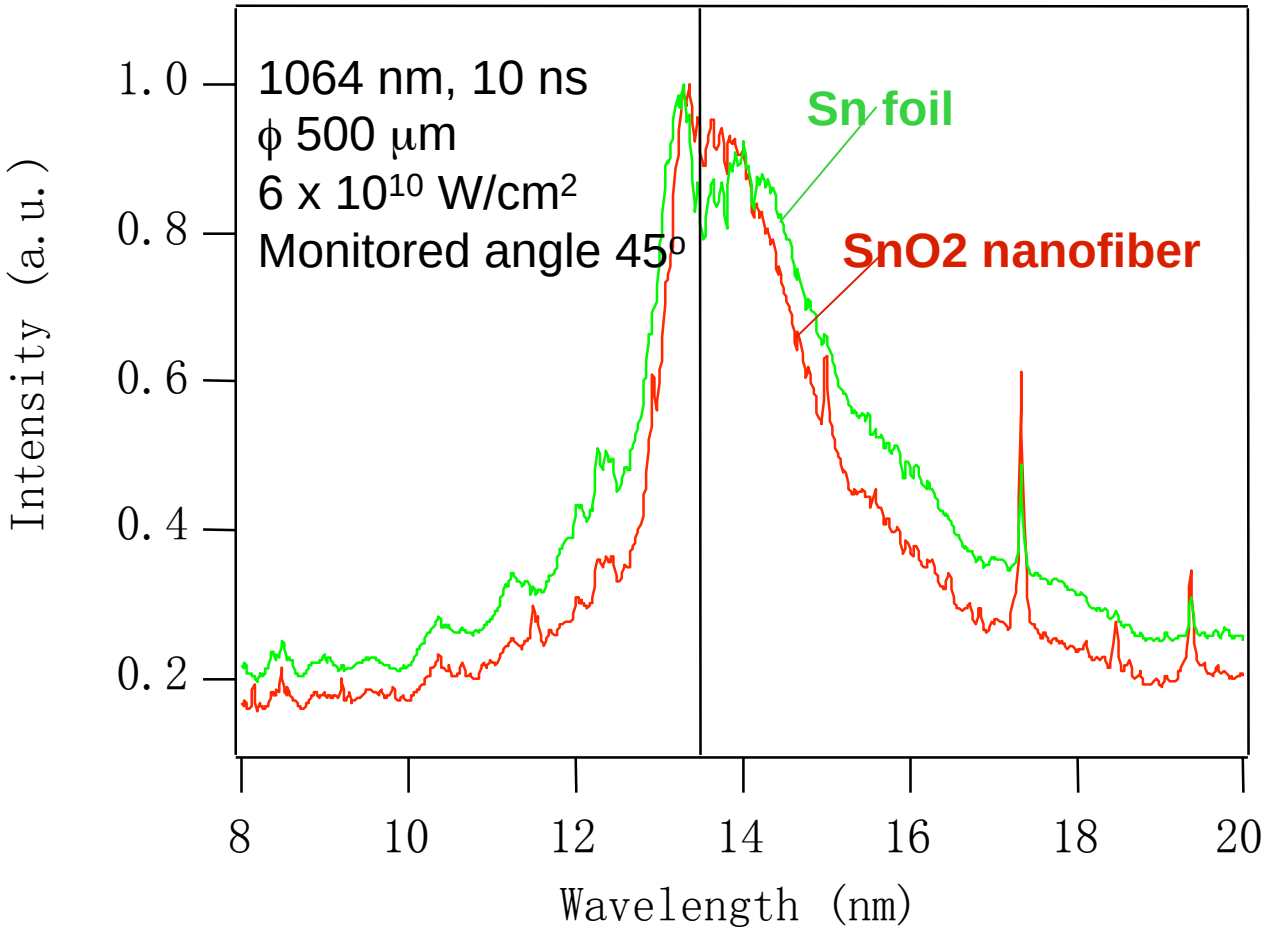


After calcined in air at 500 °C for 2h.
$SnCl_4$ concentration (5% wt)
Feeding rate (1mL/h)
Electric field strength (0.67kV/cm).
Distance between the injection orifice and the collector (15 cm)
ambient temperature (24 °C); ambient humidity (70%) for all experiments.

C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

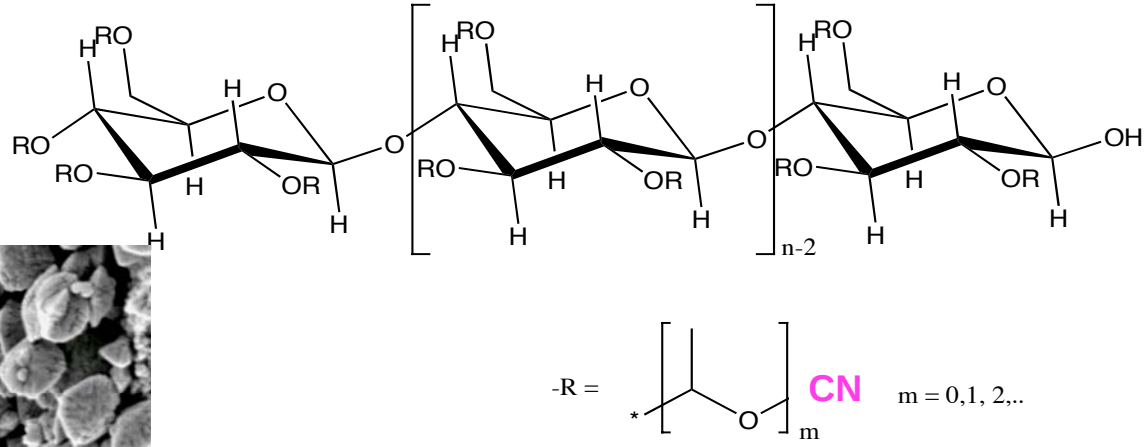
EUV emission spectra from nanofiber

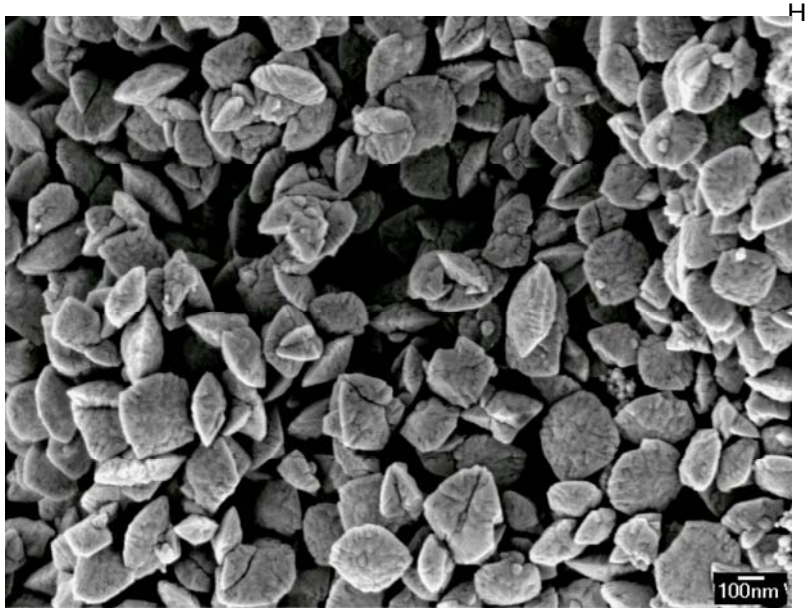




C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

A cellulose derivative having slightly different chemical structure induced completely different nanostructure of SnO_2.



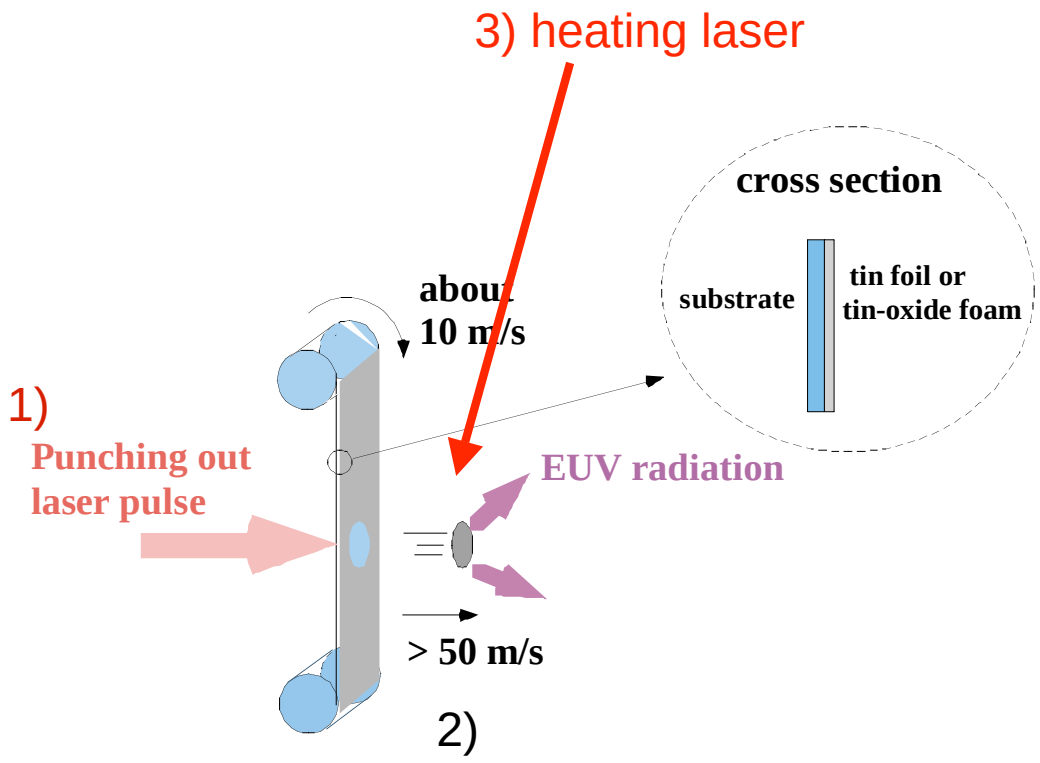


100 nm

The nanoparticles may be applied for the “punch out” supplement system.

Q.C. Gu et al., *Colloid and Polym. Sci.*, **284** (4), 429-434, (2006).

A novel target supplement, called the punch-out method, to supply mass-limited targets.



1) The punch-out laser (PoL) pulse is irradiated from the back surface of the substrate that is transparent to the pulse.

2) The tin-foil is ablated by the PoL pulse and produces a tin plasma at the boundary of the foil and substrate.

3) The rest of the tin-foil (mass-limited) is driven to a high velocity due to the expanding plasma.

Sn dots film target of tin was fabricated using an inkjet printer.

Summary (low density SnO_2)

1. Low density SnO_2 for database experiments was prepared using nanotemplate.

2. Various micro morphology of SnO_2 was prepared keeping the same density as 0.5 g/cm^3.

3. Low-density SnO_2 having more normal face radiated uniform angular distribution of EUV emission. This phenomena may be applied for control of wave face and efficiency of extraction of photon.

4. Hydroxypropyl cellulose was used as matrix of tin. The composite forms transparent wide area thin film, and gave wavy nano crystals by heating.

5. Cyanoethyl cellulose was used as matrix of tin. The composite forms liquid crystalline film, and gave UFO like nanocrystals by heating.

6. Nanofiber of SnO_2 was prepared using electrospining.

7. Tin dots target for “punch out” supplement was fabricated using ink jet printer.

Contact address

Patent

Akihiro Kitano, Kansai TLO co. ltd. a-kitano@kansai-tlo.co.jp

Target fabrication and supply

Keiji Nagai, Osaka University knagai@ile.osaka-u.ac.jp