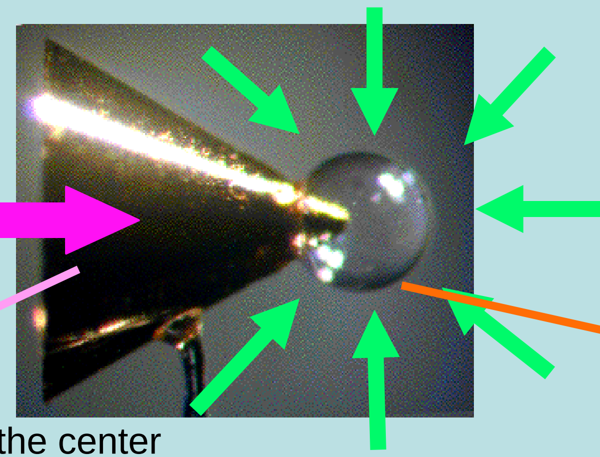
Low density aerogel capsule for FIREX (Fast Ignition Realization EXperiments) project –control of nanostructure-

PW(10^{15}W) for heating
1 beam / 300 J
1.053 μm / 0.6ps

Au cone
30 º open angle (the picture: 60deg)
Thickness of the cone top: 5μm
Distance of the cone top: 50μm from the center



GXII for implosion
9 beams / 2.5 kJ/0.53 μm

1.2ns Flat Top w/ RPP

Deuterated polystyrene
shell 500μmϕ/6-7μmt

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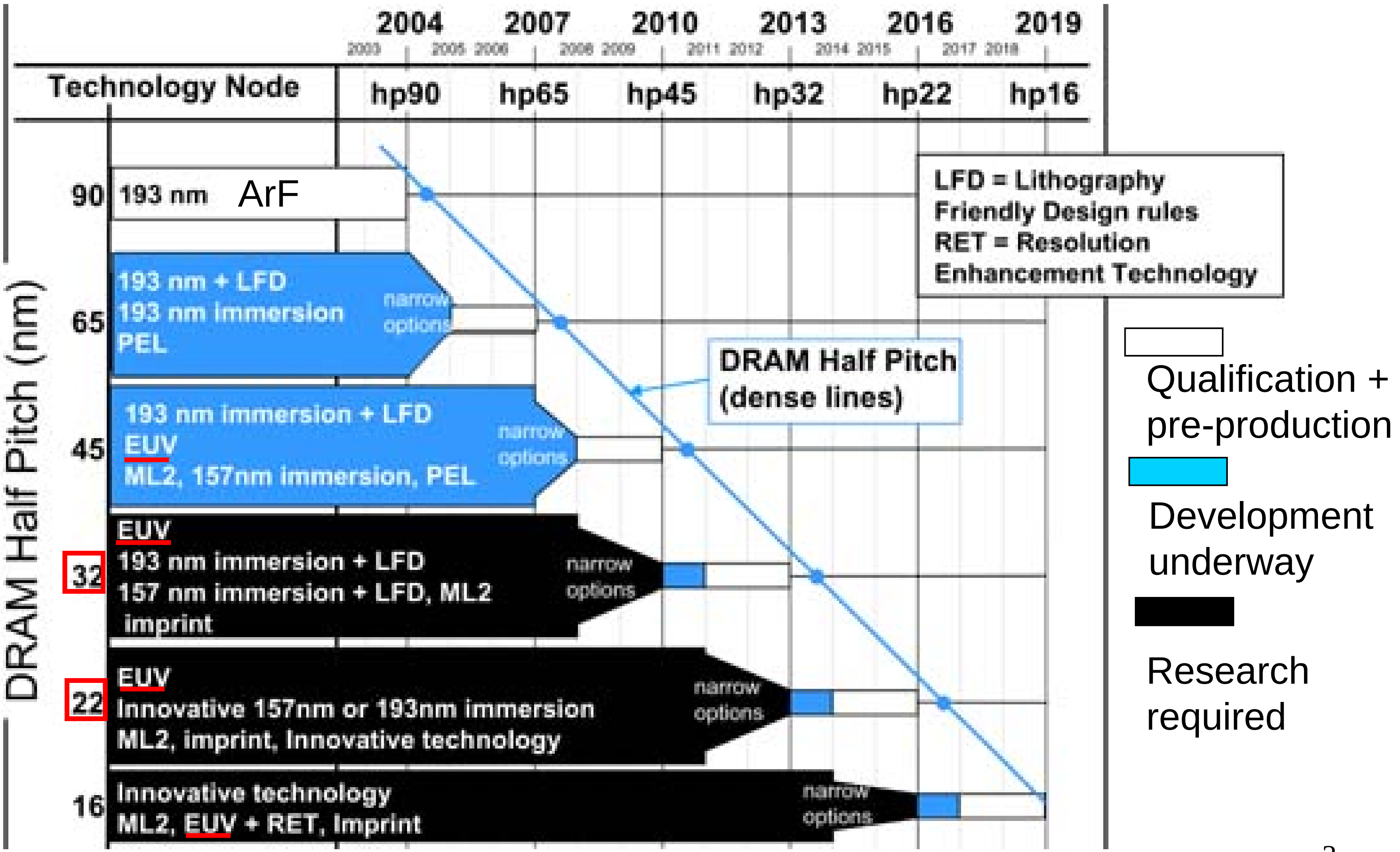
ILE Osaka Univ.[1], Nihon Univ.[2], NIFS[3]

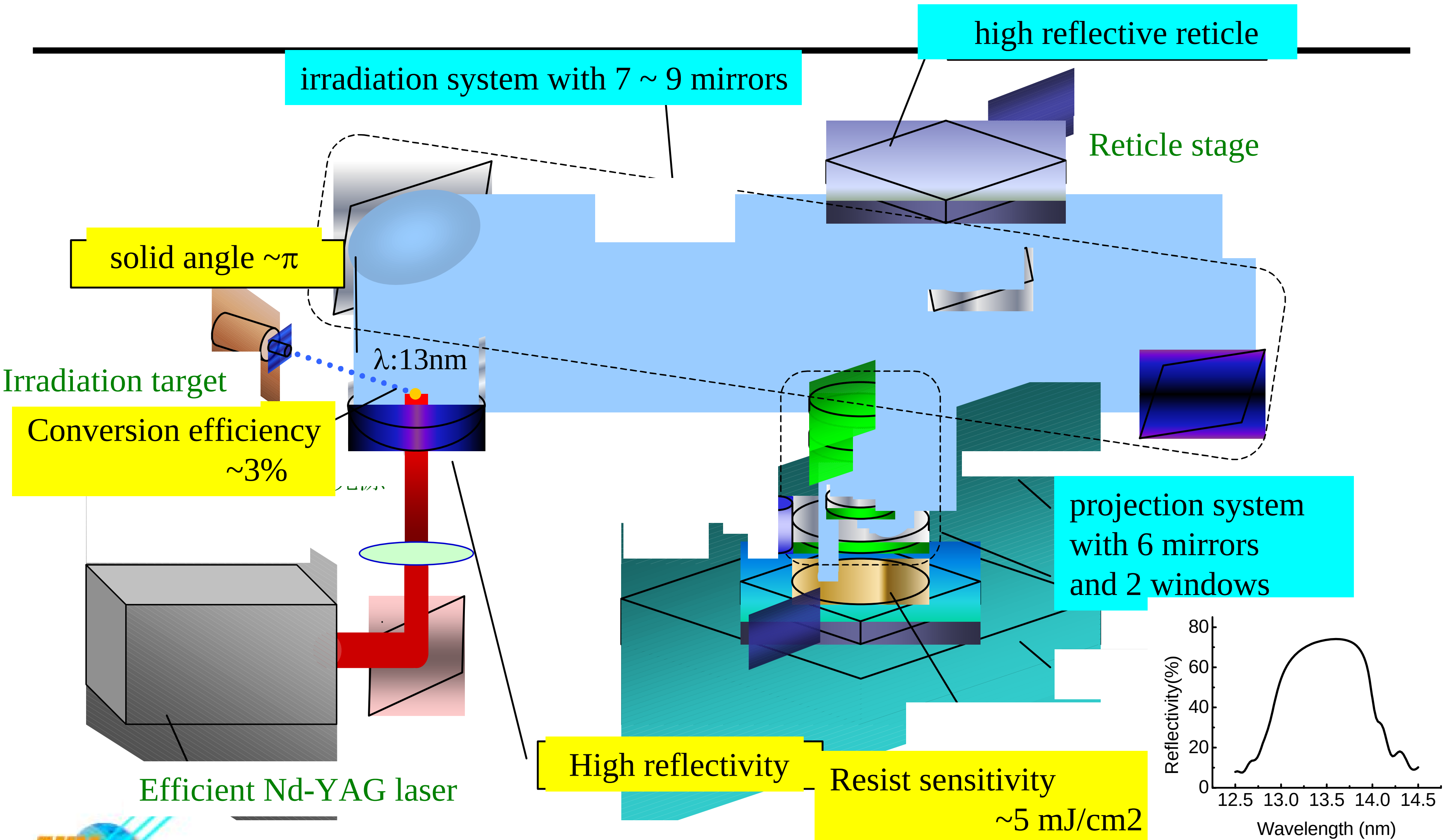
Outline

1. Low density Sn and Au using template, electrospining
2. High rep target ----necessity of minimum mass target
3. Organic aerogel capsule
4. Discussion of nanostructure control

Lithography load map shown in ITRS 2004 update



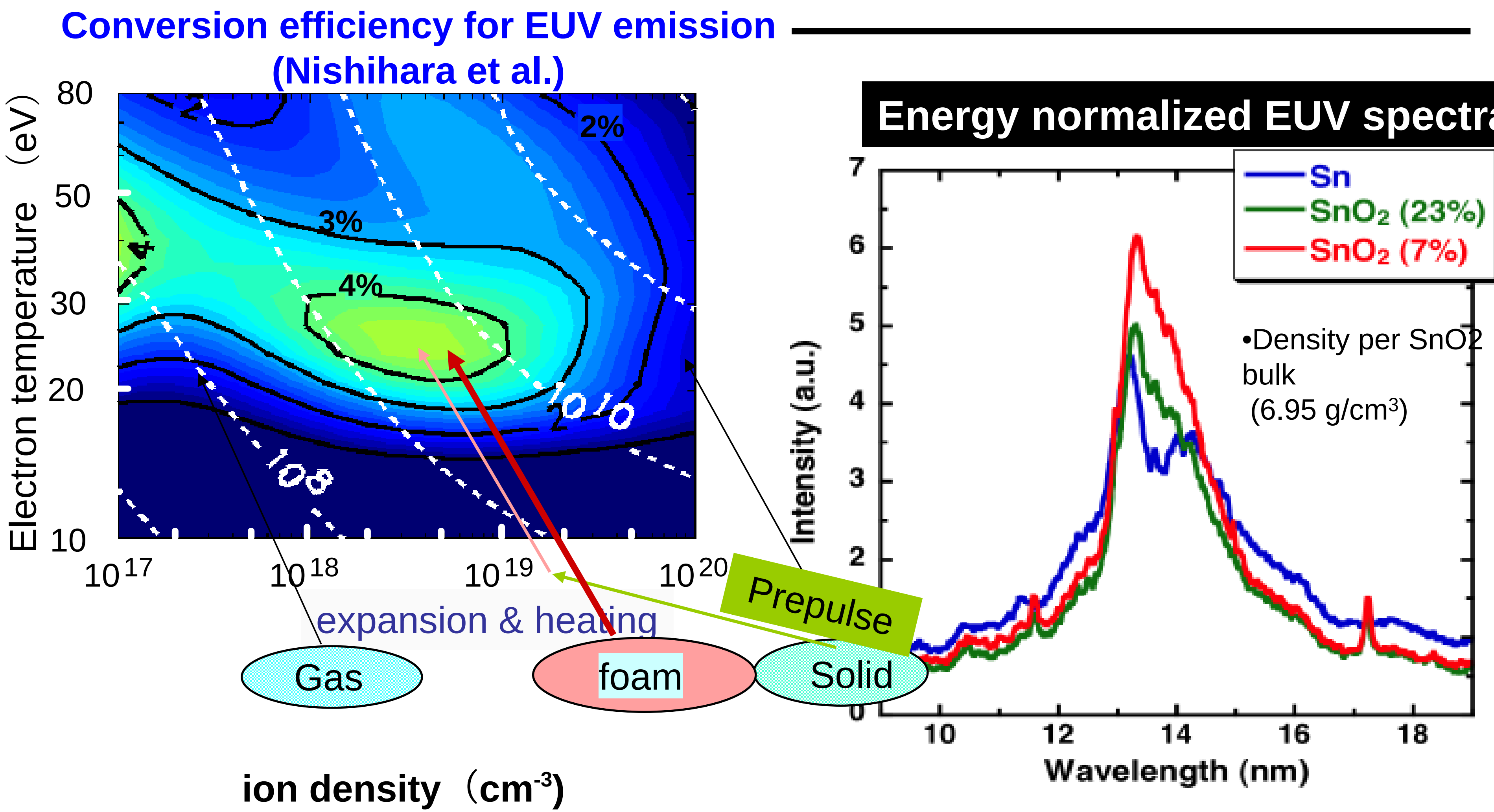
Extreme UV (EUV) lithography system design



Reflection of Mo/Si mirror

Theoretical analysis gave a mapping of conversion efficiency

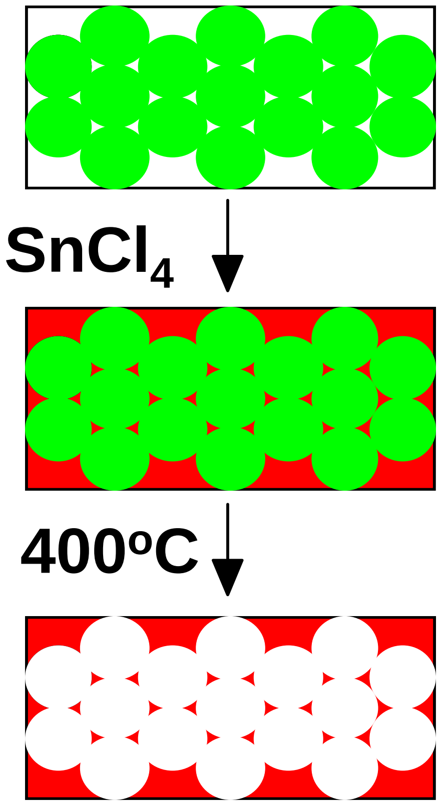
30 eV, $10^{18} \sim 10^{19}$ cm^3



10 ns, 1064 nm

Appl. Phys. Lett., **88** (16), 161501 (2006).

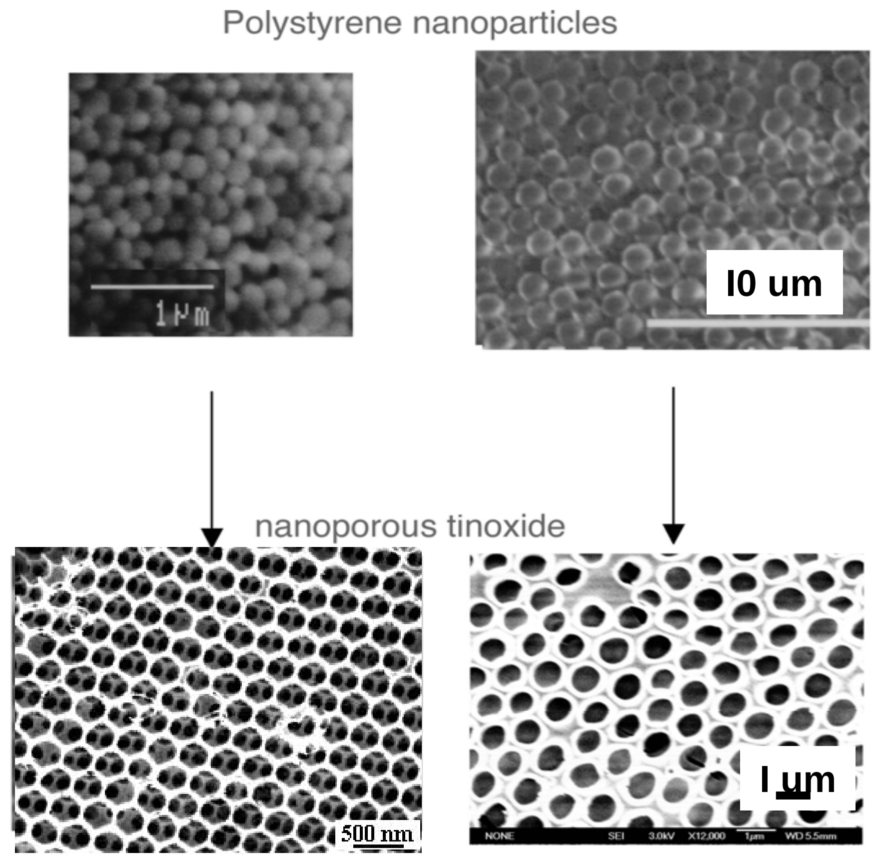
Low density tin oxide (d=1.5g/cm^3) using nanotemplate (23 % of bulk crystal)



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.

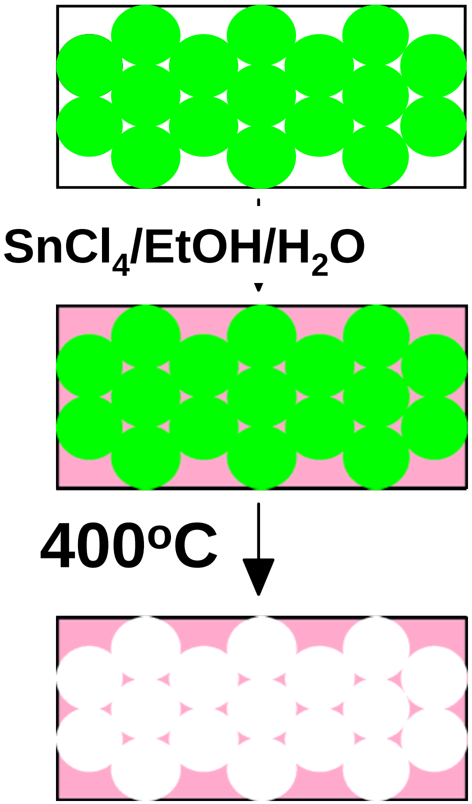


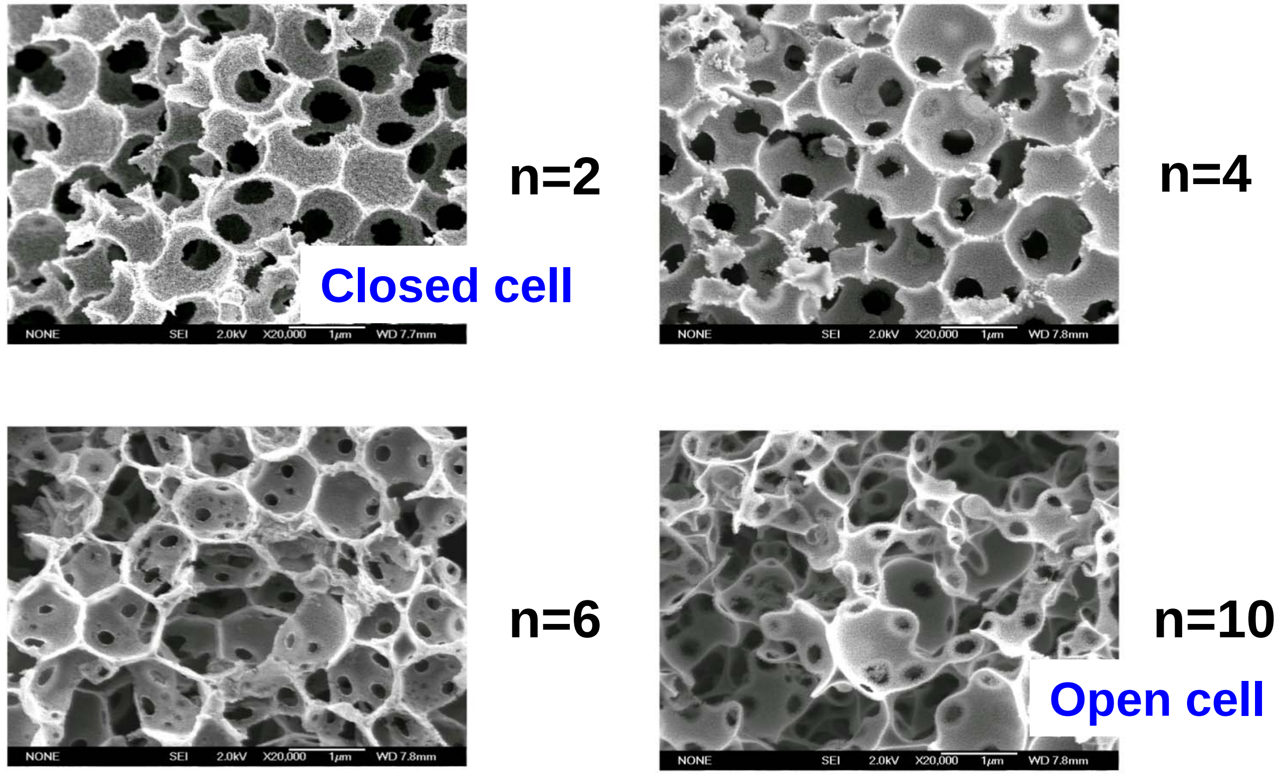
Pore size was well controlled by the template spheres.

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)

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



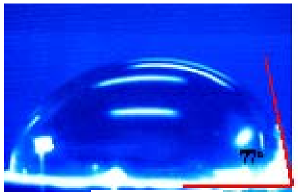


There were various morphologies.

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

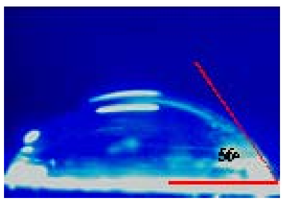
Volume template vs. Surface template

Contact angle on polystyrene film

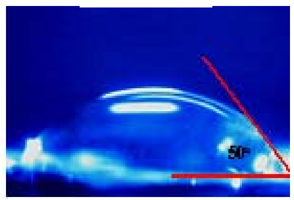


n=2

n=4



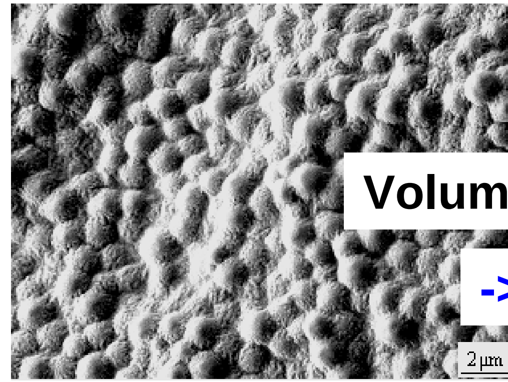
n=6



n=10

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

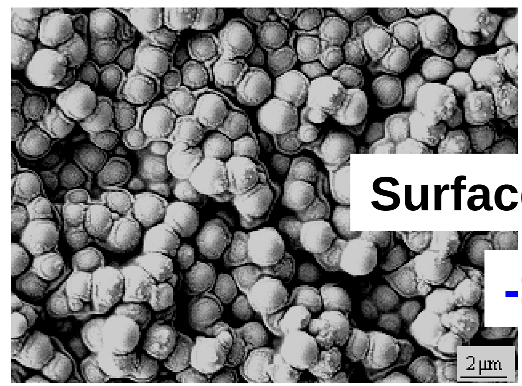
SEM images before heating at 400 ^{o}C



n=2

Volume template

-> Closed cell



n=10

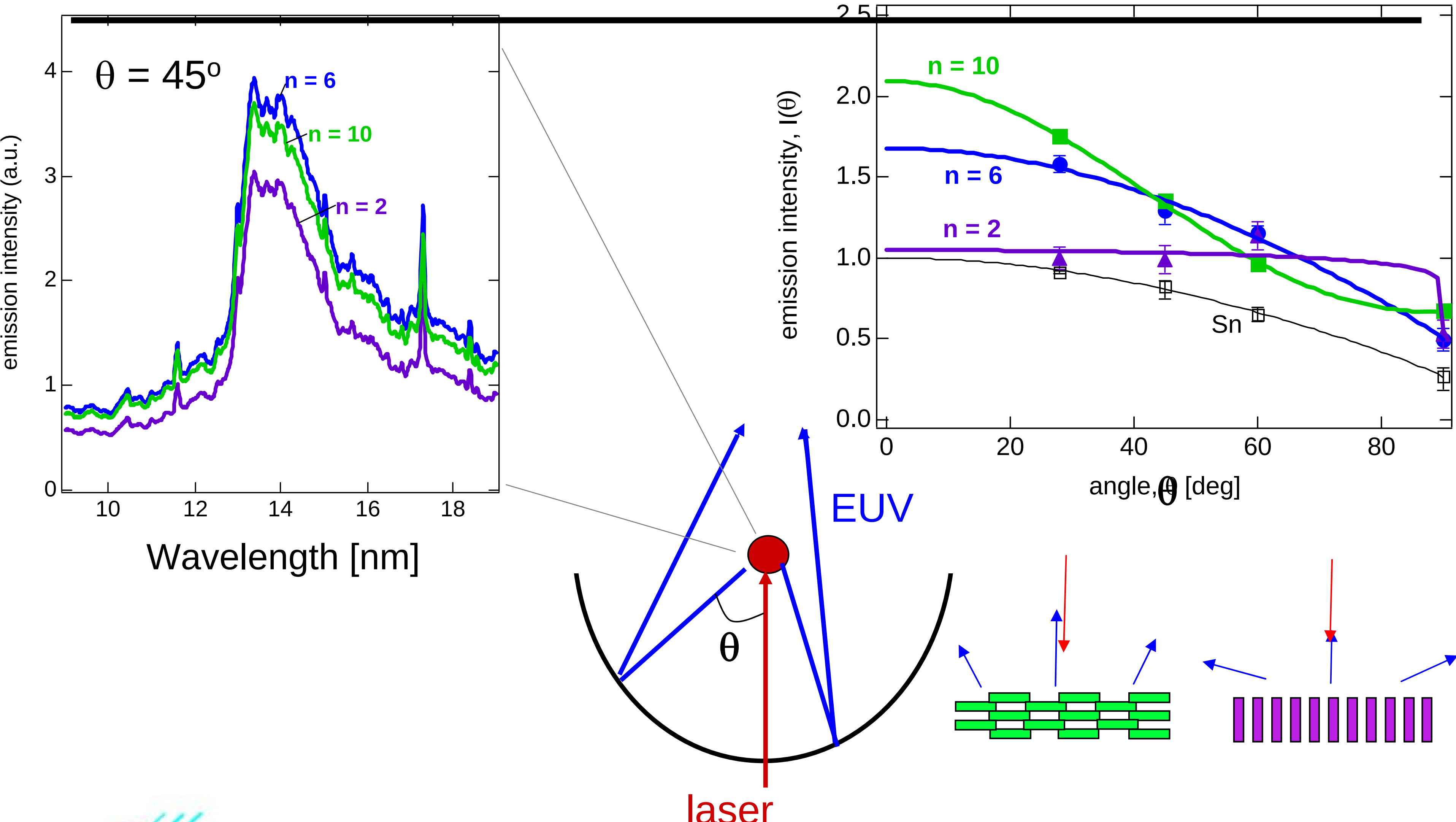
Surface template

-> Open cell

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

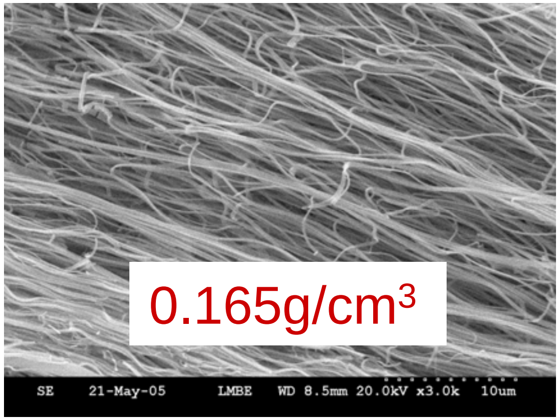
Q.C.Gu et al., Chem. Mater., **17** (5), 1115-1122, (2005).

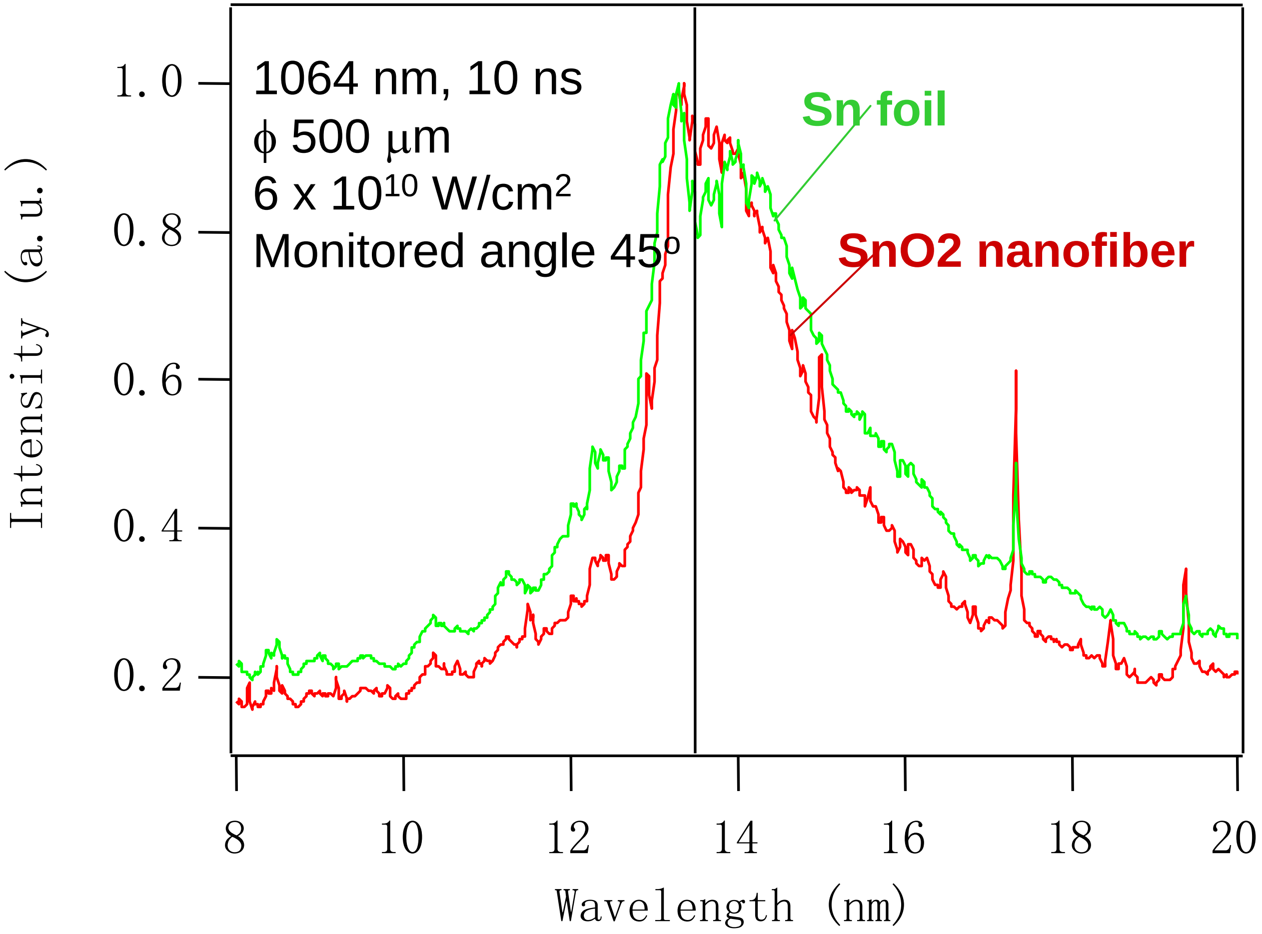
Control of angular distribution depending on target surface morphology



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

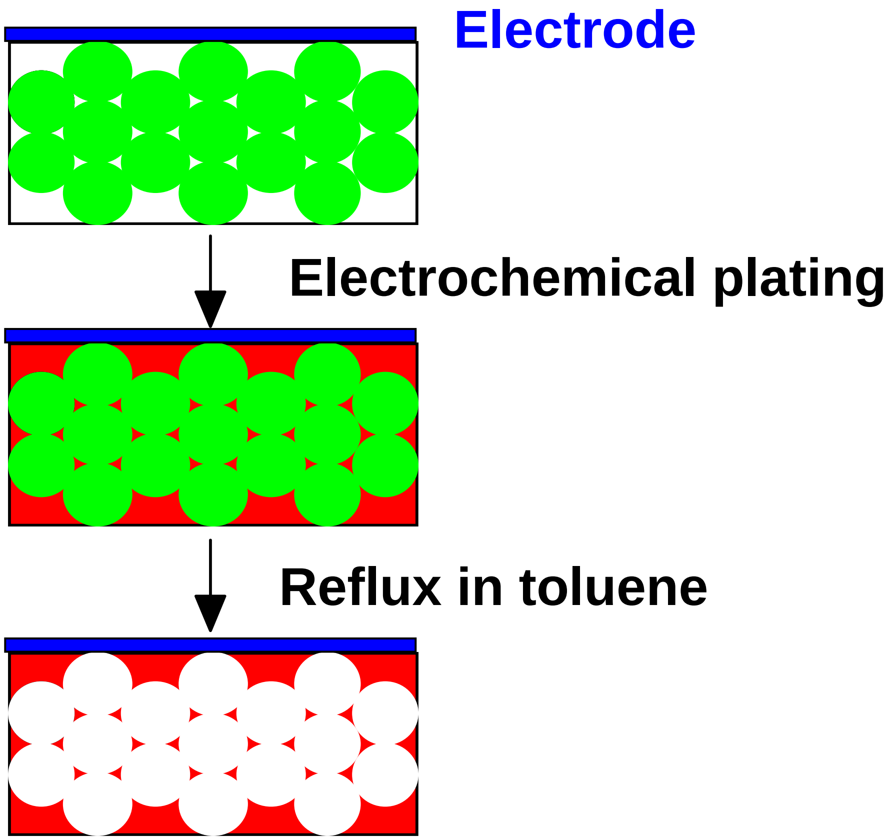
Nanofiber is an oriented low-density target.

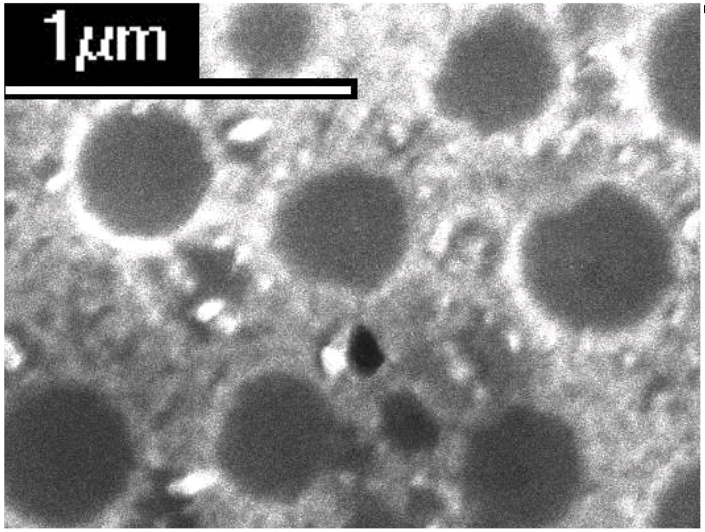


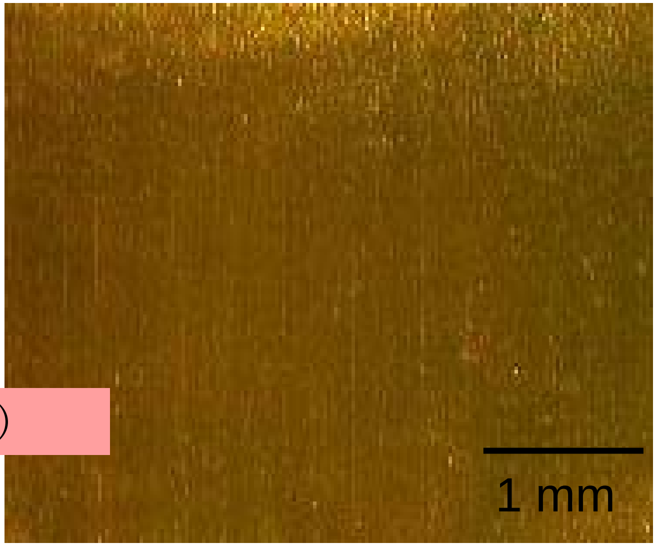


C. Pan, Z.-Z. Gu, K. Nagai, T. Norimatsu, et al., *J. Appl. Phys.*, **100** (1), 016104, (2006).

Au foam was prepared using nanosphere template.







Thickness: 2 μm, Density: 4.3g/cm^3 (23% of Au)

Fusion Sci. Technol., **49** (4), 686-690, (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

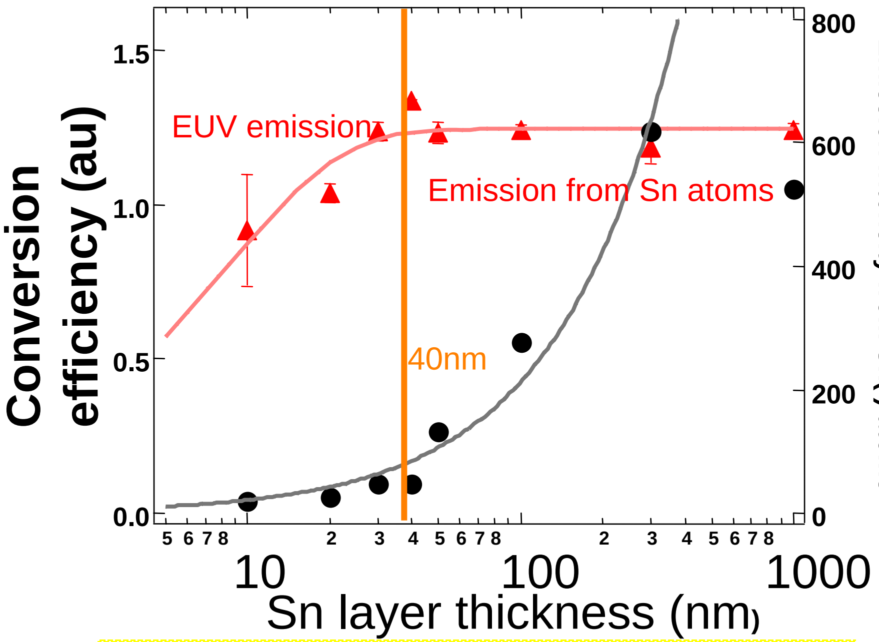
Lifetime of apparatus > 30, 000 hours （3.4 year）

Cost of Ownership

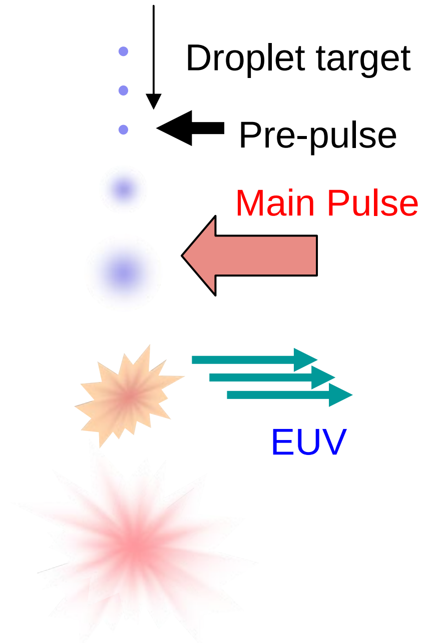
High rep irradiation requires

not only mass production but also minimum mass target.

Coating thickness of 40 nm is enough to produce high power EUV emission.



Emission from Sn neutrals linearly increases with coating thickness while keeping constant in EUV intensity.

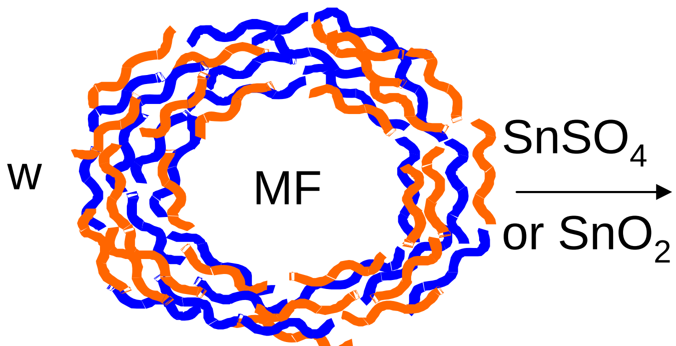


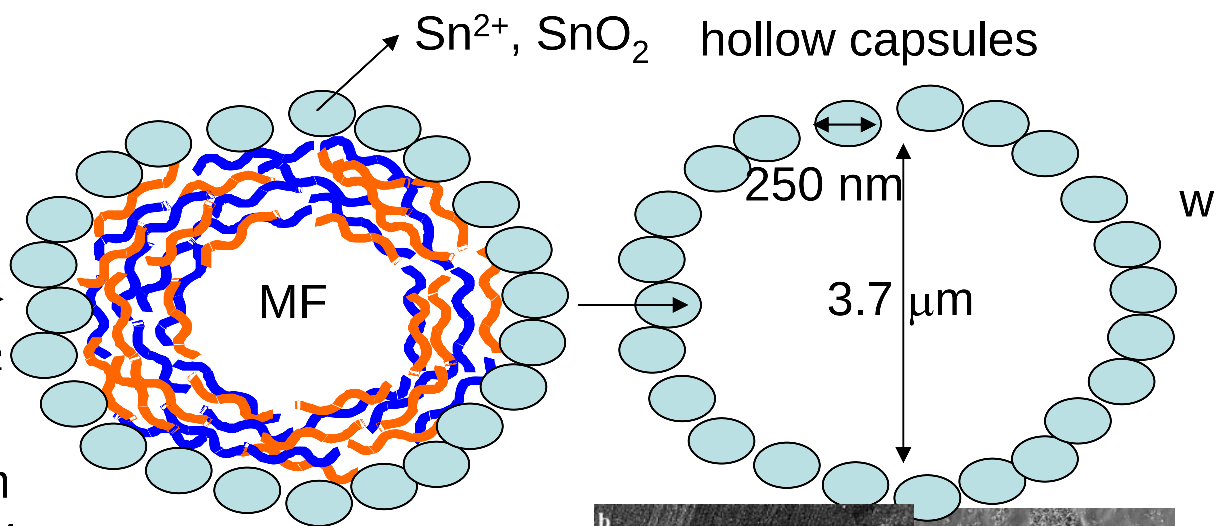
Sn droplet

Main pulse irradiation
Intensity: ~10^{11} W/cm^2
Pulse width: ~10 ns

S. Fujioka et al., Appl. Phys. Lett. 87, 241503 (2005), S. Namba et al., Appl. Phys. Lett. 88, 171503 (2006).

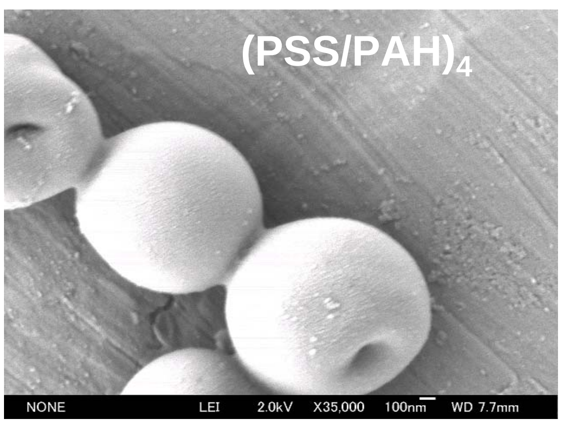
Microbubble targets prepared from a MF template and layer by layer (LBL) coating

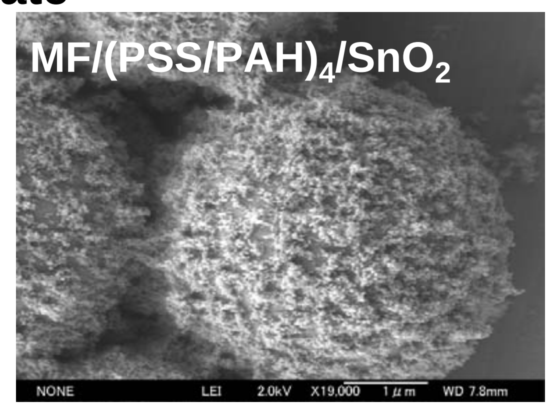


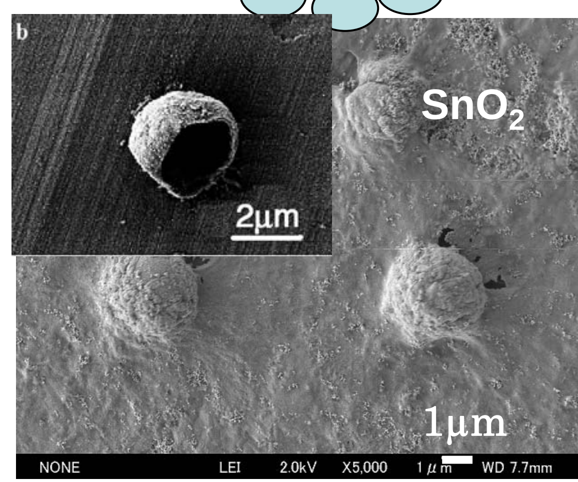


Capsule size: 500nm, 1um, 4um

Obtained from **colloidal template**





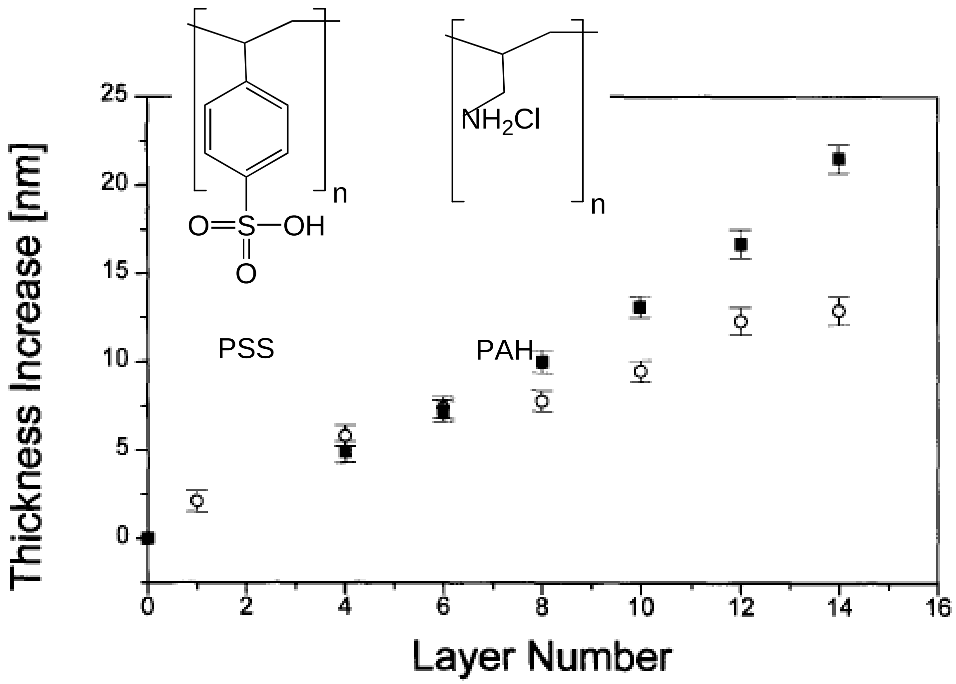


72% length (shrinkage)

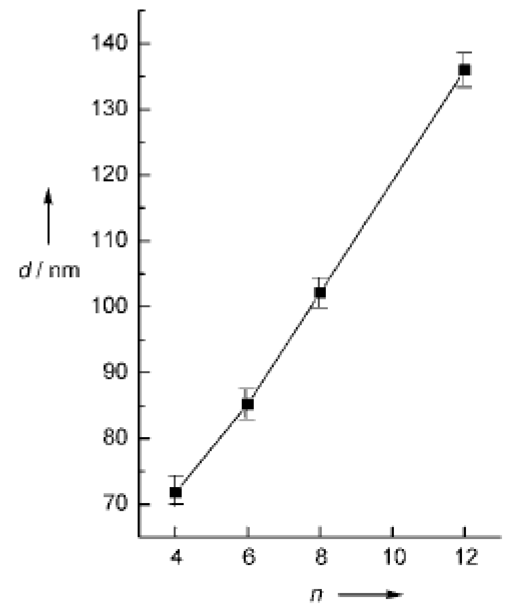
14 mg/cm³

LBL coating is well established technique.

The thickness of each layer has been reported to be 2~7 nm.



Layer thickness as measured by single particle scattered light intensity as a function of layer number. PAH/PSS coated 640 nm Ø polystyrene sulfate latex particles. Data calculated assuming n_{layer}= 1.47. • =layer deposition with the centrifugation technique;O = subsequent addition of polyelectrolyte without centrifugation.

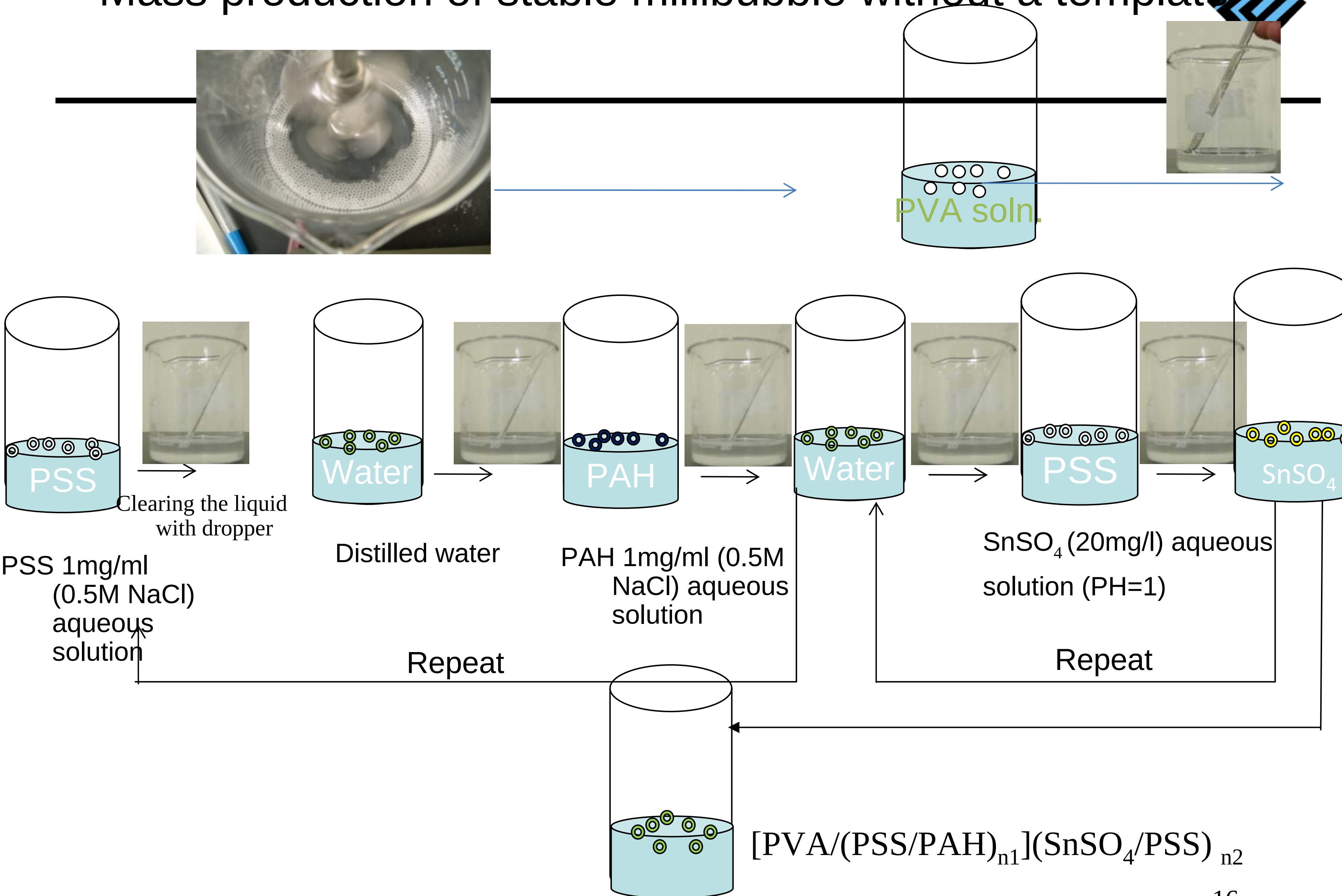


The relationship between the thickness d and the layer number n. (tween:span/(PAH/PSS)$_n$

Angew. Chem. Int. Ed. 2005, 44, 3310 –3314

Colloids Surfaces A: Physicochem. Eng. Aspects 137 (1998) 253-266

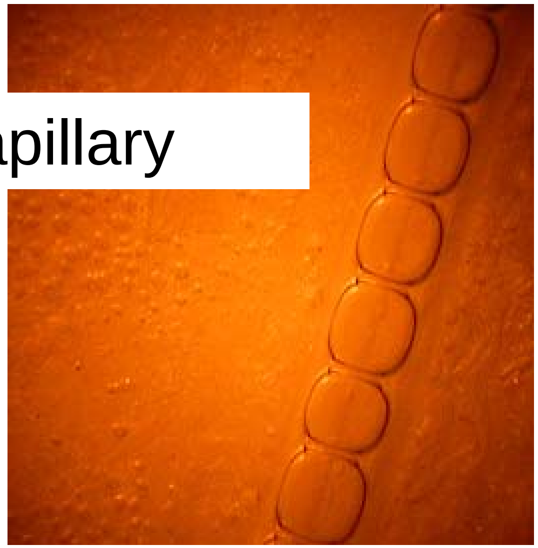
Mass production of stable millibubble without a template



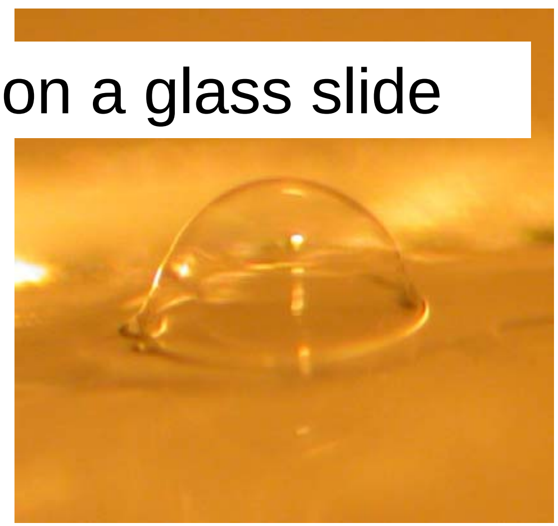
Tin coated millibubble

$[PVA/(PSS/PAH)_3](Sn^{2+}/PSS)_3$

- in a capillary



- Dried on a glass slide



The amount of tin atom per one capsule was estimated to be

0.9×10^{15} atom for $[PVA/(PSS/PAH)_3](Sn^{2+}/PSS)_3$

3.2×10^{15} atom for $[PVA/(PSS/PAH)_3](SnO_2/PSS)_3$

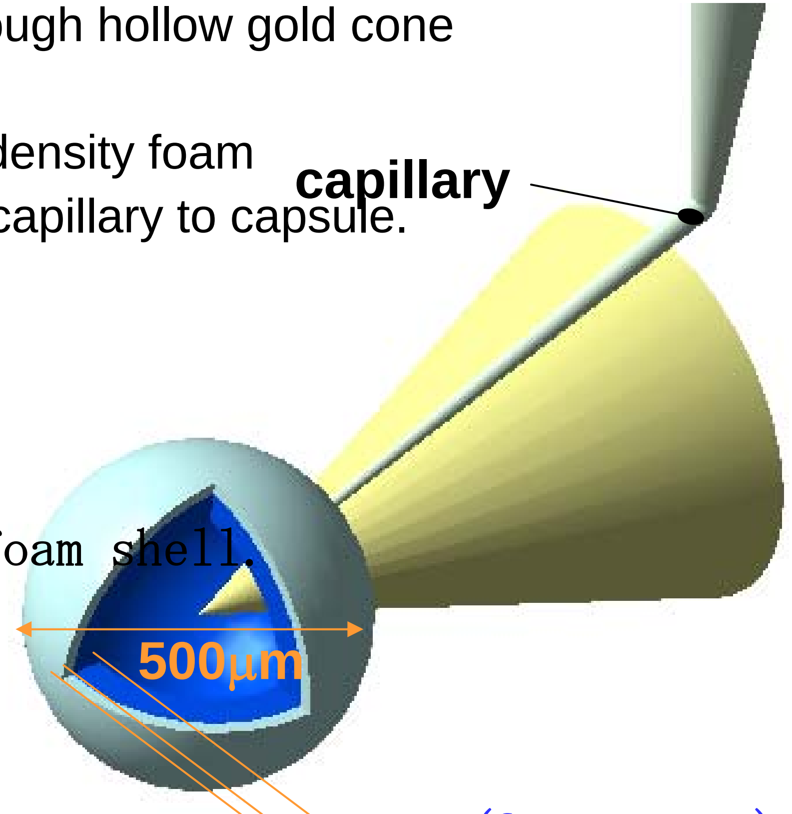
Low density materials for cryogenic foam targets

- Compression of fuel (spherical DT) using Gekko XII laser.
- Heating by LFEX (new petawatt) laser through hollow gold cone

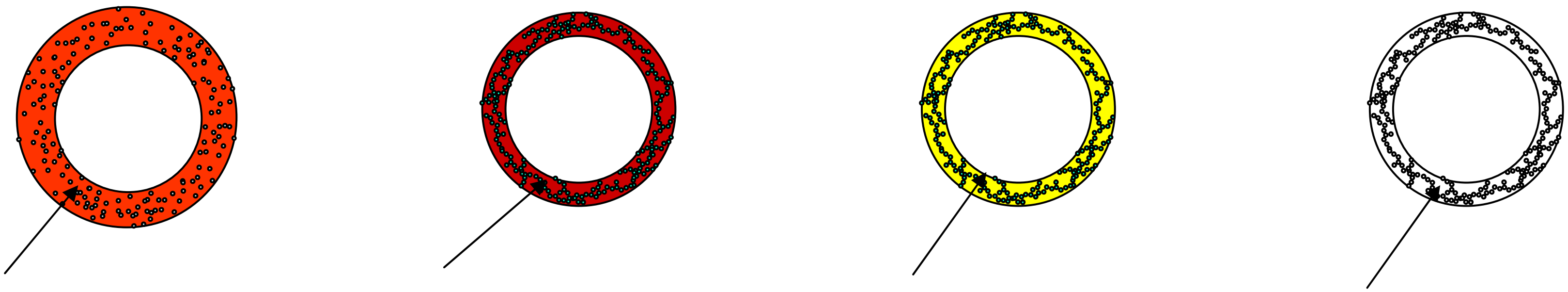
- The fuel capsule was prepared using low density foam and liquid DT will be infiltrated through an capillary to capsule.

Specification

- D_2 or DT fuel is infiltrated into a foam shell.
- Shell diameter : 500 μm
- Thickness of DT : ～20 μm
- Ablator thickness : ～5 μm



Aerogel capsule fabrication -4 steps-



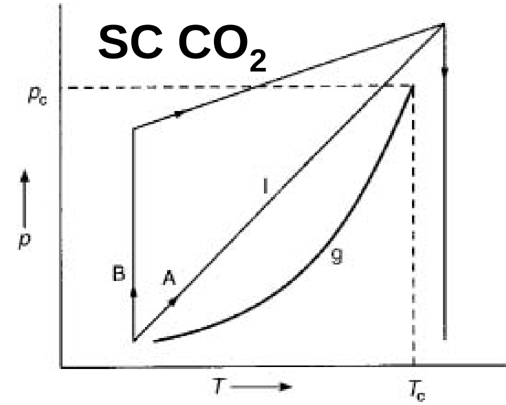
Precursor solution | Hydrogel | Wet gel | Aerogel

Droplet generator

Phase transfer catalyst

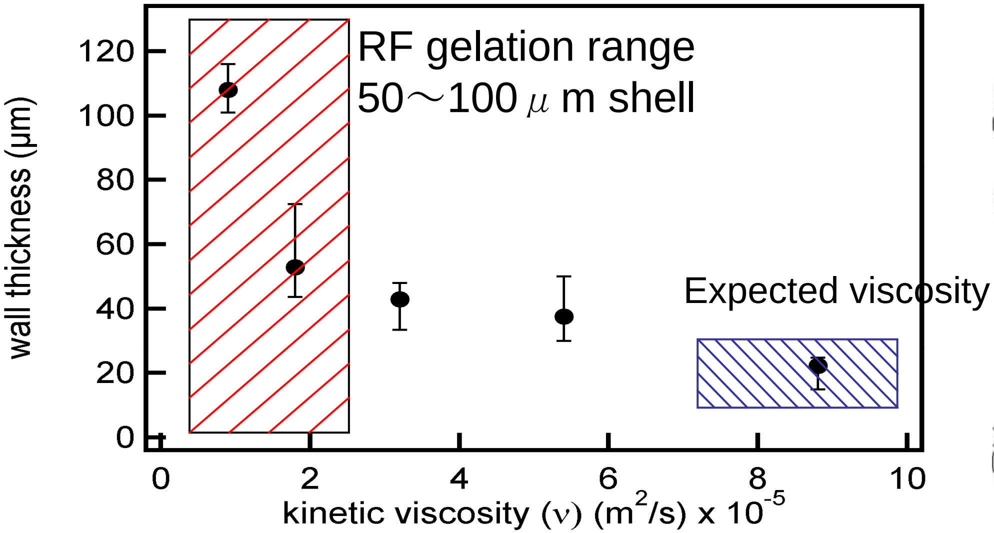
Porous structure control

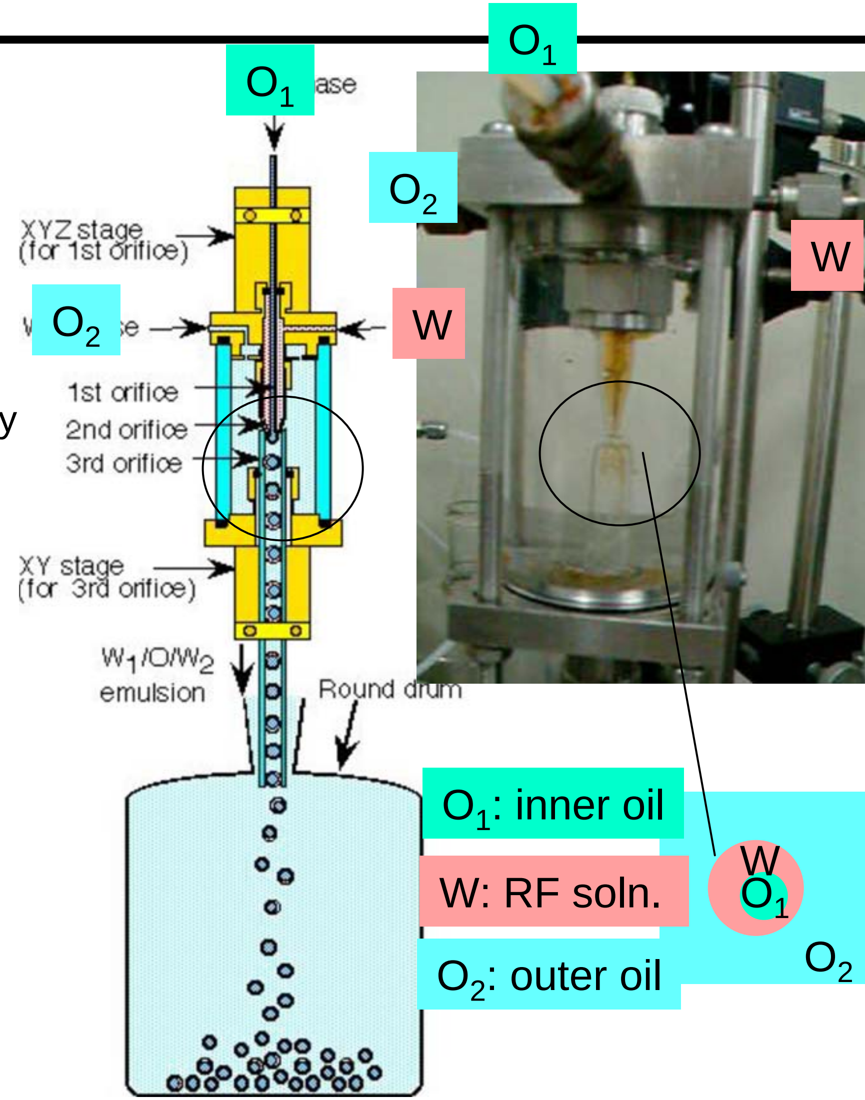
SC CO_2



aqua | aqua | organic solvent | gas

The thickness of W depends on its viscosity.



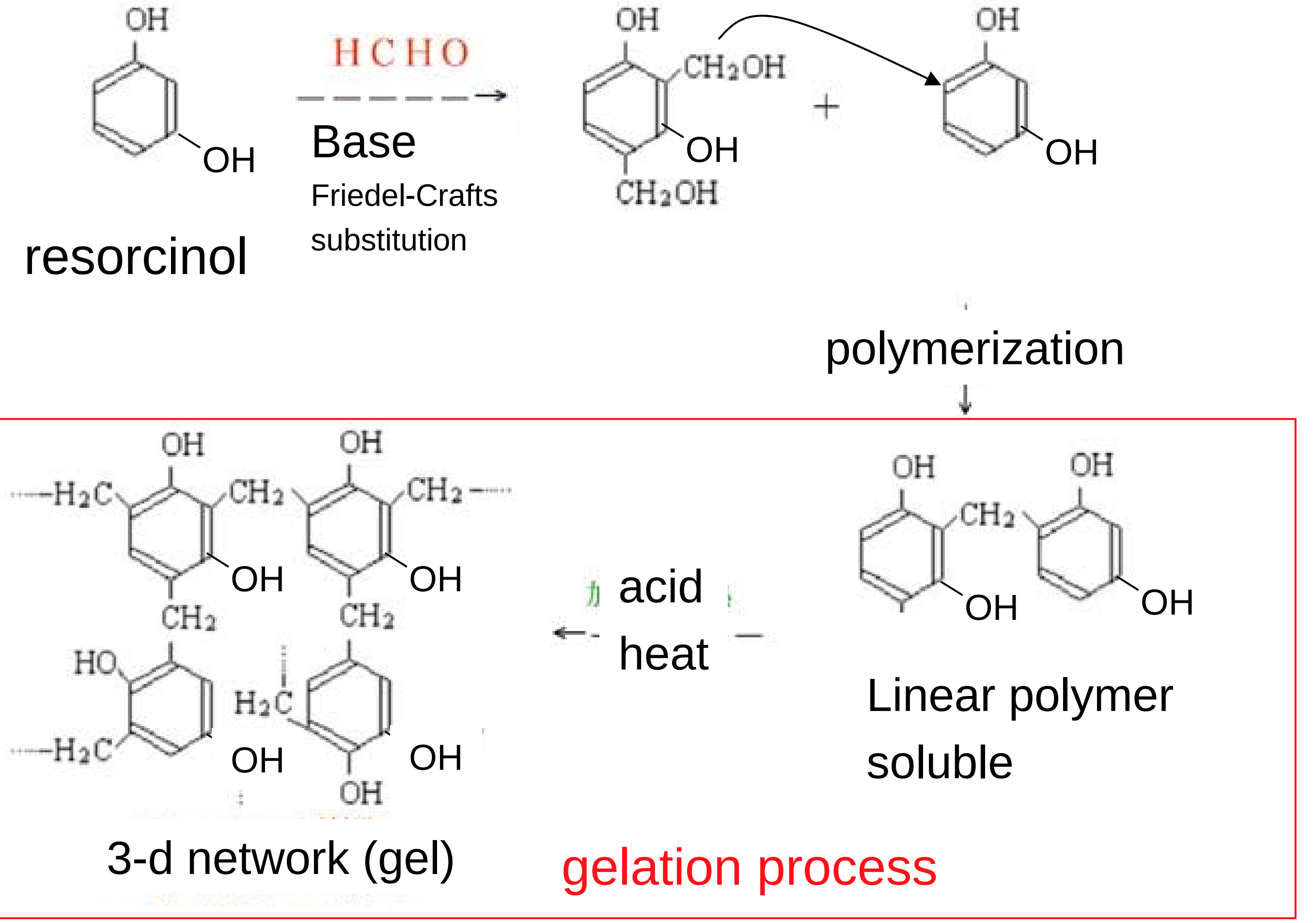


- The high viscosity induced thin wall thickness.
- Viscous RF solution is high concentration and cannot be applied for the emulsion process due to gelation.

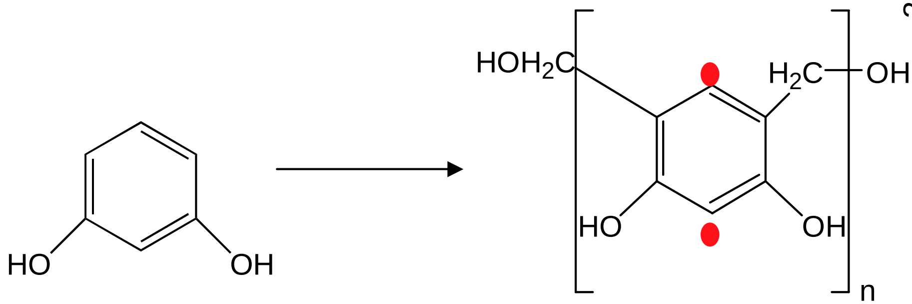
Ito, Jpn Appl. Phys. Lett. 2006

Gelation process is key issue to control density and capsule morphology, and it is chemical process of crosslinking of polymer chain.

•In the case of RF,



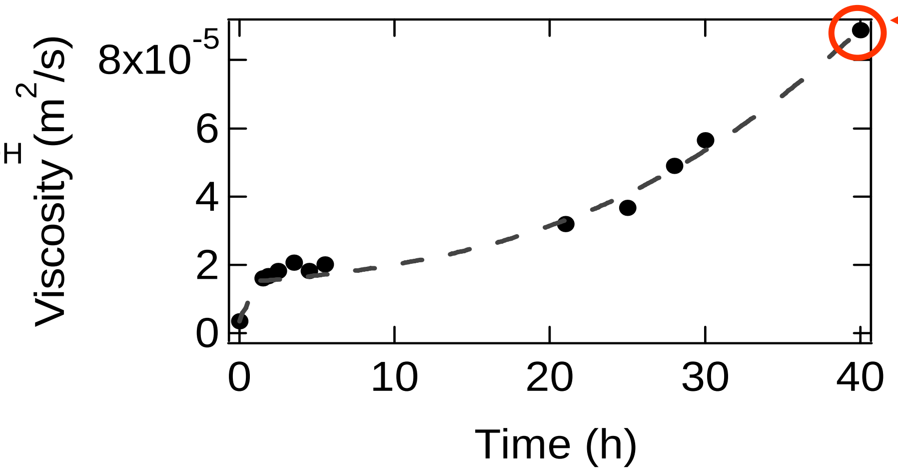
Linear polymer without crosslinker (•) increase its viscosity.



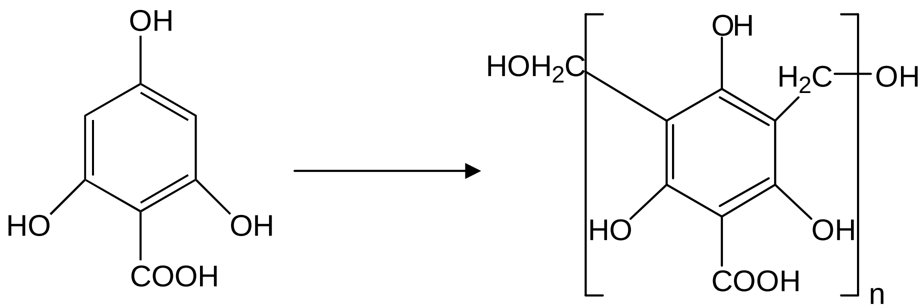
resorcinol

resorcinol/formalin (RF)

(linear)

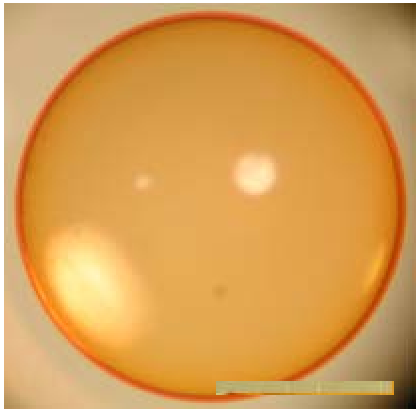


Polymerization of PF solution



phloroglucinolcarboxylic acid

phloroglucinolcarboxylic acid)/formalin (PF)

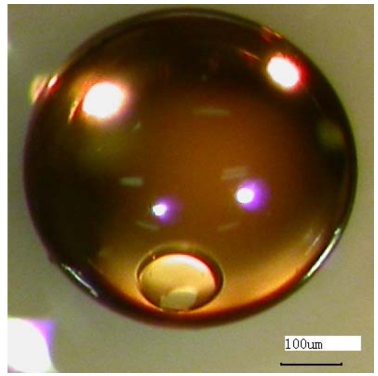


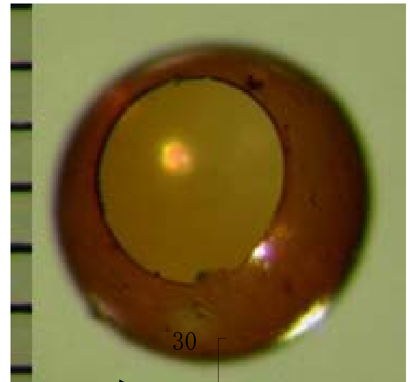
Yang, Laser Partcl. Beams 2008

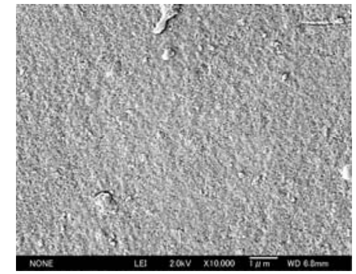
RF/PF foam shell

radius 252±0.3 μm
Wall thickness 19.3±1.3 μm

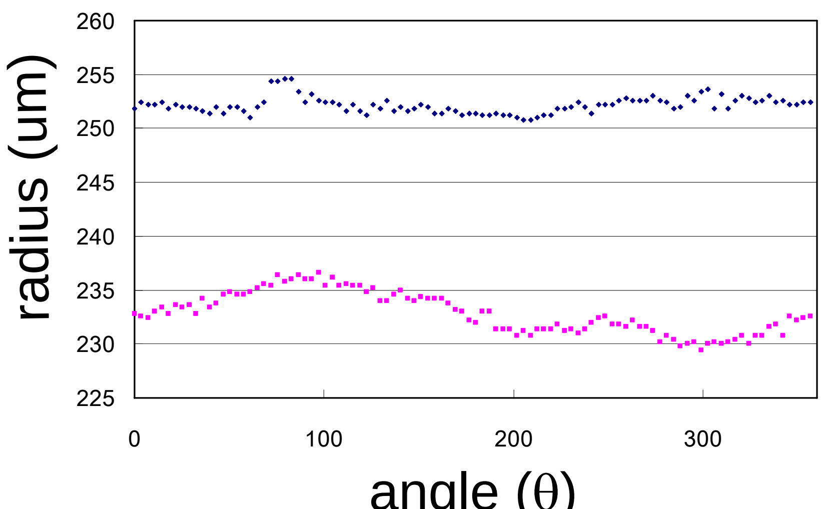
Target assembly



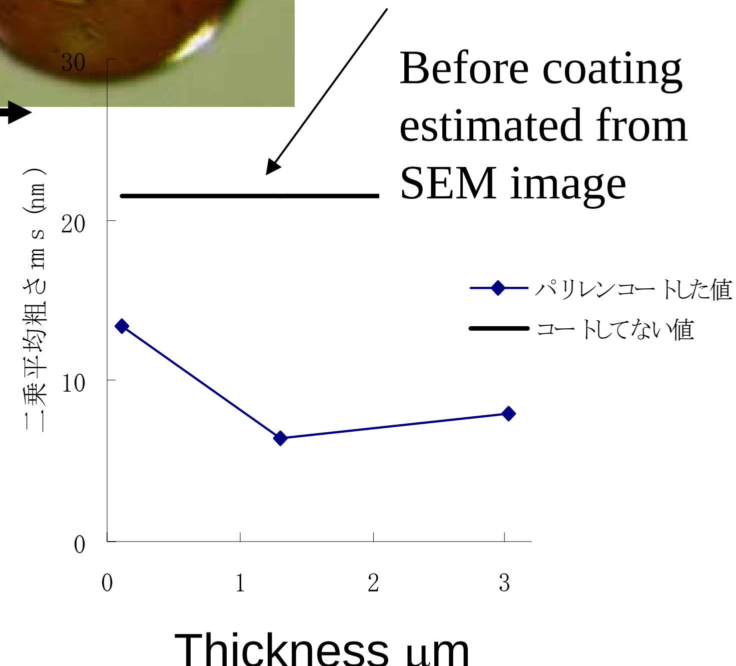




Hole drilling



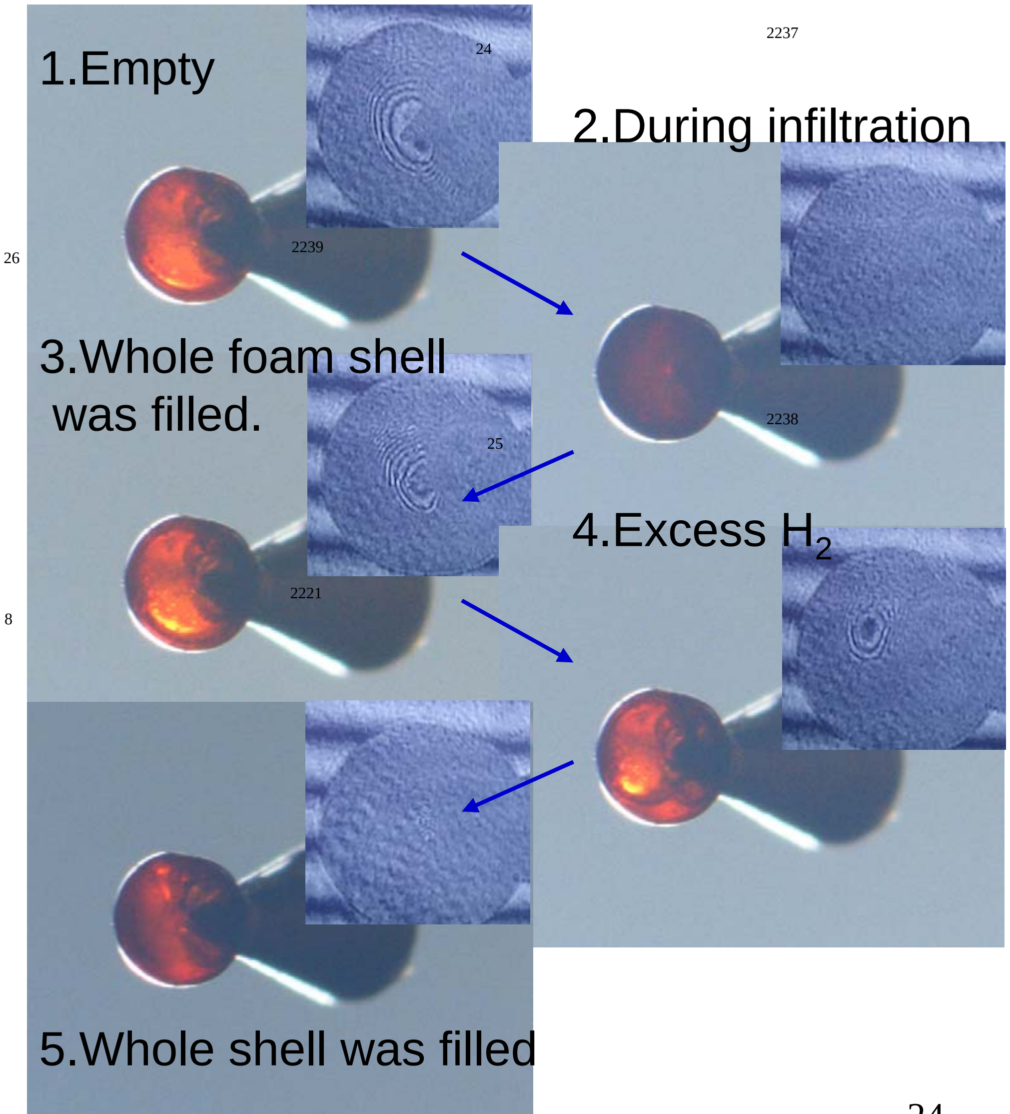
Inner and outer radius of foam layer depending on the angle.



Roughness estimated from AFM images depending on the ablator thickness

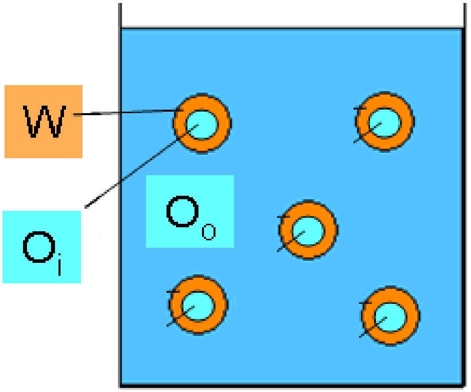
Cryogenic fueling test

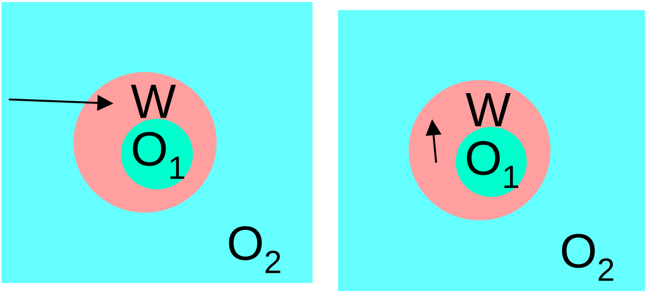
conditions
- gas temperature：12.5 K
- H_2 pressure：7.3 kPa



Iwamoto, Fusion Eng. Design 2007

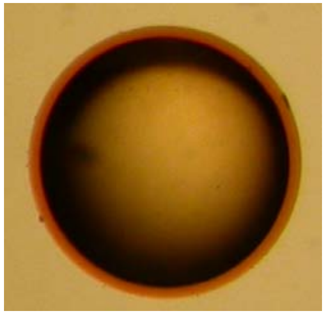
Phase transfer catalyst to keep density matching.





O_O: silicon oil mixture
$\rho = 1.018\ g/cm^3$
O_I: 1-methylnaphathlene
$\rho = 1.02\ g/cm^3$
W: PF aqueous solution
$\rho = 1.02\ g/cm^3$

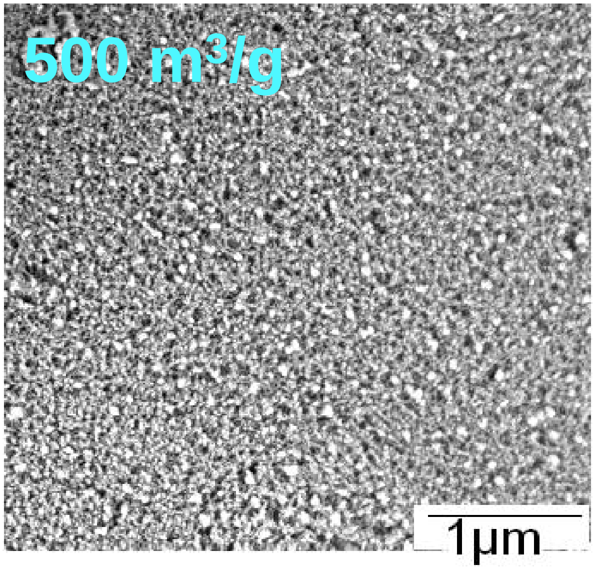
A phase transfer catalyst for gelation transfers from O to W (RF solution), while the previous catalyst for gelation was dissolved in W (RF solution) phase, and activated by heating.

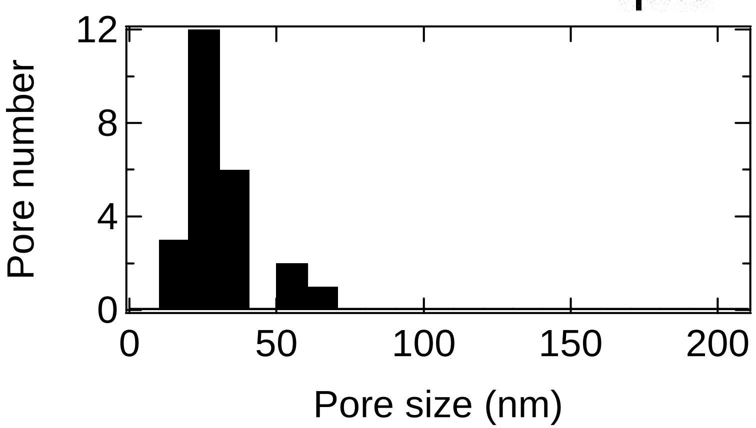


F. Ito, K. Nagai, M. Nakai, and T. Norimatsu: *Macromol. Chem. Phys*. **206** (2005) 2171.
F. Ito, K. Nagai, M. Nakai, and T. Norimatsu, *Fusion Sci. Technol*. **49** (2006) 663-668.

PF aerogel has finer pore than RF aerogel (32 ± 10 nm) with smaller distribution.

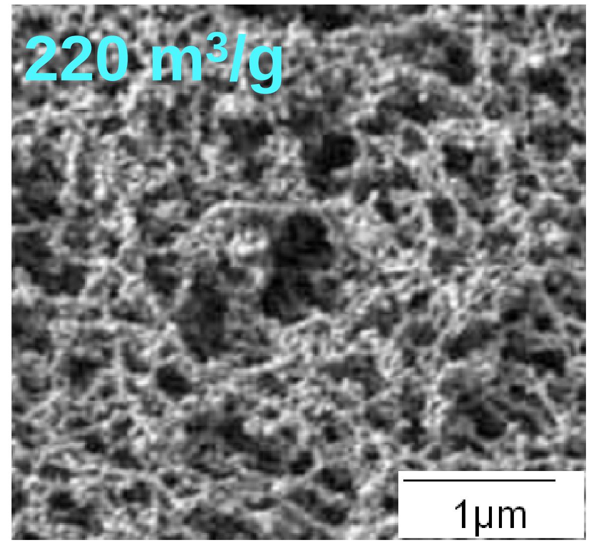
PF

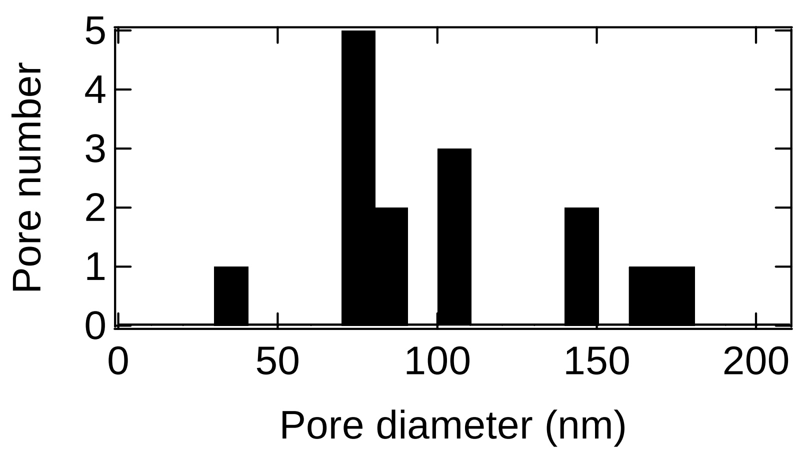




Particle network

RF



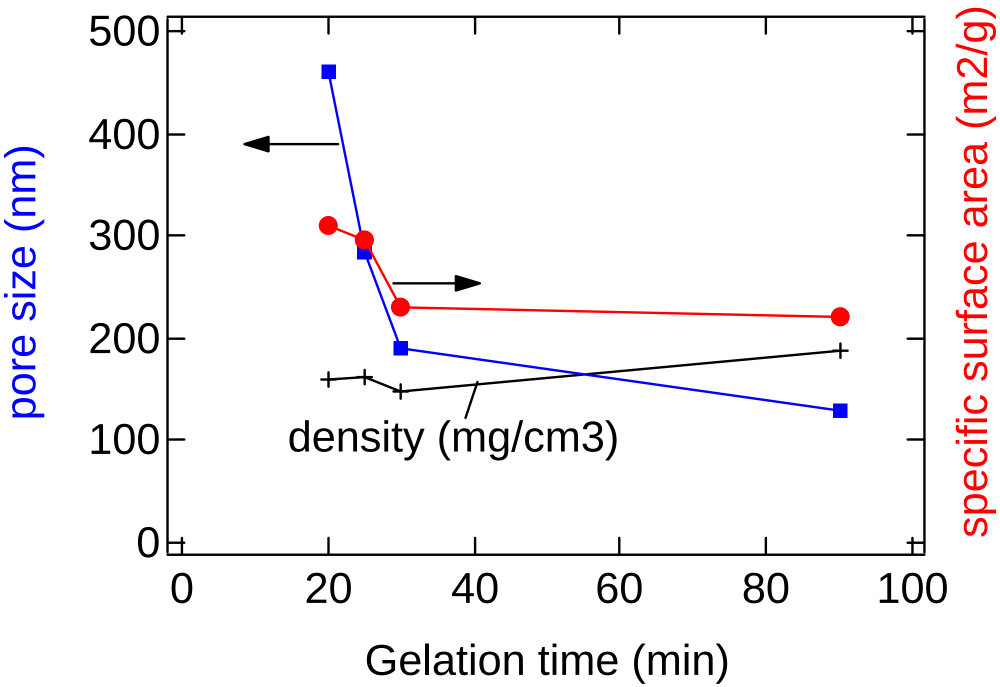


Fiber network

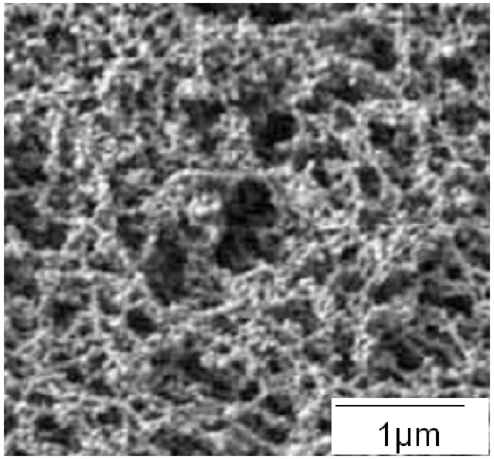
Yang, Laser Partcl. Beams 2008

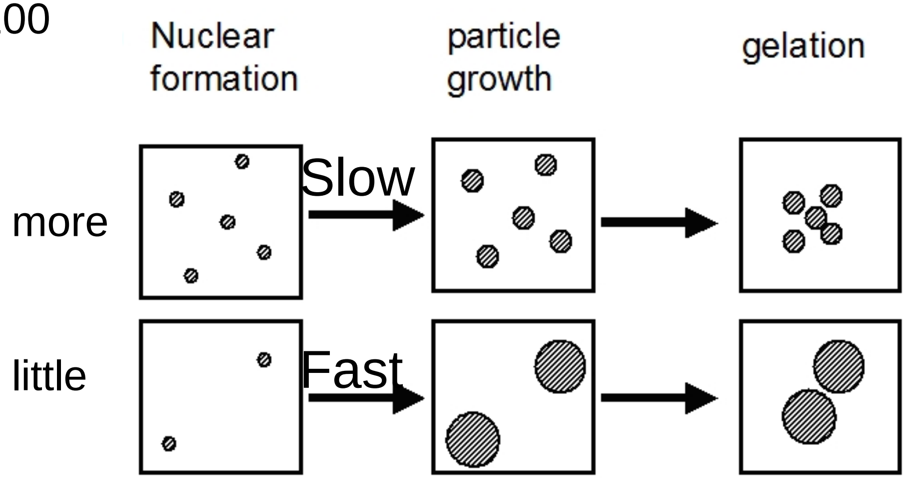
Network size:

little nuclear, fast particle growth -> high pore size, high surface area

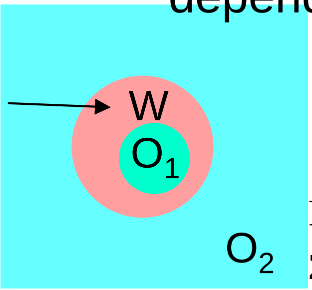


RF





Characterization of RF aerogel depending on gelation time.



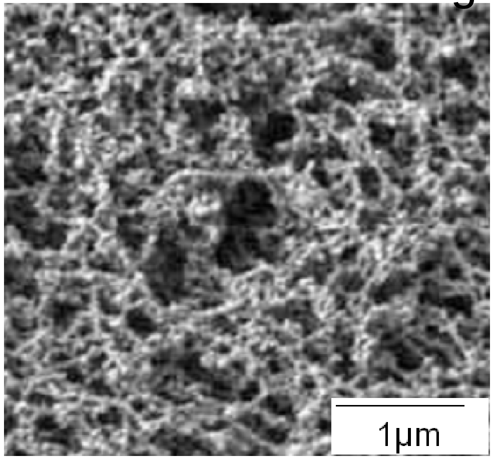
The gelation time was controlled by catalysts.

F. Ito, et al., *Macromol. Chem. Phys.*, **206** (21), 2171-2176, (2005).

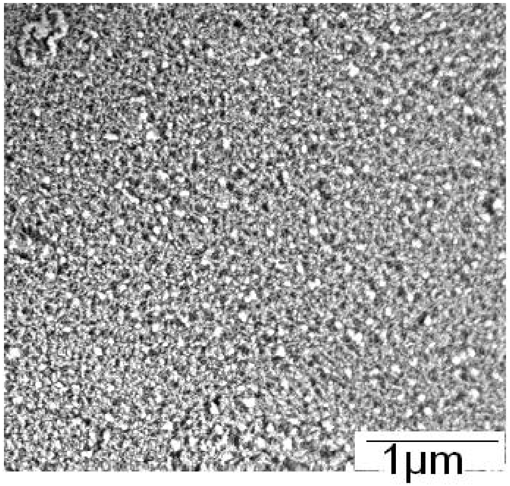
Network structure:

Labile bond -> particle like (reorientation of linkage)

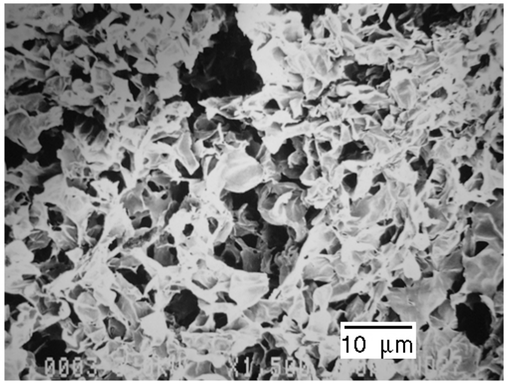
RF: covalent bond linkage (inert)



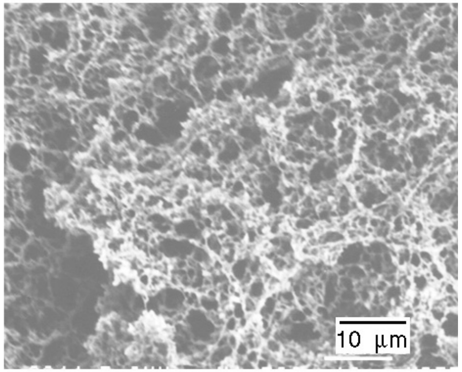
PF: hydrogen bond linkage (labile)



TMP (TPX) : van der Waars interaction (labile)



Gelation in a hexanol



Gelation in a butanol

Summary

1. Low density Sn and Au using template, electrospining
2. High rep target ----necessity of minimum mass target
3. Organic aerogel capsule
4. Discussion of nanostructure control