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EUV generation using a droplet of tin particle suspension

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This work is supported by NEDO

for EUV Power of 120 W @IF

(assumption: 1 collector of **R=60%**, & debris mitigation **T= 80%**)

collection angle	120 degree (0.5 x 2π sr)	60 degree (1/7 x 2π sr)
Conversion Efficiency	= **3.5 % /2π sr**	
Laser Power or Heat dissipated in vacuum	14 kW	50 kW
	= **0.5 % /2π sr**	
Laser Power or Heat dissipated in vacuum	100 kW	350 kW

CE>2% x **π sr collection** & **small spot** is critically important !!

Unique choices

Sn & **uniform density gas target**

from the work by G.O'Sullivan

LPP

from the work at AIST

Tatsuya Aota and Toshihisa Tomie*, PRL **94,** 015004 (2005)

Ultimate Efficiency of Extreme Ultraviolet Radiation from a Laser-Produced Plasma

Conclusion of the theory

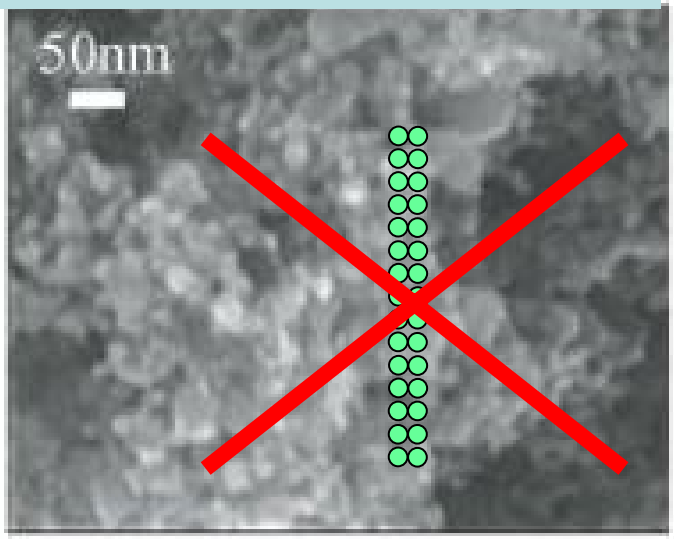
Ions should stay in the emitting region during laser heating

=>Deepness of target is essential for a high CE

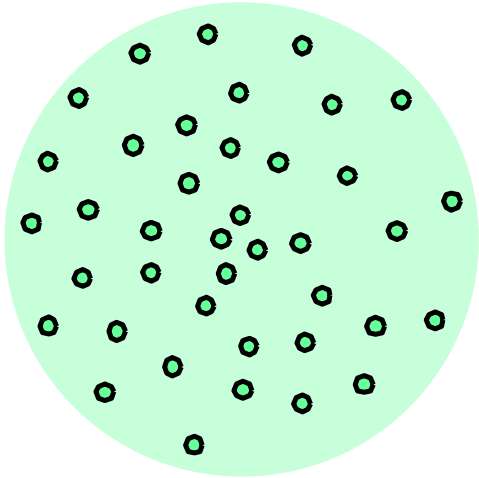
For ultimate CE $t_{laser} = L_{abs}/V_{exp}$;

$1/n_{e;opt} = (aZV_{exp}t_{laser})^{1/2}$

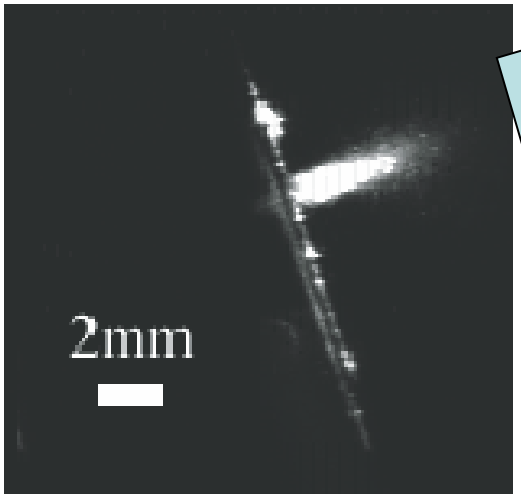
low density **Thin biscuit**

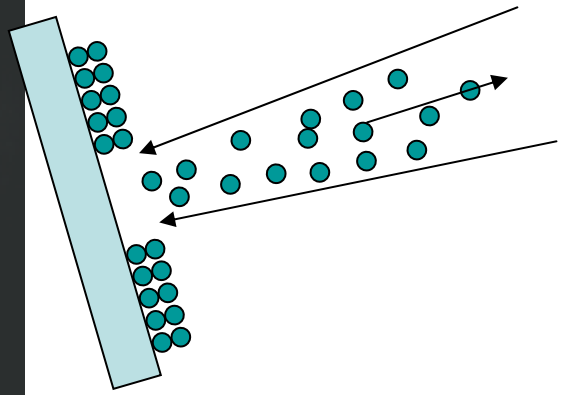


low density **Cotton candy**



High CE by a dispersed particle target

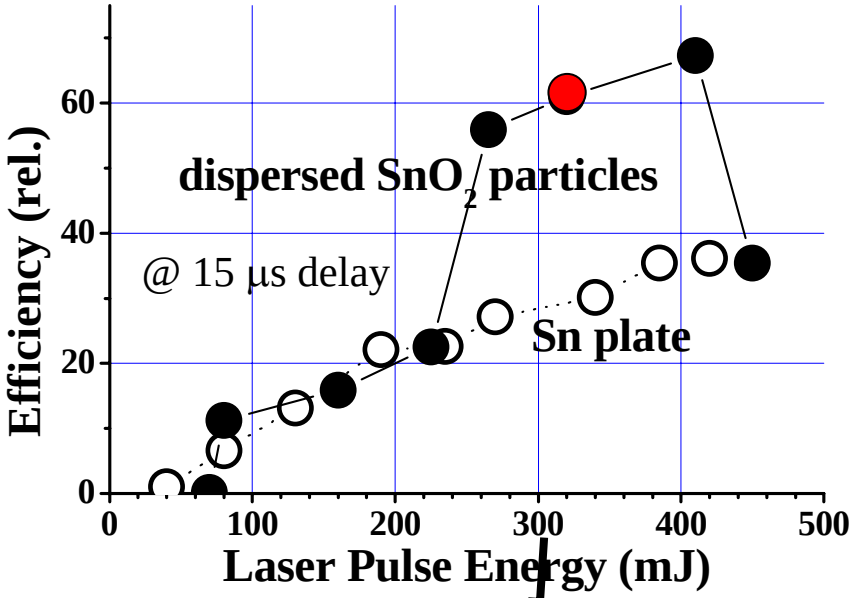




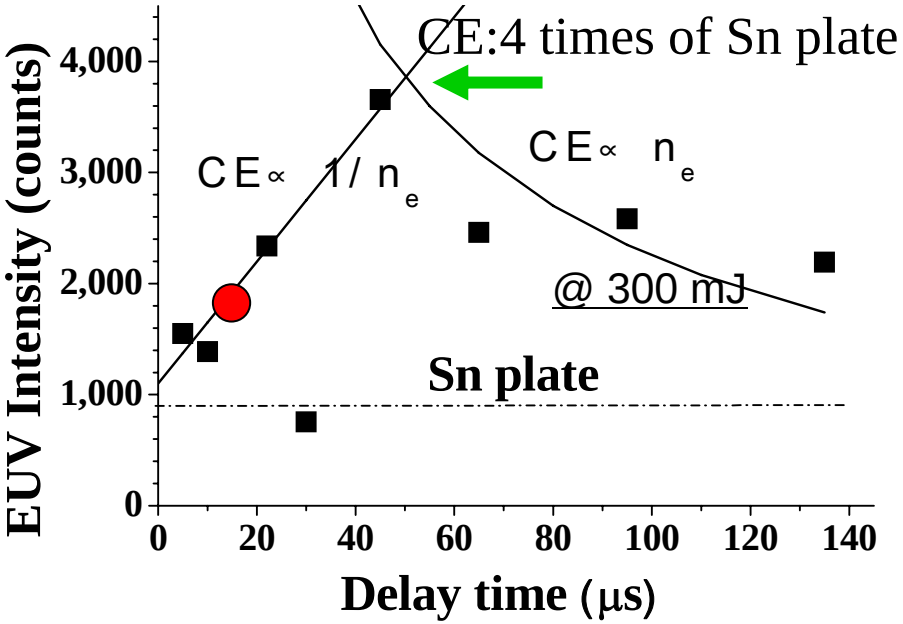
Dispersion of particles
by a laser-induced shock

for 1. deep target
2. low density

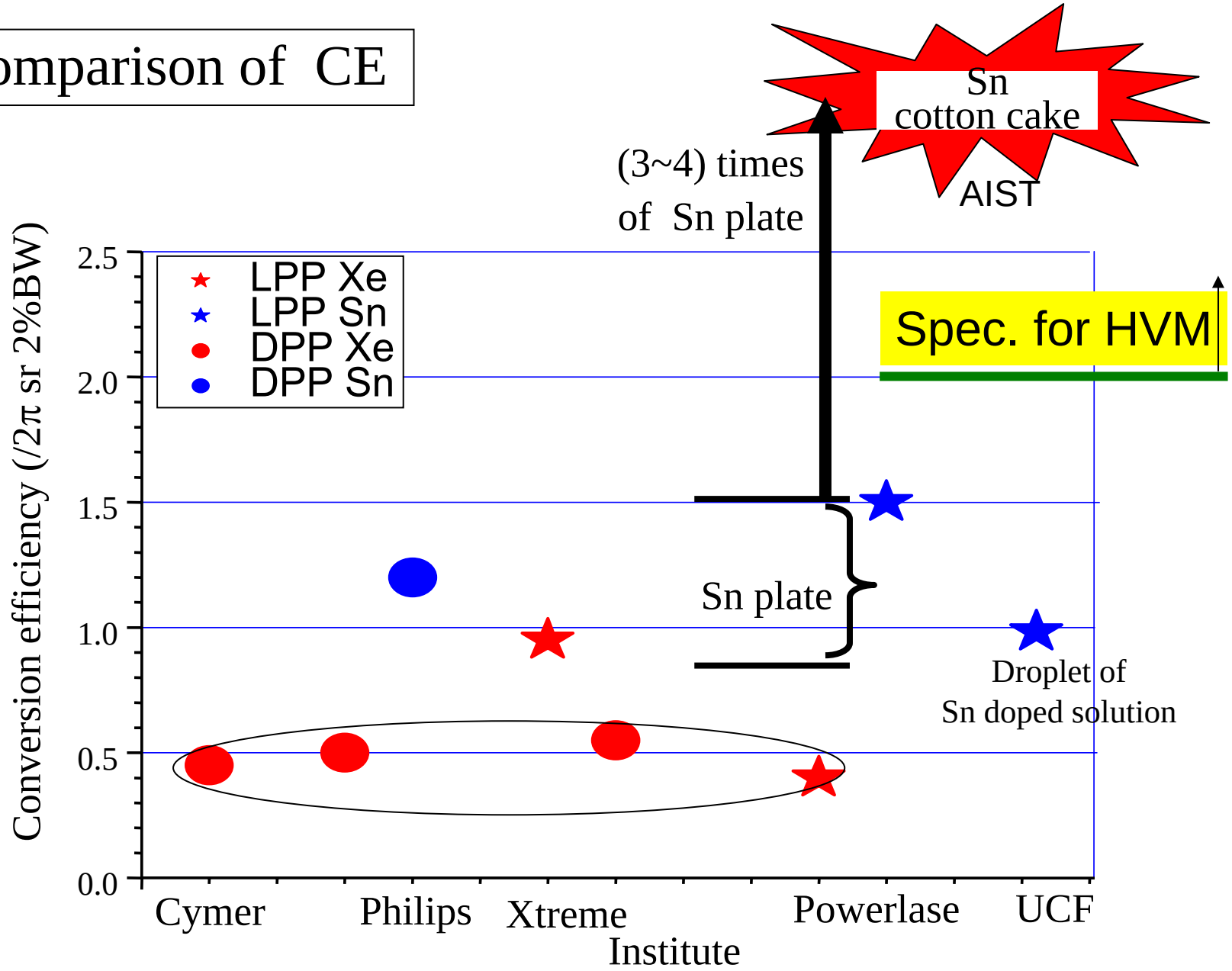
from PRL **94,** 015004 (2005)



5E10 W/cm^2



Comparison of CE



from “Optimized parameters for generating a laser-produced tin plasma as a source for high volume production” Poster

Expected efficiency

CE = 10%/2 x 0.86 x 0.94 = **4% /2πsr**

spectral efficiency laser absorption radiation efficiency

Parameters

Electron temperature T_e ~ 50 eV

I_{laser} ~ 2.5E10 W/cm^2 E_{laser} ~ 1.5 J /pulse

t_{laser} ~ 8ns

Sn ion density n_i~2**E18cm^2**

Pumping laser λ_{laser} ~ 1 μm

Cost of YAG laser

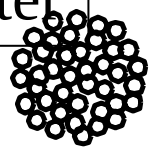
LD power: **15kW**/20% =75 kW LD cost: $10/W X75 kW= **$0.75M**

Specifications for target delivery

1. repetition rate **10 kHz**
2. mass equivalent to **30-50 μm diam. solid** sphere
3. cost $0.3 M/ year (=3E11 shots) => **$ 1 /1E6 shots**

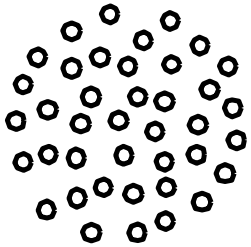
How can we supply cotton-cake-like Sn target

Particle-cluster



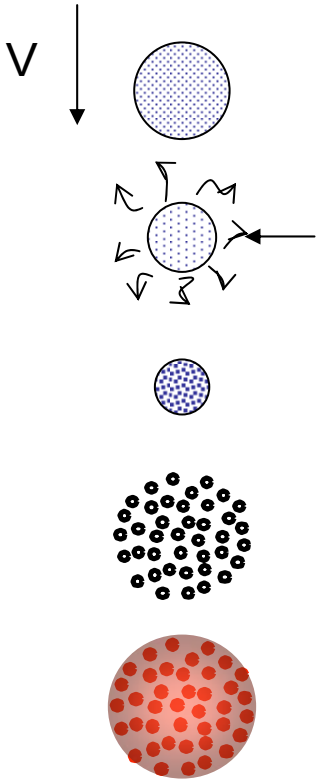
during delivery

Dispersion of the cluster



Cotton cake

just before plasma generation



#1 suspension

#2 evaporation

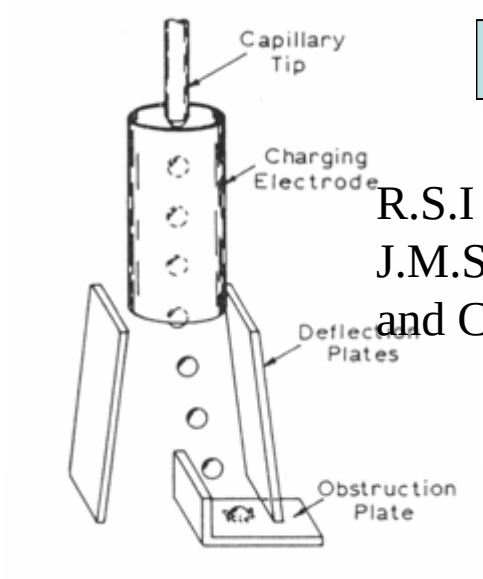
particle-cluster

#3 cotton cake

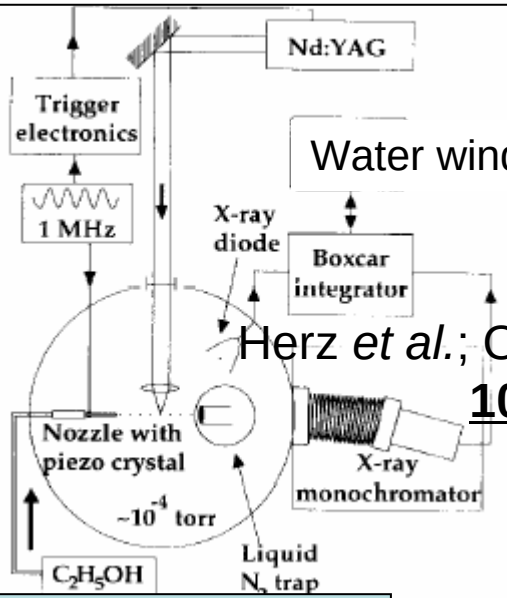
#4 no-gradient density plasma

Use of a suspension itself was historically obvious

1. Use of droplets



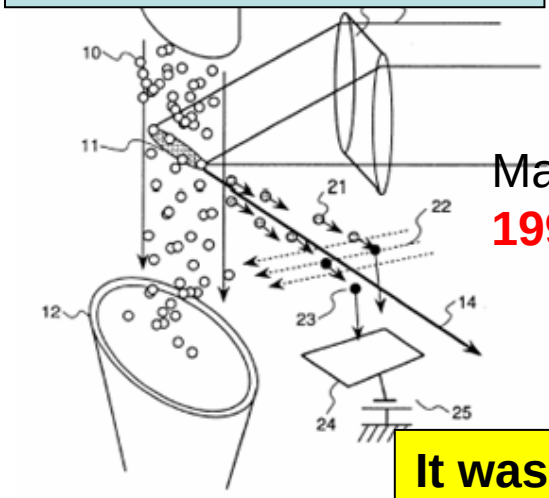
R.S.I **35** (**1964**) 1349
J.M.Schneider
and C.D.Hendricks



Water window emission

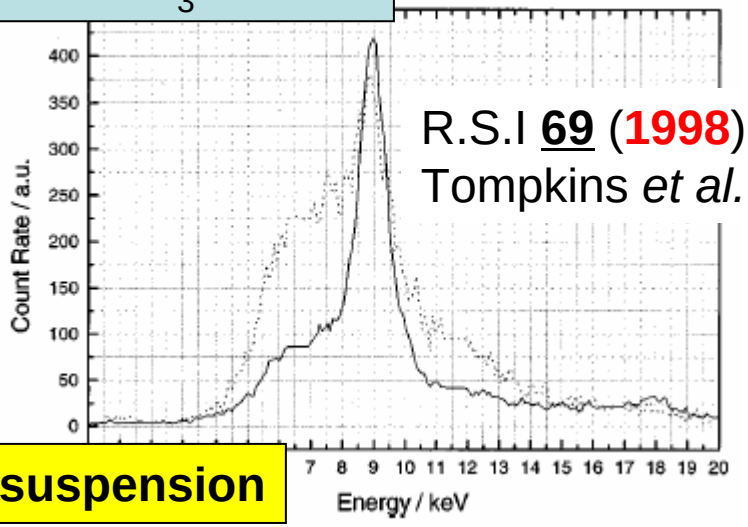
Herz *et al.*; Opt.Commum. **103** (**1993**) 105

2. use of nano-particles



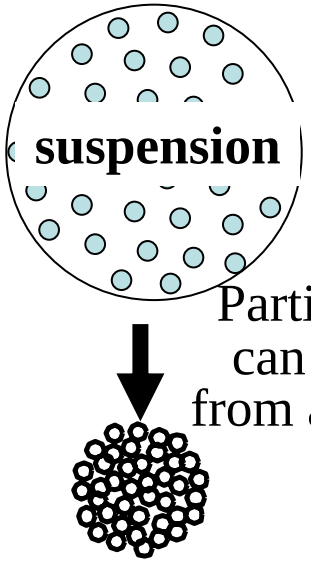
Matsui *et al.*
1997 Feb.

3. Droplet of $CuNO_3$ solution



R.S.I **69** (**1998**) 3113
Tompkins *et al.*

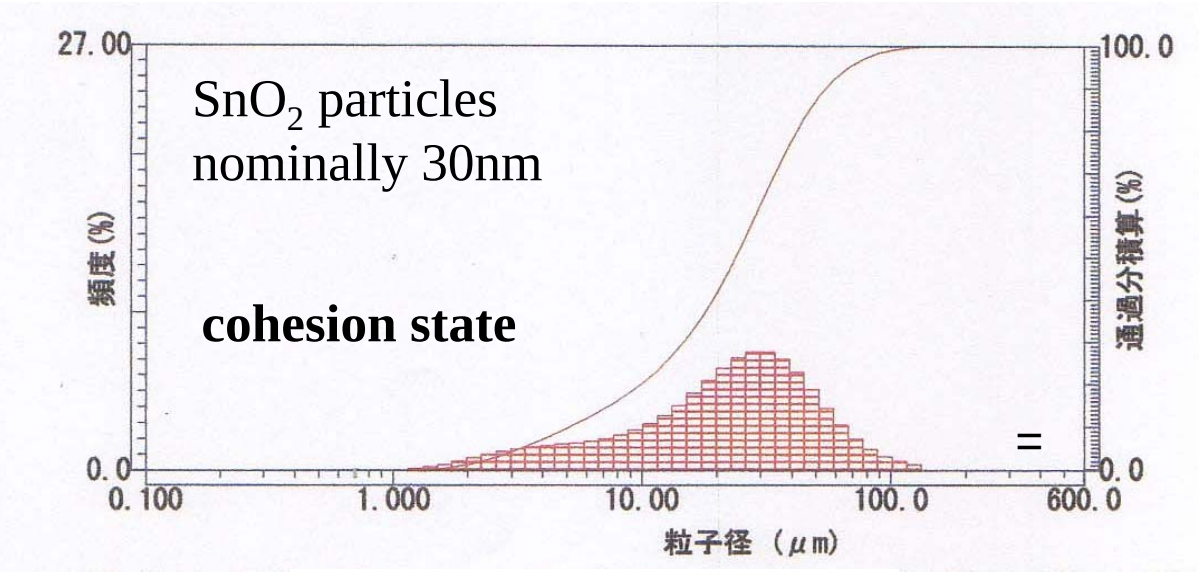
It was obvious to use a suspension



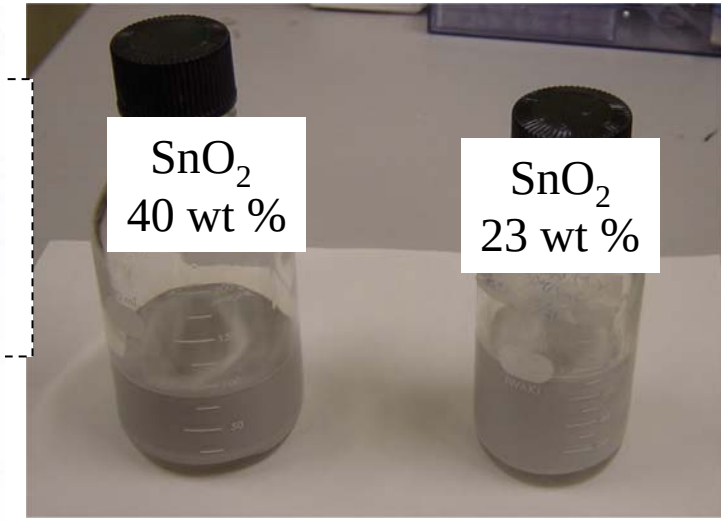
Particle-cluster can be formed from a suspension

Issues in using a suspension

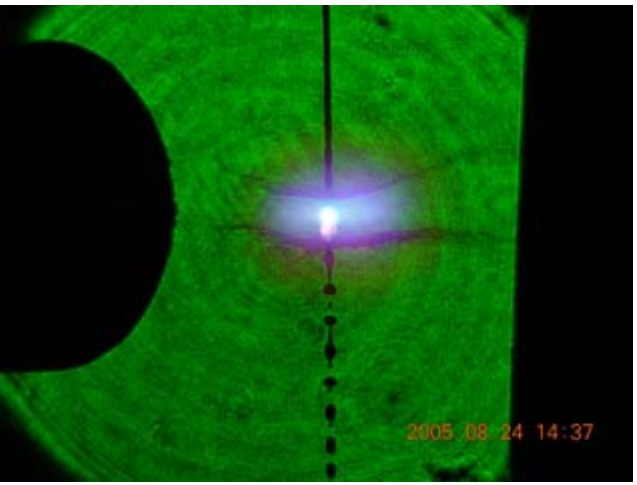
1. avoid cohesion and sedimentation
2. avoid clogging up of a nozzle
3. increase of particle density

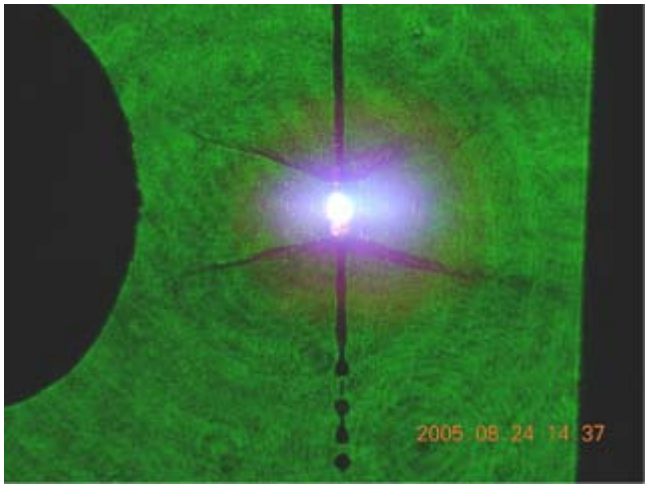


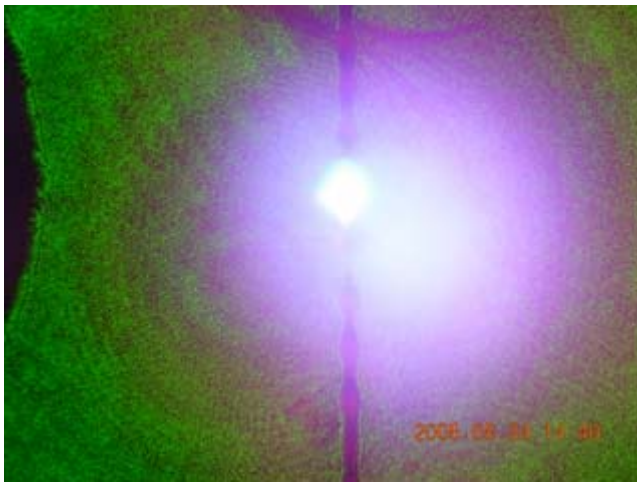
Diameter of particles (μm)



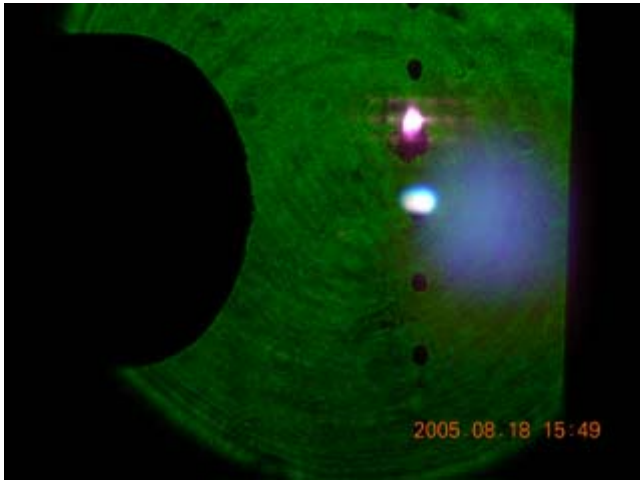
Jet of a SnO_2 suspension







Droplets

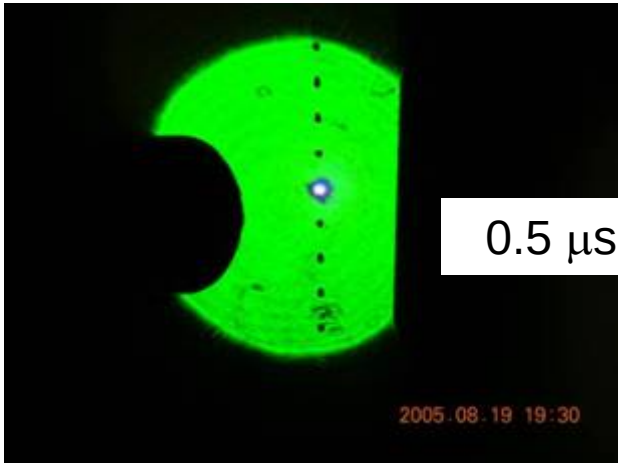


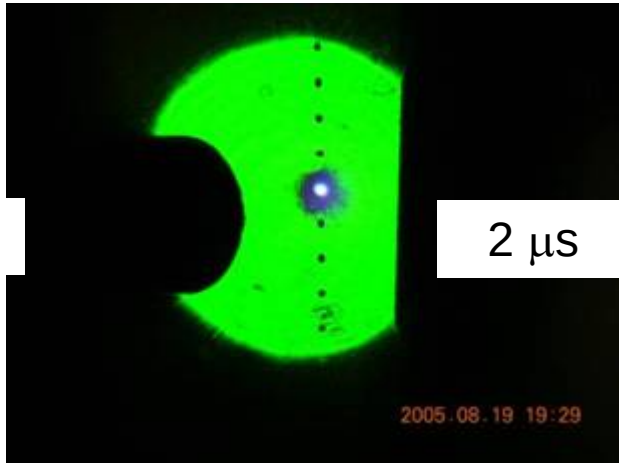
Now, a SnO_2suspension liquid flows continuously for several hours until a reservoir becomes empty.

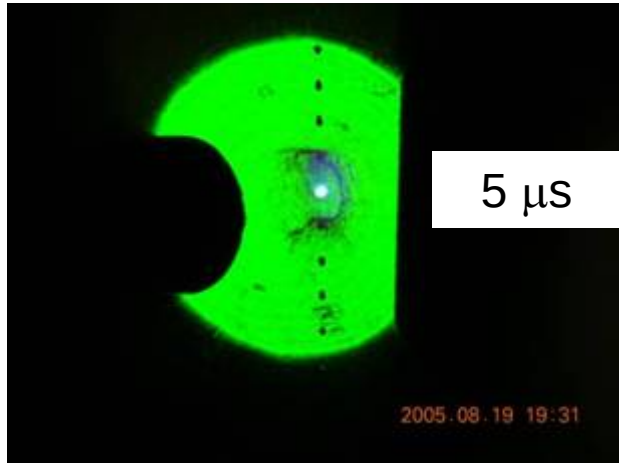
Expansion of solvent

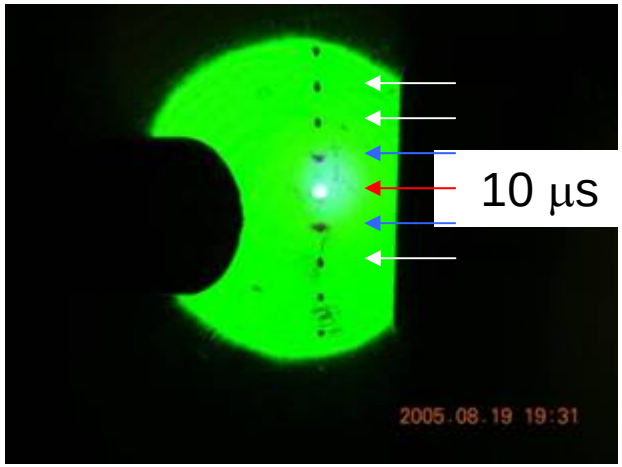
SnO_2 suspension

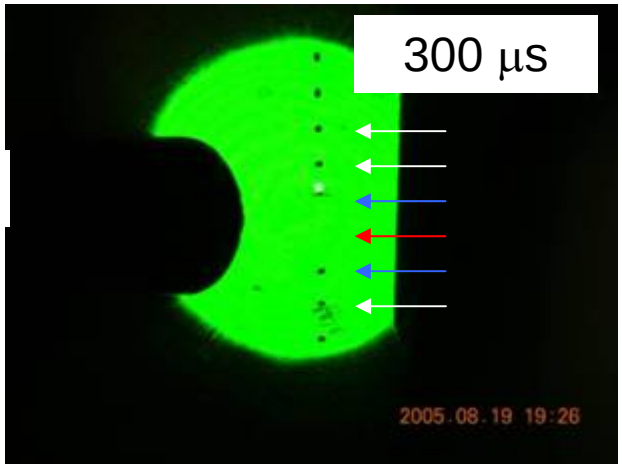
Nozzle diam. 0.3mm, frequency 7 kHz

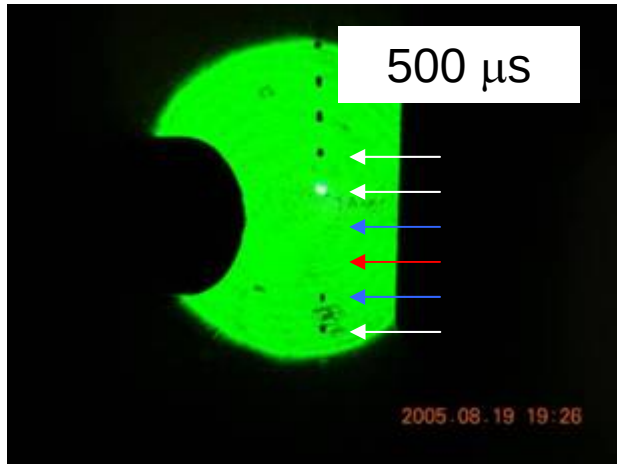






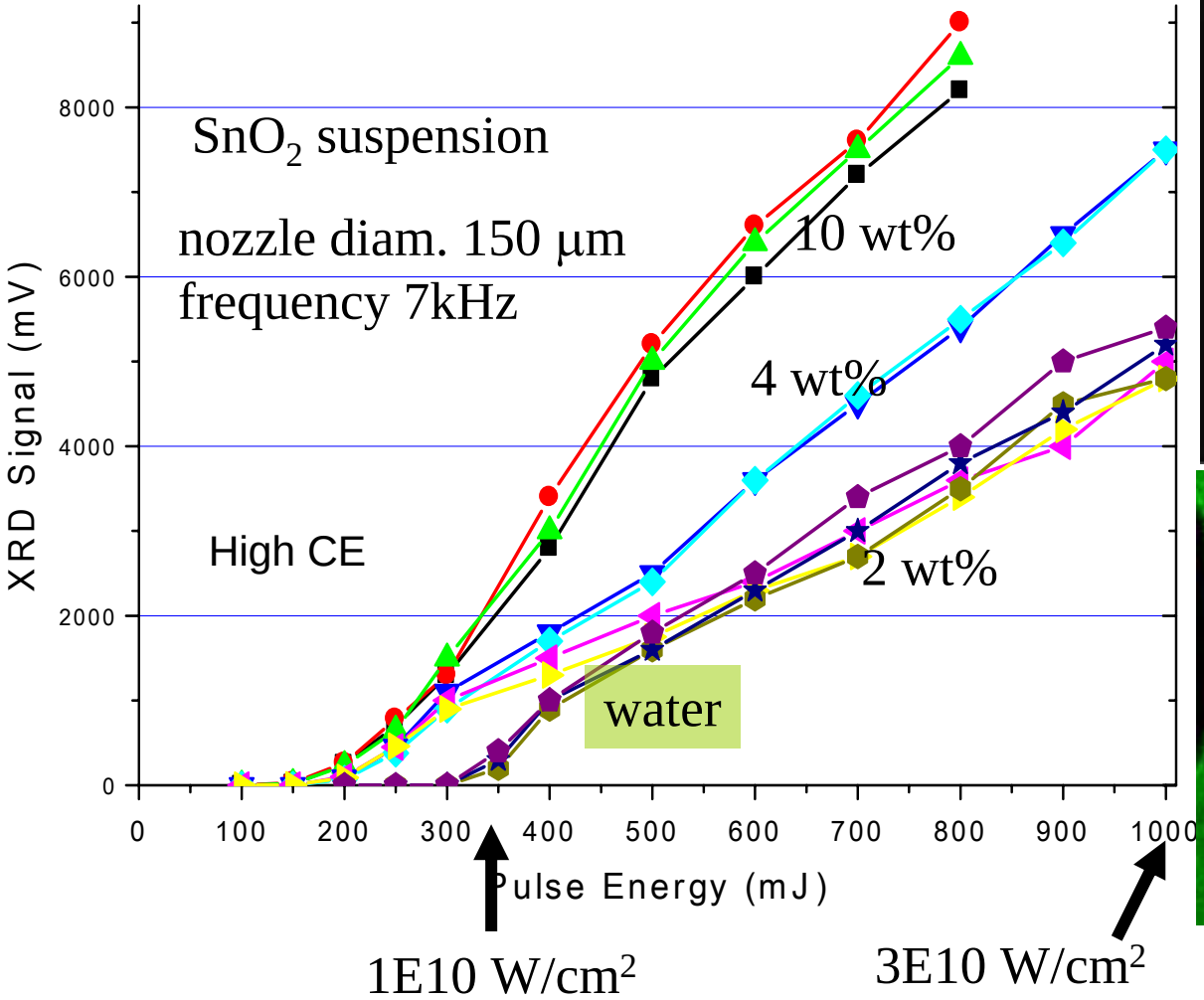


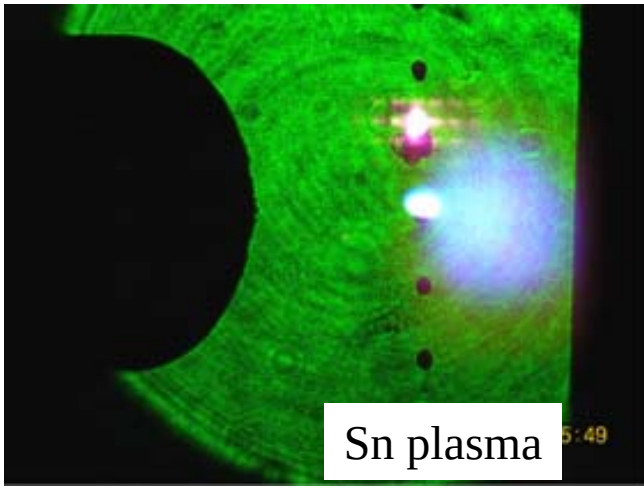


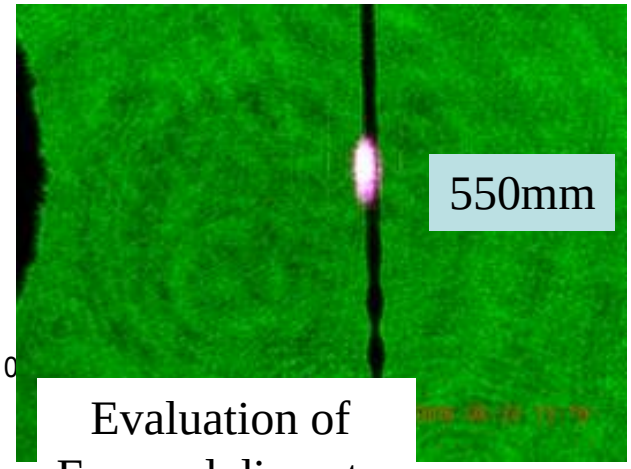


Neighbor droplet disappeared

EUV intensity (whole spectra)



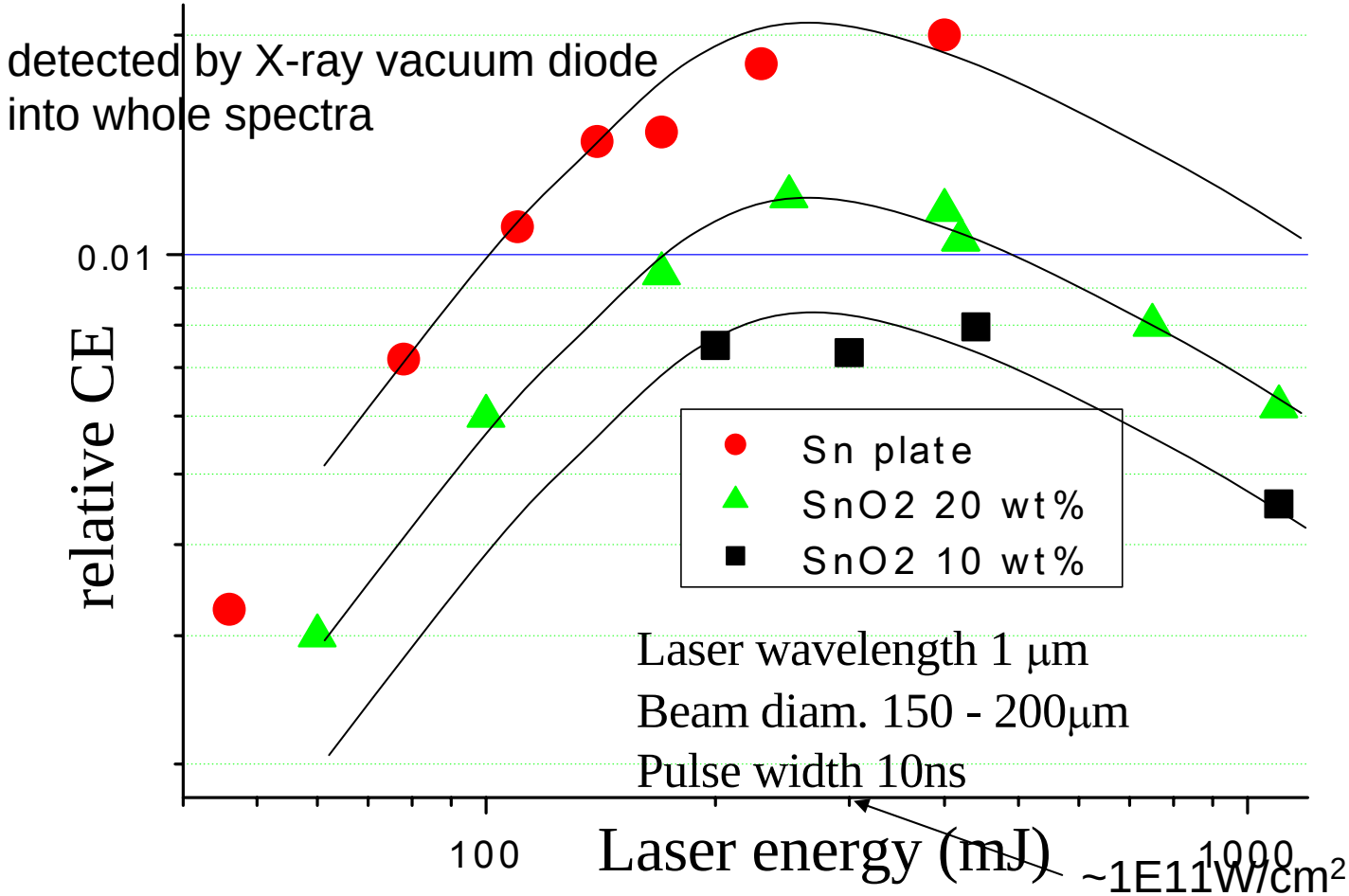




Evaluation of Focused diameter

Low irradiance => good indication of a high CE

Radiation efficiency of a suspension jet plasma

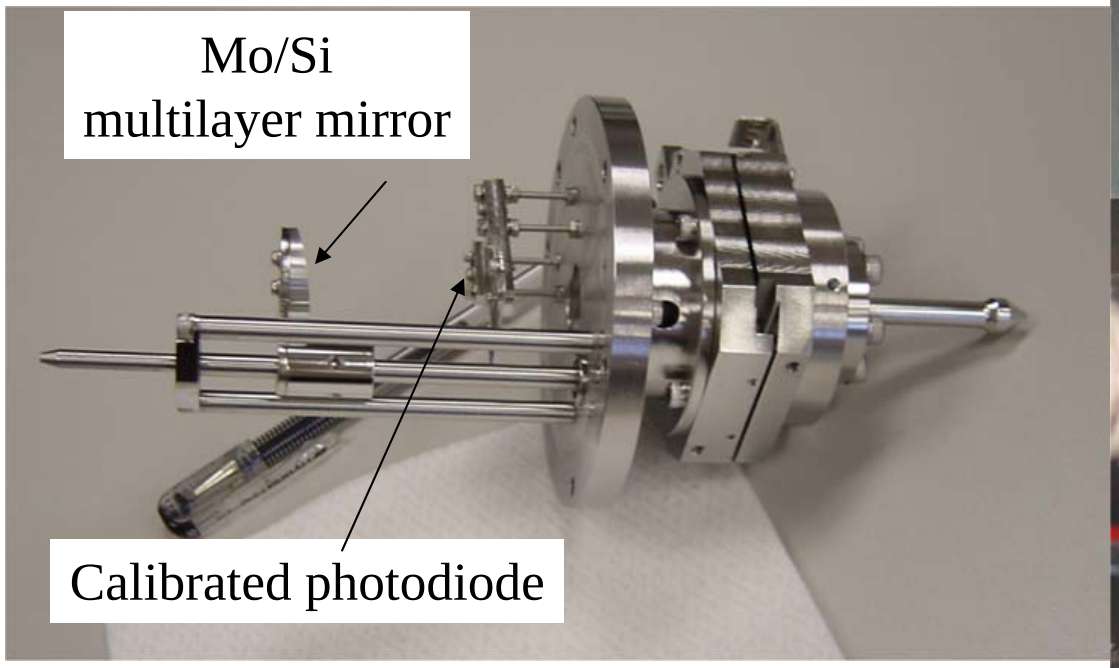


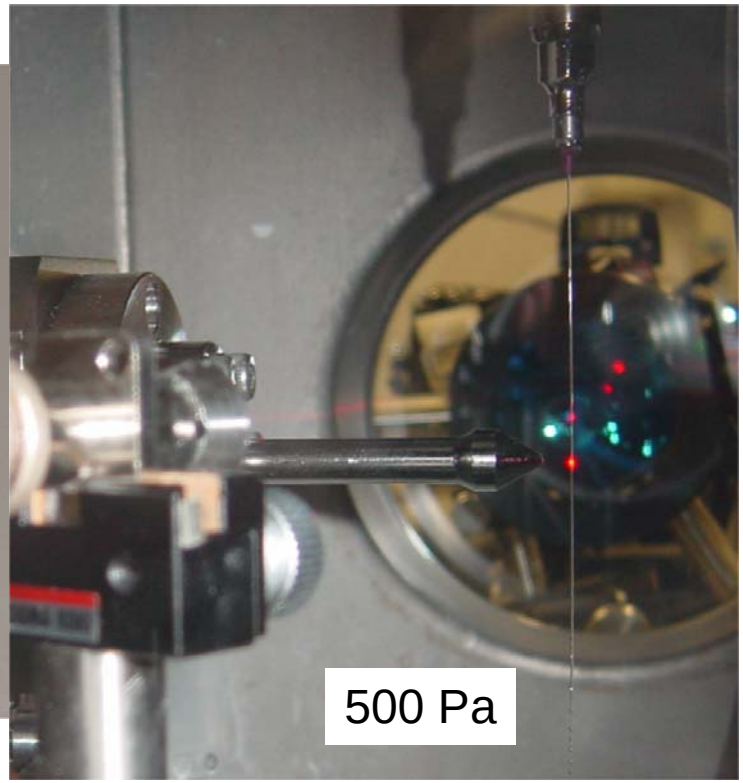
A suspension of 40wt%(= Sn atom number density is only 6%) will give the same radiation power as a Sn plate.

Suspension droplet =>particle-cluster =>cotton cake should give a higher CE

Before challenging a cotton cake target,
A suspension jet showed a radiation power comparable to a Sn plate,
Number density is only a few % =>optically thin => high in-band CE?

Differential pumping type
13.5nm in-band detector





Summary

1 . Ultimate CE is achieved by cotton candy-like Sn target.
3-4 times higher CE than a Sn plate
has been demonstrated by distributed SnO_2 particles
CE=**4%/2πsr** should be attainable if everything is optimized

2 . A cotton candy-like Sn can be realized by
delivering a particle-cluster
formed by evaporating a droplet of a suspension
supplied at multi kHz
with extremely low target cost of less than $1 /1M shots

3 . A suspension up to 40 wt% is successfully prepared

4 . A suspension of 20 wt%
gave EUV emission comparable to a Sn plate target