NIKON CORPORATION

Silica Aerogel Can Capture Flying Particles in EUV Tools

OTA Kazuya and INOUE Jiro, Nikon Corporation

1 October, 2012

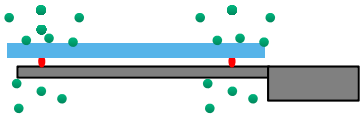
2012 EUVL Symposium, Brussels, Belgium

Contents

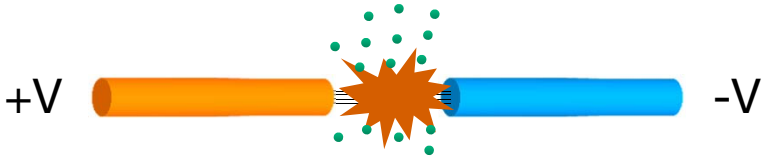
1. Properties and behavior of particles in vacuum
    1. Materials
    2. Velocities
    3. Flying range
2. Characteristics of silica aerogels
    1. Silica aerogel as particle catcher
    2. Structure of silica aerogels
    3. Outgassing rate of silica aerogels
3. Particle capture performance of silica aerogels
    1. Experimental setup
    2. Experimental conditions
    3. Experimental results

1-1. Particles in vacuum: Materials

- **Potential particle generating events**
  - **Physical contact**
    - Collisions: wafer/reticle transfer, pod open/close, valve o/c, grounding pin contact, …
    - Rubbing: bearings, ultrasonic motors, …



  - **Physical reaction**
    - Sputtering: corona ionizers, EUV sources, …
    - Evaporation and condensation: pumping down in loadlock
  - **Electrical discharge/spark**
    - EUV sources
    - Discharge between reticle and pod during a transitional region in loadlock
    - Micro-discharge between wafer/reticle backsides and e-chucks.



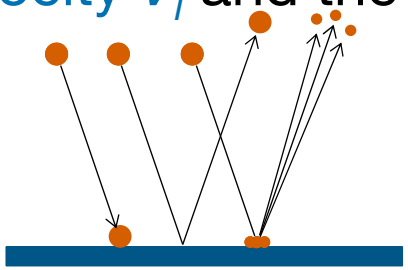
- **Potential materials**
  - Metal/metalloid: Na, Al, Si, K, Ca, Ti, Cr, Fe, Ni, Mo, Ru, Sn, Ta, …
  - Inorganic: SiO_2, …
  - Organic: $C_xH_yO_z$

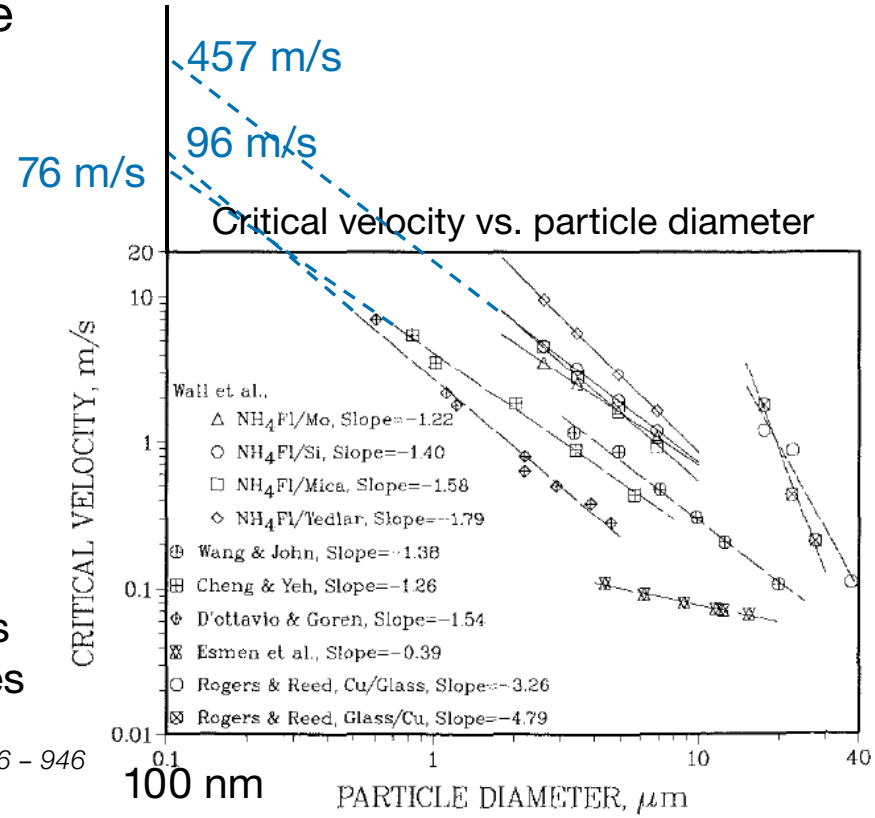
HEAVY! > 7 g/cm^3

cf. PSL~1 g/cm^3

1-2. Particles in vacuum: Velocities

- Interaction with surfaces "bounce or stick" depends on the relationship between the particle impact velocity V_i and the critical velocity V_c.
  - $V_i < V_c$: stick
  - $V_i > V_c$: bounce
  - $V_i >> V_c$: split and stick/bounce
- V_c is determined by the surface material, the particle material, the particle size, etc.
- Particles that have lower velocities than the critical velocity cannot continue to fly.





FAST!

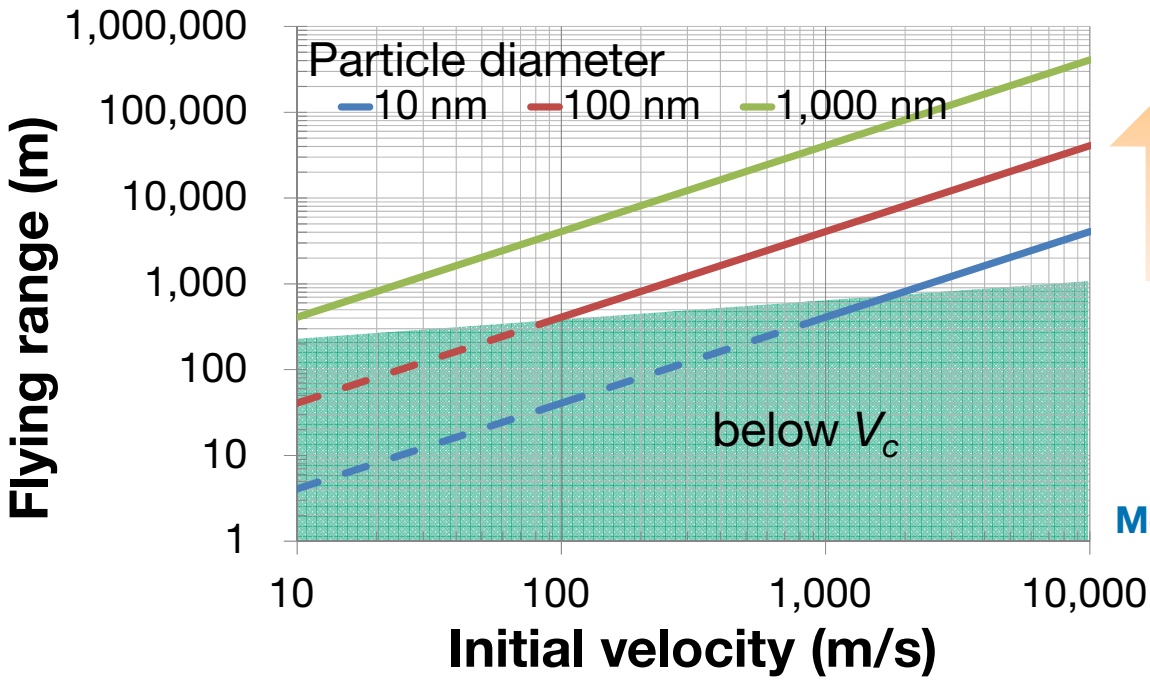
Typical *Vc* :
100 m/s for 100-nm particles
2,000 m/s for 10-nm particles

S. Wall, et al., Aerosol Science and Technology, Volume 12, Issue 4, 1990, Pages 926 – 946

1-3. Particles in vacuum: Flying range

- Forces acting on particles in vacuum
  - **Gravity**: $\propto r^3$, dominant force but not decelerating force
  - **Drag force**: $\propto r^2$, weak, depends on the gas pressure
  - Coulomb force: weak, depends on ***E*** and amount of electric charge
  - Thermophoretic force: very weak, depends on the thermal gradient

Flying range vs. Initial velocity



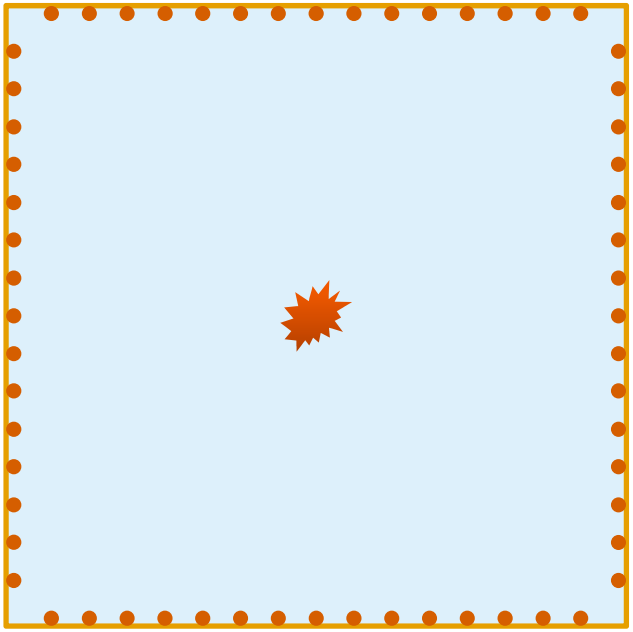
LONG!

> 100 m

Mo particles in 0.01-Pa O_2 gas

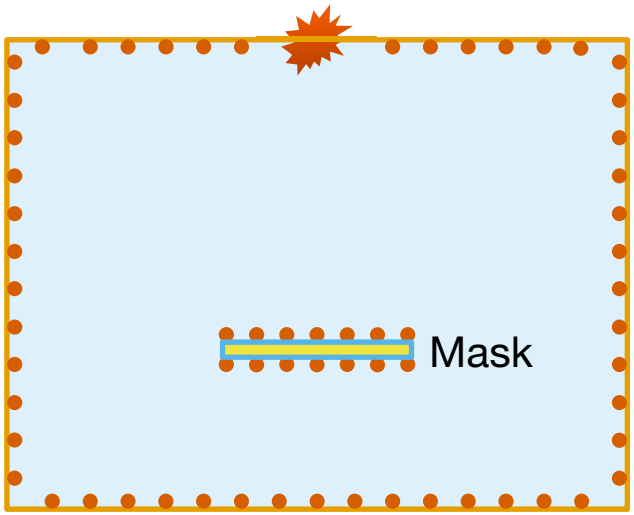
Animated motion of particles in vacuum

Particles in vacuum tools ➔ HEAVY / FAST / LONG range



Particle source at the center.
No objects in the chamber.

→ **Particles adhere to the wall throughout.**



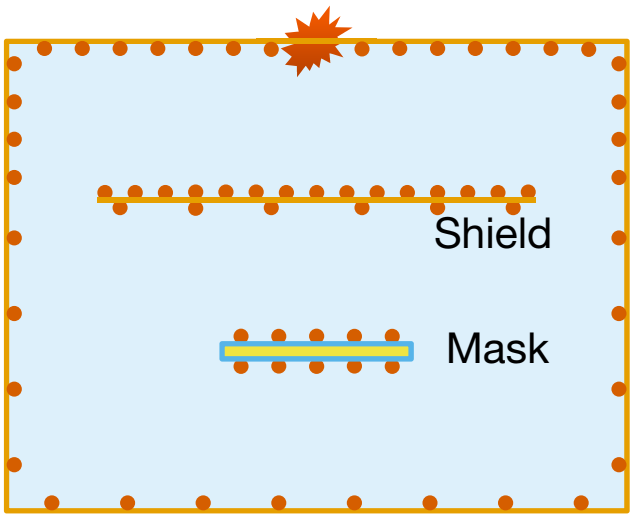
Particle source at the top.
No objects in the chamber but a mask.

→ **Particles adhere to the front and the back surfaces of mask as well.**

To simplify the models, gravity is neglected and the same coefficient of restitution (COR) is used for both the vertical component and the parallel component to the wall.

Particle reduction system

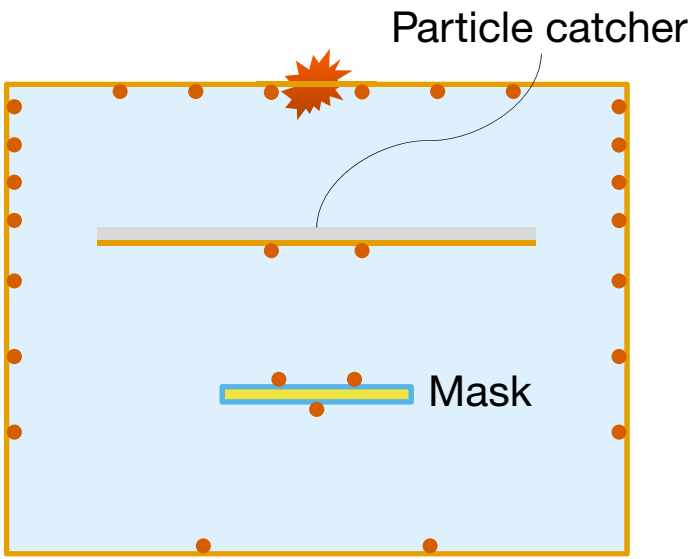
Particle shield



Particle source at the top.
Shield between the particle source and the mask.

→ **Performance of shield is insufficient.**

Particle catcher



Particle source at the top.
Particle catcher on the shield.

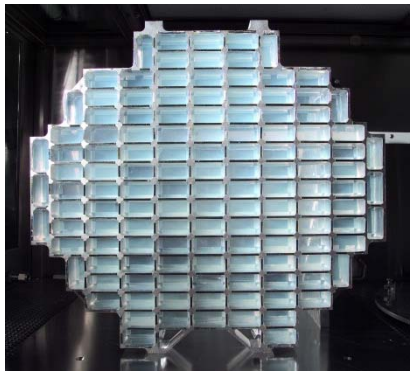
→ **Particle catcher can dramatically reduce the number of flying particles.**

To simplify the models, gravity is neglected and the same coefficient of restitution (COR) is used for both the vertical component and the parallel component to the wall.

2-1. Silica aerogel as particle catcher

STARDUST: NASA′s comet sample return mission, 1999 - 2011

February 7, 1999
Stardust Launch



Dust Collector with aerogel

Comet particles

Velocity: ~ 6.5 km/s
Diameter: 40 - 300 μm

Vacuum tool particles

Velocity: 10 m/s - 1 km/s
Diameter: 1 μm - 10 nm

1

Kinetic energy

$10^{-13 - -15}$

Thinner sheet is enough for EUV tools.

Aerogel In Hand

Photos from jpl.nasa.gov

Particle Tracks in Aerogel
(experiment)

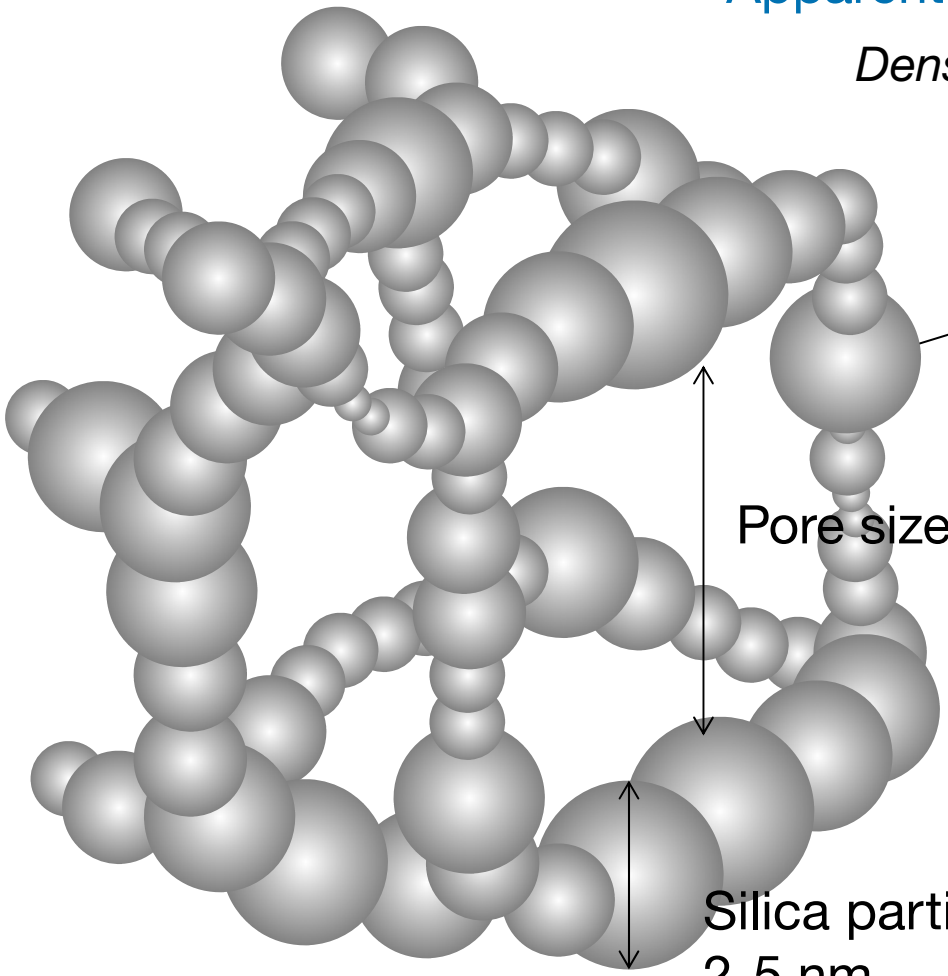
Comet Ejecta in Aerogel

2-2. Structure of silica aerogels

Pore network

Apparent density: 0.003-0.35 g/cm^3

Density of air: 0.0012 g/cm^3 at 20 ° C



micropores: < 2 nm

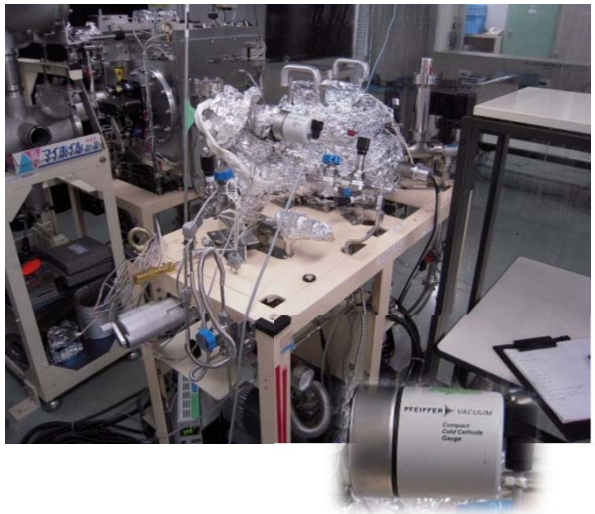
mesopores: 2-50 nm

macropores: > 50 nm

2-3. Outgassing rate of silica aerogels

Hydrophobic silica aerogel samples

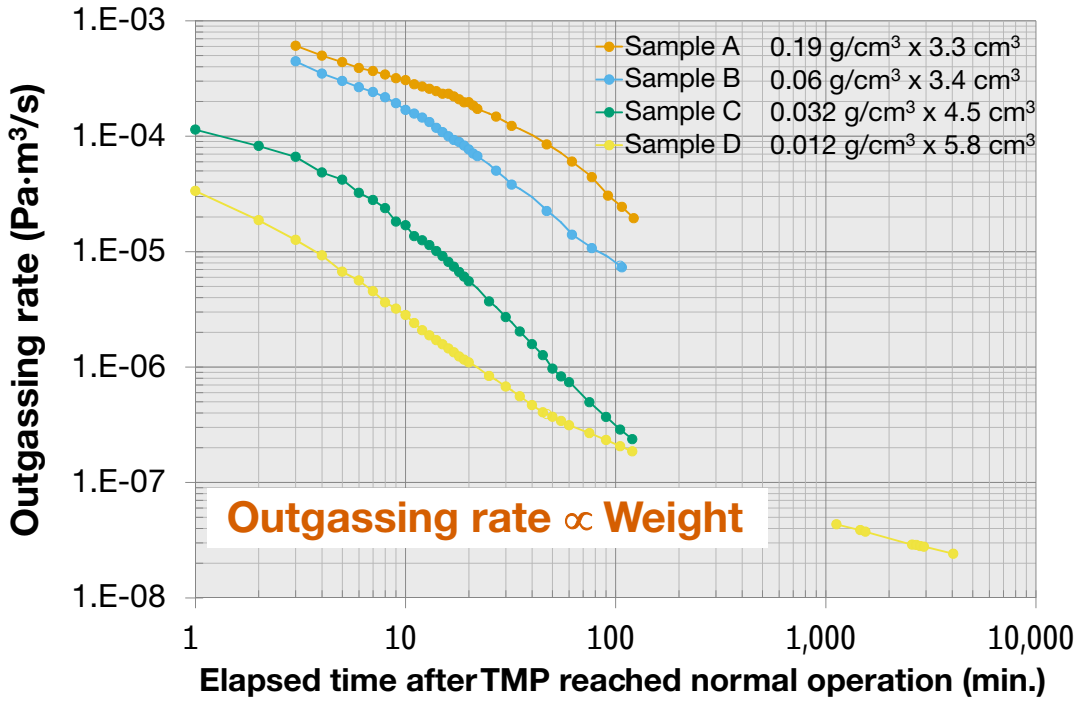
A : 0.19 g/cm^3, supplier A
B : 0.06 g/cm^3, supplier A
C : 0.032 g/cm^3, supplier B
D : 0.012 g/cm^3, supplier B



Experimental setup

- A mini chamber using vacuum fittings
- A turbomolecular pump 50 litter/s and a scroll pump
- A cold cathode gauge.

Experimental results



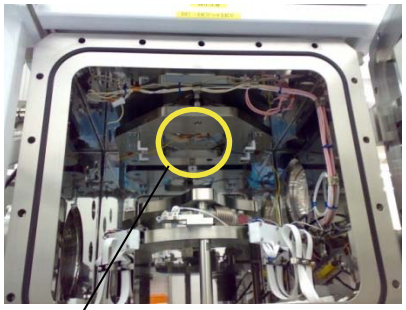
Five pressure decay curves were measured just after TMP started each: sample A, B, C, D, and no sample (=a baseline). Aerogel outgassing was calculated by subtracting the baseline from each sample data and outgassing rates were obtained by being multiplied by the effective pumping speed (=TMP spec x 0.25, assumption).

It is possible to place aerogels in a vacuum tool, if the amount is limited.

➢ Ex.) Sample D (0.012 g/cm^3): 5mmt x 100~1,000 cm^2

3-1. Experimental setup

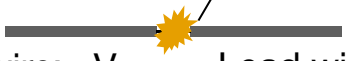
MPE Tool



Particle generator installed in ESC chamber

High voltage feedthroughs

Induction coil

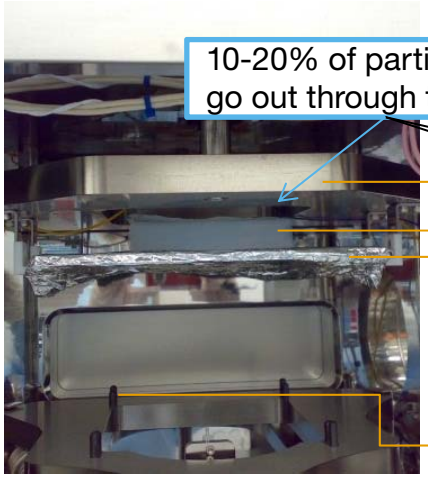


Lead wire: –V Lead wire: +V

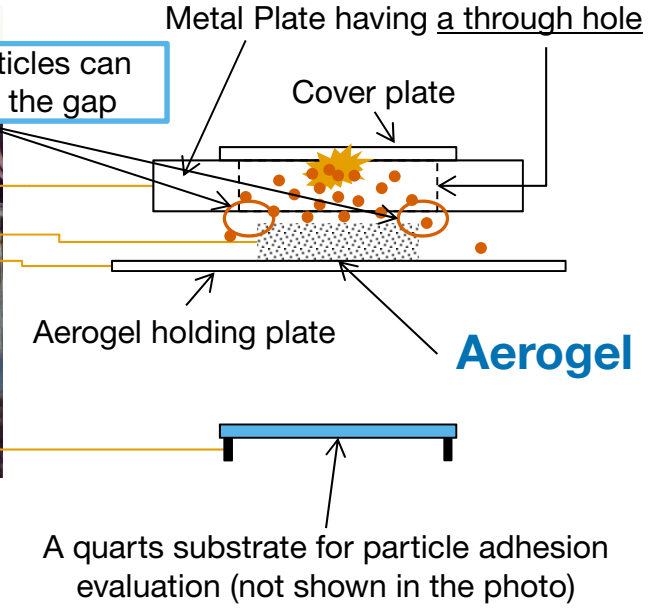
Particles were generated by discharging
(Air pressure ~5E-3 Pa)

Photos of aerogel tested:
bare (left) and covered by a foil (right)

Size: 100 mm (W), 100 mm (D), 15 mm (H)
Density: 0.012 g/cm^3



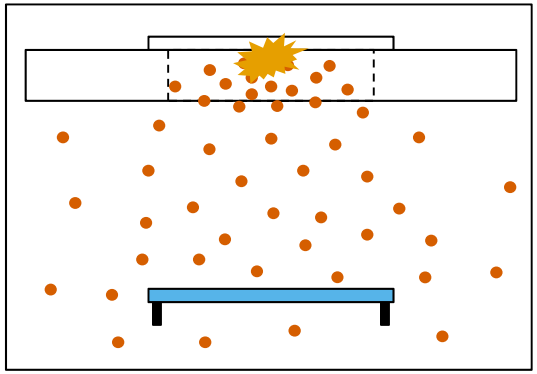
Aerogel in ESC chamber



3-2. Experimental conditions

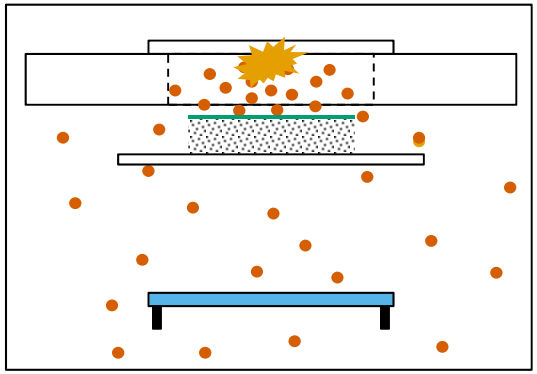
#1: No obstacle

- Nothing between the quarts substrate and the particle generator. Particles can reach the substrate directly.
- Discharging was intermittent and the total time was about 10 seconds.



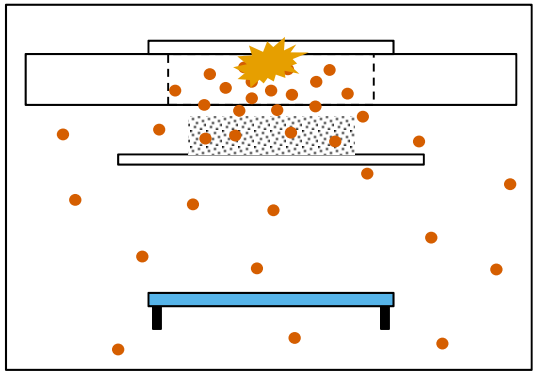
#2: Aerogel sheet covered by a foil

- An aerogel sheet covered by a foil on the holding plate was put between the quarts substrate and the particle generator.
- Discharging was continuously and the total time was about 8 seconds.



#3: Bare aerogel sheet

- The foil was removed.
- Discharging was continuously and the total time was about 8 seconds.

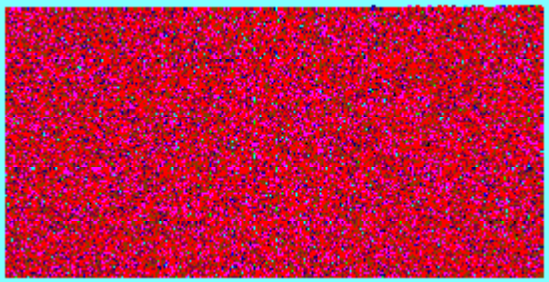


3-3-1. Experimental results #1: No obstacle

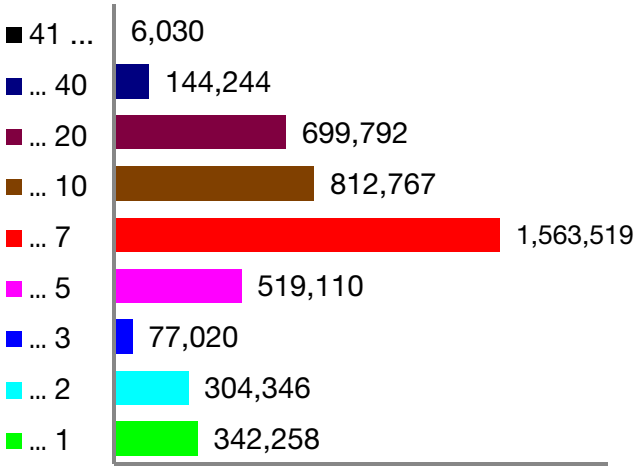
Up

Too many; 50% measured

Particle density: 44,327 particles/cm^2



Pixel Histogram

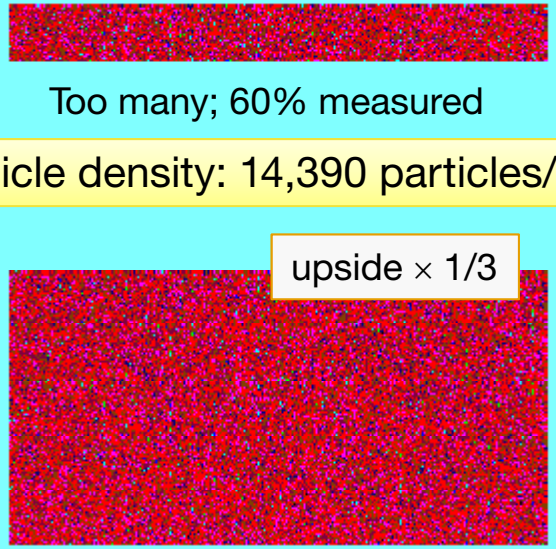


Total = 4,469,086

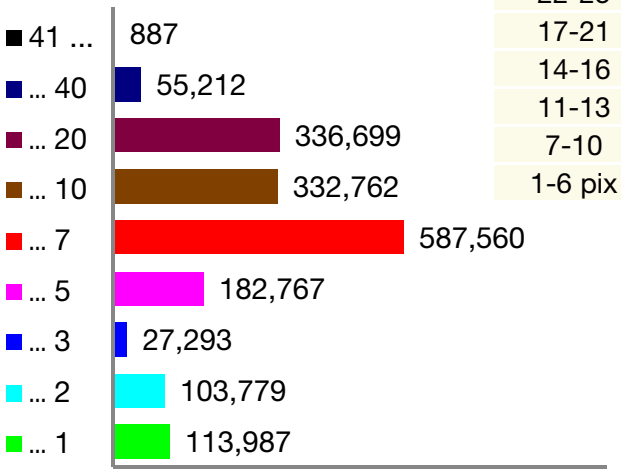
Down

Too many; 60% measured

Particle density: 14,390 particles/cm^2



Pixel Histogram

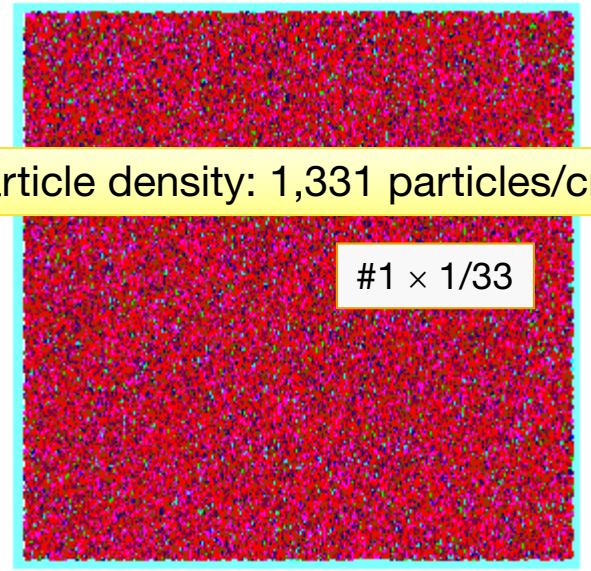


Total = 1,740,946

26-	>=300 nm
22-25	200 nm
17-21	100 nm
14-16	80 nm
11-13	70 nm
7-10	60 nm
1-6 pix	=< 50 nm

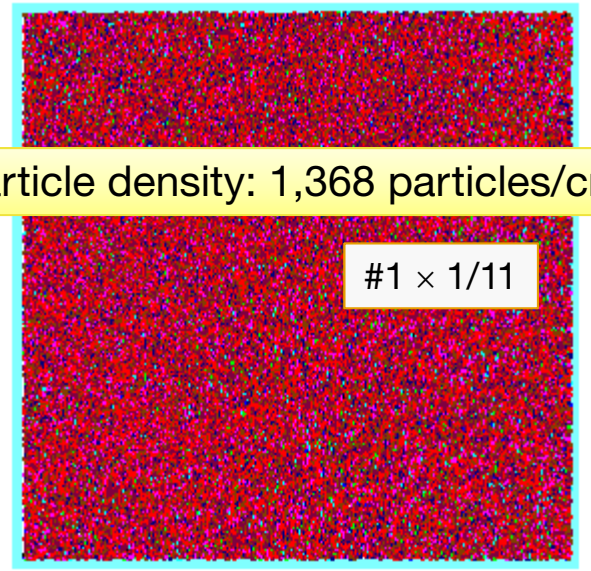
3-3-2. Experimental results #2: Foil

Up



Particle density: 1,331 particles/cm^2

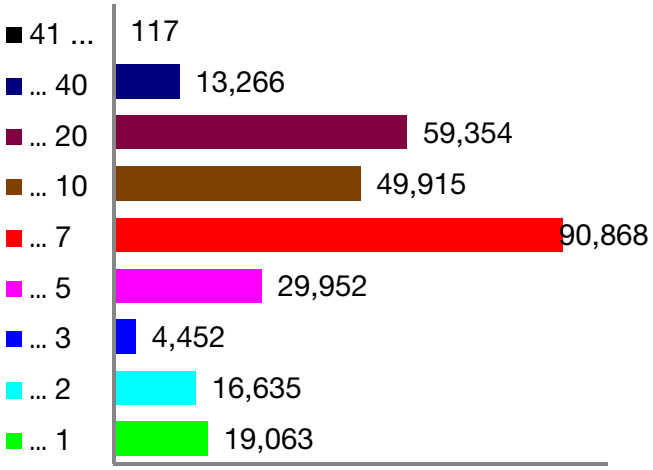
Down



Particle density: 1,368 particles/cm^2

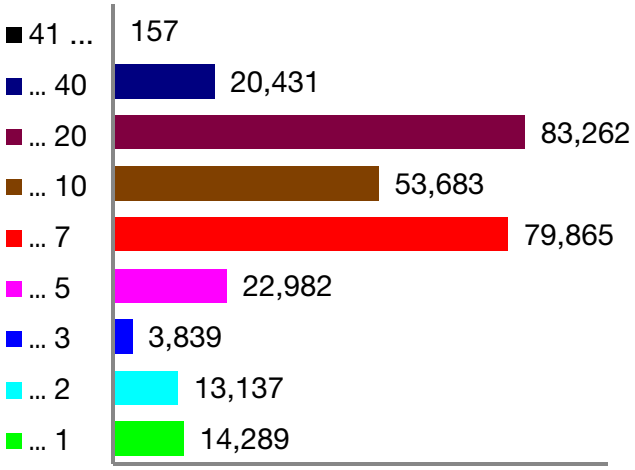
Almost the same density

Pixel Histogram



Total = 283,622

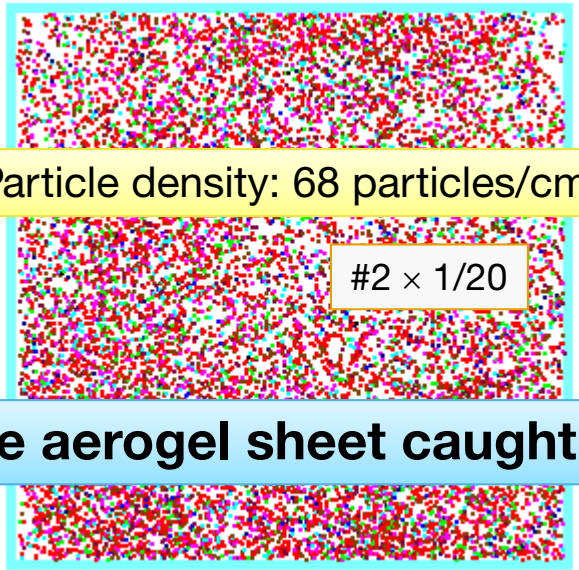
Pixel Histogram



Total = 291,645

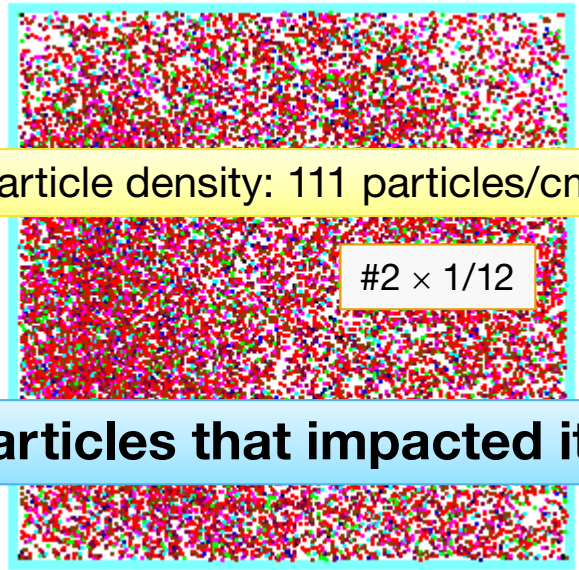
3-3-3. Experimental results #3: Aerogel

Up



Particle density: 68 particles/cm^2

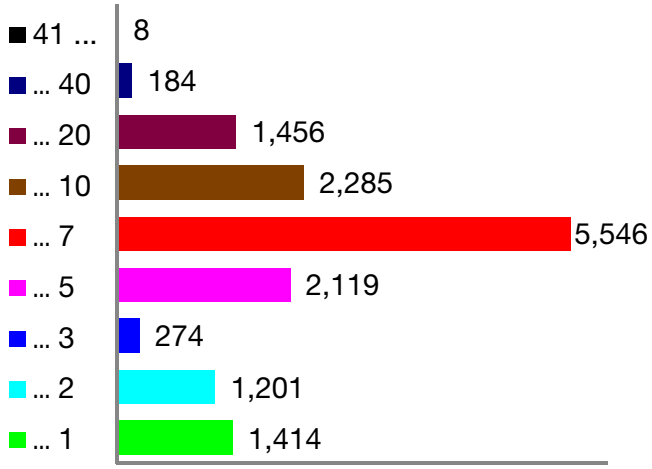
Down



Particle density: 111 particles/cm^2

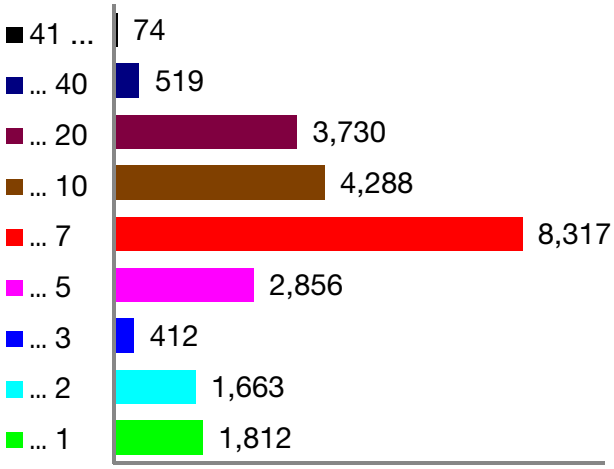
The aerogel sheet caught almost all particles that impacted it !!

Pixel Histogram



Total = 14,487

Pixel Histogram



Total = 23,671

Summary

- Properties and behavior of particles in vacuum.
  - Metal particles can be generated in tools.
  - Particles that have lower velocities than the critical velocity cannot continue to fly.
  - Particles in vacuum tools can travel more than 1 km.
- Silica aerogel is one of the suitable materials to capture flying particles in vacuum tools.
- Initial data shows that the silica aerogel sheet caught almost all particles that impacted it.

Silica Aerogel Can Capture Flying Particles in EUV Tools

Acknowledgements

Hydrophobic silica aerogel samples

- TABATA Makoto of Chiba University
- YOKOGAWA Hiroshi and KUGIMIYA Kazuya of Panasonic Electric Works Co., Ltd. (Pansonic Corp.)

Technical support

- MAGOSHI Shunko and WATANABE Hidehiro of EIDEC

This work was partially supported by NEDO.