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Oxygen Deficient Alumina Formation in a Process of Laser Ablation

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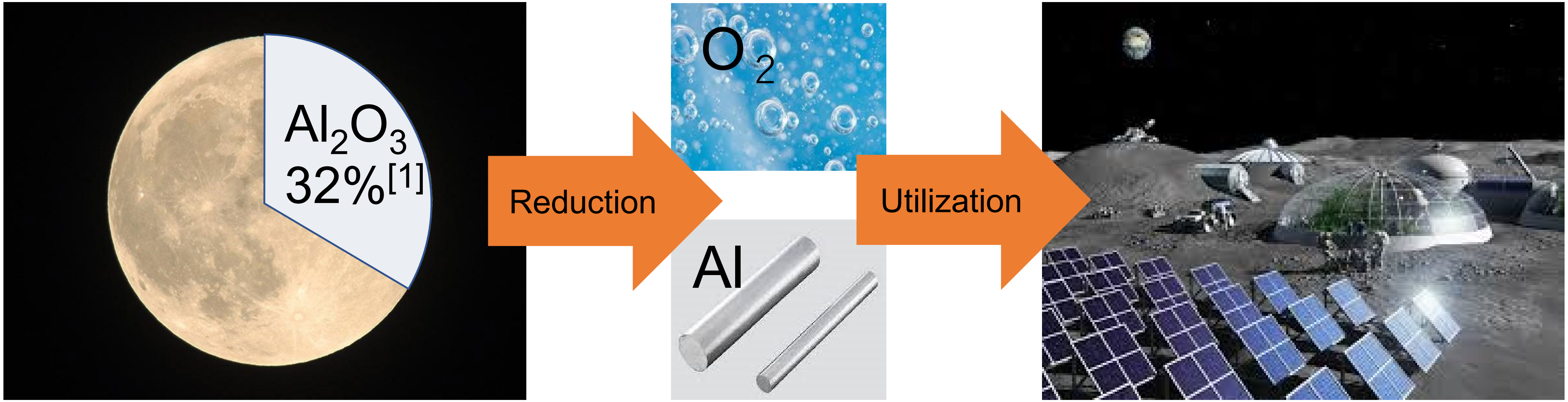
Utilization of lunar resources

Lunar regolith

Manned lunar base



Hall-Heroult method consumes carbon → cannot be mined on the Moon

Cost for transportation (Earth→Moon): $100,000/kg

New carbon-free reduction method

[1] G. H. Heiken, "Lunar Sourcebook," *Cambridge University Press*, 1991.

Oxygen-deficient alumina formation and Al precipitation

The black layer was observed on the collection plate and alumina rod surface.

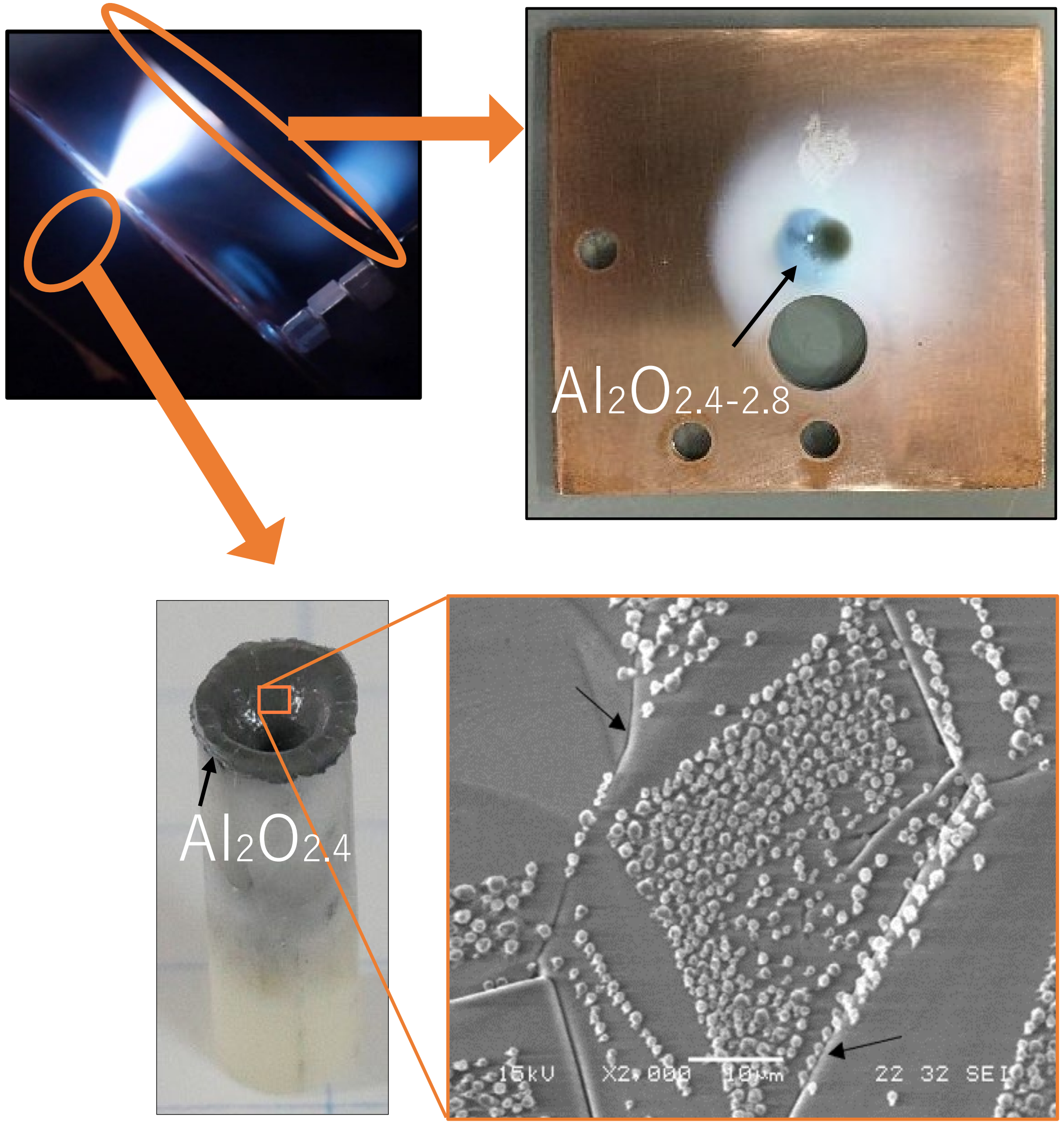
Oxygen-deficient alumina

Alumina with lower oxygen content:
On the plate: $Al_2O_{2.4\text{-}2.8}$
On the rod: $Al_2O_{2.4}$

Aluminum particles

Al particles were precipitated on the surface of the oxygen-deficient alumina of the rod

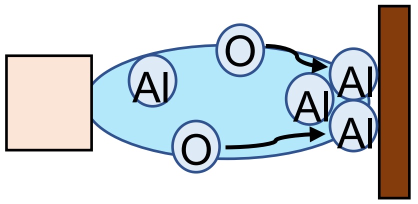
→ Clue for efficient aluminum collection



Oxygen-deficient alumina formation

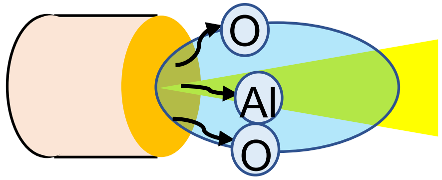
・On a collector plate

Some of O atoms are repelled on a plate.



・On a rod

Excess oxygen atoms are evaporated in the ablation process.



Expected oxygen-deficiency Al_2O_X

X=2.4 is minimum in solid state

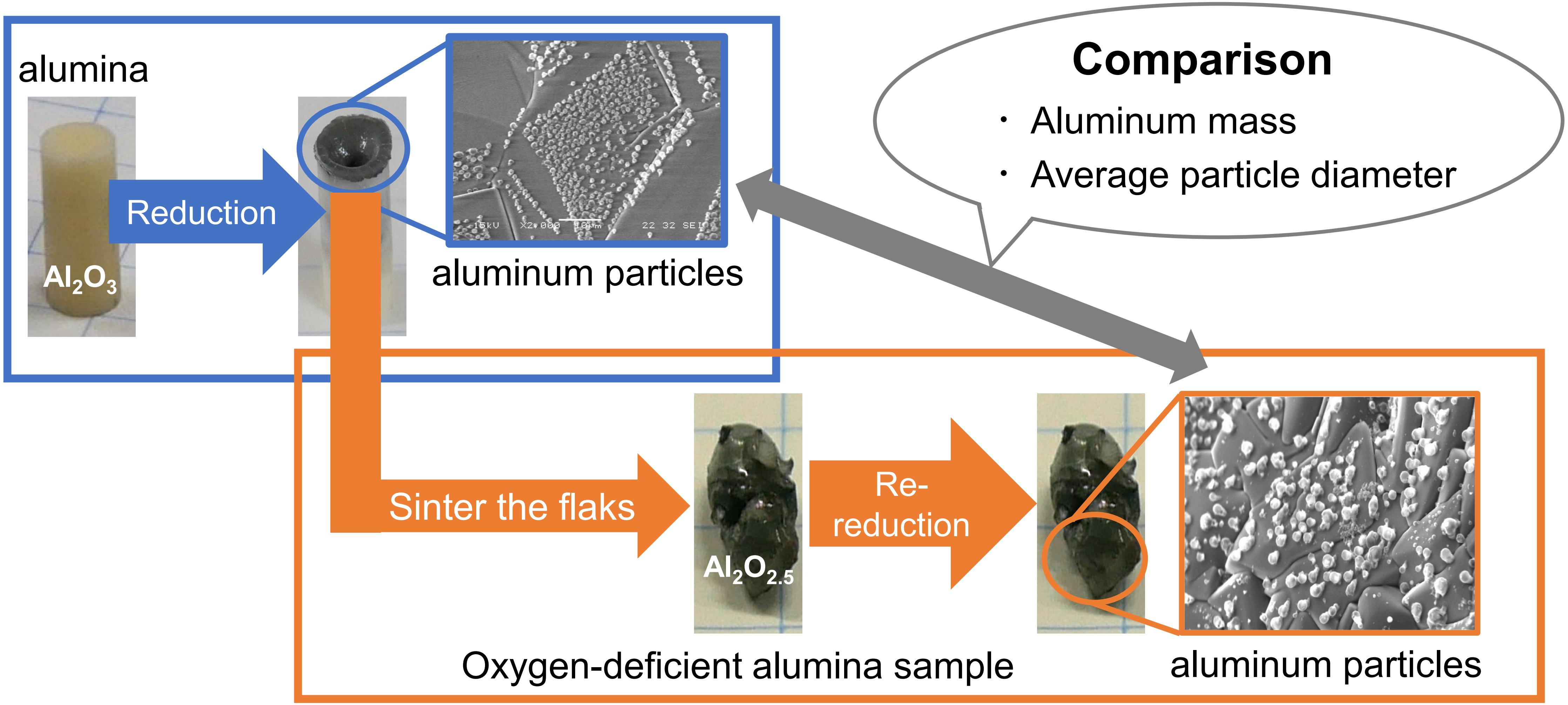
In liquid state, no data, probably lower than 2.4.

Aluminum particles are precipitated in the cooling process

$$Al_2O_X(l) \rightarrow \frac{X}{2.4} Al_2O_{2.4}(s) + \frac{2.4-X}{1.2} Al(s) \quad (X<2.4)$$

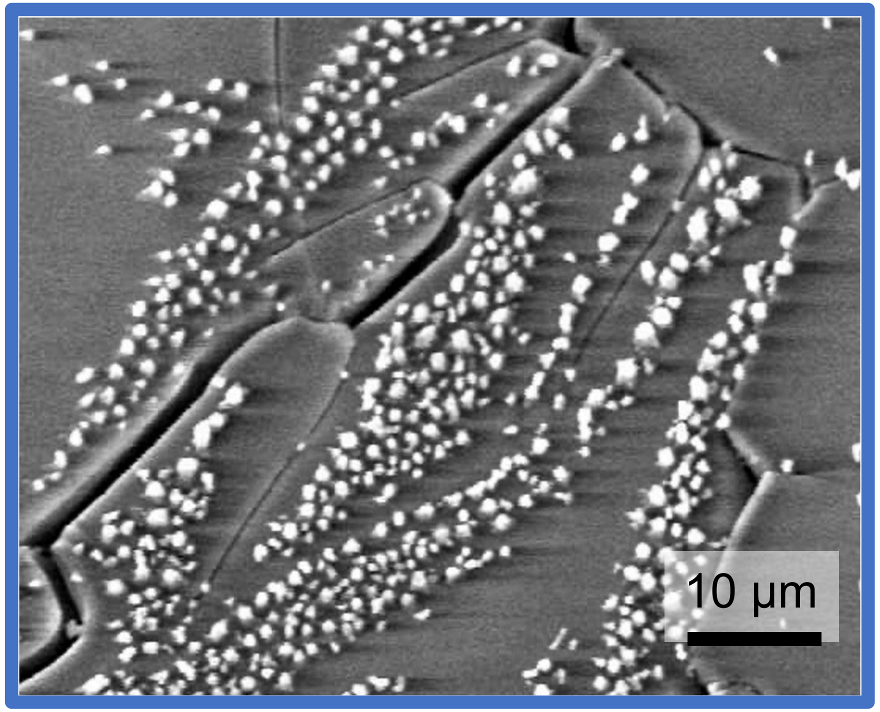
1. Re-reduction of oxygen-deficient alumina

Objective: To **increase the precipitated Al** by re-reduction of oxygen-deficient alumina.



Result: Increased Al precipitation in mass and particle size

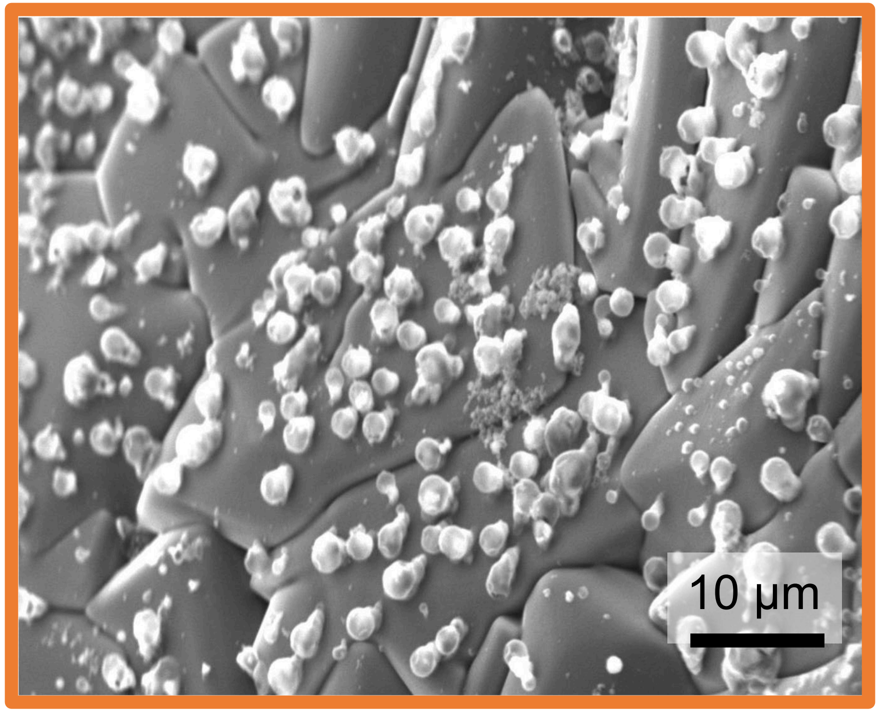
Reduction of Al_2O_3



Aluminum mass：13 µg

Average diameter ：1.7 µm

Re-reduction of $Al_2O_{2.5}$

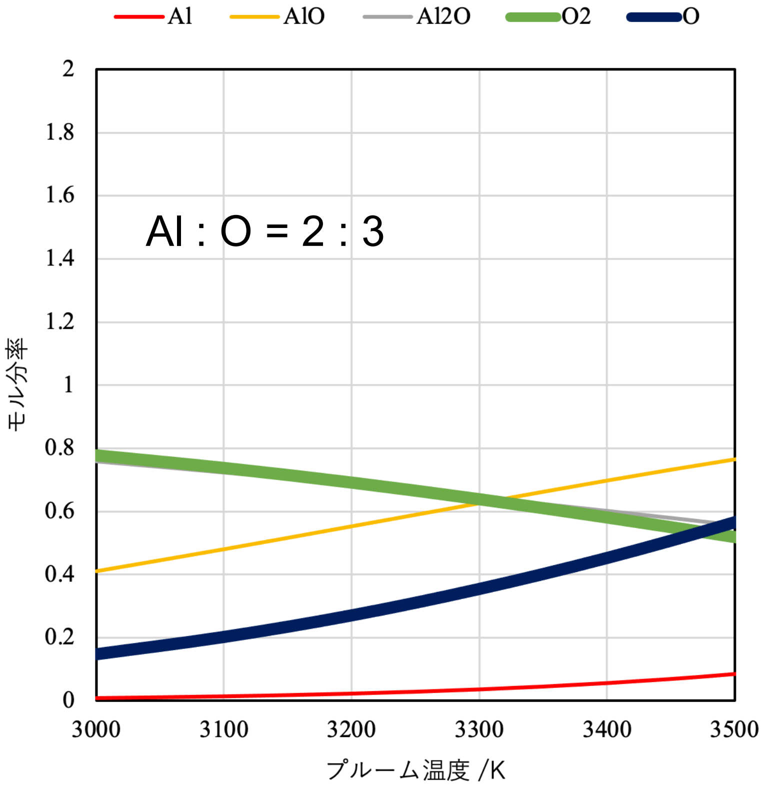


Aluminum mass：**22** µg ×1.7

Average diameter ：**2.8** µm ×1.6

2. Reduction in hydrogen atmosphere

Objective: To **increase the oxygen deficiency** by catching O atoms by H_2.



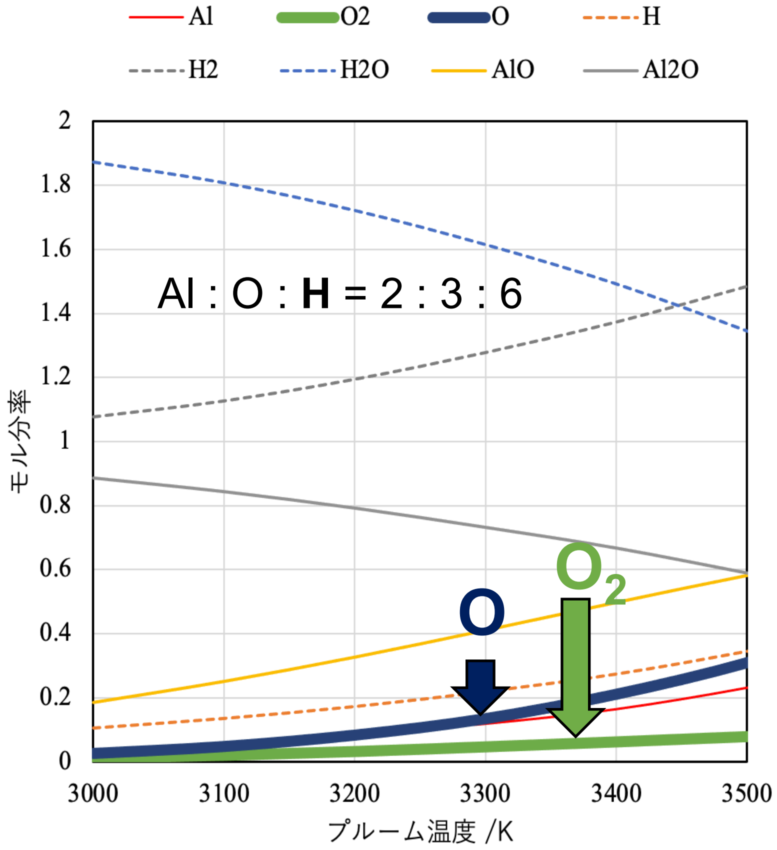
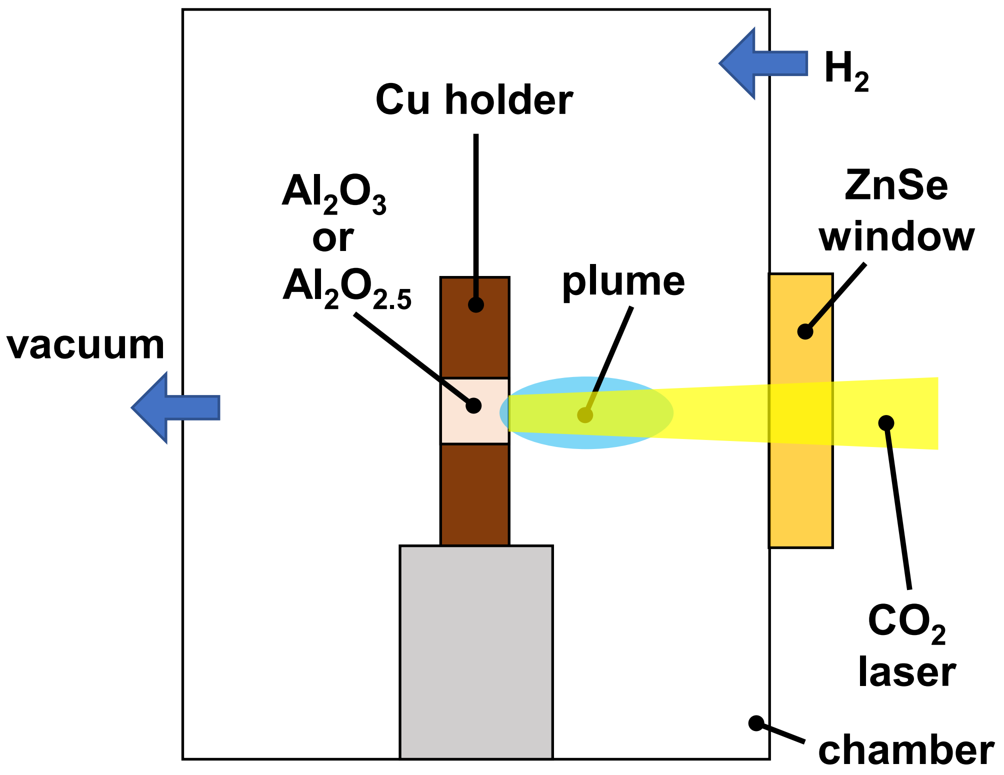


Fig. Mole fraction under thermochemical equilibrium

Decrease in O_2 and O fraction → O is recovered as water

Experimental conditions

Experimental system



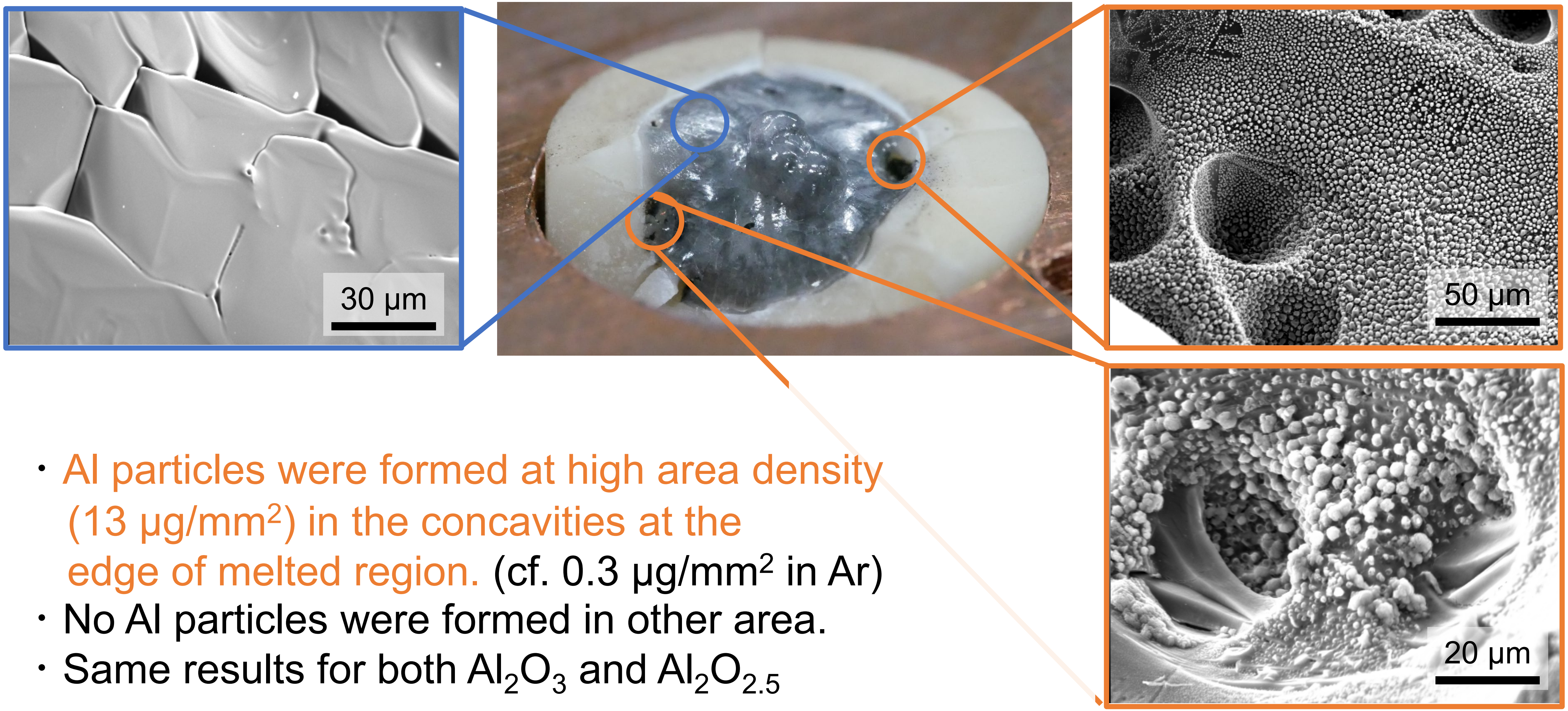
Experimental conditions

Laser power : 2.0 kW
Laser spot radius : 2 mm
Atmosphere : H_2 1 atm
Irradiation time：1.0 s
Chamber volume : 18 L
Used sample：**Al_2O_3, $Al_2O_{2.5}$**

Measurement Method

・ Reaction with NaOHaq
・ Surface observation by scanning electron microscope (SEM)

Result: Al particles were formed at high area density



- Al particles were formed at high area density (13 μg/mm^2) in the concavities at the edge of melted region. (cf. 0.3 μg/mm^2 in Ar)
- No Al particles were formed in other area.
- Same results for both Al_2O_3 and $Al_2O_{2.5}$

Discussion : Generation of water vapor in liquid alumina

Dissolution of hydrogen in alumina

・ 10^{-5} mol of hydrogen atoms dissolve in 1 mol of alumina crystals According to Ref. [4].

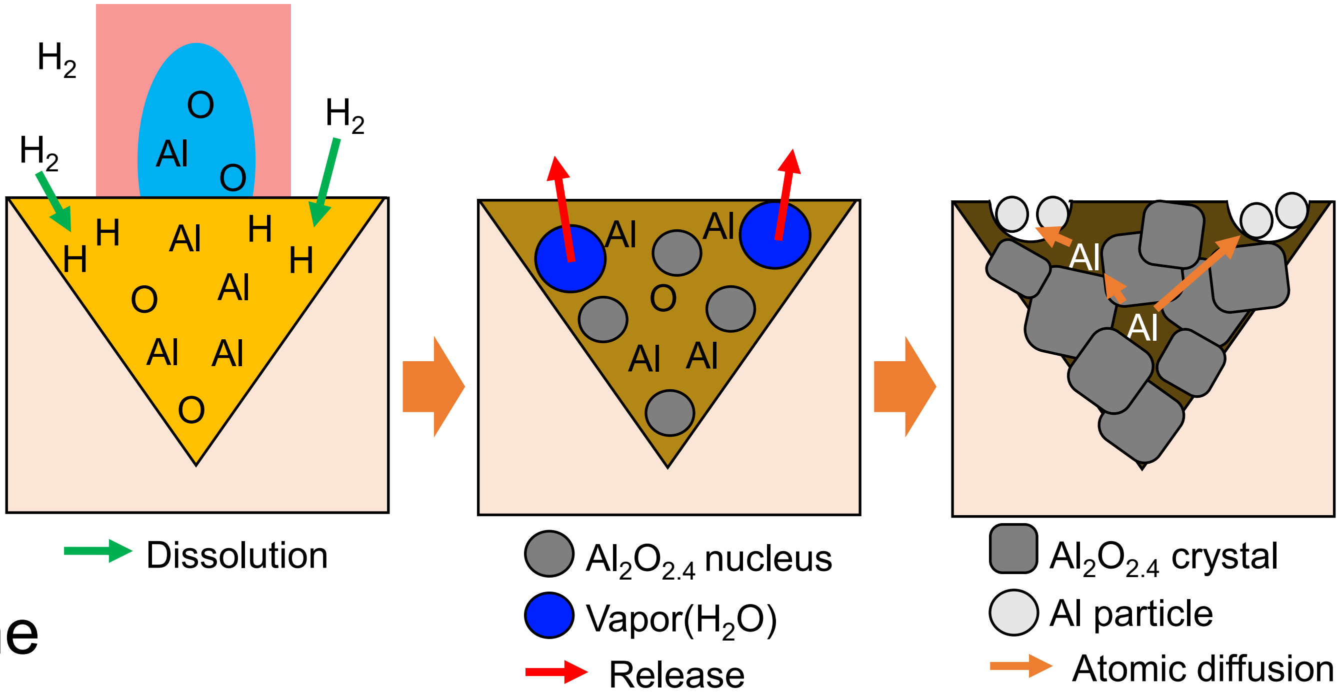
・ No literature on hydrogen dissolution in liquid alumina (probably at high speed)

Explanation of results

・Hydrogen dissolves in liquid alumina during ablation

・In cooling process, concavities are formed due to the release of water vapor

・Exess Al is concentrated inside the the concavities.



[4] 山中伸介, “水素と金属, 酸化物セラミックス,” *生産と技術 第49巻 第3号*, 1997.

Conclusion

Experiment 1 **Re-reduction of oxygen-deficient alumina**

Aluminum precipitation is increased by a factor of 1.7 reducing oxygen-deficient alumina $Al_2O_{2.5}$. The reason is presumably the increase in the degree of excess oxygen deficiency in its liquid state.

Experiment 2 **Reduction in hydrogen atmosphere**

Aluminum particles were observed at high area density inside the concavities formed at the edge of ablating zone. The concavity is considered to be generated by the dissolution of hydrogen into liquid alumina in the ablation process and the release of water vapor in the cooling process.