

Refining alumina from Japan-abundant  
resources:  
 $\text{Al}_2\text{O}_3$ -enrichment via laser-based  
selective volatilization

Author Lucas-Brian Christen, Maho Matsukura, Hiroto Yamakami,  
Kimiya Komurasaki

Affiliation PhD Student (D2), Komurasaki-Koizumi Lab.  
Graduate School of Engineering  
The University of Tokyo

E-mail [christen-lucas-brian@g.ecc.u-tokyo.ac.jp](mailto:christen-lucas-brian@g.ecc.u-tokyo.ac.jp)



# Introduction

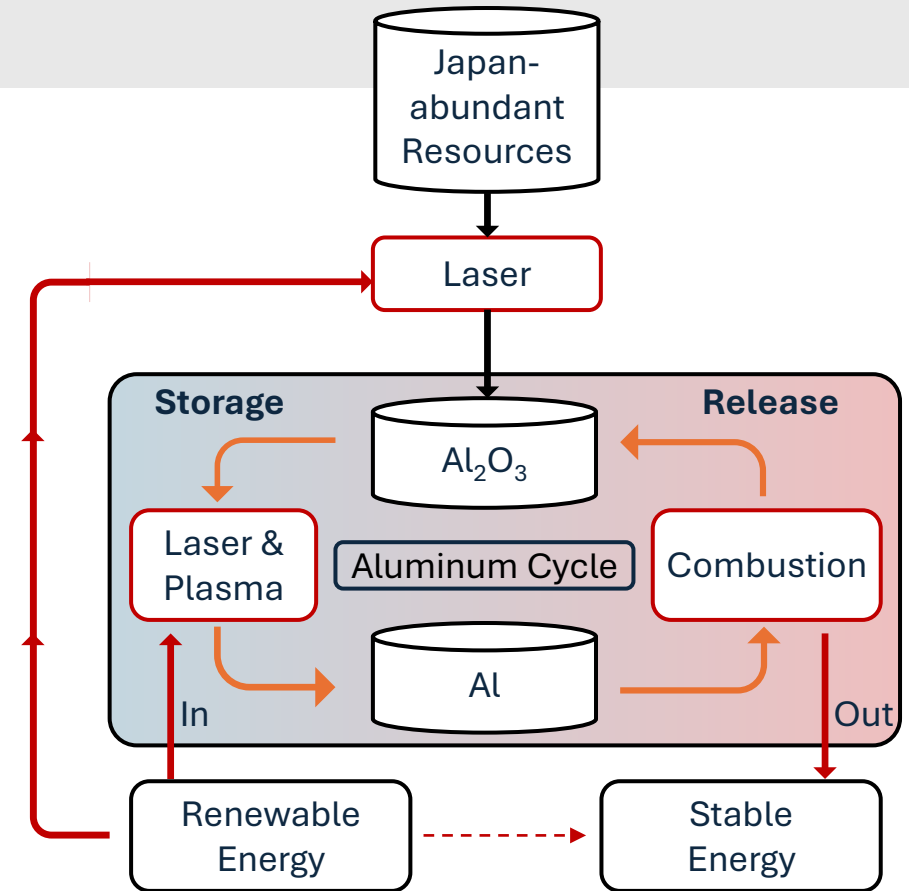
- Keyword of this research group:  
“Green Transformation (GX)”
- Aluminum cycle as an enabler for GX
- Demand for  $\text{Al}_2\text{O}_3$  and Al increasing

## Motivation:

- Large amounts of alumina required
- Alumina production harmful to environment
- Japan lacks Bauxite reserves

## Lead Question

- Are there **green ways** to **produce alumina** from **Japan-abundant resources**?



[1] Christen, et al., (2025),  
アルミエネルギーサイクル研究会

# Japan-Abundant Aluminum Sources

Resource Category	Primary Mineral(s)	Base Composition	Key Japanese Locations	Source
Hydrothermal Clays	Kaolinite, Halloysite	$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$	Aichi, Gifu, Yamagata	[2]
Volcanic Feldspars	Anorthite (Plagioclase)	$\text{CaAl}_2\text{Si}_2\text{O}_8$	Izu-Bonin Arc, Shimane	[3]
High-Alumina Fly Ash	Mullite, Amorphous Ash, "HAFA"	$3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$	Nationwide (Thermal Power Plants)	[4]



Industrial waste

Coal: 26% of total energy supply in 2024 [5]

[2] Nagasawa, K. (1978). *Developments in Sedimentology*

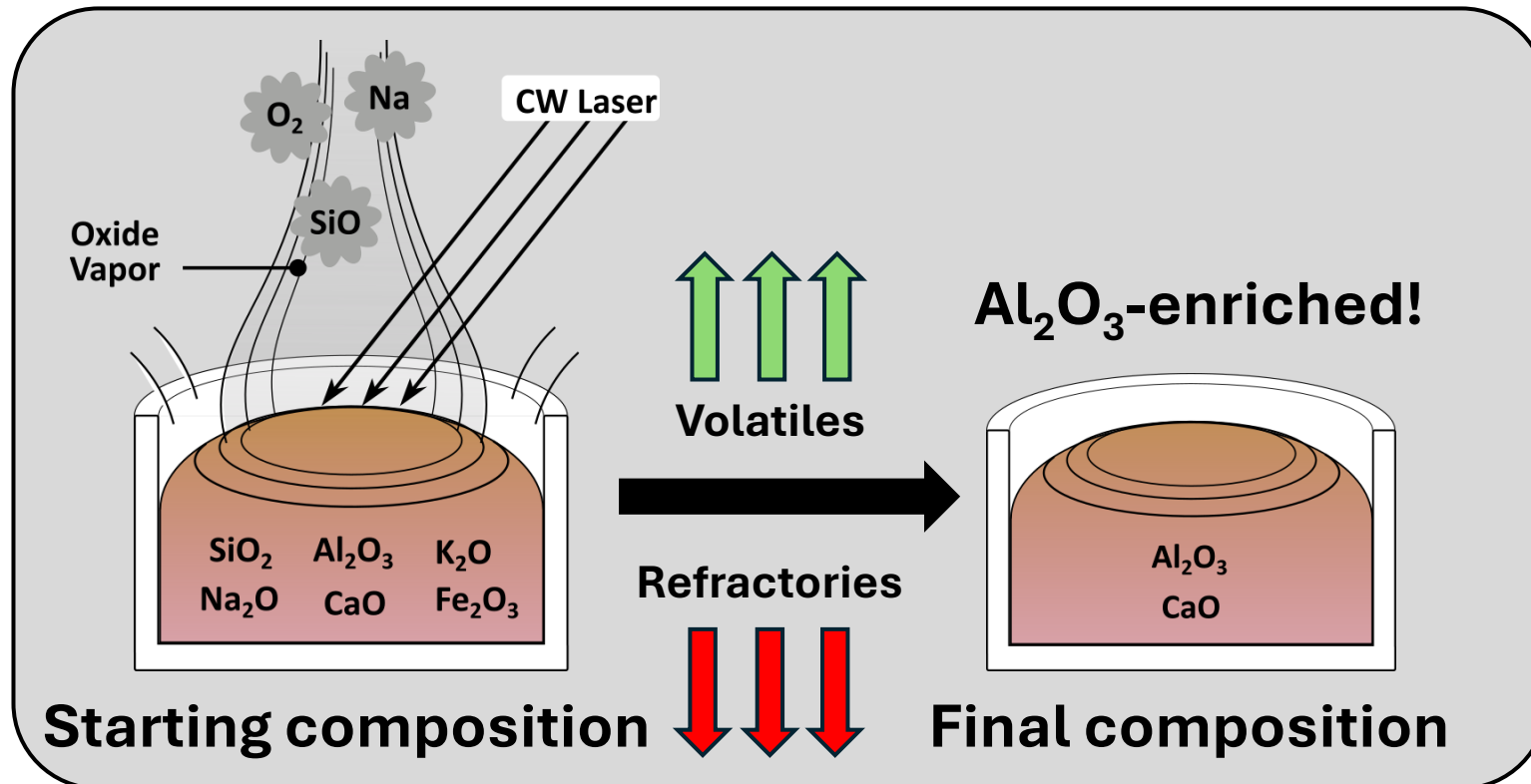
[3] Aizawa, et al., (2020). *Journal of Mineralogical and Petrological Sciences*

[4] Liu, et al., (2018). *Fuel Processing Technology*

[5] IEA, Japan, 2024

# Thermal fractionation / vaporization

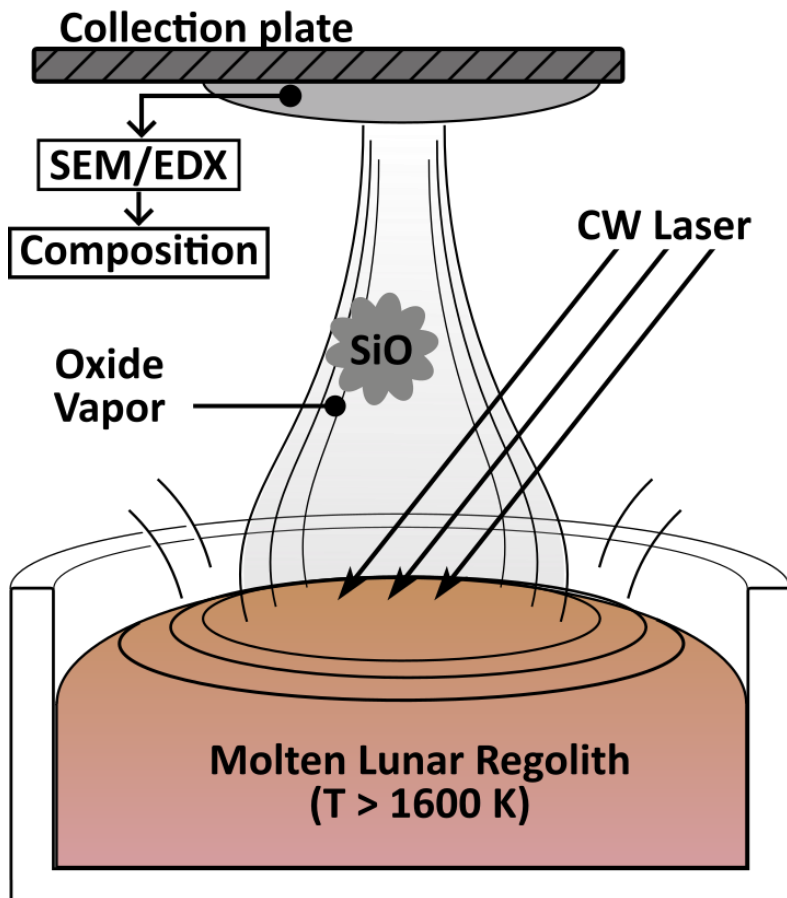
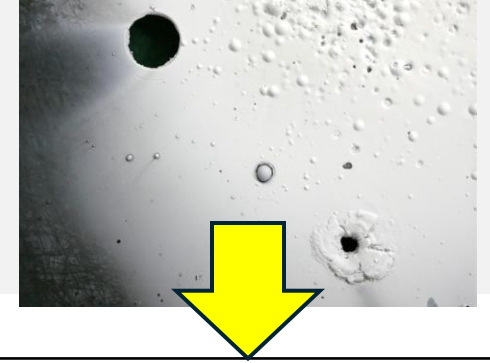
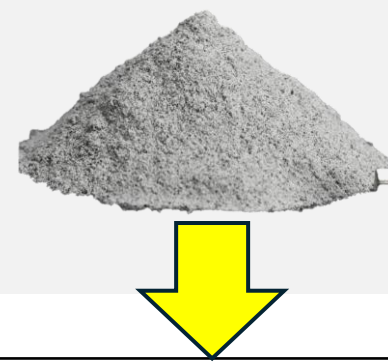
- Localized thermal energy (Solar / laser energy → GX conformity)
- Utilize vapor pressure of constituent oxides to distill the mineral



Oxide	Boiling point	
$\text{K}_2\text{O}$	623 K	} Volatile
$\text{Na}_2\text{O}$	2223 K	
$\text{SiO}_2$	2503 K	
$\text{CaO}$	3123 K	} Refractory
$\text{Al}_2\text{O}_3$	3250 K	

# Vapor collection experiment

Previous success



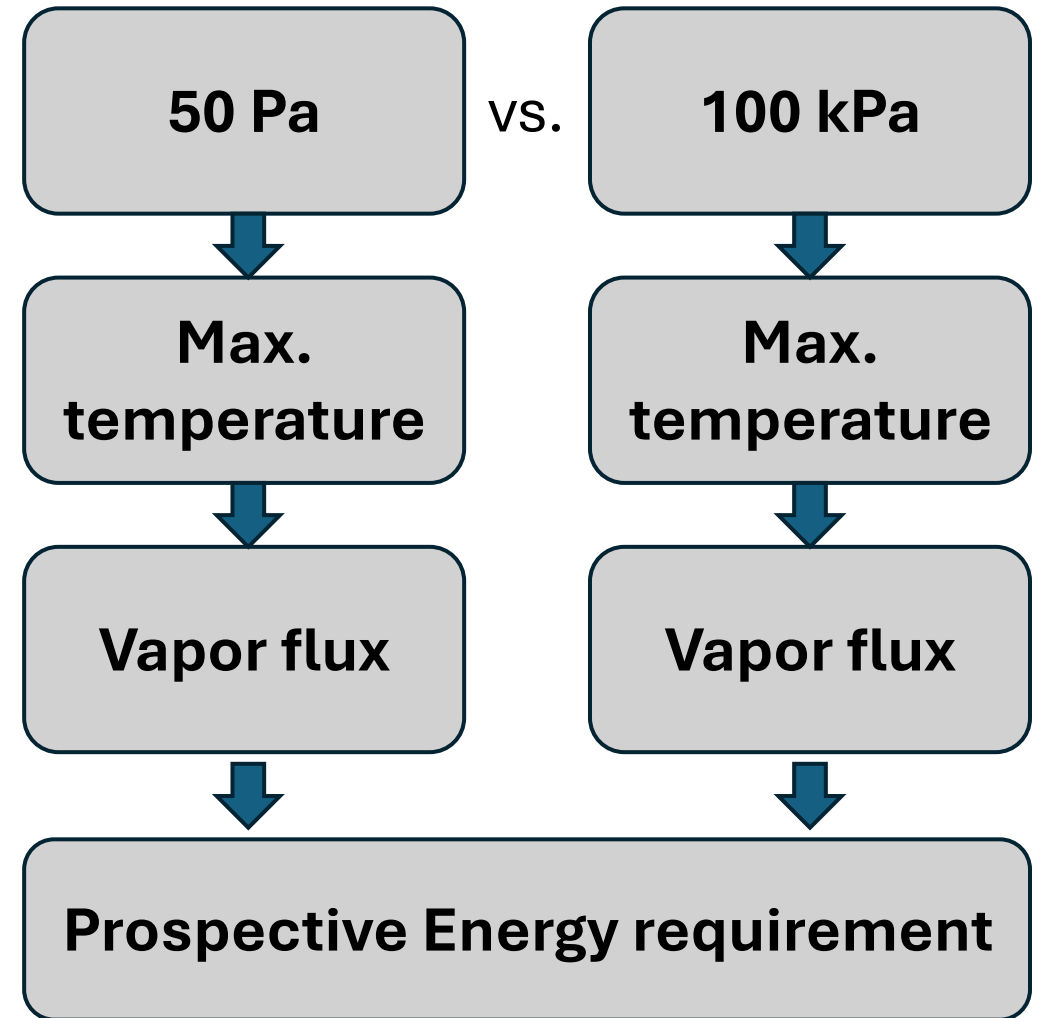
Oxide	Lunar regolith JSC-2A wt%	Extracted vapor at 2600 K, 100 kPa wt%
Na <sub>2</sub> O	3.14	10.82
K <sub>2</sub> O	0.98	2.81
Fe <sub>2</sub> O <sub>3</sub>	15.02	5.28
<b>SiO<sub>2</sub></b>	<b>43.38</b>	<b>78.27</b>
MgO	3.82	0.97
<b>Al<sub>2</sub>O<sub>3</sub></b>	<b>18.30</b>	<b>0.11</b>
<b>CaO</b>	<b>11.47</b>	<b>0.14</b>

[6] Christen, et al., (2025). *ISTS*

# Today's Objective

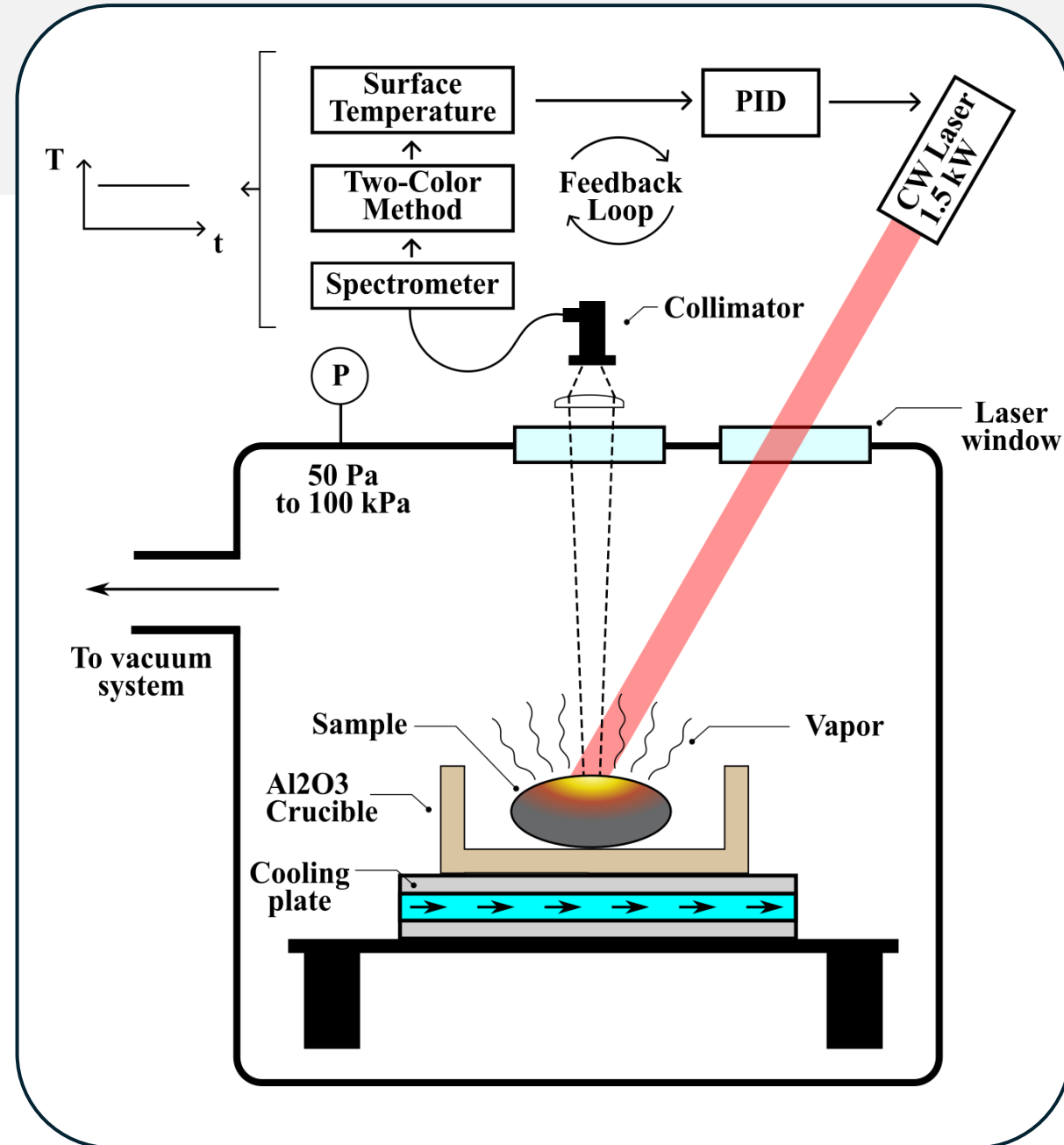
➤ Identify system engineering metrics

- Pressure dependency
- Maximum temperature
- Vapor flux
- Energy consumption



# Experimental Set-up

- **Continuous-wave (CW) Fiber laser**
  - 150 W to 1500 W
  - 1080 nm
  - Automatically controlled (PID) via temperature feedback
- **Temperature measurement**
  - Two-color method
  - 650 nm & 850 nm
- **Vacuum chamber**
  - 20 L
  - 50 Pa to 100 kPa
- **Material**
  - Anorthosite ( $\text{CaAl}_2\text{Si}_2\text{O}_8$ )
    - $\text{SiO}_2$  49 wt%
    - $\text{Al}_2\text{O}_3$  29 wt%
    - $\text{CaO}$  19 wt%



# Results & Discussion

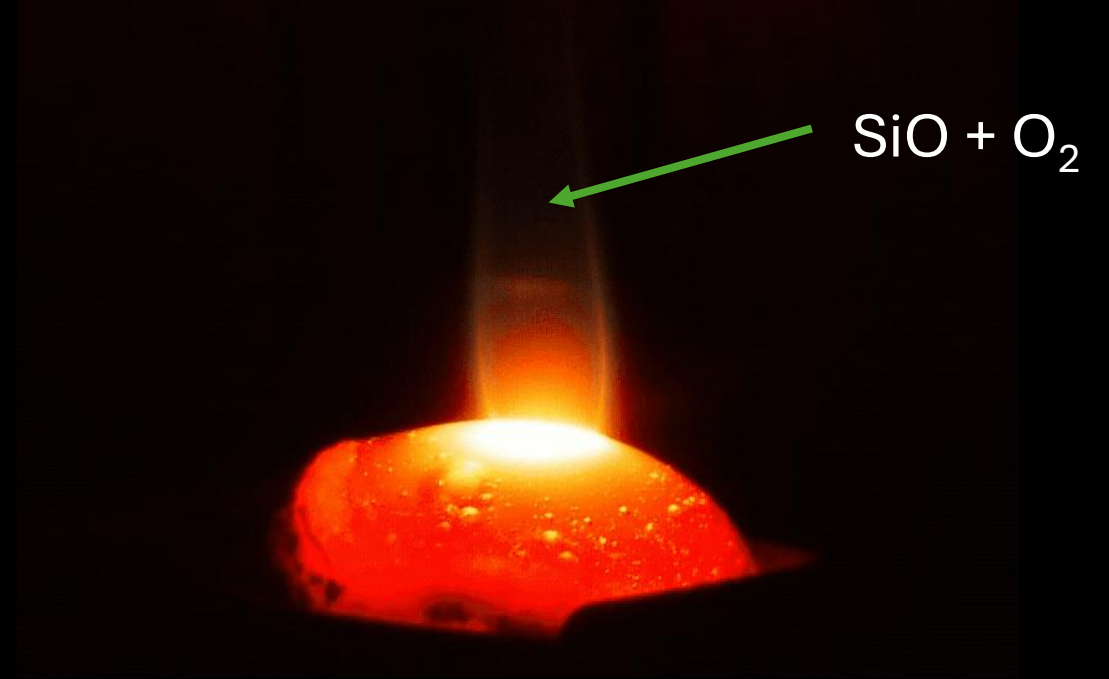
Low pressure



55 Pa 2000 K

$$\dot{m}_{vap} = 2.17 \times 10^{-3} \text{ mg/s}$$

Atmospheric Pressure (Ar)



100 kPa 2500 K

$$\dot{m}_{vap} = 1.13 \times 10^{-1} \text{ mg/s}$$

# Results & Discussion

Pressure	Ejection threshold	Vapor rate*	Vapor flux*
Pa	K	mg/s	kg/(m <sup>2</sup> ·s)
55	~2200	$2.17 \times 10^{-3}$	$8.86 \times 10^{-6}$
100k	~2700	$1.13 \times 10^{-1}$	$2.20 \times 10^{-2}$

\*200 K below threshold

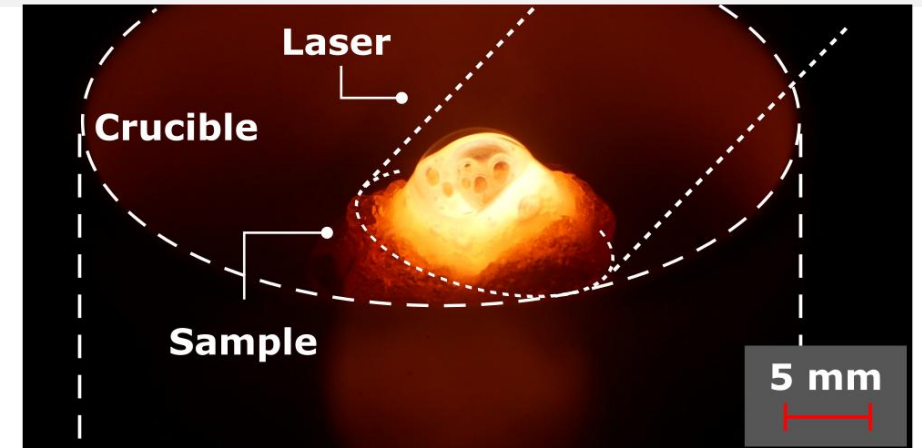
Boiling effect suppressed at higher pressure



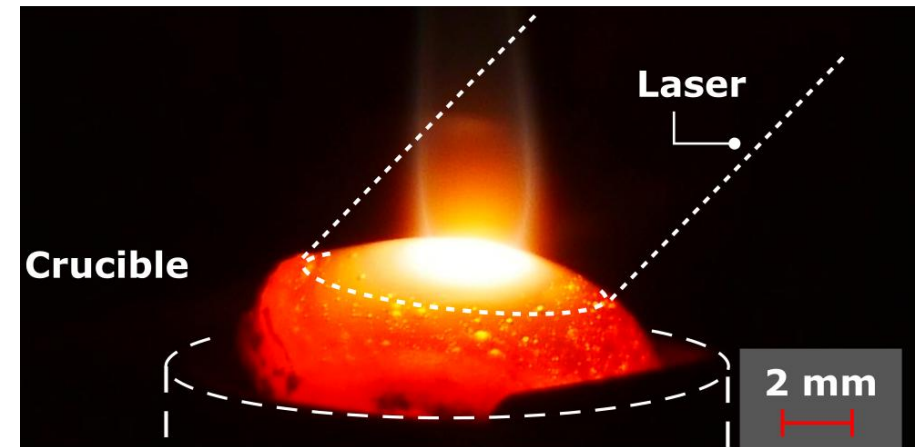
Higher temperature before melt ejection



Higher vapor flux



(a) 55 Pa, 2000 K



(b) 100 kPa, 2500 K

# Results & Discussion

- Laser intensity at 2500 K condition  $I_{\text{Laser}} = \frac{255 \text{ W}}{1.13 \times 10^{-4} \text{ m}^2} = 2.25 \text{ MW/m}^2$
- Vapor flux  $J_{\text{vap}} = 2.20 \times 10^{-2} \text{ kg}/(\text{m}^2 \cdot \text{s})$
- Energy cost for 1 kg Anorthosite (49.3% SiO<sub>2</sub> -  $f_{\text{SiO}_2} = 0.493$ )

$$\frac{E_{\text{total}}}{\text{kg}_{\text{An}}} = P_{\text{Laser}} \left( \frac{f_{\text{SiO}_2}}{\dot{m}_{\text{vap}}} \right) = 1.112 \times 10^9 \frac{\text{J}}{\text{kg}_{\text{An}}} = 1112 \frac{\text{MJ}}{\text{kg}_{\text{An}}} = 309 \frac{\text{kWh}}{\text{kg}_{\text{An}}}$$

# Results & Discussion

- Latent heat of vaporization of SiO<sub>2</sub>

$$\Delta H_{\text{vap}} \approx 10 \text{ MJ/kg}$$

$$P_{\text{vap}} = \Delta H_{\text{vap}} \cdot \dot{m}_{\text{vap}} = 1.13 \text{ W}$$

- Thermal efficiency

$$\text{Efficiency} = \frac{P_{\text{vap}}}{P_{\text{Laser}}} = \frac{1.13 \text{ W}}{255 \text{ W}} = 0.44 \%$$

$$P_{\text{rad}} \approx 150 \text{ W}$$

$$P_{\text{Cond}} \approx ?$$



**Reflects current experiment conditions only**

**Next steps:** Improve efficiency (Process optimization)

# Summary & Conclusion

- **Japan has alumina-rich resources**
  - HAFA (High Alumina Fly Ash) offers great recyclability
- **Thermal fractionation offers a path for  $\text{Al}_2\text{O}_3$ -enrichment**
  - Higher pressures offer higher processing speed
    - Suppression of violent boiling, allowing higher thermal input
  - Achieved vapor flux at 100 kPa & 2500 K:  $J_{\text{vap}} = 2.20 \times 10^{-2} \text{ kg}/(\text{m}^2 \cdot \text{s})$
- **Process efficiency needs improvement (<1 % efficiency)**
  - Gaussian profile vs. flat top profile
  - Reduce thermal losses (radiation, conduction) → Process design
  - Shape optimization (surface vs. volume)

Thank you for your attention!

Author Lucas-Brian Christen, Maho Matsukura, Kimiya Komurasaki,  
Hiroyuki Koizumi

Affiliation PhD Student (D2), Komurasaki-Koizumi Lab.  
Graduate School of Engineering  
The University of Tokyo

E-mail [christen-lucas-brian@g.ecc.u-tokyo.ac.jp](mailto:christen-lucas-brian@g.ecc.u-tokyo.ac.jp)



# Appendix 1

- ❑ Continuum spectrum via spectrometer (200 nm to 1000 nm; EPP2000 by StellarNet Inc.)
- ❑ Two-Color Method (assuming  $\frac{\varepsilon_1}{\varepsilon_2} = 1$ )

Where

$T$  = Temperature [K]

$R$  = Ratio of measured signals

$h$  = Planck's constant [ $\text{kg m}^2 \text{s}^{-1}$ ]

$c$  = Speed of light [ $\text{m s}^{-1}$ ]

$k$  = Boltzmann's constant [ $\text{m}^2 \text{kg s}^{-2} \text{K}^{-1}$ ]

$\varepsilon_i$  = Emissivity at wavelength  $i$  [-]

$\lambda_i$  = Wavelength  $i$  [m]

$$T = \frac{hc}{k} \frac{1}{\ln R - 5 \ln \lambda_2 / \lambda_1} \left( \frac{1}{\lambda_1} - \frac{1}{\lambda_2} \right)$$

With

$$\lambda_1 = 650 \text{ nm}$$

$$\lambda_2 = 850 \text{ nm}$$

# Appendix 2

## ☐ Anorthosite from Exolith Lab

<i>Compound</i>	<i>Concentration (wt%)</i>
Al <sub>2</sub> O <sub>3</sub>	29.4
SiO <sub>2</sub>	49.3
P <sub>2</sub> O <sub>5</sub>	1.0
SO <sub>3</sub>	0.1
Cl	0.1
K <sub>2</sub> O	0.3
CaO	19.0
TiO <sub>2</sub>	0.1
Fe <sub>2</sub> O <sub>3</sub>	0.7
Total	100.0

# Appendix 3

□ 55 Pa, 2000 K

Within 2000 K  $\pm$  200 K:

□ Total Time (Stable): 704.92 s

□ Avg Temperature: 1947.48 K

□ Avg Laser Power: 24.22 %

