UNOOSA Webinar Series on Hypergravity/Microgravity

Physical Science   Part1. Materials Science

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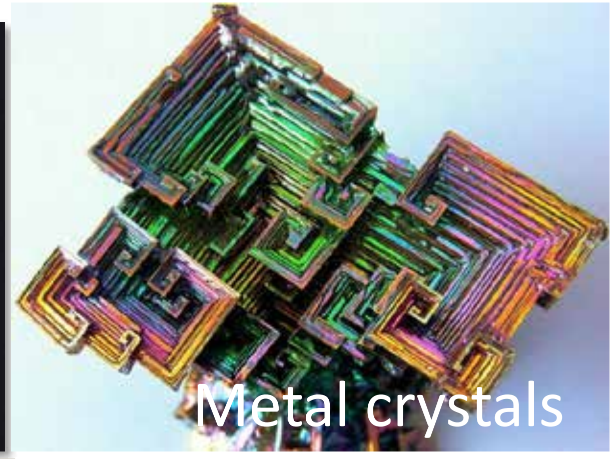
学習院大学 GAKUSHUIN UNIVERSITY   北海道大学 HOKKAIDO UNIVERSITY   JASMA

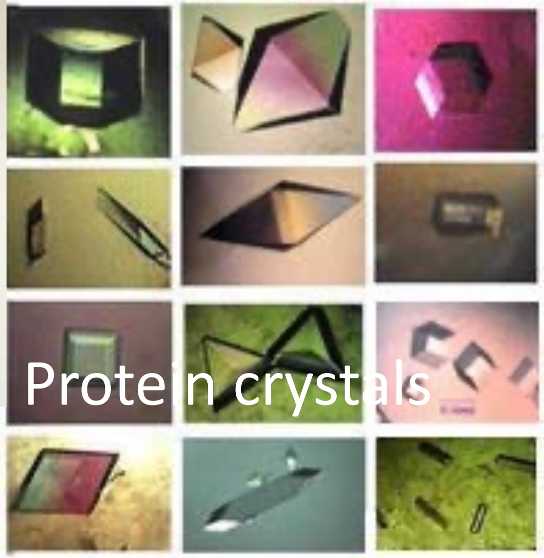
Crystal Growth in Materials Science

Why and how are these beautiful patterns formed in nature?

Prof. Furukawa's Talk

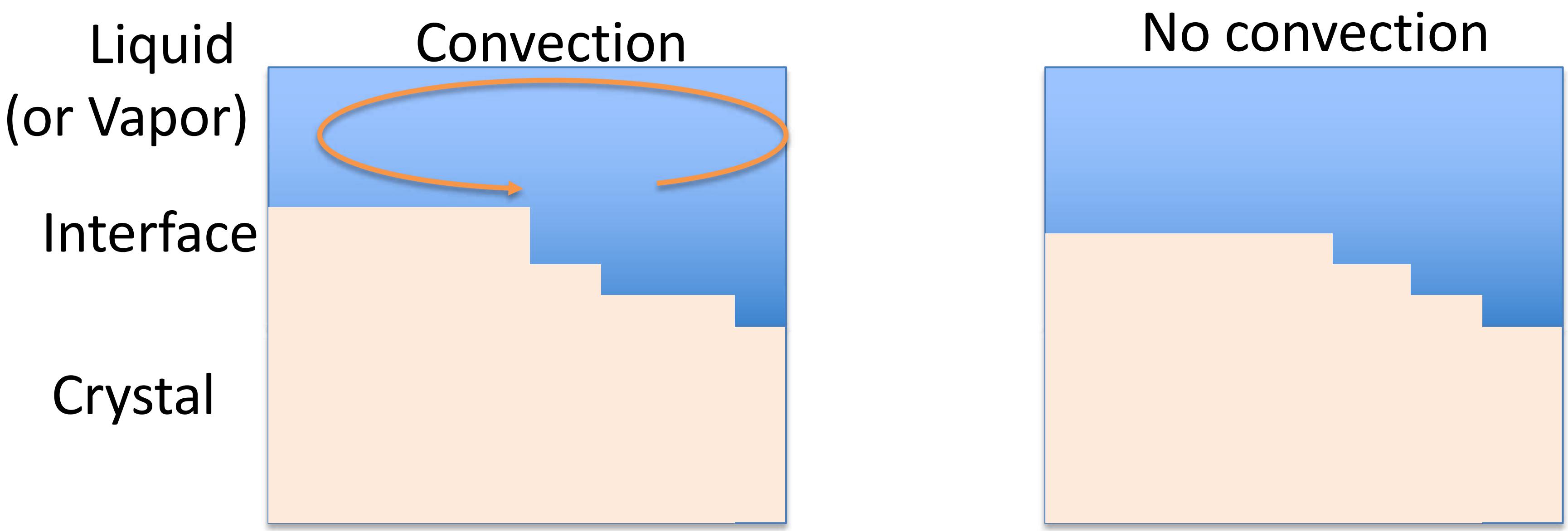


Next, Watanabe



Crystal growth mechanism is a key concept for the material science researches.

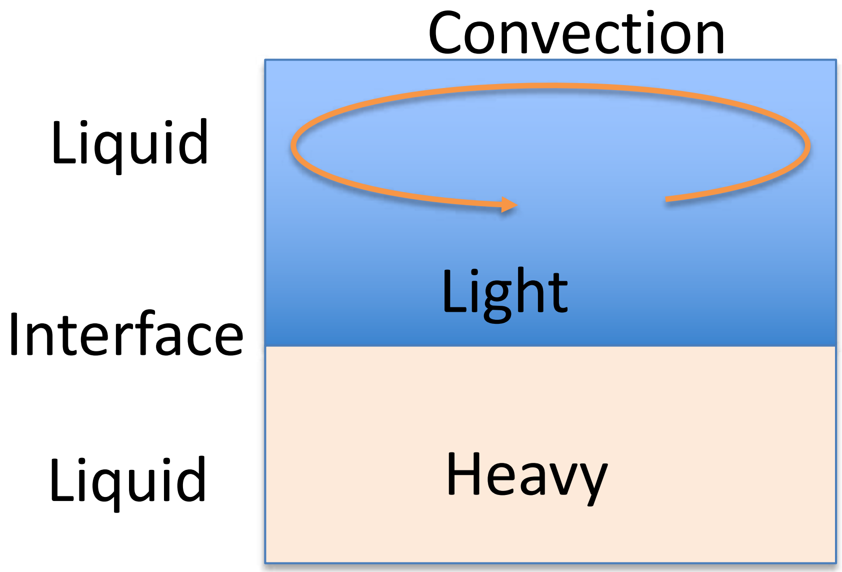
Crystal growth and materials processing under microgravity

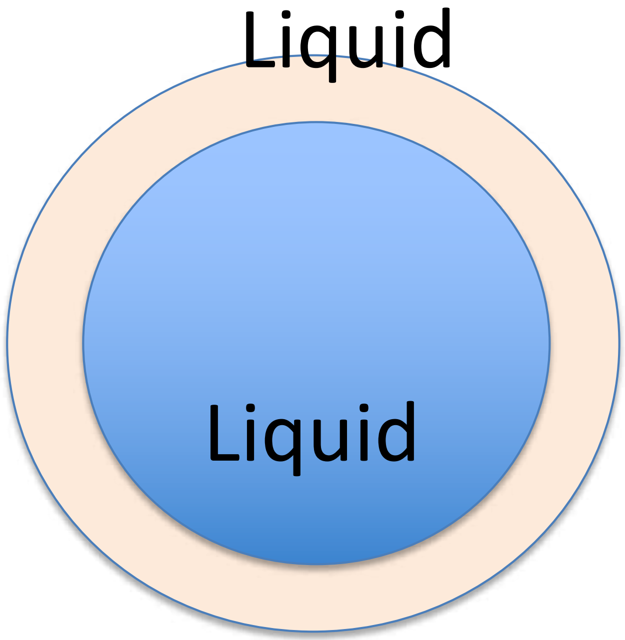


1G conditions on ground **microgravity conditions**

We can pick up pure interfacial phenomena.

Interfacial phenomena in immiscible liquids process
- Refining, smelting and welding processes -





1G conditions on ground **microgravity conditions**

We can pick up pure interfacial phenomena using microgravity conditions.

Interfacial phenomena and thermophysical properties of high temperature liquids
-INTERFACIAL ENERGY PROJECT-

Masahito Watanabe[1], Toshihiro Tanaka[2], Takao Tsukada[3], Takehiko Ishikawa[4], Shumpei Ozawa[5]

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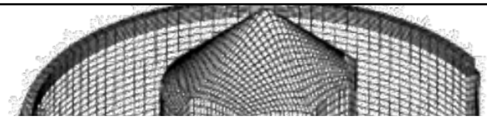
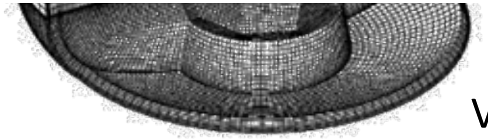
High Temperature liquids in Material Processing

Crystal growth

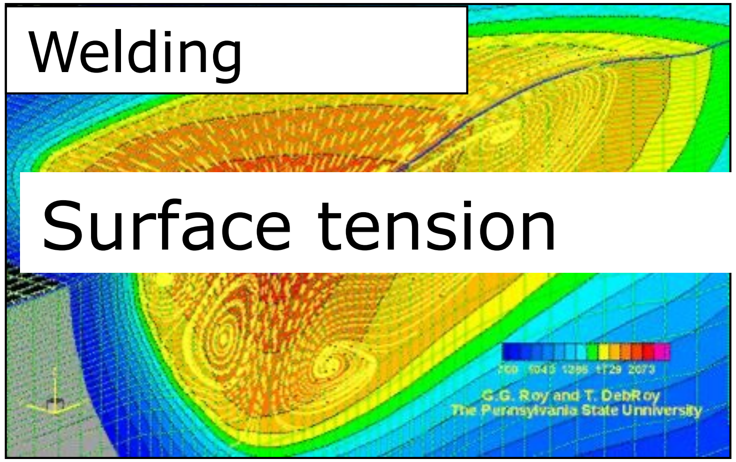


Density,
Thermal expansion



V.V. Kalaev *et al.*

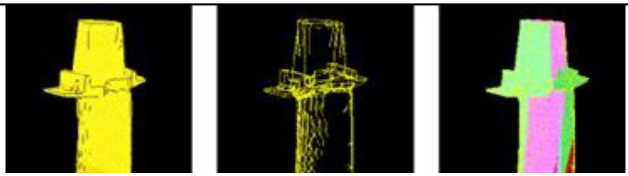
Welding



Surface tension

G.G. Roy & DebRoy

Unidirectional solidification



Viscosity,
Thermal conductivity

P. Thevoz *et al.*

Thermophysical properties need for process control of production engineering

Electronic Property

$\mu(T)$ *Electrical resistivity*

$\varepsilon(T)$ *Emmisivity*

$\sigma(T)$ *Surface tension*

$\kappa(T)$ *Thermal conductivity*

Thermophysical Properties for Materials Processing

$\eta(T)$ *Viscosity*

$\alpha(T)$ *Thermal diffusivity*

$\beta(T)$ *Thermal expansion*

$C_P(T)$ *Specific heat*

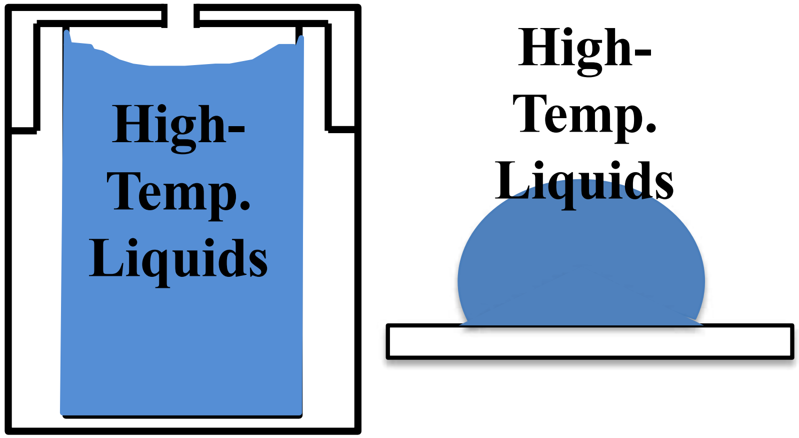
$\rho(T)$ *Density*

Mechanical Property

Thermal Property

Advantage of Microgravity for High Temperature Liquids Handling

High-Temperature Liquids Sample Handling on Ground

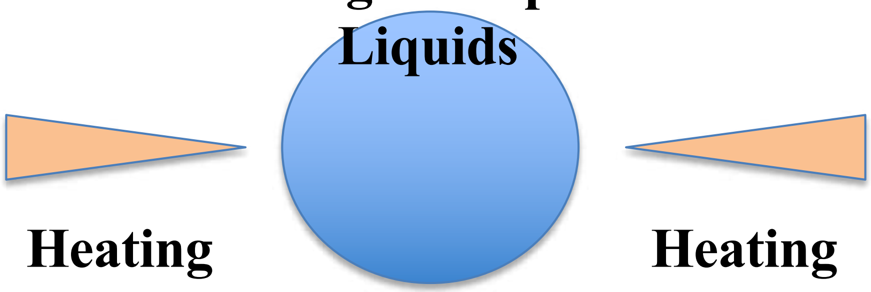


Refractory Materials Crucible

Refractory Materials Substrate

Temperature limits by crucible or substrate materials

High-Temperature Liquids Sample Handling under Microgravity

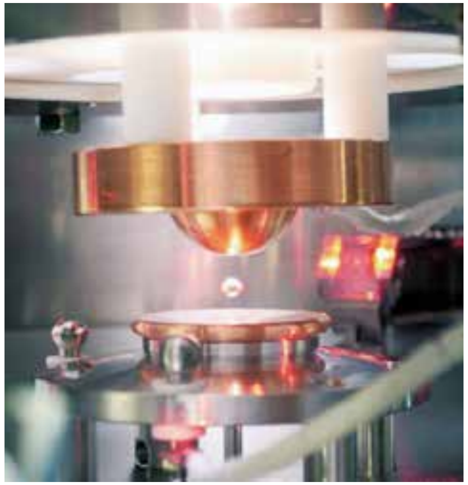


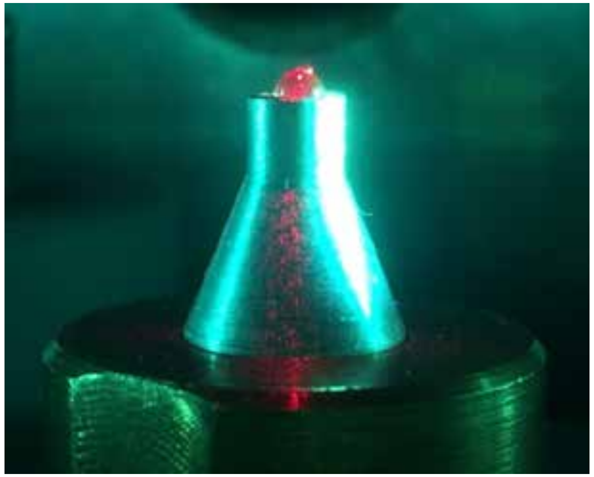
Heating Power

Heating Power

No Temperature limits, if we have heat sources

Containerless Sample Handling
Levitation Techniques





Electromagnetic Levitation (EML)

MSL-EML Facility of COLUMBUS in ISS

Electrostatic Levitation(ESL)

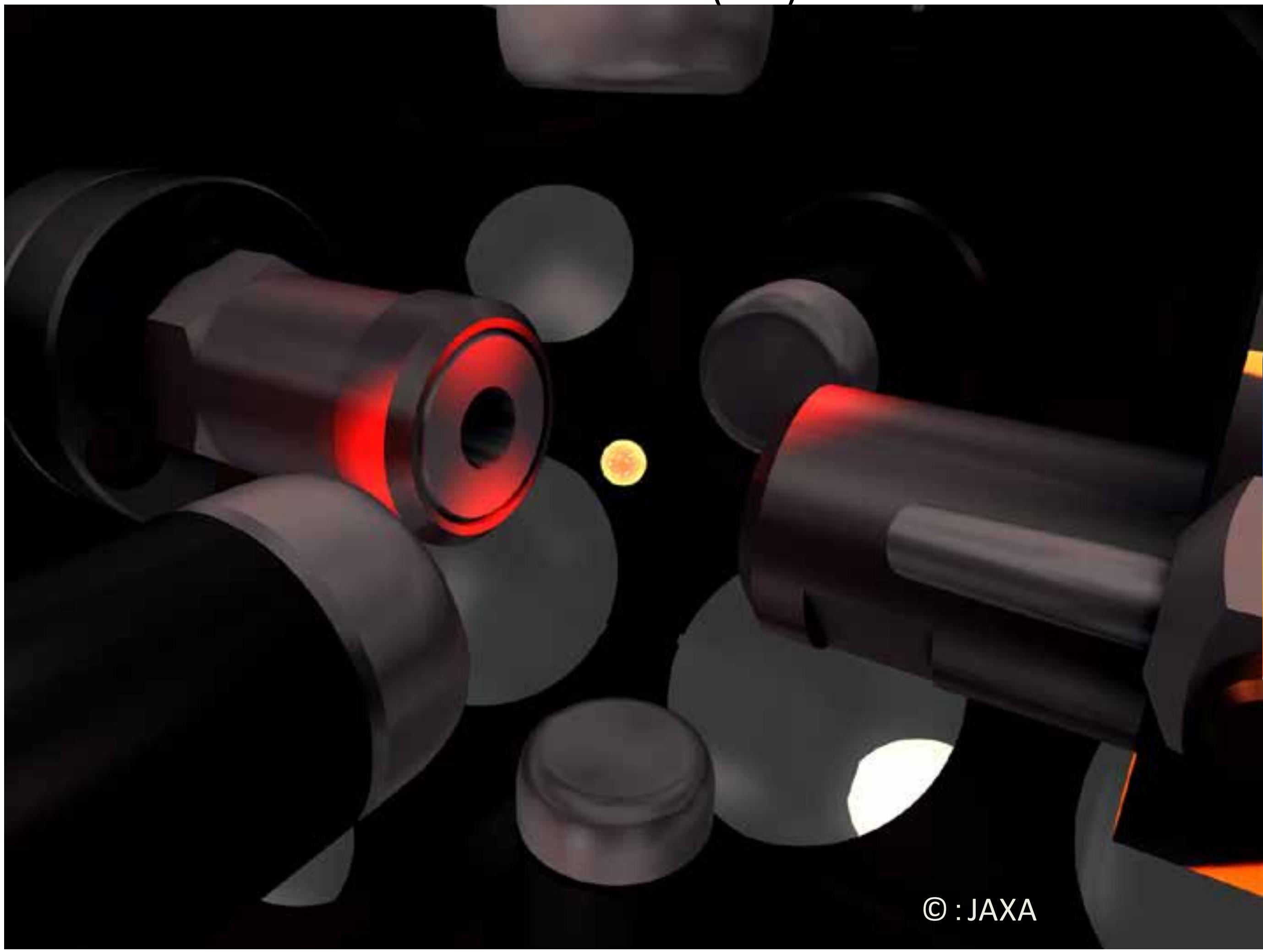
ELF of KIBO in ISS

Aerodynamic Levitation (ADL)

On ground

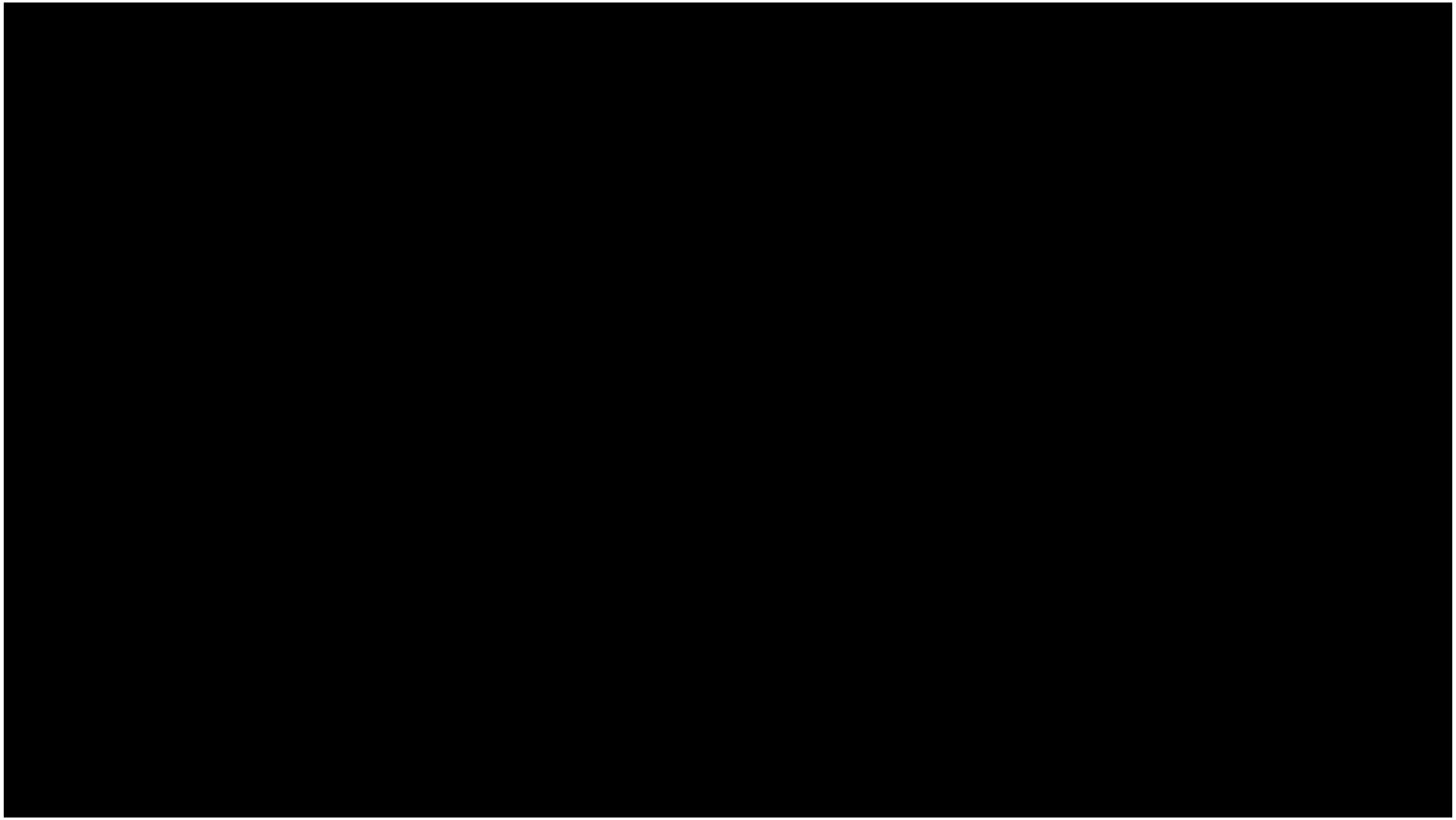
Interfacial Tension Measurement by Electrostatic Levitation Furnace (ELF) in International Space Station (ISS)

Electrostatic Levitation Furnace(ELF) in ISS “KIBO”



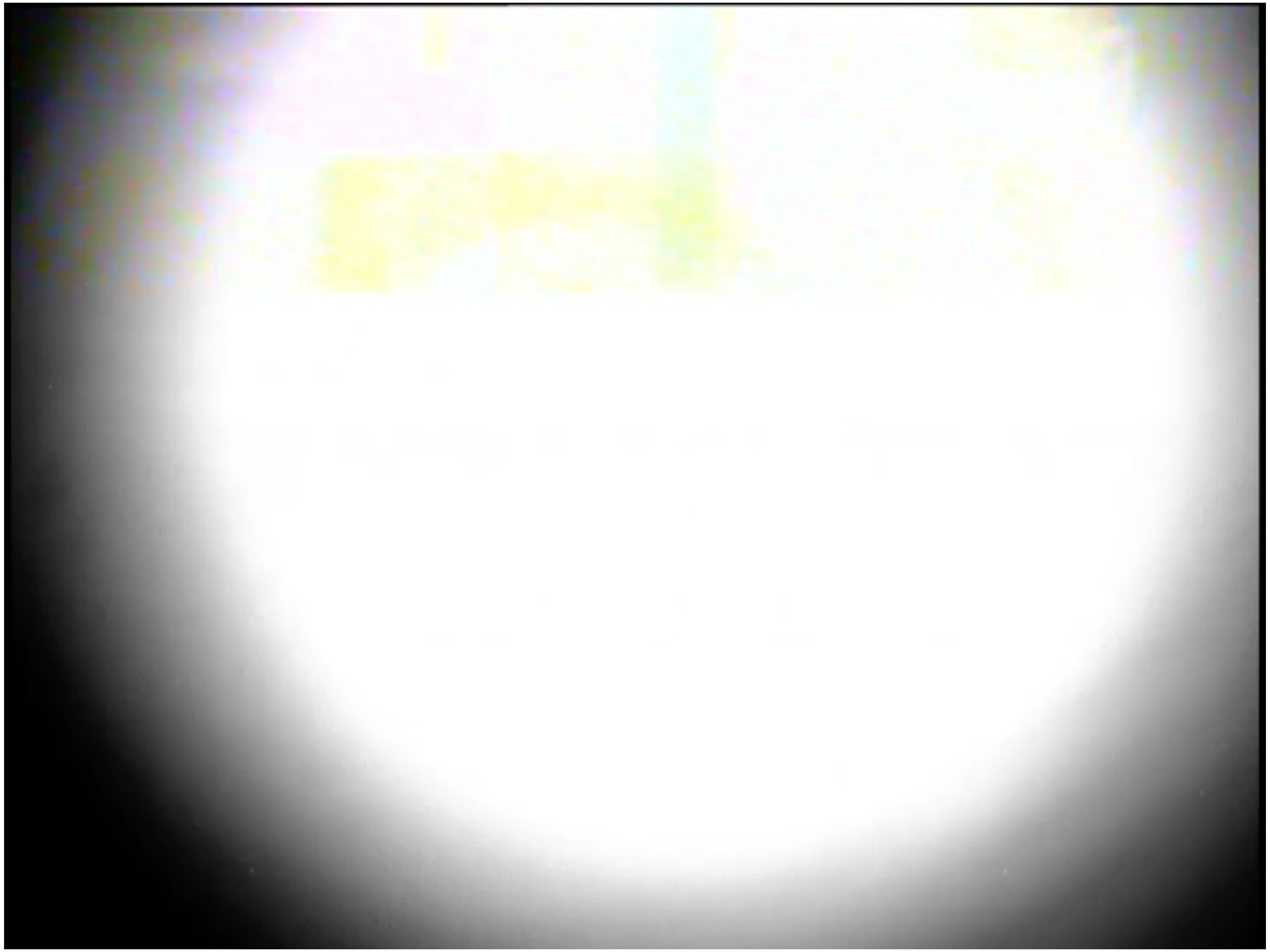
Electrostatic levitation of molten SiO_2-CaO-Mn_3O_4-TiO_2-Fe_2O_3 in ISS

SiO_2:CaO:Mn_3O_4:TiO_2= 22:12:16:50 (wt%)

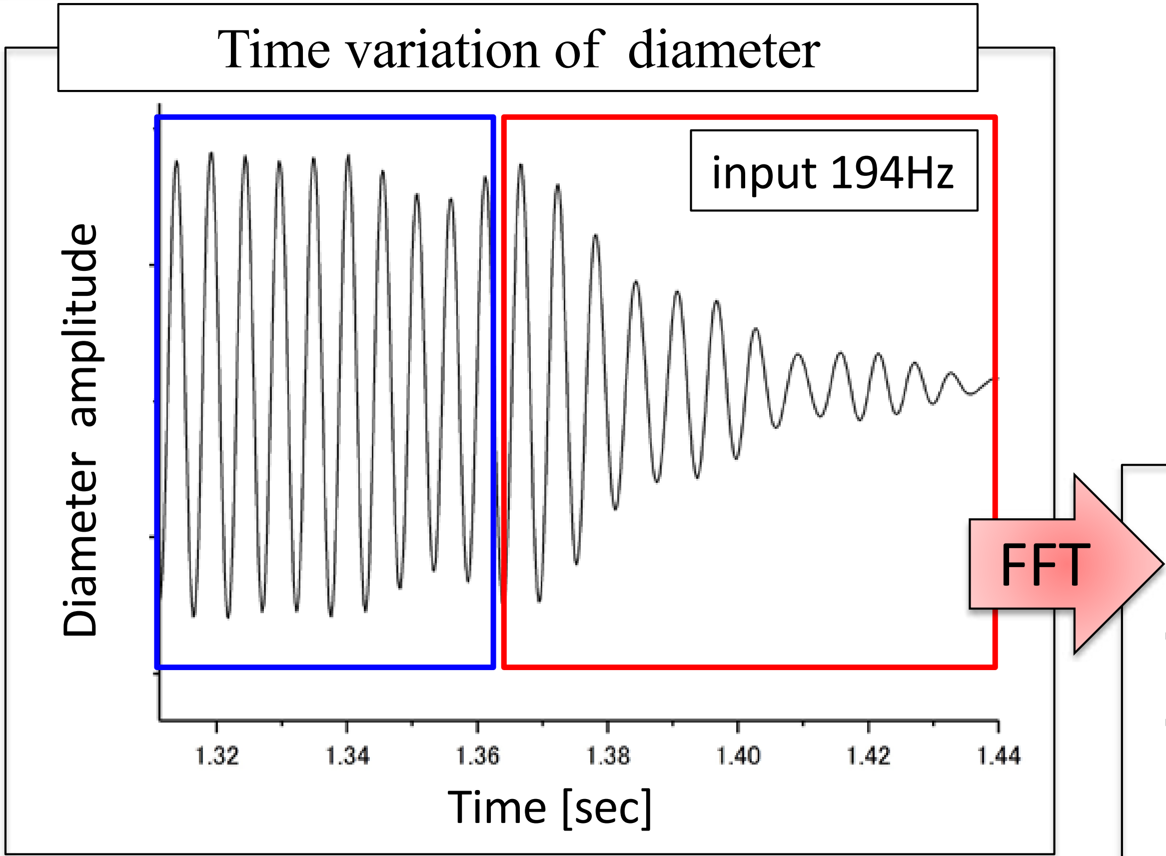


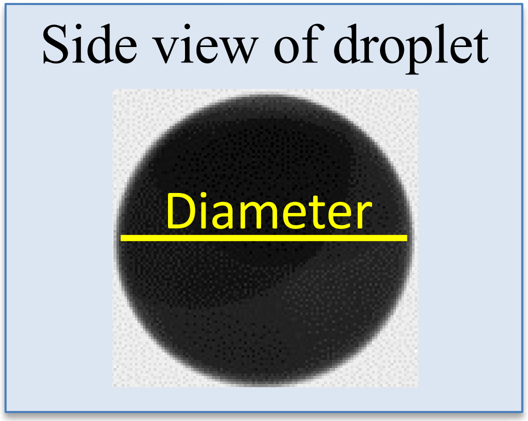
Electrostatic Levitation of Molten SiO_2-CaO-Mn_3O_4-TiO_2-Fe_2O_3 in ISS

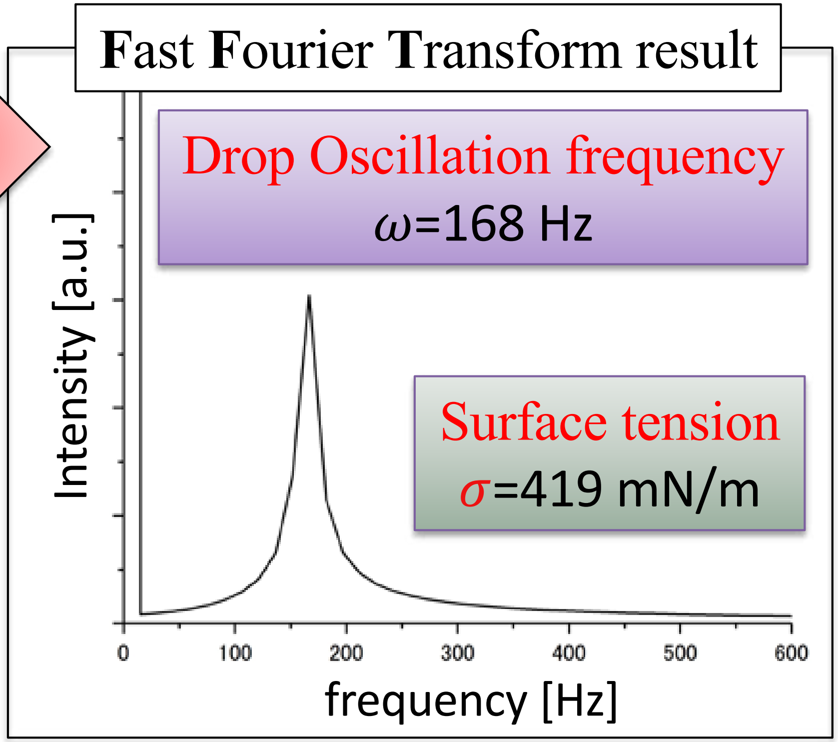
SiO_2-CaO-Mn_3O_4-TiO_2-Fe_2O_3 = 25:7:23:18:27 (wt%)



Surface oscillation of levitated molten SiO_2-CaO-Mn_3O_4-TiO_2 system droplet in ELF





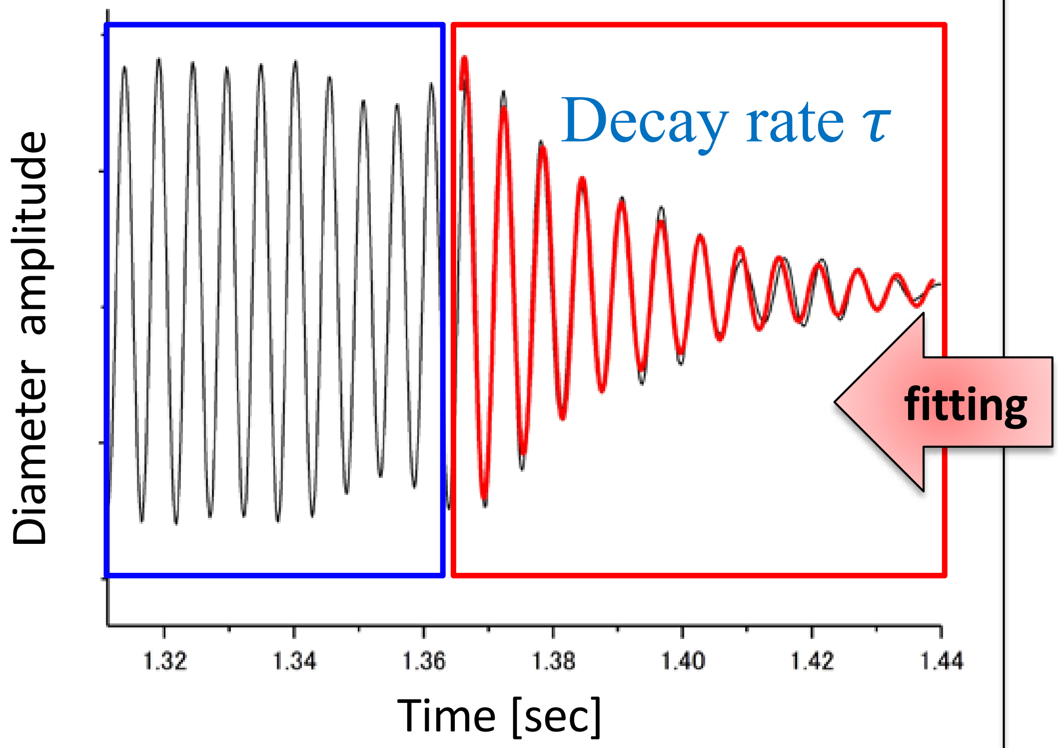


Surface tension –Rayleigh–

$$\sigma = \frac{\rho R^3}{l(l-1)(l+2)}\omega^2$$

Surface oscillation of levitated molten SiO_2-CaO-Mn_3O_4-TiO_2 system droplet in ELF

Time variation of diameter



Side view of droplet

Sine dump function fitting

$$a(t) = A_0 + A\exp\left(-\frac{t}{\tau}\right)\sin(\omega t)$$

ω : Drop oscillation Frequency

t : time

A_0 : Radius

A : Constant

Viscosity –Lamb–

$$\eta = \frac{\rho R^2}{(l-1)(2l+1)}\tau$$

Decay rate

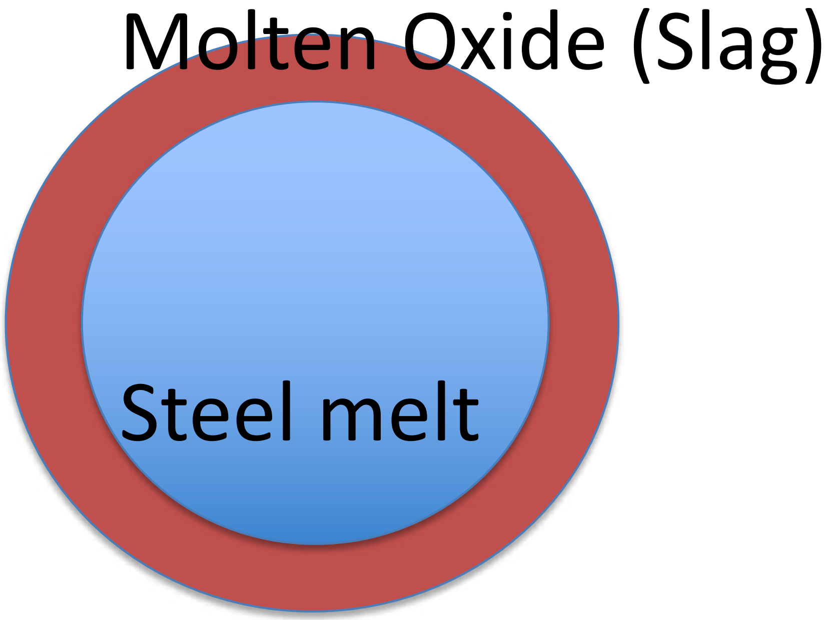
τ=168 s

Viscosity

η=24.7 mPa·sec

Interfacial Tension Measurement by Core/Shell Droplets with Containerless Technique

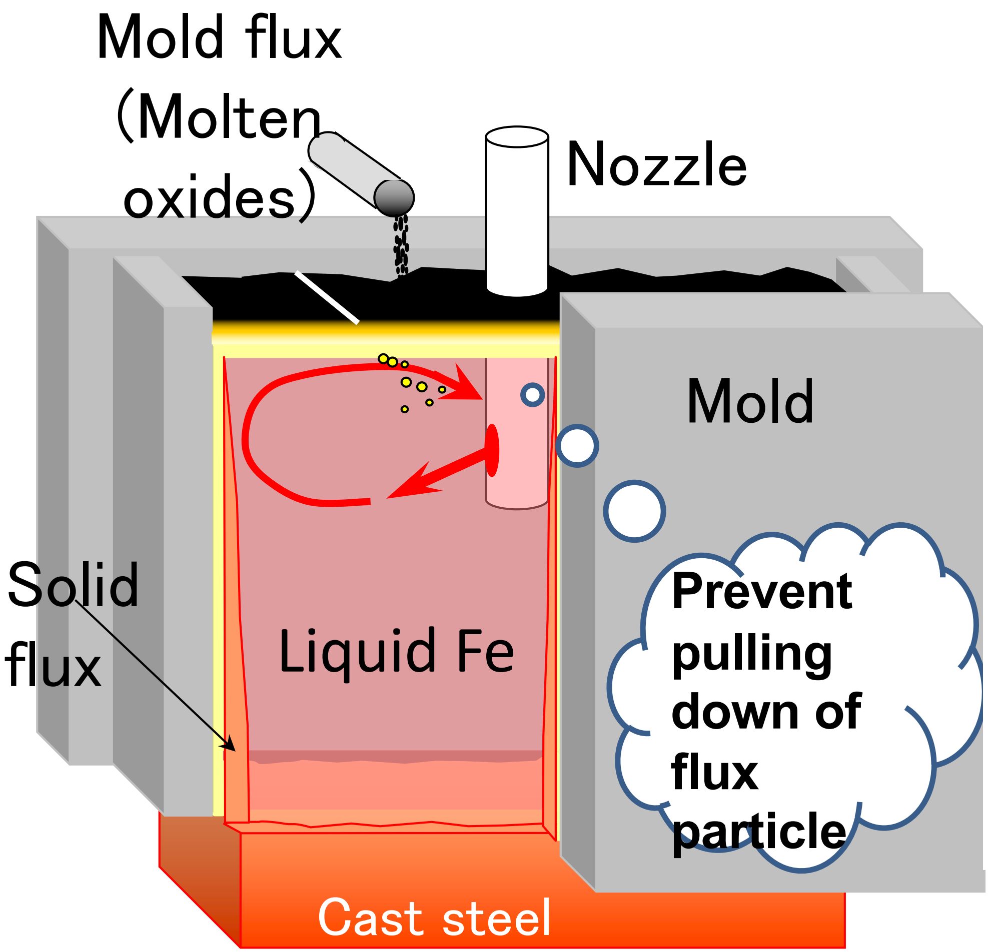
Container-less approach for understanding interfacial phenomena between steel melts and molten slag system using core/shell droplet



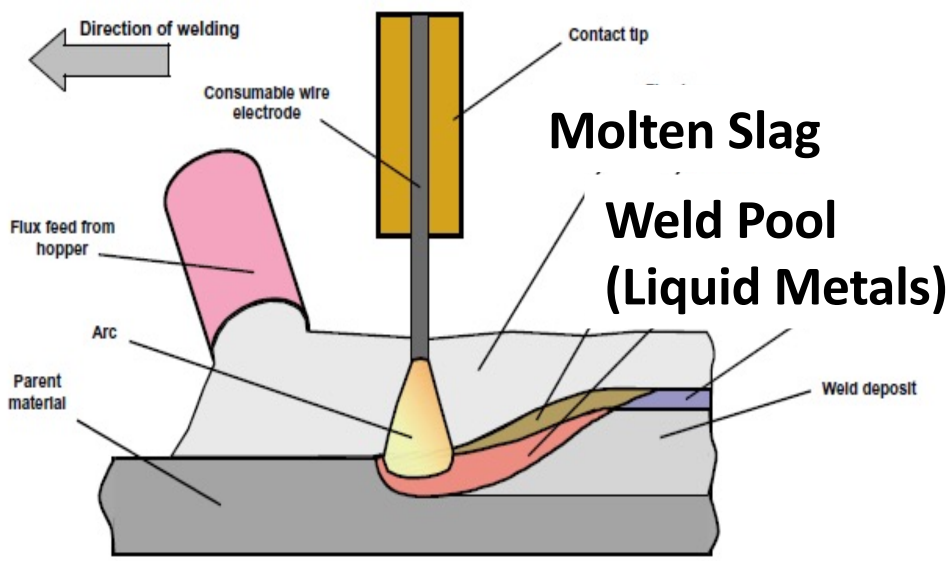
(Slag: SiO_2-CaO-Al_2O_3+other oxides)

Interface in Materials Processing

Continuous casting processes



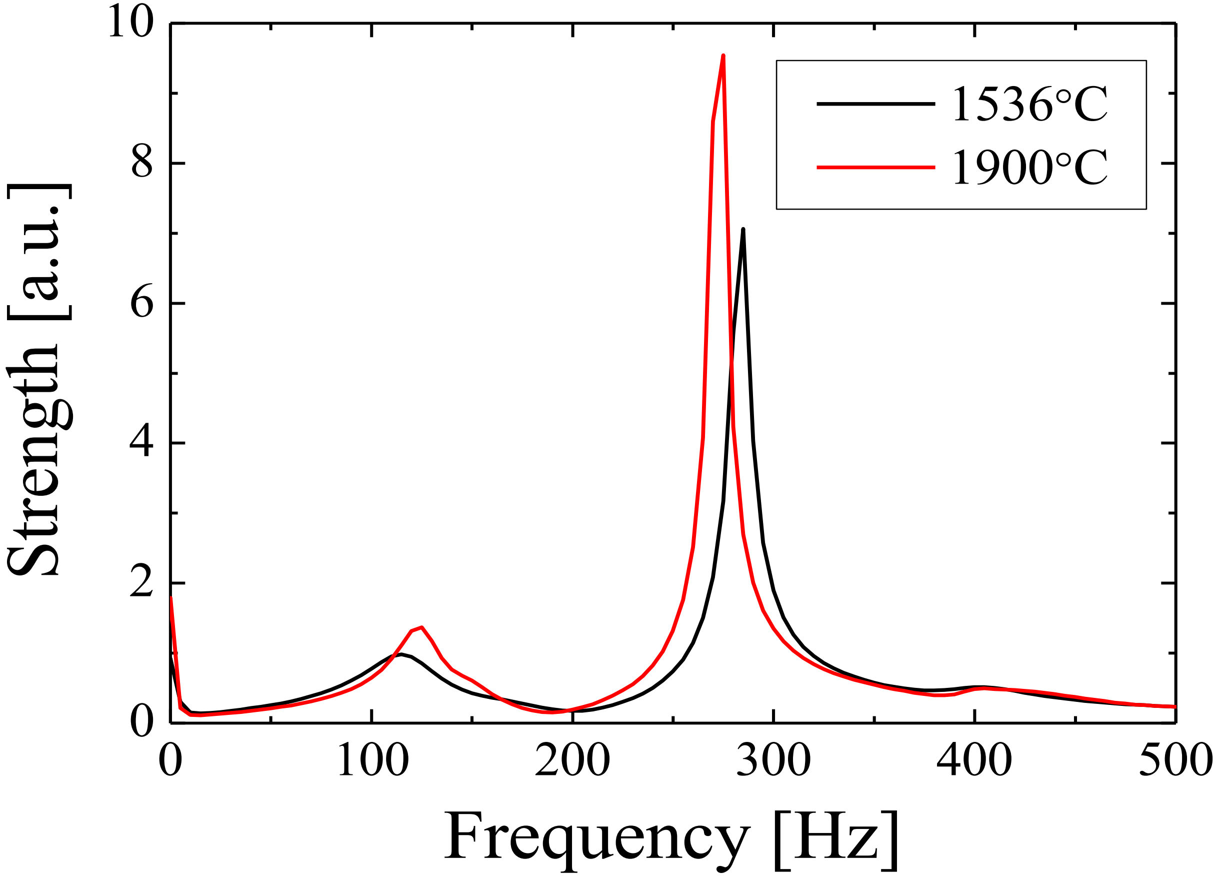
Welding processes



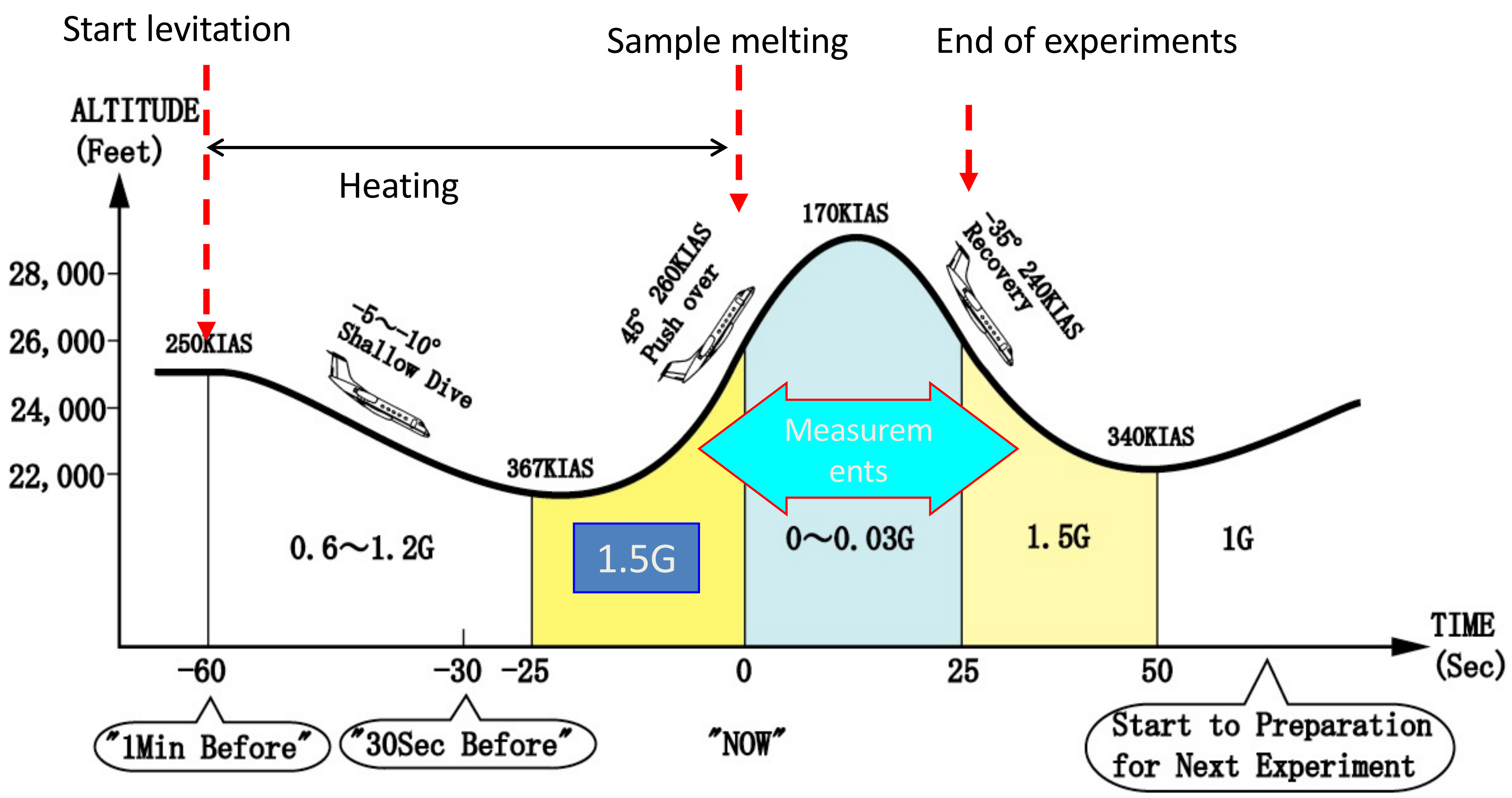
http://www.steelconstruction.info

Surface Oscillation Frequencies of Core/Shell Droplets with molten oxide viscosities

SiO_2:CaO:Mn_3O_4:TiO_2= 22:12:16:50 (wt%)



Microgravity Experiments by Parabolic Flight of Airplane



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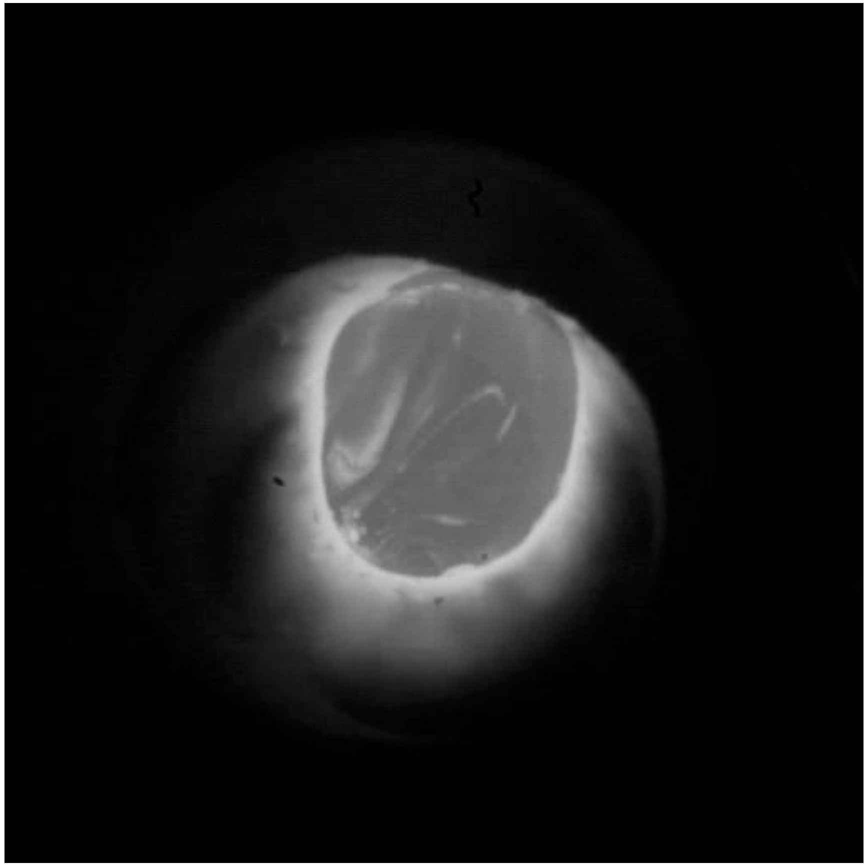
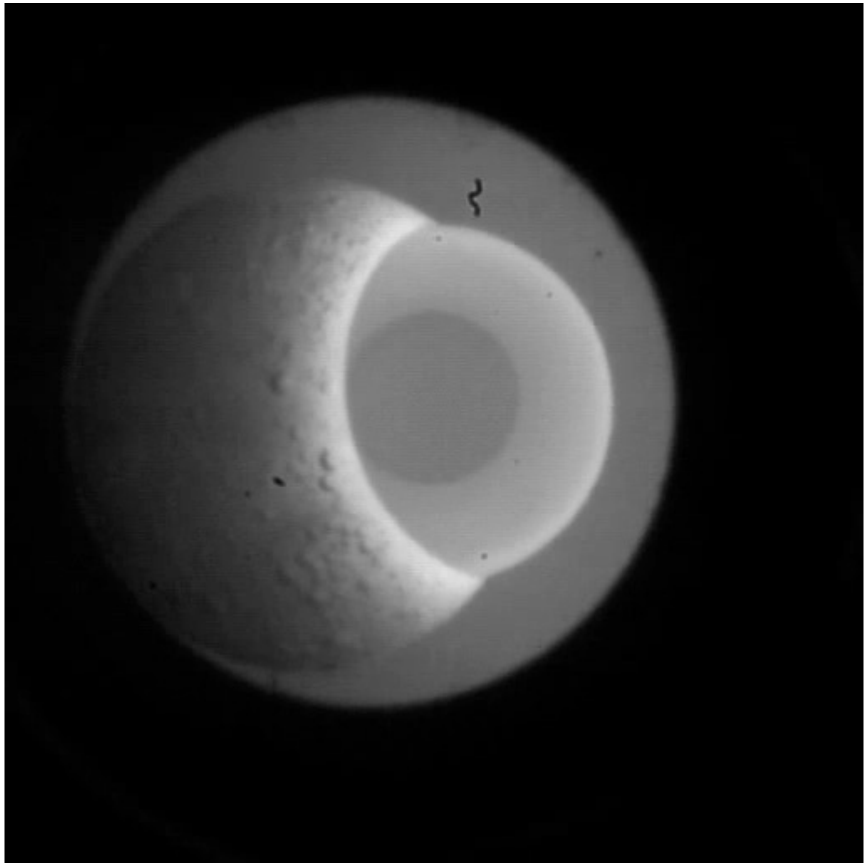
Fe/Oxide Droplet under Microgravity Conditions

Fe/Welding Flux
($CaO-SiO_2-TiO_2-FeO$)



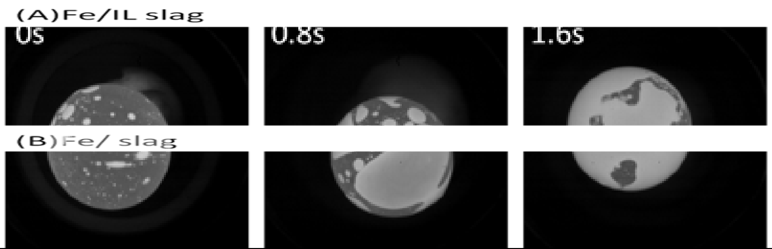
Core/Shell Droplet

Fe/BF Slag
($CaO-SiO_2-Al_2O_3$)

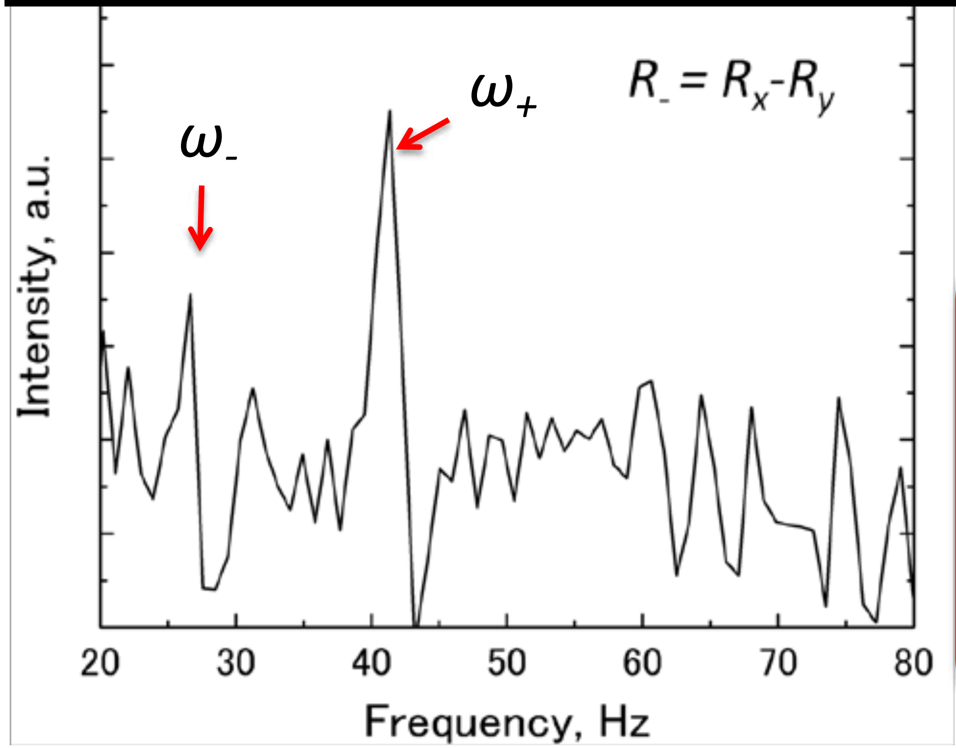


Janus Drop

Surface Oscillation of Fe/Welding Flux



Confirm two frequency by experiments



K. Onodera et.al.: Int. J. Microgravity Appl.. 33(2016)330218

Analytical solutions of core/shell droplet oscillation

$$\omega_{\pm}^2 = \omega_0^2 K_{\pm} \frac{\tau^8}{\sigma} \frac{1}{(1+\Delta\tilde{\rho}_{\rm i})\,\tau^{10} + 2/3\Delta\tilde{\rho}_{\rm i}}$$

$$K_{\pm} = \frac{1}{2}\left(\frac{\sigma m_{\rm i}}{\tau^3} + \frac{m_{\rm o}\tau^3}{\sigma}\right) \pm \sqrt{\frac{1}{4}\left(\frac{\sigma m_{\rm i}}{\tau^3} - \frac{m_{\rm o}\tau^3}{\sigma}\right) + 1}$$

Frequency of Fe/Welding flux

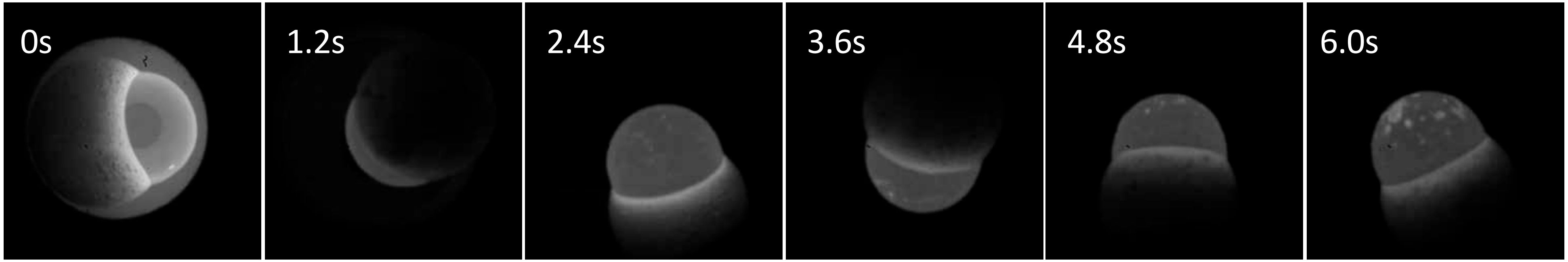
- $\omega_- = 26.2$Hz
- $\omega_+ = 41.1$Hz

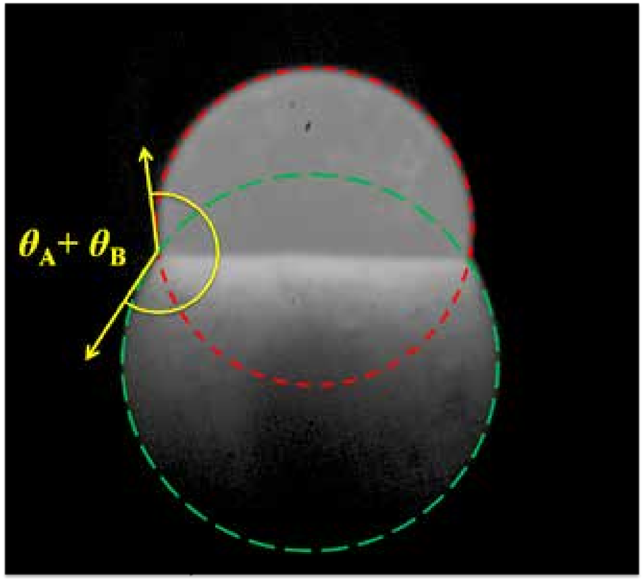
Interfacial tension

<u>700～1000mN/m</u>(@Iron M.P.)

Non Core-Shell (Janus) Drop Case for Fe/CaO-SiO_2-Al_2O_3 Slag

Fe/ BF slag (SiO_2:CaO:Al_2O_3=20:30:40)





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Interfacial tension from contact angle

$$\sigma_{12} = \cos\theta_{slag} + \sigma_{metal}\cos(\theta_{slag} + \theta_{metal}) + \sigma_{slag}$$

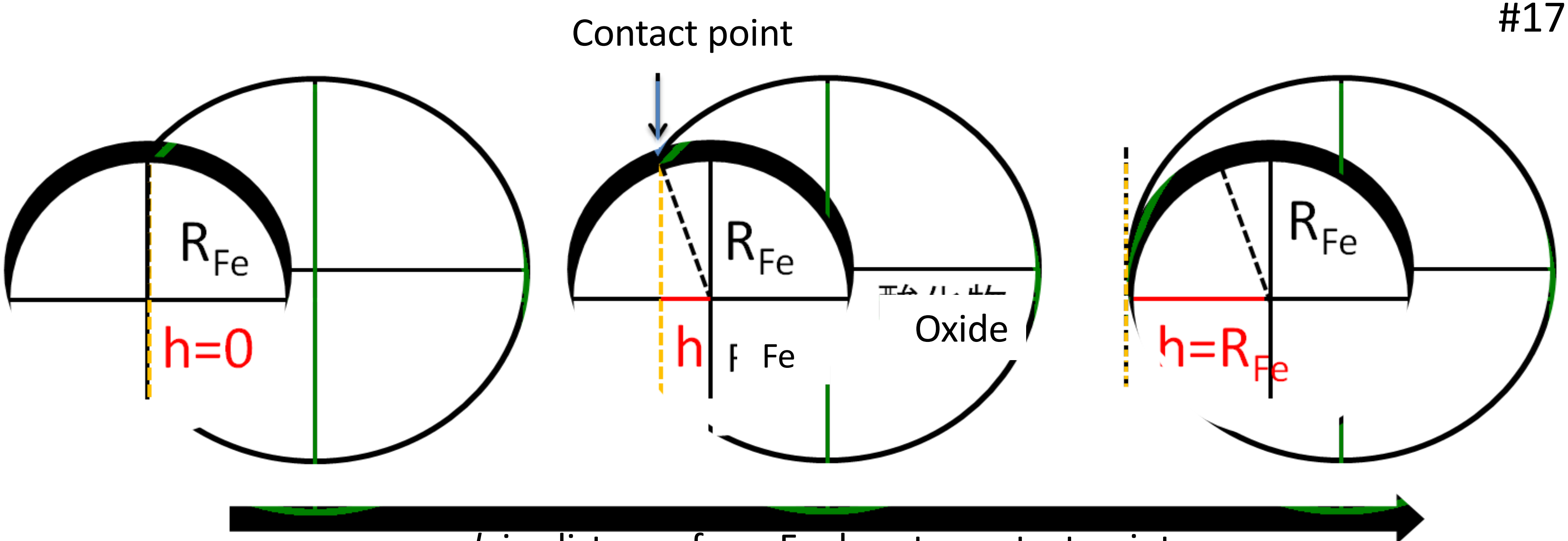
Contact angle between Fe melt and molten slag

$$\theta_A + \theta_B = 222^\circ$$

σ_{slag}=570mN/m
σ_{Fe}=1590mN/m

Interfacial tension
1.22x10^{-3}N/m（@1953K）

Total Energy of Surface and Interface for Two Drops Connecting



h is distance from Fe drop to contact point

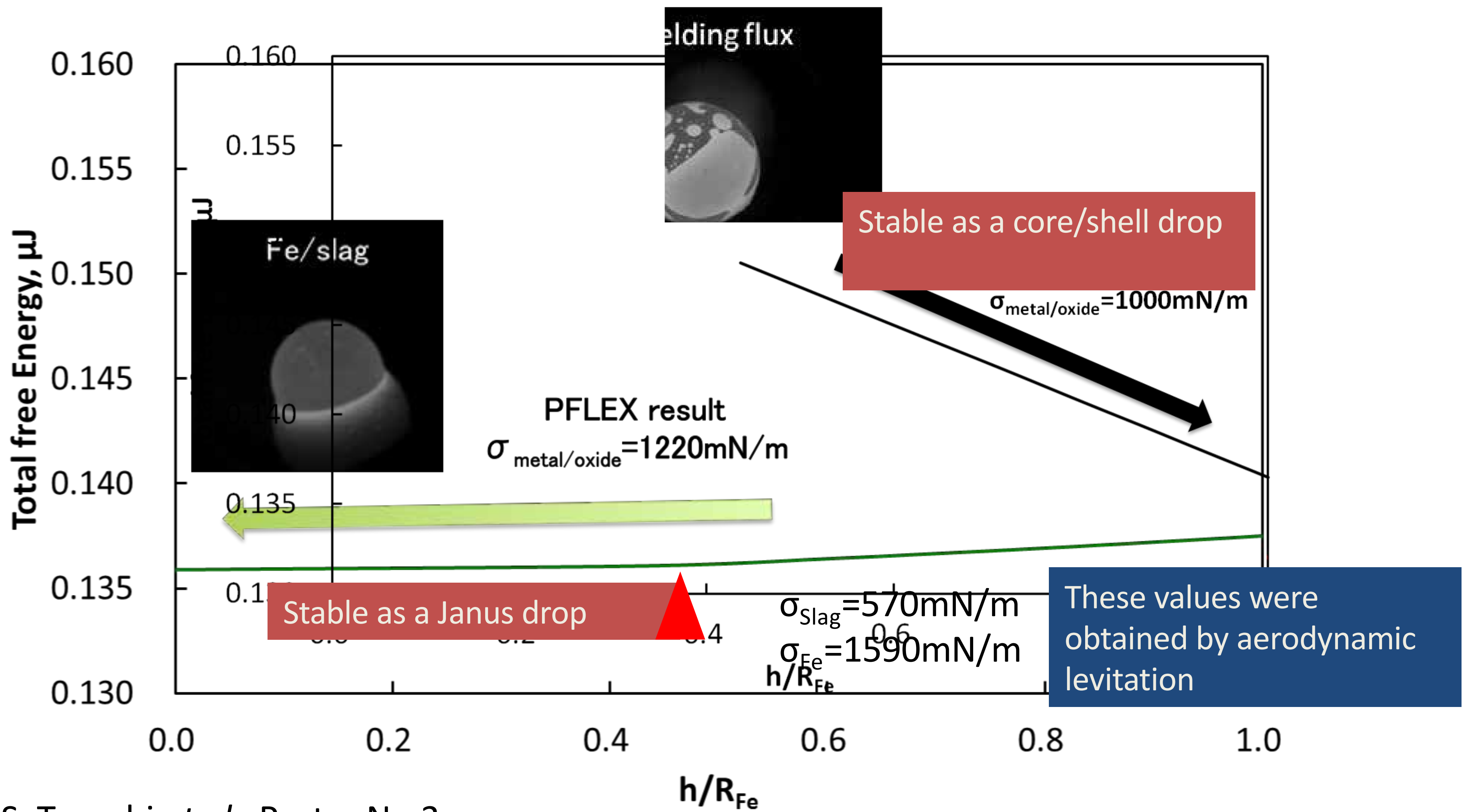
Change of surface and interface free energy as a function of *h*

($-1 \leqq h \leqq 1$, $h=1$ is $h=R_{fe}$)

$$G_S = \gamma_{Fe} S_{Fe} + \gamma_{slag} S_{slag} + \gamma_{AB} S_{int}$$

S : Area γ : Surface tension γ_{int} : Interfacial tension

Drop Shape Prediction from Energy Balance Between Total Surface and Interface for Fe/Oxide



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Summary

-I introduced levitation techniques under microgravity conditions for high-temperature liquids studies in materials sciences.

-For understanding interfacial phenomena in materials processing, microgravity conditions combined with levitation techniques have big advantages.

-Near future, we hope clarify the interfacial phenomena between Fe melts and molten oxides by our INTERFACIAL ENERGY projects.

Reference Papers: M. Watanabe *et al.*, Int. J. Microgravity Sci. Appl. 32(2015) p330212.
K. Onodera *et al.*, Int. J. Microgravity Sci. Appl. 33(2016) p330218.
S. Ueno *et al.*, Int. J. Microgravity Sci. Appl. 32(2015) p330408.
M. Watanabe *et al.*, Int. J. Microgravity Sci. Appl. 33(2016) p330212.
E. Shouji *et al.*, Int. J. Microgravity Sci. Appl. 36(2019) p360207.

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