TOHOKU UNIVERSITY

Institute of Fluid Science
Tohoku University
IFS

(融合センター最終成果報告会)

実事象融合計算研究分野
Reality-Coupled Computation Laboratory

教授　石本淳

Current research staff

流体研附属流体融合研究センター
実事象融合計算研究分野
2005年－2012年（8年間）

- 教授：石本 淳（流体研，情報科学研究科）
- 落合 直哉（教育研究支援者，2012年4月～）
- Guanghan Zhao (COLABS, October 2012
  From Technischen Universität Darmstadt, German)
- 客員研究員：㈱HONDA，㈱ケーヒン　他の研究者
- 共同研究者：5名
- 学生：　修士1名
  学部1名

25年度より
未到エネルギー研究センター
混相流動エネルギー研究分野

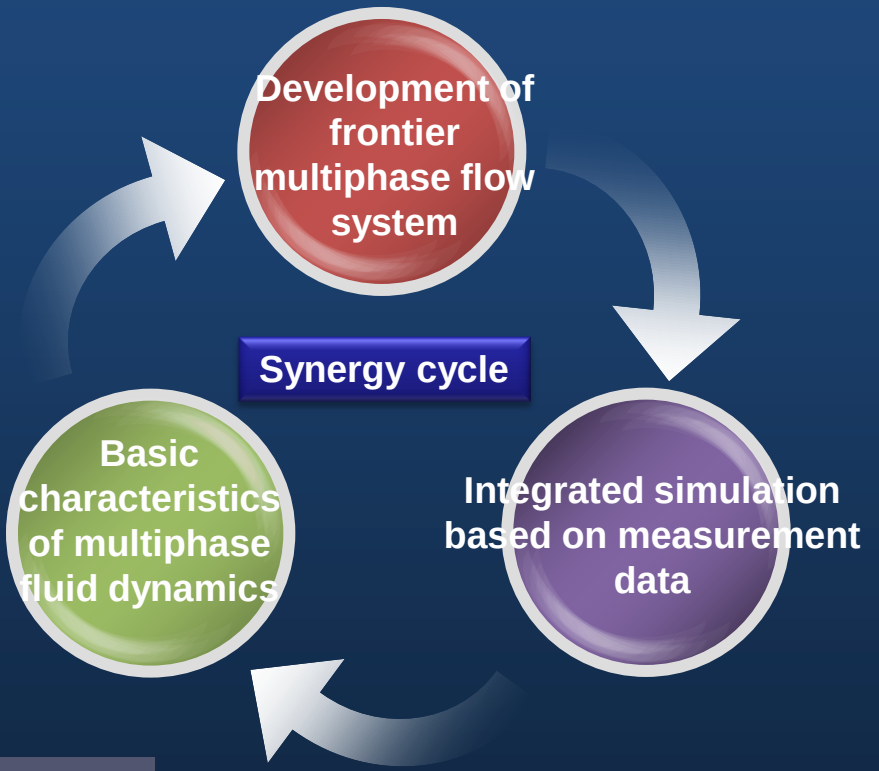
実事象融合計算手法

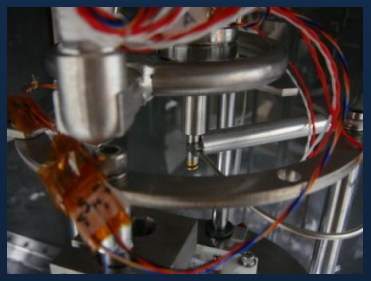
Phenomenologically verified computation

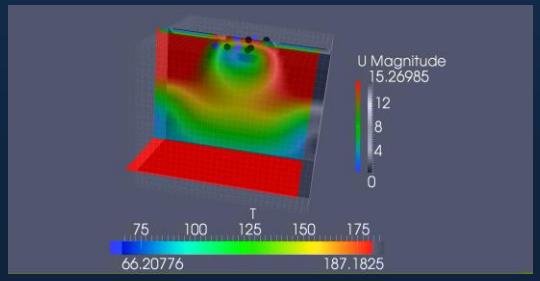
For the development of sustainable multiphase fluid machinery system which contributes to the green innovation.

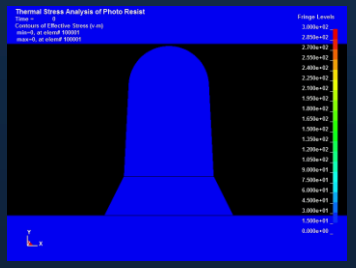
Development (Application)	Frontier multiphase flow system. Solid N_2 spray nano-device cleaning
Basic approach	Atomization and interfacial phenomena
Integrated simulation	Cryogenic spray heat transfer, multi scale tsunami simulation

Research focus of our laboratory is









融合センターにて実施した研究紹介

＊概要

先端混相流工学の基盤となる以下の2研究テーマを設定

混相流動に関する基盤研究を推進する上で重要となる現象を取り上げる.

- 異相界面間相互作用
  1. 全ての混相流には異相界面が存在するが，異相界面間の相互作用，エネルギー収支に関しては特に気液二相流の測定データに基づいた整理式しか存在しないのが現状.
  2. そこで相間の相互作用を正確にモデル化し，特に**氷(固体)の塑性変形－有機マテリアル・液体・固体相互作用**に関して両相の変形と相変化を考慮した融合解析を行う.

- 反応性界面流動（反応を伴う界面流動研究の重要性）
  1. 反応生成物により表面張力係数が変化する流れ
  2. 触媒－流体接触により反応性物質を生成する場合の界面流動
     （例:金(Au)を触媒としたアルコール酸化反応の際の界面流動など）
  3. キャビテーションに伴うOHラジカルの生成

  現象としてはとらえられているがメカニズムが不明であり，解析対象としては非常に重要.

- 震災復興関連の混相流安全科学（原子力安全，津波混相流動コンピュテーション）

Core research representative:
Interface tracking simulation of capillary phenomenon of "*Tears of wine*"

- Interface tracking simulation by **marangoni effects** due to the spacial gradient of surface tension coefficient as functions of temperature and density (due to evaporation effect of alcohol).
  (Taking into account the effect of surface tension coefficient σ variation.
  Application to the interfacial phenomenon of "*Tears of wine*")

濡れ性，撥水現象の解明に応用

Capillary flow of "*Tears of wine*"

Computation of Marangoni force $\boldsymbol{f}_\tau$

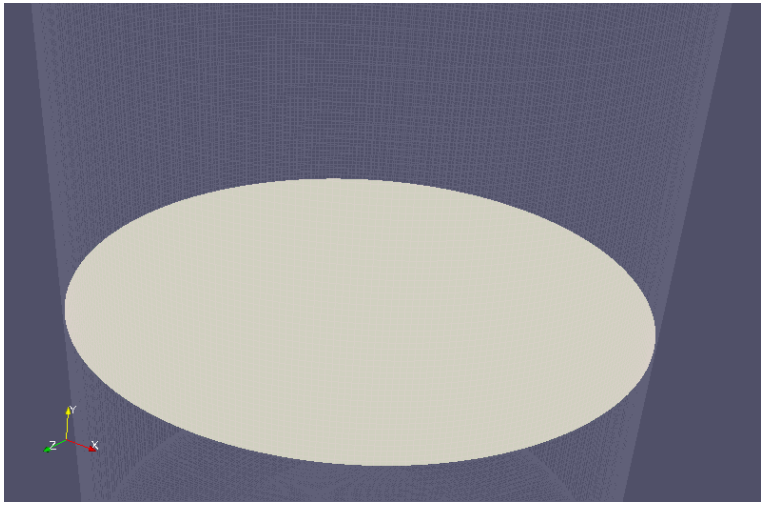
$$f_\tau = \nabla\sigma - (\nabla\sigma \cdot n)n$$

$$f_\tau = \left[\nabla\sigma - \left(\frac{\nabla\gamma}{|\nabla\gamma|}\cdot\nabla\sigma\right)\frac{\nabla\gamma}{|\nabla\gamma|}\right]\cdot|\nabla\gamma|$$

$$= |\nabla\gamma|\cdot\nabla\sigma - \left(\frac{\nabla\gamma}{|\nabla\gamma|}\cdot\nabla\sigma\right)\cdot\nabla\gamma$$

σ is included to the differential Eq.

Vector of marangoni force around the interface



Supercomputing of marangoni capillary flow of "*Tears of wine*

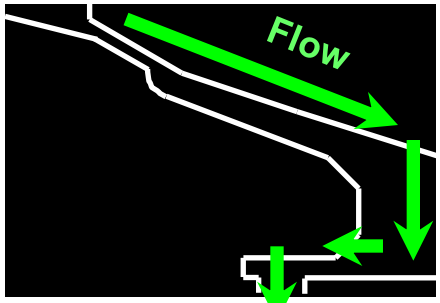
Computational Prediction of the Effect of Micro-cavitation on an Atomization Mechanism in a Gasoline Injector Nozzle

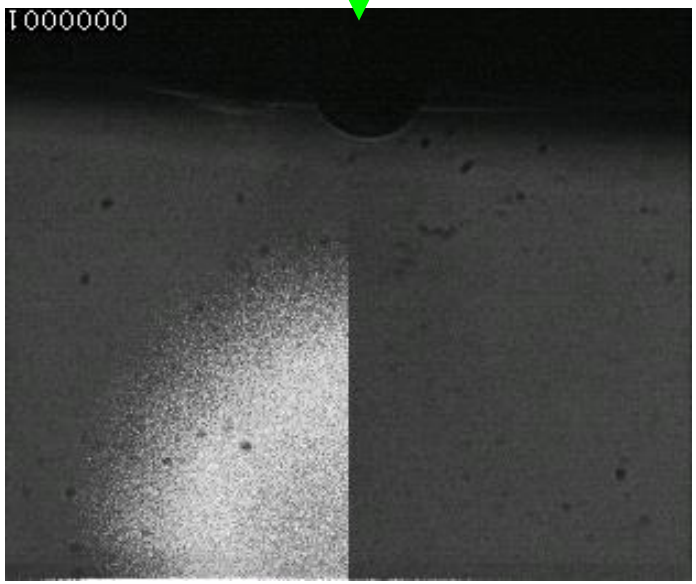
Trans. ASME, Journal of Engineering for Gas Turbines and Power, Vol. 132, Issue 8 (2010) 082801 doi:10.1115/1.4000264.

Numerical results quantitatively reproduces the actual atomization behavior

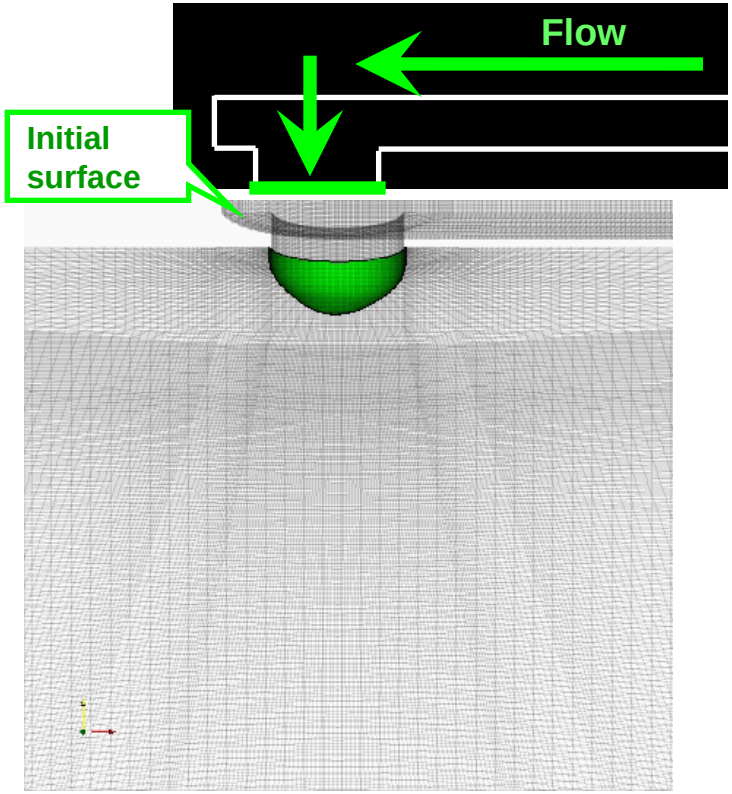
Spray formation ～ 0.58[ms] : 100,000 FPS

Measurement result



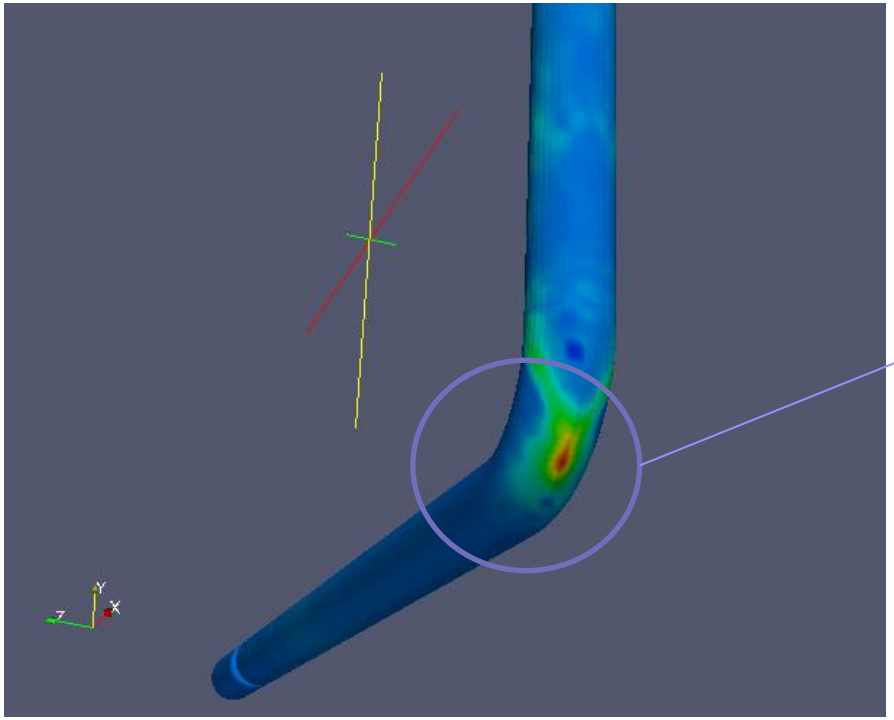


Computational result

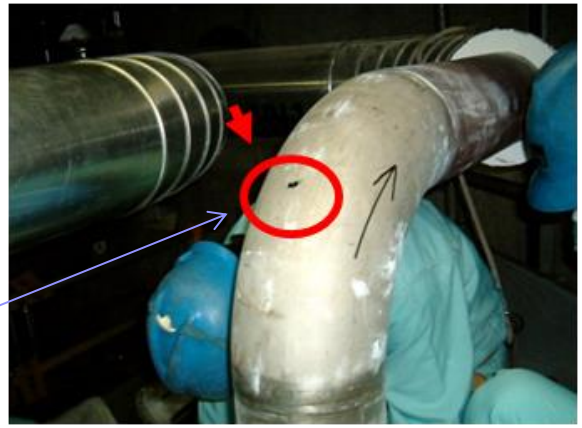


Comparison between numerical and experimental results

Super Computational Study of High-Speed Droplet-Vapor Flow and LDI Erosion （流体ー材料相互作用解析の具体例）



(a) Numerical result



(b) Actual image of LDI erosion phenomena

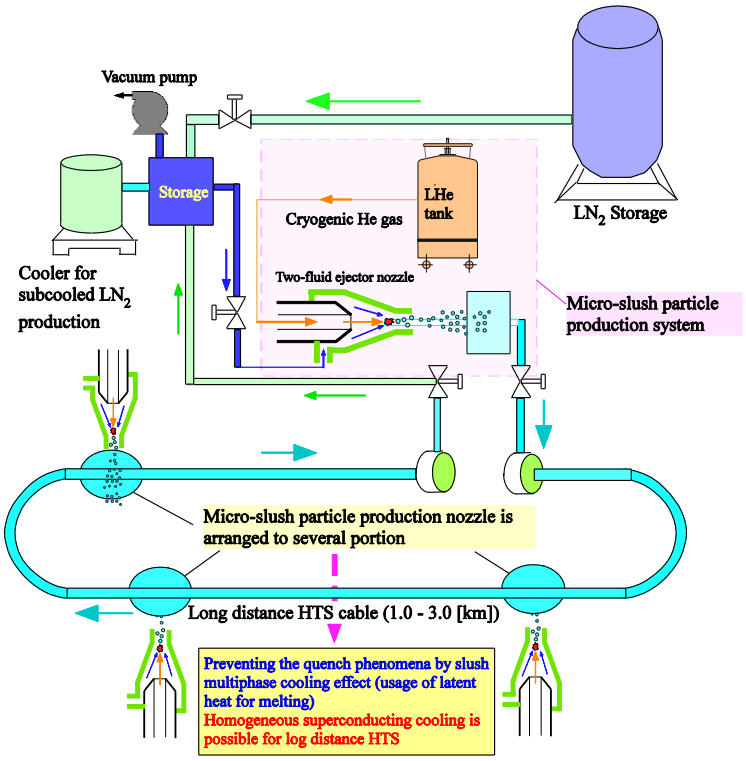
Figure 5 Numerical result of LDI erosion rate and actual image of LDI erosion phenomena.

it is found that the aspect of LDI erosion reasonably agree with both the numerical results and the actual fact.

The magnitude of erosion rate extensively increases around the elbow central of bent portion. The large size particle (about 2.0 mm) causes the LDI erosion by high-speed impact pressure of its inertia force. The erosion is also caused by the rebounded liquid-droplets flow around the bent section.
Furthermore, erosion rate increases just downstream region of the orifice throat. It is considered that the erosion is caused by the liquid-droplets impinging which follow to the counterflow of the steam flow downstream the orifice.

極低温マイクロスラッシュ流体の高温超伝導ケーブル冷却への応用

Jun ISHIMOTO, U Oh and Daisuke Tan,
Integrated Computational Study of Ultra-High Heat Flux Cooling Using Cryogenic Micro-Solid Nitrogen Spray, *Cryogenics*, Vol. 52 (2012) [Accepted]

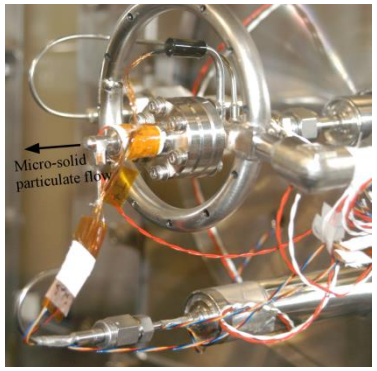


Homogeneous cryogen particle dispersion in HTS cable cooling is possible by using micro-slush flow

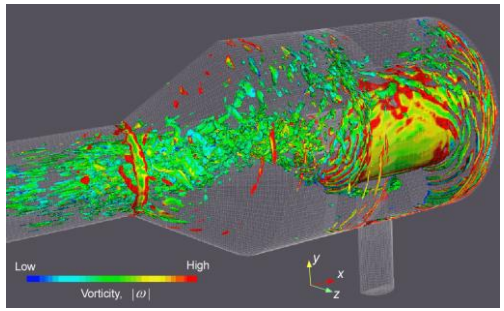
To accomplish the effective cooling performance in slush two-phase cooling system, the homogeneous dispersion and homogeneous two-phase flow pattern are extensively required. For the realization of these requirements, the research on the continuous production method for **finer slush particles** is very important.

Main Research Theme:

1. Continuous production and atomization mechanism of micro-slush particles.
2. Two-phase thermal flow characteristics of micro slush flow in a superconducting cable.

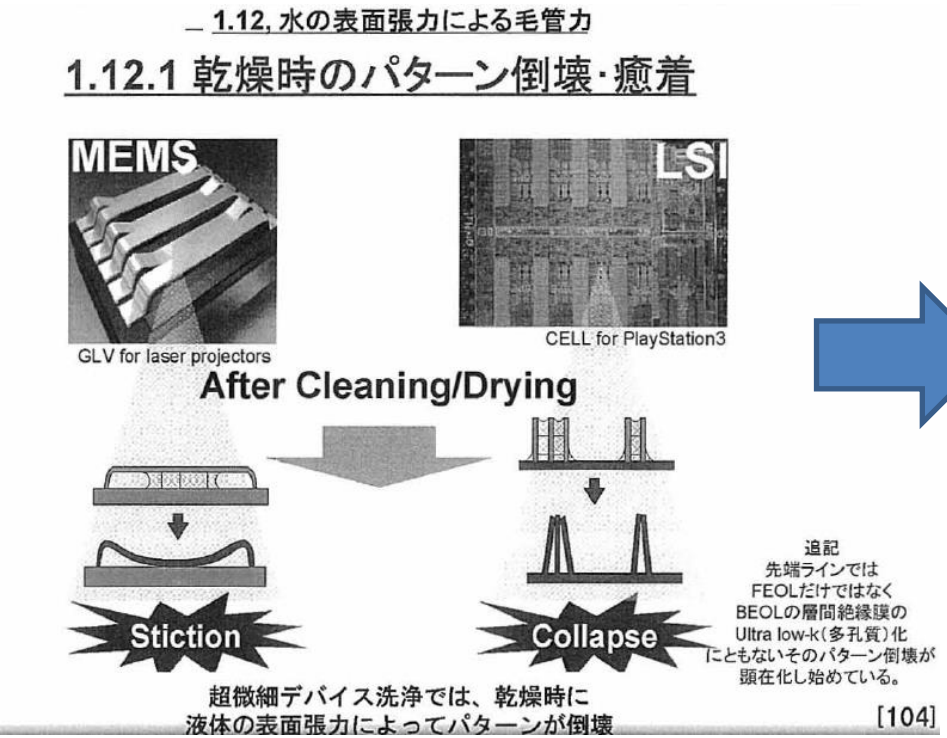


Superadiabatic two-fluid nozzle for cryogenic solid nitrogen particle production



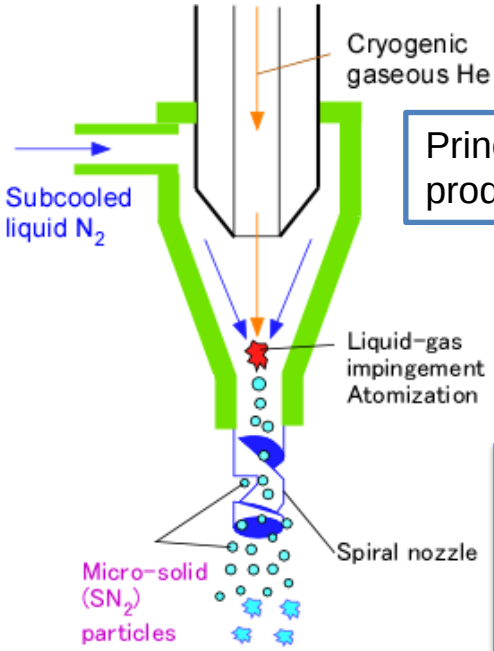
Integrated super-computation for cryogenic solid nitrogen particle production in a nozzle

極低温マイクロ固体窒素噴霧を用いた環境調和型半導体洗浄法の開発



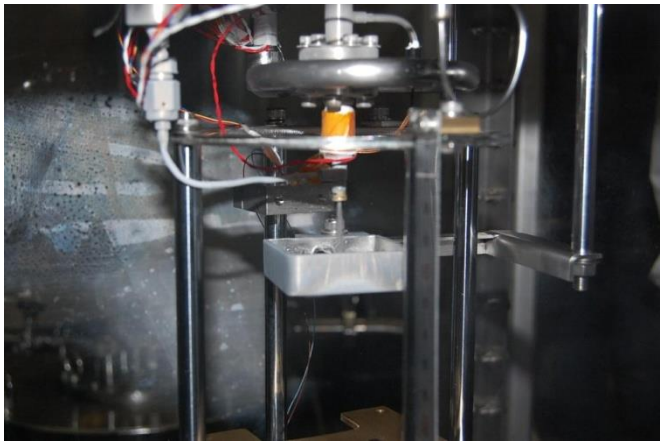
出典：2011半導体クリーン化・洗浄技術　徹底解説
服部毅 著，電子ジャーナル（2011）

超細線化に伴い水の表面張力によるパターン倒壊が問題となっている



Principle of micro-solid production nozzle

水を使用しない，新型のナノデバイス洗浄法が求められている



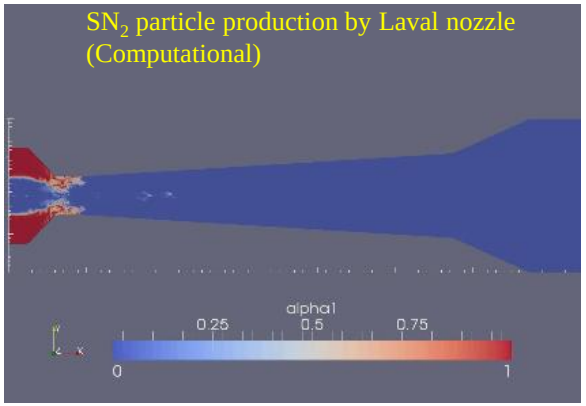
Aspect of micro-solid production nozzle

極低温マイクロ固体窒素噴霧の活用による
環境調和型半導体洗浄技術の開発

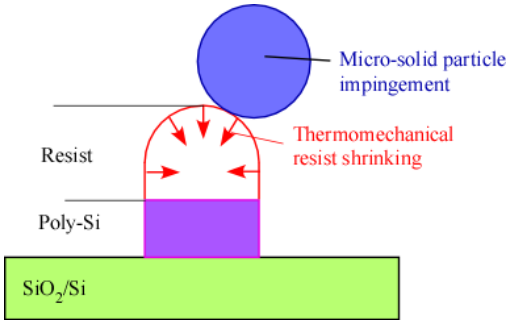
Jun ISHIMOTO, U Oh and Daisuke Tan, Integrated Computational Study of Ultra-High Heat Flux Cooling Using Cryogenic Micro-Solid Nitrogen Spray, *Cryogenics*, Vol. 52 (2012) [Accepted] http://dx.doi.org/10.1016/j.cryogenics.2012.07.002
International collaboration: Hanyang Univ., Korea (Prof. Jin-Goo Park, NEMPL), Northeastern Univ. (Prof. Ahmed A. Busnaina, NSEC)

Objectives:

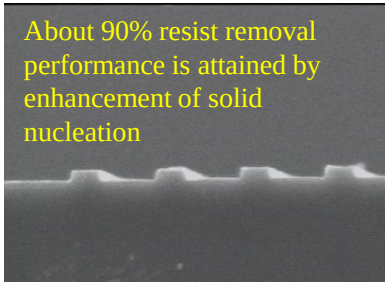
- To develop wafer resist removal and cleaning technology using micro-nano solid nitrogen spray (SN_2) which becomes applicable to the special device whose plasma damage becomes serious problem, and applicable to the device that the reactivity of the O_2 radical is high such as CCD or photovoltaic passive device.
- New physical wafer resist removal and cleaning technology which is not required O_2 plasma or UV ashing. Chemical free, damage-less cleaning system should be developed.



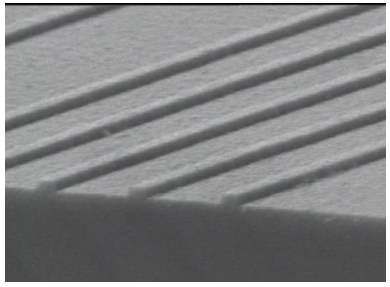
SN_2 particle production by Laval nozzle (Computational)



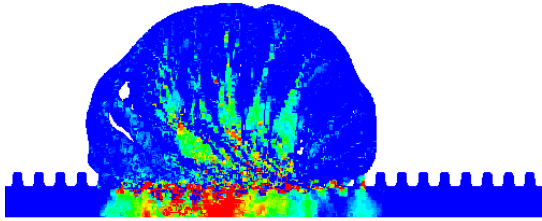
Thermomechanical effect of resist contraction by SN_2 particle impingement



About 90% resist removal performance is attained by enhancement of solid nucleation



90% resist removal performance has been achieved by micro-nano SN_2 spray cleaning without use of plasma ashing

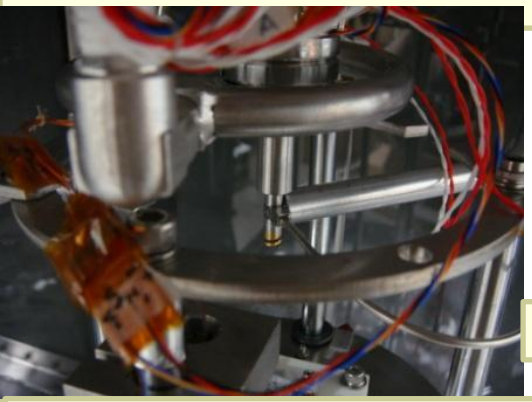


Stress profile while SN_2 particle impingement to resist (Computational)

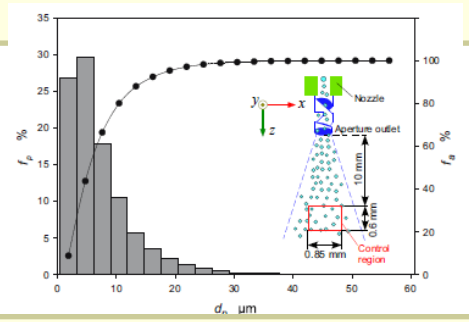
The magnitude of pressure in SN_2 particle and wafer resist increases with SN_2 impingement and fragmentation.

Integrated measurement coupled super computation

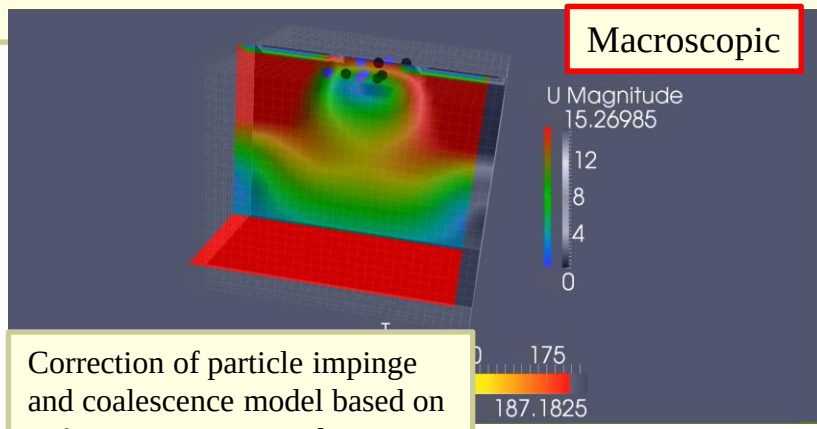
Integrated computation coupled with PIA (Particle Image Analyzer) laser optical measurement and parallel super computation



Micro-SN2 production system



SN2 particle diameter distribution



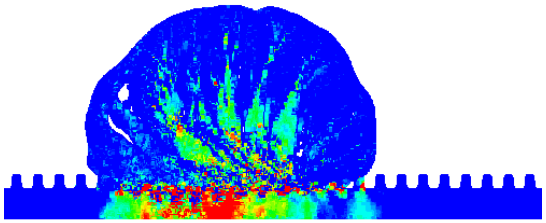
Correction of particle impinge and coalescence model based on PIA measurement results

High-speed measurement data is stored to small database

Data acquisition and reload

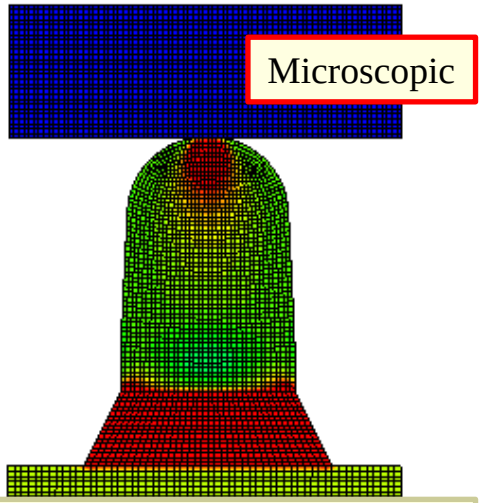
Data acquisition and reload

Measurement data of unsteady heat flux, temperature profile



Scalar parallel super computation for micro-SN2 particle impingement to the resist and its plastic deformation

Renewal of thermal boundary condition between particle and resist



Integrated computation of thermal stress and thermal contraction rate of resist

先端混相流工学の実事象融合研究を推進

相互連携

基盤研究

- 反応性界面流動
- 異相界面間相互作用

に関係する基本現象

（表面張力が変化する流れ，キャビテーションを伴う微粒化等）

プロジェクトタイプ研究
（共同研究により実施）

- マイクロ･ナノ固体窒素利用型ナノデバイス洗浄
- 漂流物混入型津波に関するスーパーコンピューティングと災害被害予測
- メガソニックキャビテーションによる殺菌･クリーニング
- 移動境界を伴う直噴インジェクタ噴霧に関するスーパーコンピューティング
- 除雪車における氷雪混相流動の解析と堆積氷雪の高速除去

以上の異分野融合研究により環境調和型・低エミッション（無駄の少ない）エネルギー循環システムへの貢献を目指す