# Selected Novel Technologies for Licensing

2014 MRS Fall

# Innovative Technologies for Your Products

| | |
|---|---|
| **Material** | ・Barnacle mimetic - fascinating underwater adhesion<br>・LUCID: A simple and versatile technique for tissue optical clearing<br>・Advanced Polymer Materials via Sophisticated Structural Control<br>・Highly Bright Mechanoluminescence Material<br>・Commercialization Challenges in Graphene and Carbon Nanotube Fields |
| **Electronic Device** | ・SiNx - Passivated Single-Electron Transistors Having Top-Gate Electrodes<br>・Energy Efficient Power Gating Architecture using NV-SRAM & NV-FF<br>・Semiconductor Structure provided with AlON film on top of Ge layer |
| **Optical Device** | ・A micrometre-scale Raman silicon laser with a microwatt threshold<br>・Novel Terahertz Polarizer for Extremely High Extinction Ratio |
| **Spin Device** | ・Spin Motor and Spin Rotary Member<br>・Spin transistor utilizing Rashba SO interaction |
| **Sensor** | ・High Performance Magnetic Coating |
| **Measurement Equipment** | ・Infrared Detector of single-photon sensitivity<br>・Radiation Detector using Low-Dimensional Semiconducting Scintillator<br>・Measuring Properties of an object with Acoustically Induced Electromagnetic Waves ( ASEM ) |
| **Cryogenics** | ・Helium Circulation System (HCS) for MEG |
| **Energy** | ・3.8V Earth-Abundant Sodium Battery Electrode<br>・Thermochemical Fuel Production by Non-Stoichiometric Perovskites |
| **Water** | ・Safety Disinfection Technique by Plasma Treated Water |

**Japan Science and Technology Agency**

Material (Polymer)

# Barnacle mimetic - fascinating underwater adhesion

Prof. Atsushi TAKAHARA ( Kyushu University )

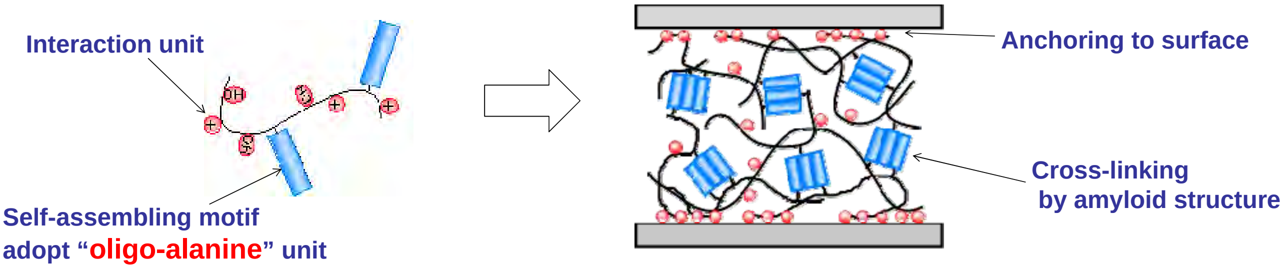
A new type of underwater adhesion was created in imitation of barnacle's adhesion.

## 1. Interesting Points in barnacle's adhesion

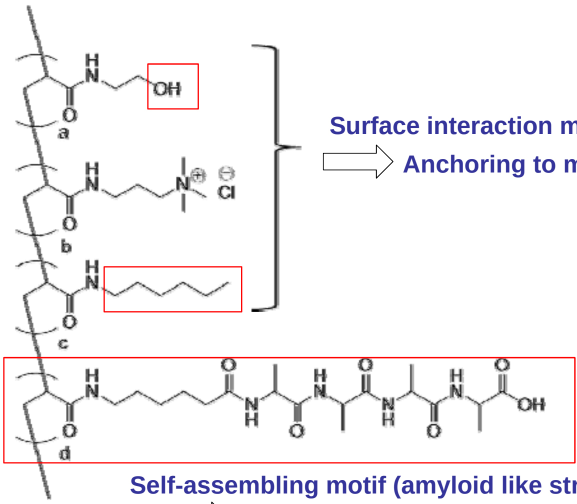
1. No covalent bonding between protein (no catechol) crosslinking by molecular interaction
2. Cp-19k may interact with various surfaces

## 2. Design of barnacle adhesive cement mimetics

**Essense** ①Self-assembling of polymer (cross-linking)
②Interaction with material surface

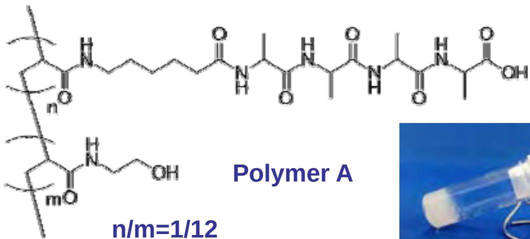



## 3. Mimetic of barnacle adhesive cement



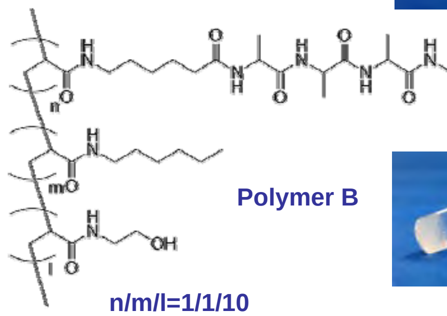
Surface interaction moieties
⇨ Anchoring to material surface

Self-assembling motif (amyloid like structure)
⇨ Gelation of polymer solution



Polymer A

n/m=1/12

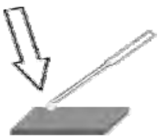


Polymer B

n/m/l=1/1/10

## 4. Adhesion of various materials by gelation of aqueous solution of barnacle mimetic polymer solution

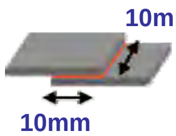
10 wt% polymer sol. + WSC
+ HONSu + hexylamine



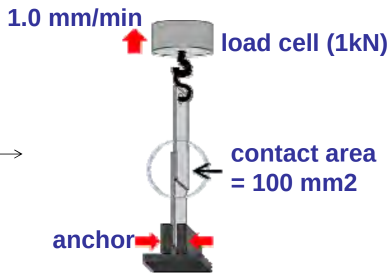
stainless-steel plate
polyethylene
PMMA
6-nylon

→

cured at room
temperature in humid air




24hours →




tensile tester

| material | Polymer A | Polymer B |
|---|---|---|
| stainless-steel | 24kPa | 21kPa |
| polyethylene | 128kPa | 132kPa |
| PMMA | 91kPa | 402kPa |
| 6-nylon | 74kPa | 283kPa |

## Patent Licensing Available

Patent No.: PCT/JP2014/068499
JST/ IP Management & Licensing Group
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Material (Polymer)

# LUCID: A simple and versatile technique for tissue optical clearing

Dr. Hiroshi ONODERA (University of Tokyo, JST-CREST)

## 1. Abstract


- For 3D-imaging of tissue structure, a simple and versatile method that turns organs transparent benefits every biological research field.
- We present a new tissue clearing technique, LUCID (ilLUminate Cleared organs to IDentify target molecules), which does not need a delipidation process or a special device.
- LUCID is a safe, simple, and versatile tool for 3D-visualization of target molecules in every research field including cancer, bone diseases, joint diseases, leukemia, hematopoiesis, and drug discovery.

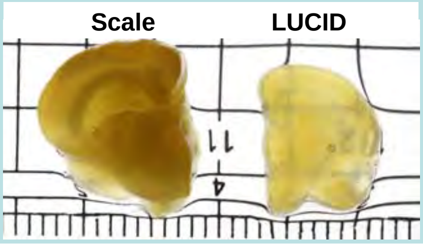

## 2. Procedure

1. Organs are simply immersed in Solution-1 (thiodiethanol+sucrose) for 0.5 to 1 day followed by Solution-2 (thiodiethanol + glycerol + non-ionic organic iodine compound) for 1 to 5 days.

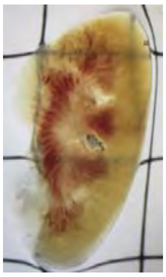
(2) LUCID-cleared samples are observed with a multiphoton microscope.

(3) Cleared samples can be further examined with routine histochemical analyses.

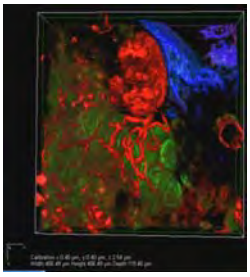
## 3. LUCID-cleared organs (macroscopic and multiphoton microscopic images)



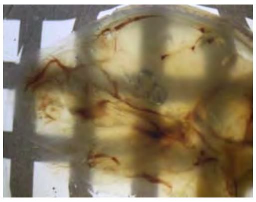

Comparison of cleaning ability between LUCID and Scale (rat brain sections)



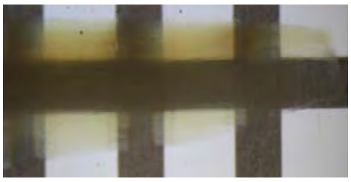
Adult rat kidney



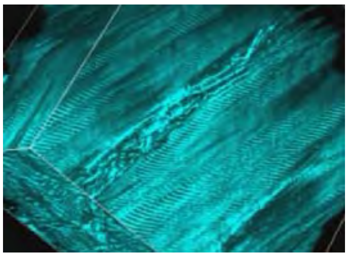
Renal cortex multiphoton microscopy rendered image
red=blood vessel,
green=renal tubule
blue=SHG (collagen fiber)



3 day-old rat pup head

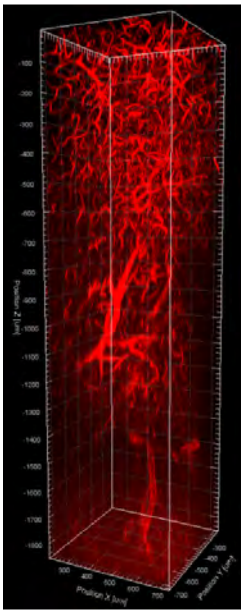


Adult rat muscle



Adult rat muscle multiphoton microscopy Sarcomere stripes in muscles are visible.

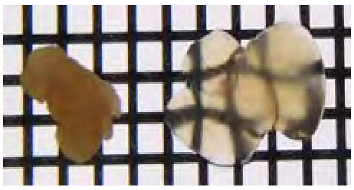
Adult EGFP transgenic rat hindlimb (knee joint). Femur and tibia bones become transparent and bone marrow (red color because of hemoglobin) is clearly visualized.

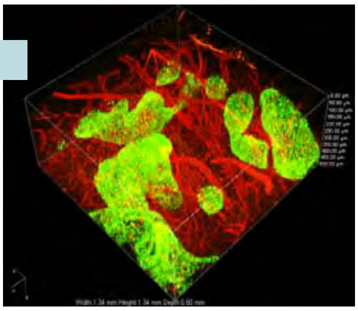


Adult rat brain (hippocampus) blood vessels

Inoculated lung tumor

Uncleared LUCID-cleared





Tumor cells expressing EGFP (green) and blood vessels (DyLight594-bound Lycopersicon esculentum lectin, red) are visualized. Tumor structures are visualized to the limit of the working distance of our objective lens.

## Patent Licensing Available

Patent No. : WO2014/115206

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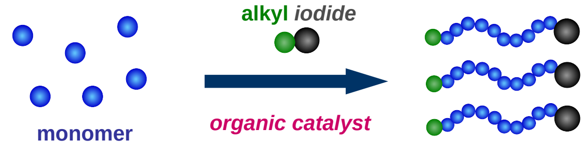
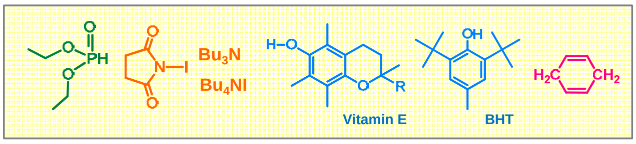
**Material (Polymer)**

# Advanced Polymer Materials via Sophisticated Structural Control

Associate Prof. Atsushi GOTO (Kyoto University)

## 1. What can be controlled by Living Radical Polymer (LRP) ?



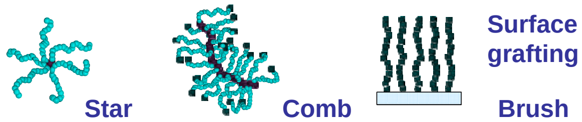

- Non-metal catalysts
- Inexpensive little-toxic catalysts

(a) Uniform chain length

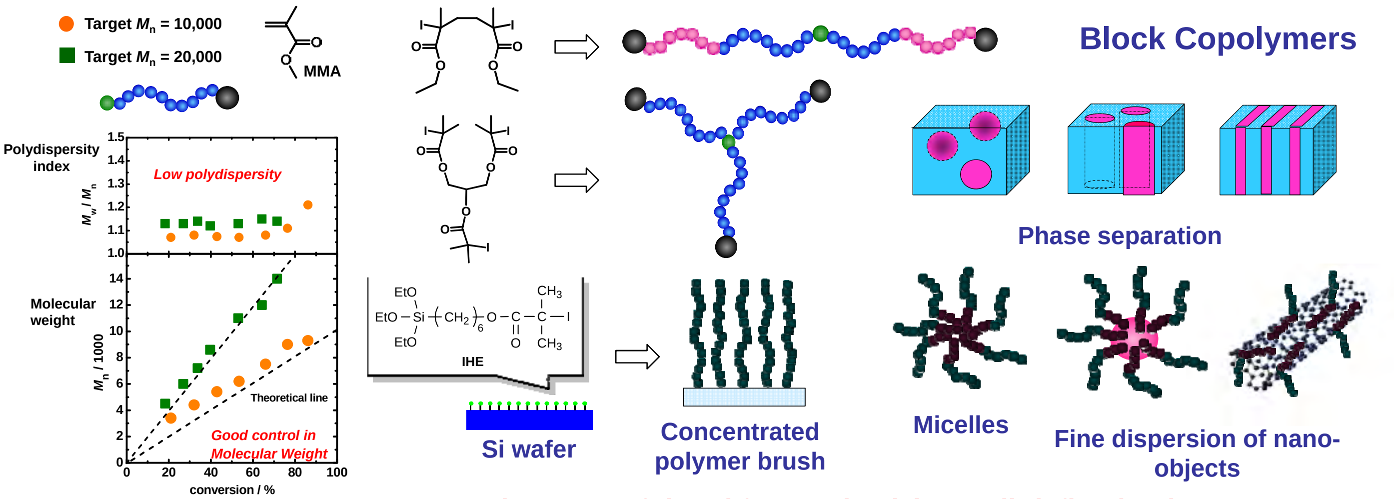
(b) Chain-end functionality

(c) Copolymerization type


(d) Topology (shape)




## 2. Characteristics of LRP

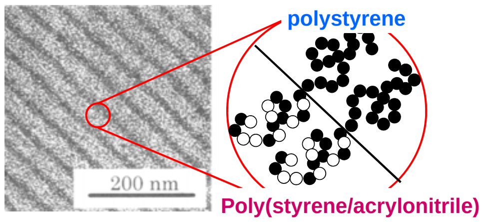



*LRP is a powerful tool for synthesizing well-defined polymers*

## 3. Applications of Well-Defined Polymers

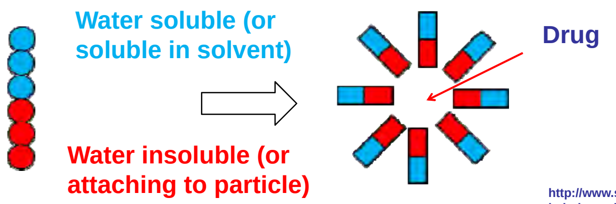
***Potential market***

- paints, pigments & coatings
- personal care & cosmetics
- medical materials
- plastics, textiles & rubber
- Ink jet media




Phase separation

*Commercial Use*

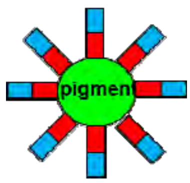



Prepared by LRP

Micelle in water

http://www.softicons.com/web-icons/bees-help-icons-by-artbees/green-capsule-ns-icon

Drug delivery system




Pigment dispersion in water

Dainichiseika Color & Chemicals Mfg. Co., Ltd

## Patent Licensing Available

Patent No.: WO2008/139980, WO2009/136510, WO2010/027093, WO2010/140372, WO2011/016166, etc.

Kyoto University / Licensing Dept. Phone: +81-75-753-5529, E-mail: ip-eng@saci.kyoto-u.ac.jp

Material (Optical)

# Highly Bright Mechanoluminescence Material

Chao-Nan Xu (National Institute of Advanced Industrial Science and Technology)

## 1. Abstract:


■ The weak brightness and the attenuation of the light by the repetitive stress application were big issues, but the following mechanoluminescence materials have solved such issues and the practical examinations have been carried out.


Materials:

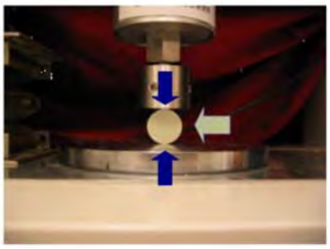
(1) $xM^1A^1 \cdot (1-x)M^2A^2$  $(0<x<1)$

$M^1, M^2$ = {Zn,Mn,Cd,Cu,Eu,Fe,Co,Ni,Mg,Ca}

$A^1, A^2$ = Chalcogen ={O, S, Te}

(2) $SrAl_2O4:Eu^{2+}$ (Stuffed Tridymite Type)

### Direct Visualization of the Stress Distribution by the Mechanoluminescence

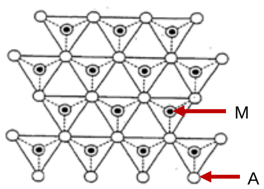


Application of the compression load to the disk sample coated with a stress illuminant

Stress distribution image via the luminescence

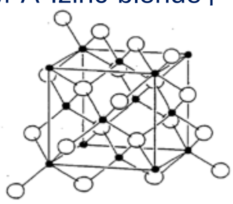
## 2. Structure of the Material

■ $xM^1A^1 \cdot (1-x)M^2A^2$ : Mixture of { $M^1A^1$ :wurtzite} and { $M^2A^2$:zinc-blende }




wurtzite type

+

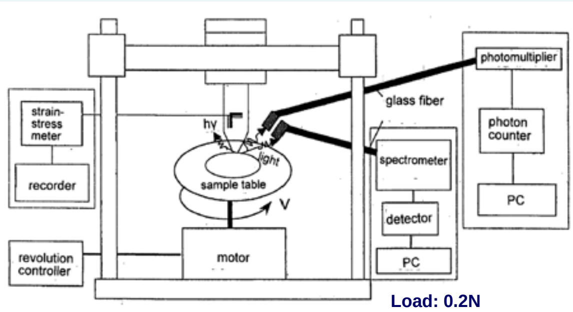


zinc-blende type

**Luminescence Intensity**

| Sample | Composition | Relative luminescence intensity | Crystal grain diameter (nm) |
|---|---|---|---|
| Control | $SrAl_2O_4$:Eu | 100 | 50 |
| Example 1 | 0.99ZnCuS · 0.01MnS | 3124000 | 10 |
| Example 2 | 0.9ZnTe · 0.1MnTe | 1999000 | 12 |
| Example 3 | 0.9ZnCuS · 0.1MnS | 51300 | 32 |
| Example 4 | 0.9ZnTe · 0.1CdSe | 4600 | 25 |
| Example 5 | 0.9CdS · 0.1MnS | 298 | 30 |
| Example 6 | 0.9CdSe · 0.1MnTe | 980 | 50 |
| Example 7 | 0.9ZnS · 0.1MnS | 869000 | 20 |
| Example 8 | 0.1ZnS · 0.9MnS | 5800 | 500 |
| Example 9 | 0.9ZnSe · 0.1CdTe | 6700 | 60 |
| Example 10 | 0.8ZnO · 0.2MnCuS | 1880 | 15 |

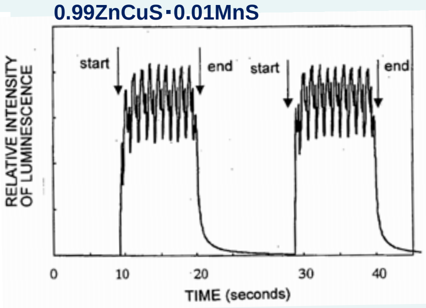
## 3. Experiment, Data



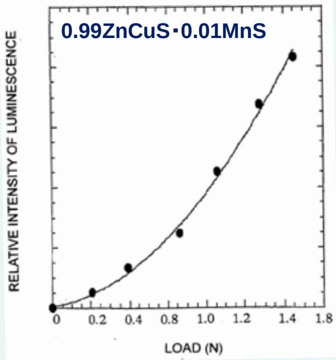

Rubbing Rod –test machine

Load: 0.2N
60 rpm

0.99ZnCuS・0.01MnS

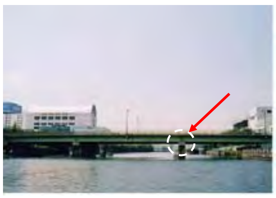



Luminescence by the rubbing rod stimuli




## 4. Application Example

■ Visualization of the crack growth in the concrete floor board of the bridge by the stress detect mechanoluminescence sheets ($SrAl_2O4:Eu^{2+}$ ) http://www.jst.go.jp/kisoken/crest/research/s-houkoku/04_03.pdf (Japanese)



Compare the crack in a box with the same color and positon.

- Cracks became much clearer in green box.
- New crack appeared in red box.

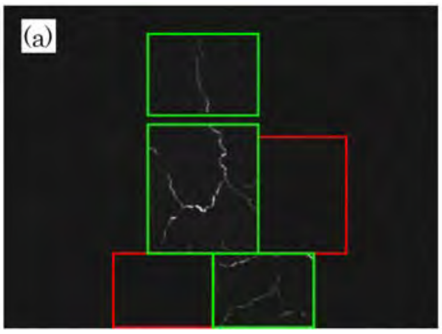



Image in 2010/11
6 months after setting.


Image in 2011/06

## Patent Licensing Available

Patent No. :USP7297295 EP1538190

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Material (Carbon)

# Commercialization Challenges in Graphene and Carbon Nanotube Fields

Prof. Jun-ichi FUJITA (University of Tsukuba)

## 1. Background

**(Market Potential)** Both **Graphene** and **Carbon Nanotube (CNT)** have great potentials for several next-generation devices, however no successful commercialization have been seen yet.

**(Major Obstacles)**

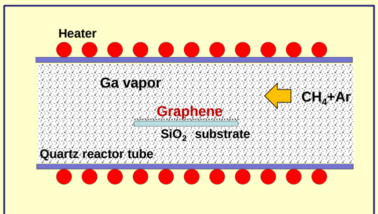
**Graphene** - a lack of prominent fabrication methods of a large area and low cost graphene

**Carbon Nanotube(CNT)** - a lack of suitable applications and low cost fabrication methods

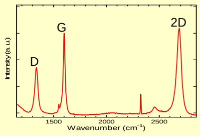
## 2. New Fabrication Method of Large-area and Stable Continuous Graphene Film

### (Method I)

This method easily synthesizes a large area graphene directly on the insulated substrate. Source gas of $CH_4$ were decomposed and promoted to graphene growth on the substrate under the assistance of catalytic reaction with Ga vapor. The uniform coverage of the gallium vapor enables graphene growth not only on a flat surface but also on a rounded surface; like a front window of Auto, and eyeglasses.




Schematics of Ga vapor assisted graphene growth

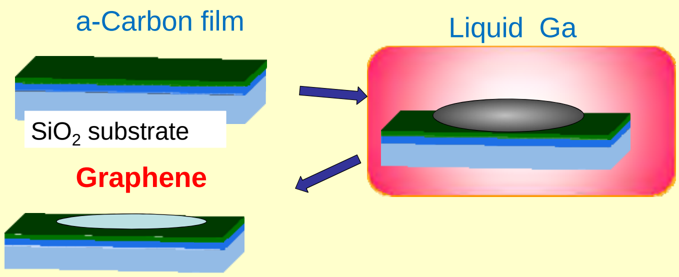



**Patent: JP5578639**

### (Method II)

This method is to synthesize a graphene sheet at the interface between solid amorphous carbon and liquid gallium, which exhibits as a good graphitizing catalyst for a large area graphene sheet.

Amorphous carbon film was transformed into graphite layer composed of a few layers of graphene sheet. This thin graphene film can be easily transferred into silicon substrate.




**Patent: WO2010/110153**

### (Applications examples)

window defoggers

-The Large-area Graphene Film can be applied to the transparent resistor elements of the **resistive-heat defoggers/demisters**. The high thermal conductivity and optical transmittance of the Graphene could give a superior performance to the transparent resistor elements.

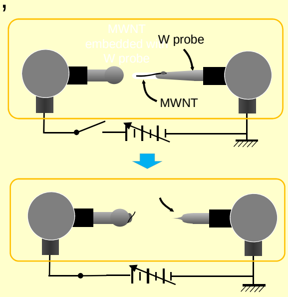
-The Large-area and Stable Continuous Graphene Film can be applied to **the electrode pattern** on heavy-duty/industrial use printed circuit boards i.e. LCD base circuit board, automobile electrical components.

flexible display

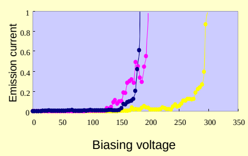
## 3. Ultra Sharp Metallic Probe having 2nm distal end curvature radius

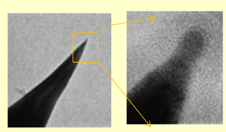
- By using the field emissions from a multi-walled carbon nanotube, which soften the bottom of the tungsten by Joule heating, and the coulomb attractions to the nanotube, which finely pulled off from the metal(i.e. tungsten) tip, an ultra sharp apex of metallic (i.e. tungsten) probe having 2nm distal end curvature radius is fabricated.
- The ultra sharp apex metallic probe has excellent durability (mechanically strong) and low contact resistance and could contribute in the field of critical nano order measurements.

**Patent: WO2008/0657790**




Production method of the ultra sharp probe



Crystal structure of the ultra sharp probe apex

## Patent Licensing Available

**Graphene Fab : WO2010/110153 and JP5578639, Metallic Probe Fab : WO2008/0657790**

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# SiNx-Passivated Single-Electron Transistors Having Top-Gate Electrodes

Electronic Device

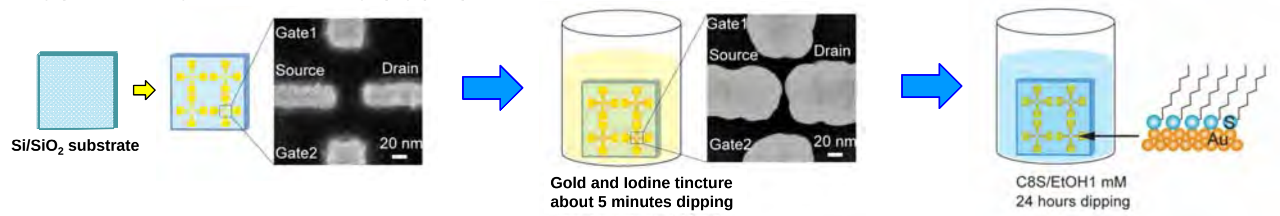
Prof. Yutaka MAJIMA (Tokyo Institute of Technology)

## 1. Abstract

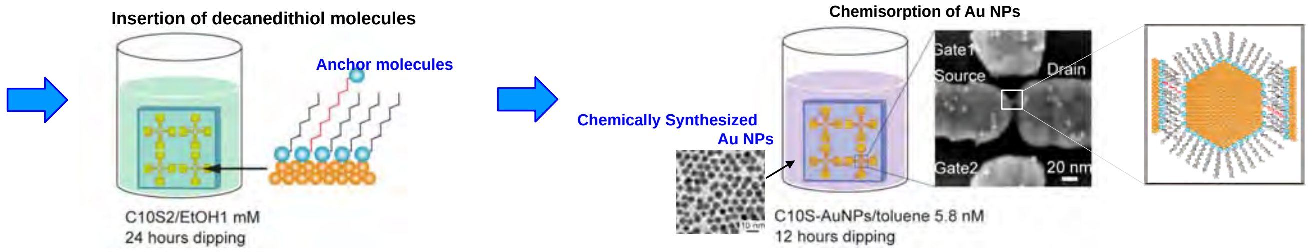

- Single-electron transistors (SETs) have been expected towards highly integrated circuits. However uniform and stable device characteristics and the possibility of large area integration, including wiring are required for their real applications.
- SiNx-passivated chemically assembled SETs were developed. With an Au top-gate electrode, the SiNx-passivated SETs showed a clear Coulomb diamond, and the gate capacitance increased 16.5-fold.


## 2. SiNx-Passivated SET made by Au Nanoparticles and Nanogap Electrodes

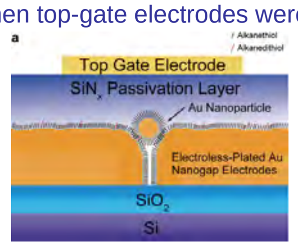
- Bottom-up processes that combine the use of synthesized Au nanoparticles (NPs), electroless plating, and self-assembled processes at a very small scale (< 5 nm) for chemically assembled SETs have been established.



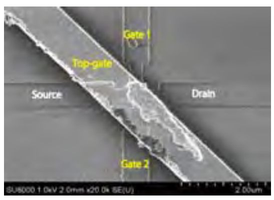

- Chemically synthesized Au nanoparticles with a core diameter of 6.2±0.8 nm were then chemisorbed using an alkanedithiol mixed self-assembled monolayer as an anchor.



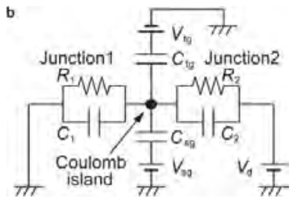

- The SiNx passivation layer was realized by catalytic chemical vapor deposition (CAT-CVD) up to a thickness of 50 nm, then top-gate electrodes were added.




Cross-sectional image



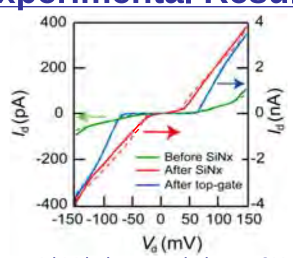

SEM image



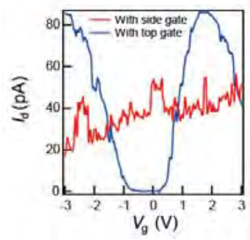

Equivalent circuit

**SiNx-passivated SET with a top-gate electrode**

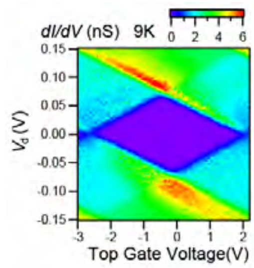
## 3. Experimental Results




Id-Vd characteristics at 9K




Coulomb oscillation observation




Stability diagram of the device at 9K

| | $R_1$ (MΩ) | $R_2$ (MΩ) | $C_1$ (aF) | $C_2$ (aF) | $C_g$ (zF) | $Q_0$ (e) |
|---|---|---|---|---|---|---|
| Before $SiN_x$ deposition | 500 | 500 | 1.0 | 0.8 | | 0.2 |
| After $SiN_x$ deposition | 110 | 100 | 1.0 | 0.8 | 2.3 | 0.35 |
| After top-gate electrode deposition | 90 | 170 | 1.0 | 1.15 | 38 | −0.07 |

Circuit parameters of the SET

- The use of the top-gate electrode allowed us to increase the gate capacitance 16.5-fold.
- The experimental Coulomb diamond corresponds to the ideal theoretical results.
- Au nanoparticle withstands the CAT-CVD process for SiNx passivation.

## Patent Licensing Available

**Patent No.: WO2013/129535**

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# Energy Efficient Power Gating Architecture using NV-SRAM & NV-FF

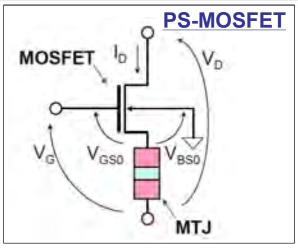
Electronic Device

Associate Prof. Satoshi SUGAHARA (Tokyo Institute of Technology)

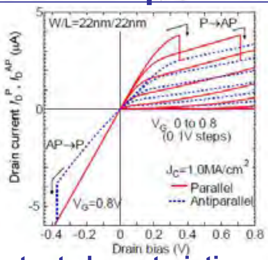
## 1. Abstract


- A new power-gating architecture using non-volatile SRAM (NV-SRAM) and non-volatile FF (NV-FF) circuits, called non-volatile power-gating(NVPG), was developed.
- Pseudo-Spin metal-oxide-semiconductor field effect transistors (PS-MOSFETs) are used in the non-volatile bi-stable memory circuits.
- The proposed NVPG architecture can dramatically reduce the energy issues caused by static power dissipation in advanced CMOS logic systems.

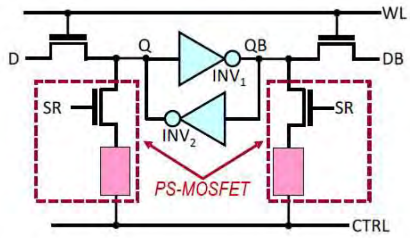

## 2. NV-SRAM consisting of Pseudo-Spin MOSFET




Circuit configuration



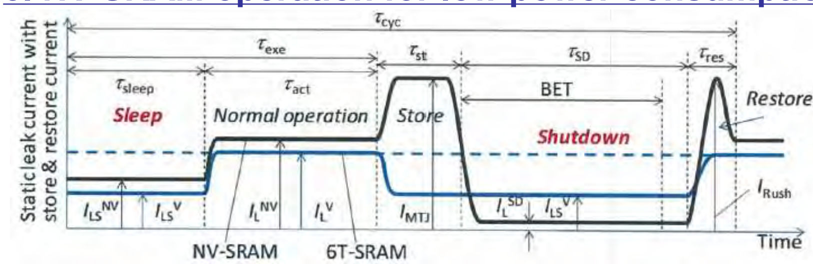

Simulated output characteristics of the PS-MOSFET



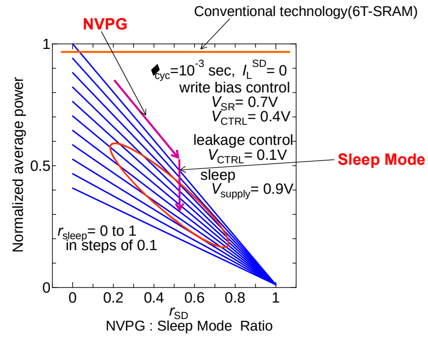

NV-SRAM cell

- The spin-transfer torque magnetic tunnel junction (MTJ) is connected to the source of the MOSFET.
- The MTJ feeds back its voltage drop to the gate, and the degree of negative feedback depends on the resistance state of the MTJ.
- In these NV-SRAM cell circuits, the MTJs can be electrically separated from the inverter loops by the PS-MOSFETs and thus have no degradation effects to fundamental circuits of the inverter loops.

## 3. NV-SRAM operation for low power consumption

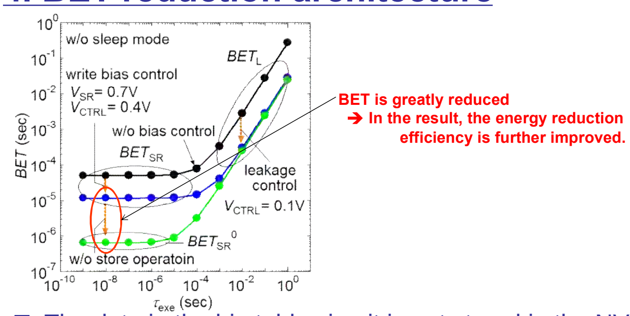



Low power operation of NV-SRAM combining with NVPG and Sleep mode



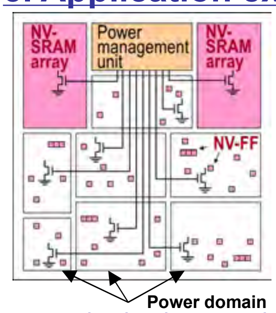

- BET (Break-Even Time): Power-shutdown time to compensate for the extra energy required to provide power gating.
- The standby power of NVPG is less than 50% of the conventional technology.
- By introducing a sleep mode, power consumption can be further reduced more than 50%.

## 4. BET reduction architecture




- The data in the bi-stable circuit is not stored in the NV-memory element (MTJ) when the data in the bi-stable circuit and the data in the NV-memory elements match.
  - ➔ This architecture which reduces the number of write into MTJ makes BET greatly reduced.
  - ➔ The energy consumption is also greatly reduced.

## 5. Application examples




Schematic of NVPG processor/SoC using NV-SRAM and NV-FF

- Logic circuits on a chip are partitioned into several circuitry domains. (power domains)
- The power domains are electrically separated from power-supply lines and/or ground lines by sleep transistors.
- These domains can be shut down during standby mode without losing their data by using NV-SRAM and NV-FF, and thereby highly energy-efficient power-gating can be achieved.
  - ➔The static power is considerably reduced even during system run-time.

## Patent Licensing Available

**Patent No.: WO2013/172065, WO2013/172066**

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Electronic Device

# Semiconductor Structure provided with AlON Film on top of Ge Layer

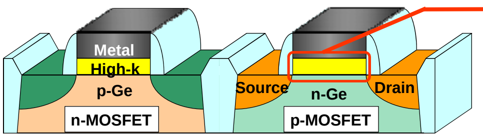
Prof. Akira TORIUMI (University of Tokyo)

## 1. Abstract


- By forming aluminum oxynitride on the Ge (Germanium) layer, high reliability thin film as the gate insulating film of MOSFET was realized.
- High-pressure inert gas post deposition annealing (PDA) using $N_2$ or Ar gas dramatically improved the electrical properties of AlON/Ge MIS gate stacks.


## 2. Ge MOSFET: Expectation, and Problems to be Solved

- Ge which has the higher carrier mobility, is a promising candidate as a channel material in the next generation of MOSFETs.
- In miniaturized MOSFETs, gate insulators with a high dielectric constant (high-k) are required in order to suppress the gate leakage current and the short channel effects.
- There is also a problem how good interface and insulating layer on Ge can be realized.



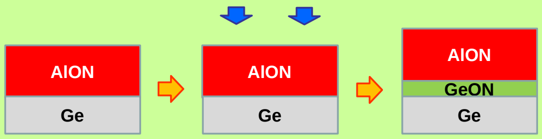

Ge MOS FET Structure

**Gate Stack**
- Ge-insulation film interface
- $GeO_2$ -High-k Interface

**Problems:**
- Degrade carrier mobility
- Less reliability
- Variation increase

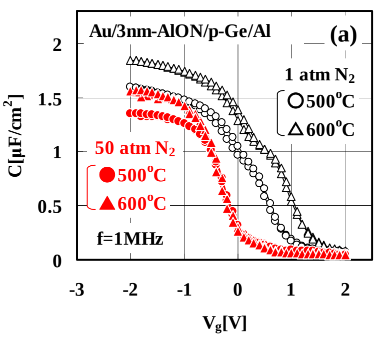
## 3. Scalable High-k/Ge Gate Stack Technology

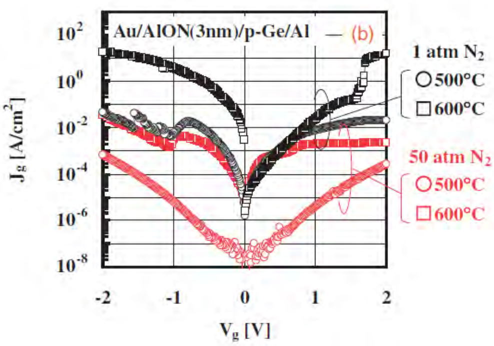
High-pressure $N_2$(HPN) (or Inert Gas) heat treatment




- We investigated the use of aluminum oxynitride film (AlON) as a gate insulating film formed on the Ge substrate. By using an AlON film, a thin EOT (Equivalent Oxide Thickness) is possible.
- However, heat treatment of AlON film in order to improve the quality of the AlON film deteriorates the interface between Ge substrate and the AlON film.
- After examining the conditions under which the interface between the AlON film and the Ge substrate is not degraded by heat treatment, we tried to apply high-pressure $N_2$ post-deposition annealing (HPN PDA) in order to suppress the $N_2$ desorption, which was analogous to high-pressure oxidation (HPO) annealing in $GeO_2$/Ge stack.

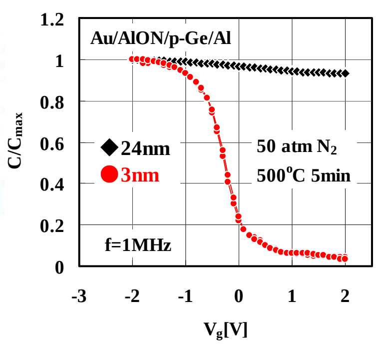
- HPN PDA dramatically improves the C-V characteristics, whereas the large interface states were observed in the same gate stack as a result of atmospheric-pressure $N_2$ (APN) post-deposition annealing.
- HPN PDA also reduces the gate leakage current.
- HPN PDA only improves the interface in the case of thin AlON/Ge.




C-V Characteristics (a) and I-V Characteristics (b)

Au/3nm-thick AlON/p-Ge(100)/Al MIS capacitors in APN and HPN PDA at 500 and 600 degree.




C-V Characteristics

Au/3nm-thick and 24nm-thick AlON/p-Ge(100)/Al MIS capacitors in HPN PDA at 500degree for 5min.

## Patent Licensing Available

Patent No.: WO2014/030371

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# A micrometre-scale Raman Silicon Laser with a microwatt Threshold

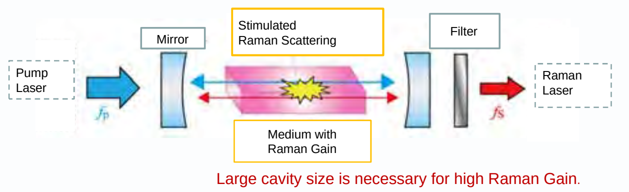
Optical Device

Associate Prof. Yasushi TAKAHASHI(Osaka Prefecture University)

## 1. Silicon Raman Laser

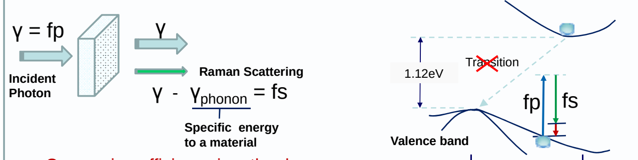
- Raman laser is the only silicon laser, but
- Currently proposed Si laser needs the improvement
  - miniaturization to micrometer dimensions
  - reduction of the threshold to microwatt powers

Stimulated Raman Scattering with cavity



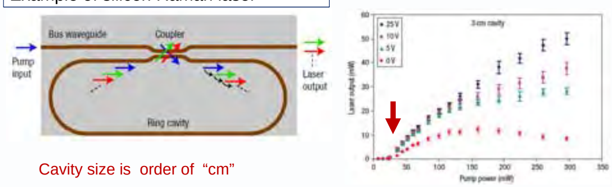

Large cavity size is necessary for high Raman Gain.

Principle of Raman Scattering




Conversion efficiency is rather low.

Example of silicon Raman laser




Cavity size is order of "cm"

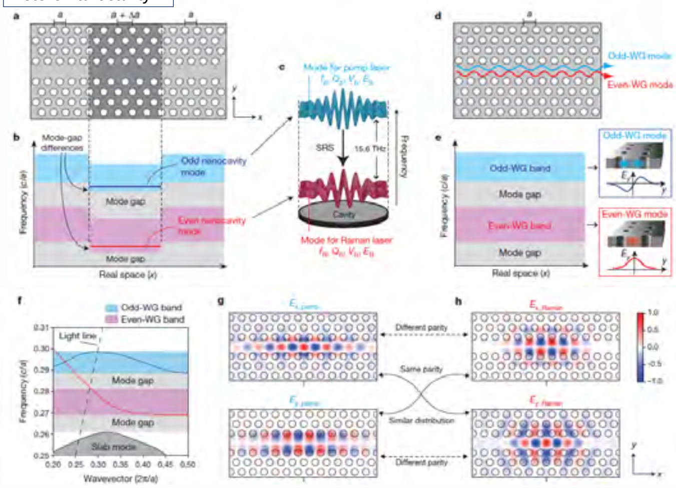
H. Rong *et. al.*, Nature Photon. 1, 232 (2007). Threshold power is ~20mW

## 2. Principle of the Invention

- To utilize two types of nanocavity mode in hetero nanocavity
- To fabricate the cavity along the [100] crystal direction

Hetero nanocavity

Y.Takahashi et.al., Nature vol.498 27 June 2013 p470-474




- Photon is localized in a cavity with a volume, ~$\lambda^3$
- Q-value > $10\times10^5$ in Odd nanocavity mode
  $10\times10^6$ in Even nanocavity mode
- Δ of frequencies is tunable by the air-hole radius

G[･]: Raman gain in each direction

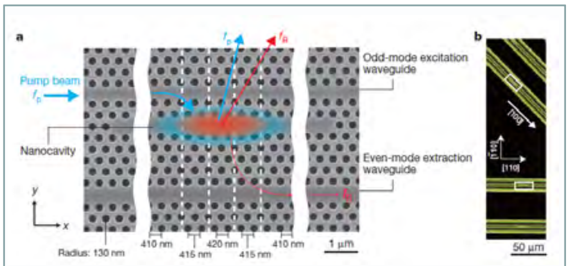
$$G_{[100]} \propto \iiint_{Si} \left| E^*_{x\_Raman} E_{y\_pump} + E^*_{y\_Raman} E_{x\_pump} \right|^2 dx\,dy\,dz$$

$$G_{[110]} \propto \iiint_{Si} \left| E^*_{x\_Raman} E_{x\_pump} - E^*_{y\_Raman} E_{y\_pump} \right|^2 dx\,dy\,dz$$

G[100] >> G[110] , then [100] is favorable

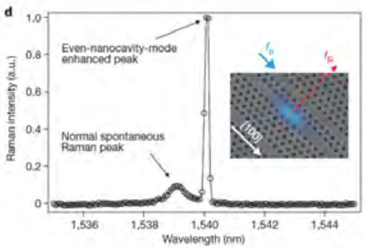
## 3. Characteristics

Both [100] & [110] devices are evaluated.

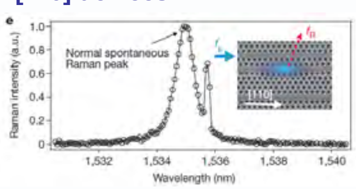



- Threshold power : 1uW, 20,000 times smaller.
- Chip size is 10,000 times smaller.

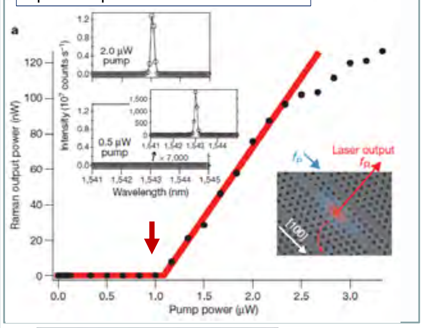
[100] device




[110] devices




Input - output characteristic

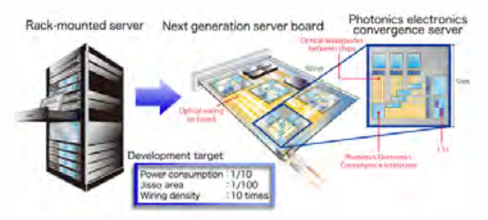




## 4. Application Examples

- Realization of the convergence between photonics and electronics
- Various industrial applications

→ Laser with the current mode excitation is under development.




http://www.petra-jp.org/pj_pecjs/en/index.html

- Inter-chip connection (Interposer)
- O/E interface inside the chip

## Patent Licensing Available

Patent No.: WO2014/030370

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Optical Device

# Novel Terahertz Polarizer for Extremely High Extinction Ratio

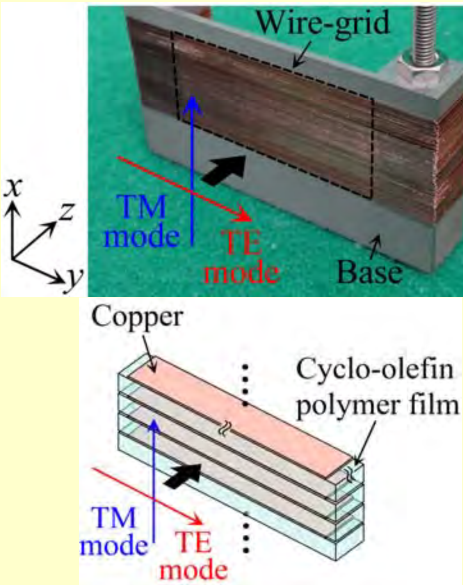
Assistant Prof. Takehito SUZUKI (Ibaraki University)

## 1. Background

- The polarizer is one of the key components in terahertz polarization sensitive measurements, which often gives fruitful information for terahertz technology innovations.
- The sophisticated design of a polarizer with both high extinction ratio and high transmission power is strongly required.

  * The extinction ratio of conventional wire-grid polarizer is $10^{-2}$~$10^{-4}$ (-20 dB~-40 dB), even though the transmission power is approximately 100%. The simultaneous pursuit of both is extremely cumbersome for conventional structures.
- Robust structures and low cost should be required for the market.

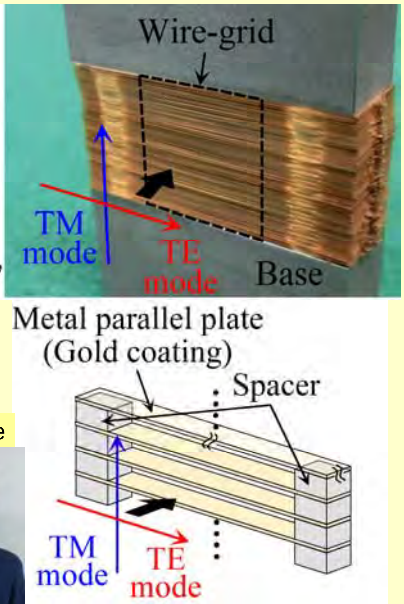
## 2. Sophisticated structures to realize extremely high performance



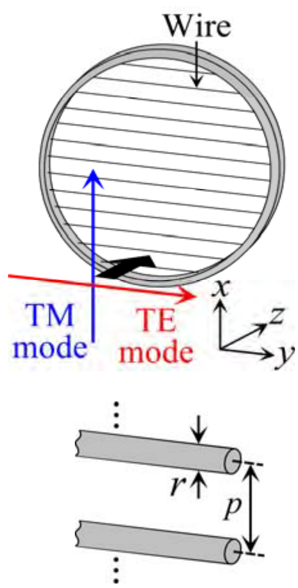

**GoIS I type**
**laminated parallel plates on a cyclo-olefin polymer film**

GoIS I type

Mr. Yudai Kishi
Graduate

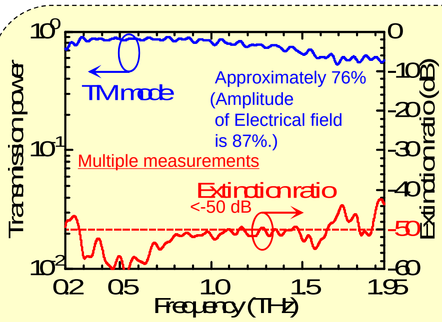



**GoIS II type**
**hollow parallel plates**

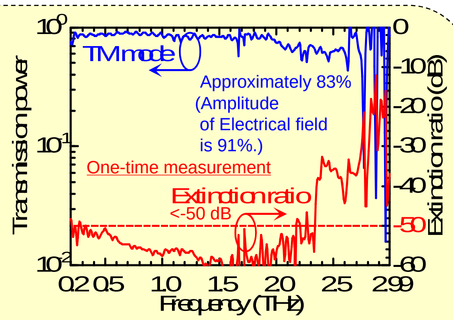



**Conventional wire-grid polarizer**

## 3. Innovation Achievements

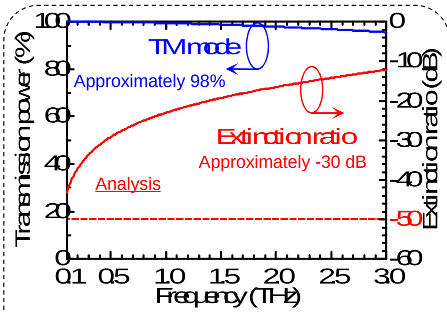



**GoIS I type**




**GoIS II type**

These measurements were performed by Dr. Masaya Nagai of Osaka University.




**Conventional wire-grid polarizer**

- The polarizers, GoIS I and GoIS II, have the sophisticated structures and realize both high extinction ratio below $10^{-5}$ (-50 dB) and transmission power of approximately 80%.
- Robust polarizers can be supplied to the market at much lower cost compared to the conventional wire-grid polarizers.

## Patent Licensing Available

Patent No. : JP5626740
PCT/JP2014/071866

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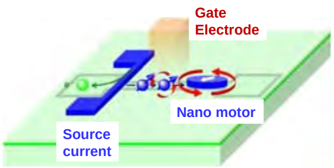
Spin Device

# Spin Motor and Spin Rotary Member

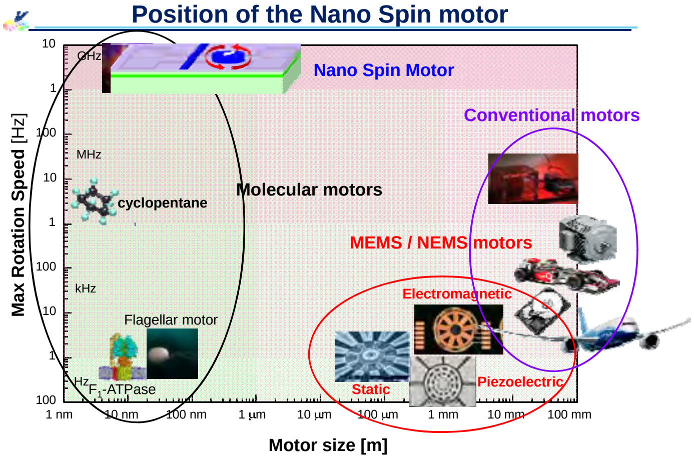
Prof. Atsufumi HIROHATA(York University)

## 1. Novel Mechanism: Nano-Spin Motor

- A magnetic moment in the ferromagnetic nano-disk rotates by the spin-polarized current flowing from the non-magnetic material under the disk.
- High efficiency and high rotation frequency are expected.

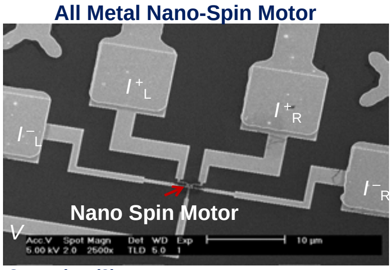



| | Conventional | This invention |
|---|---|---|
| Rotation Frequency | Hz ~ KHz | Hz ~ GHz |
| Device size | 100μm ~ mm | 100nm ~ μm |

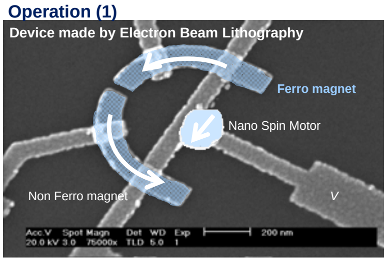



## 2. Structure and Operation Principle

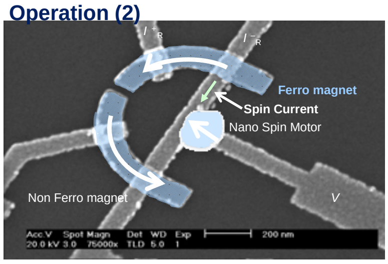
All Metal Nano-Spin Motor



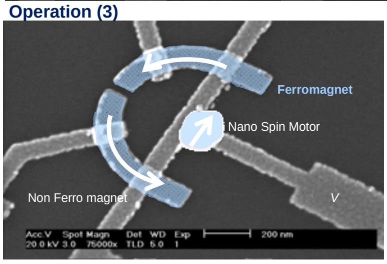

Operation (1)



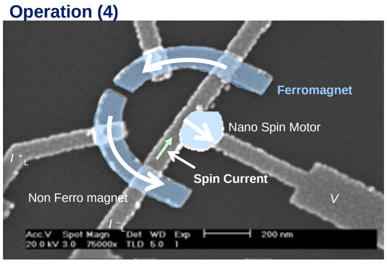

Operation (2)



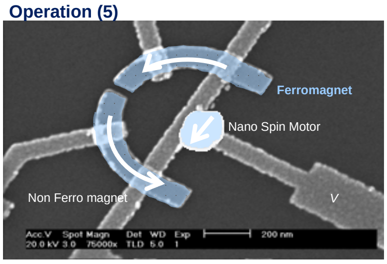

Operation (3)




Operation (4)

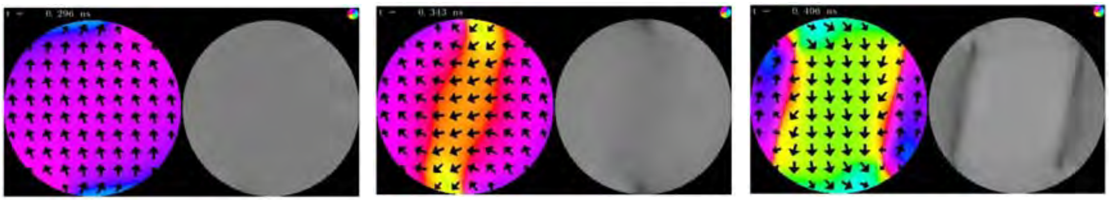



Operation (5)




## 3. Simulation ( Now, under an demonstration stage)

Rotation images of the magnetic moment: Simulation has been executed by using the LLG equation.
Left: model diagram Right: differential image of the magnetic domain



Landau-Lifshitz Gilbert Equation

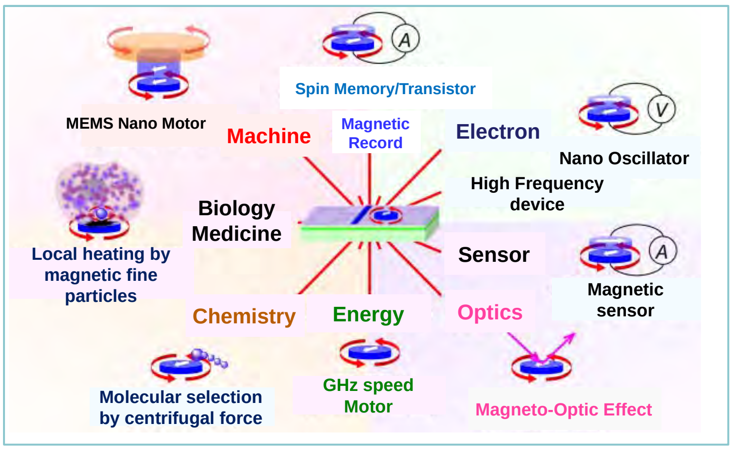
$$\frac{d\vec{m}}{dt} = -\frac{|\gamma|}{1+\alpha^2}\{\vec{m}\times\vec{H}_{Tot} + \alpha\vec{m}\times(\vec{m}\times\vec{H}_{Tot})\}$$

$$\vec{H}_{Tot} = \vec{H}_{eff} + \vec{H}_{ST} \quad (\vec{H}_{ST}\text{: Spin-Torque field})$$

$$\vec{H}_{ST} = -gA_{SL}\times\{\vec{m}_p\times\vec{m} + \beta\vec{m}_p\}$$

$$\vec{H}_{eff} = -\frac{1}{M_s}\frac{\partial E}{\partial \vec{m}}$$

## 4. Potential Applications




## Patent Licensing Available

Patent No. : WO2014/024697

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Spin Device

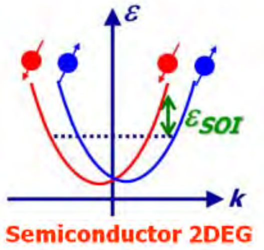
# Spin Transistor utilizing Rashba SO interaction

Assistant Prof. Makoto KOHDA (Tohoku University)

## 1. The newly proposed spin transisitor

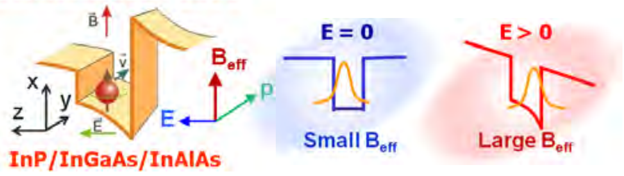
・Spin-Orbit Interaction :

No need for external B fields ($B_{ex}$) and magnetic materials

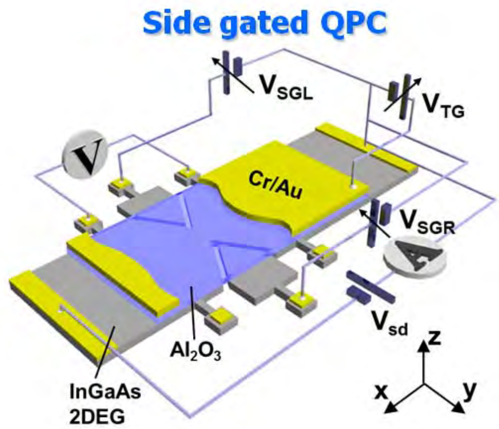



$$\varepsilon_{SOI} = \pm \alpha k_F = \pm \frac{1}{2} g \mu_B B_{eff}$$

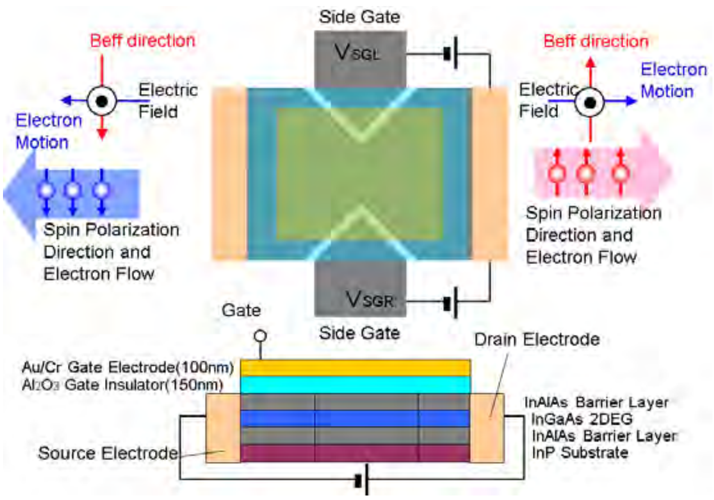
Effective B field $B_{eff} \propto \frac{p \times E}{2m_0c^2}$




・A proposed Device Structure

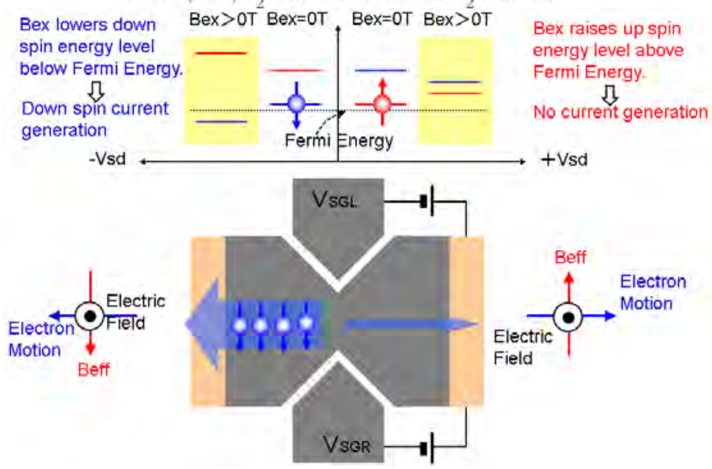



## 2. Mechanism to induce Spin Polarization and Spin Rectification Effect



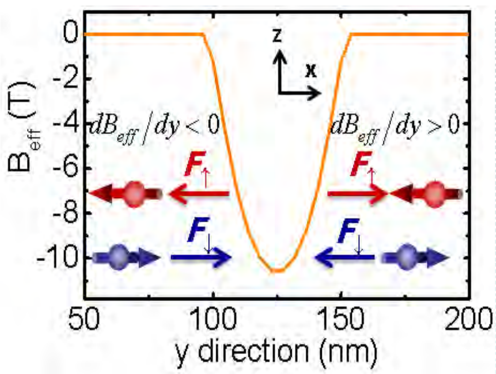

Spin Polarization Mechanism

$$H = \alpha\vec{\sigma}\cdot(\vec{p}\times\vec{E}) + \frac{1}{2}g\mu_B\vec{\sigma}\cdot\vec{B}_{ex} = g\mu_B\vec{\sigma}\cdot\vec{B}_{eff} + \frac{1}{2}g\mu_B\vec{\sigma}\cdot\vec{B}_{ex}$$

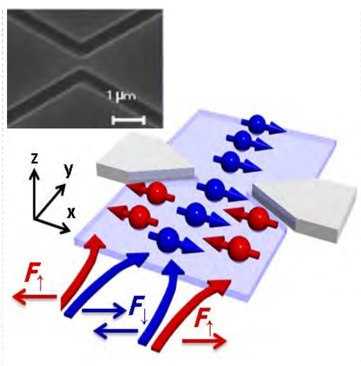



Spin Rectification Mechanism

## 3. Device Characteristics



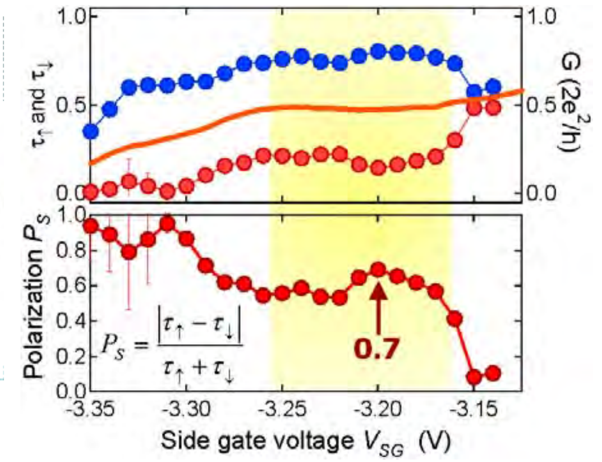

Calculated effective magnetic field $B_{eff}$ along the y direction at x = 106 nm.




Spin Polarization induced by effective magnetic field $B_{eff}$

(The inset shows an image of a QPC channel region taken by a SEM.)

Maximum spin polarization is 70% at 0.5($2e^2/h$)




$$P_S = \frac{|\tau_\uparrow - \tau_\downarrow|}{\tau_\uparrow + \tau_\downarrow}$$

Spin Polarization at 0.5 ($2e^2/h$) structure

## Patent Licensing Available

Patent No.: WO2013/027712(JP, US, EP, KR, CN)

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Sensor

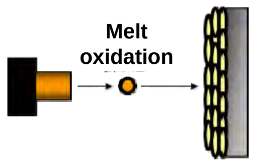
# High Performance Magnetic Coating

Prof. Emeritus Akihisa INOUE (Tohoku University)
Prof. Emeritus Hiroyuki WAKIWAKA (Shinshu University)

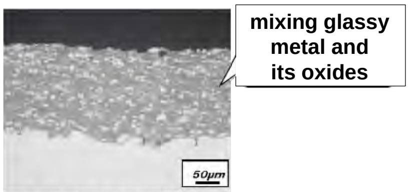
## 1. Introduction

High performance magnetic coating is materialized by a series of patented technologies-soft magnetic glassy metal , coating of the glassy metal by thermal spraying and applications of the coating as torque sensors.

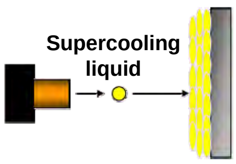
## 2. Key Features



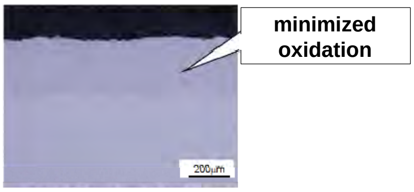

Conventional thermal spraying




Coating by conventional process




Thermal spraying of glassy metal

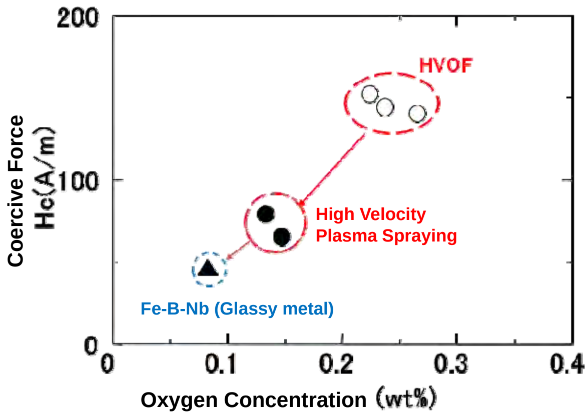


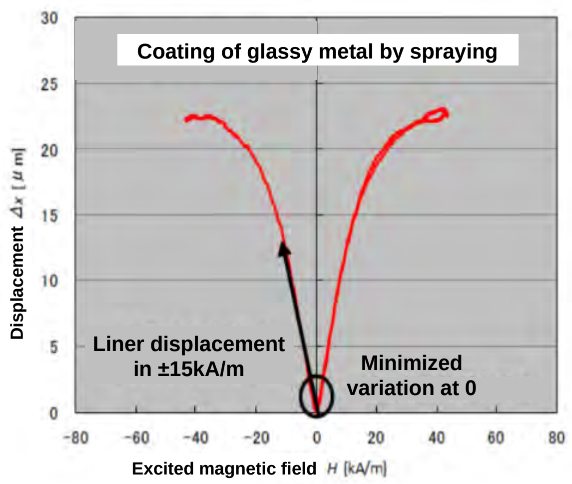

Coating by thermal spraying

a. Soft magnetic glassy metal having a basic formula of Fe-B-Nb is characterized by soft magnetic properties.

b. Coating by thermal spraying is designed specifically for keeping properties of the glassy metal by minimizing oxidation of the glassy metal.

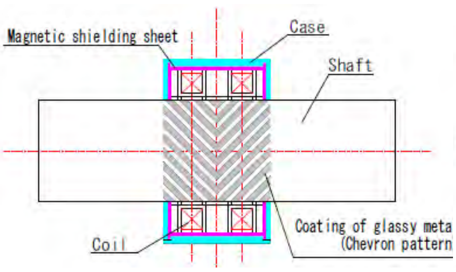
c. Coating has good magnetostrictive properties and finds applications such as torque sensors.



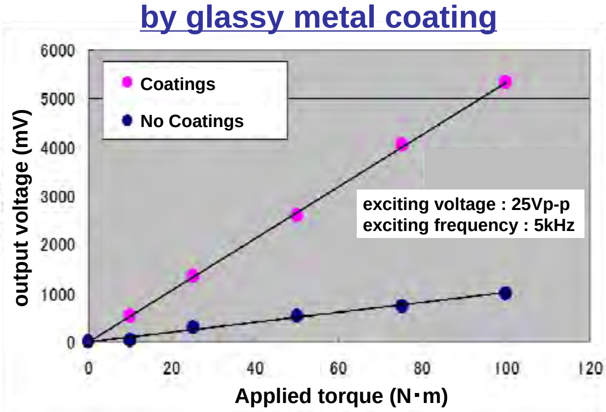




## 3. Application Examples

・Torque sensor




### Sensitivity improvement by glassy metal coating




## Patent Licensing Available

Patent No.: US7357844, US7906219B, WO2011/016399 (US, EU, JP, KR, CN, TW)

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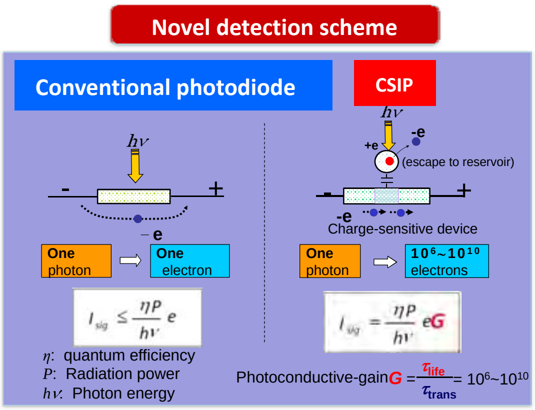
Measurement Equipment

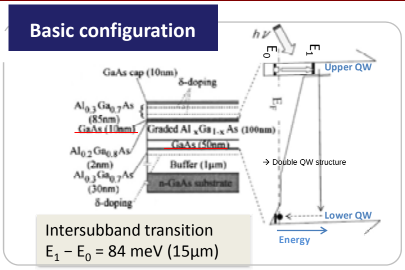
# Infrared Detector of single-photon sensitivity

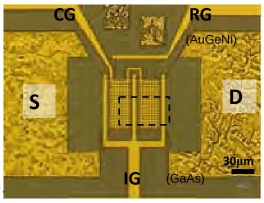
Prof. Emeritus Susumu KOMIYAMA Group (University of Tokyo)

## 1. CSIP: Charge Sensitive Infrared Phototransistor

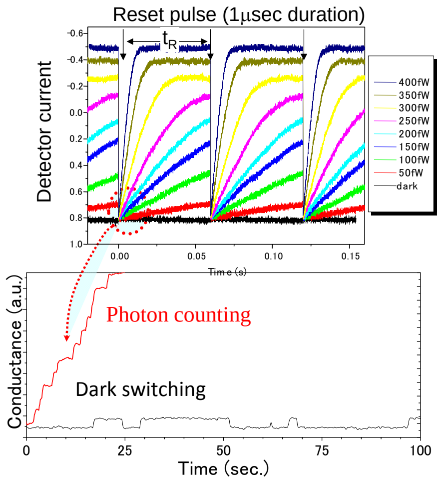



S. Komiyama, *IEEE J. Select. Topics. Quantum Elect.* 17, 54 (2011)

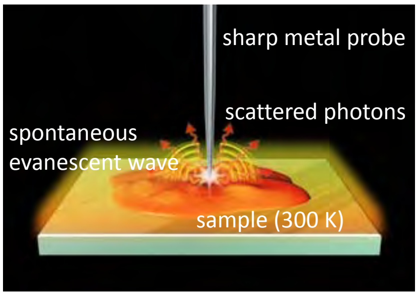


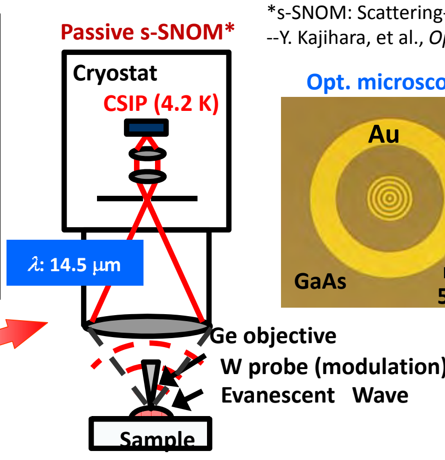

Microscope image

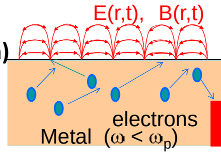



## 2. Application: "passive"near-field spectroscope

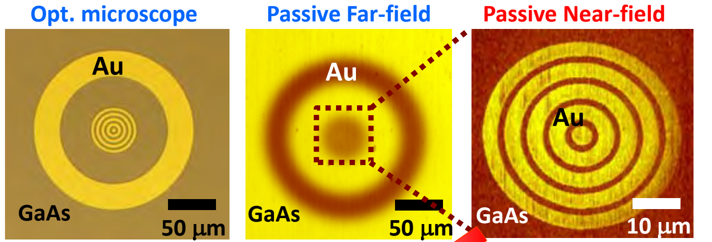



Required Specifications:
1. Detector → CSIP*
2. Resolution → Near-field microscope
3. Remove background noises



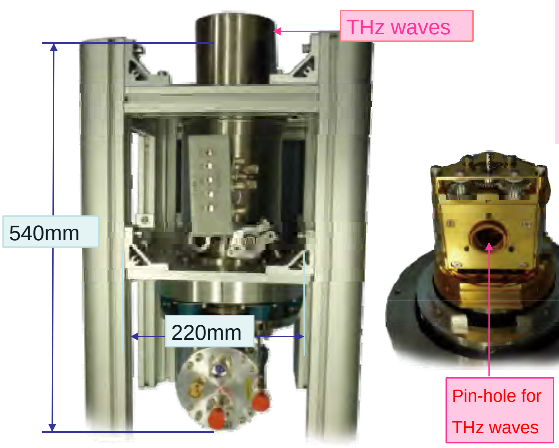

*s-SNOM: Scattering-type Scanning Near-field Optical Microscope
--Y. Kajihara, et al., *Opt. Express* 19, 7695-7704 (2011).



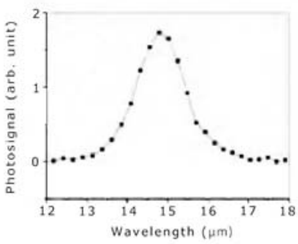

Resolution: 20 nm !

Origin: Thermal charge fluctuation

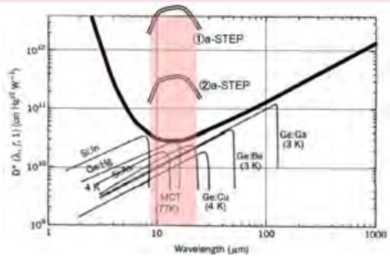
## 3. Tabletop ultrasensitive THz detector (jointly developed with UNISOKU)




| | |
|---|---|
| Sensor | CSIP (GaAs/AlGaAs quantum well crystals) |
| Spectral Range | 9 ~ 20 μm |
| Operating temperatures | 4 K (Helium free! Closed-cycle mechanical refrigerators) |
| Quantum efficiency | higher than 7% @ 15 μm |
| Measurement speed | up to 100kHz |
| Sensitivity | 100fW ~ 100nW @ 1Hz |
| Output format | analog voltage (0 ~ 10V) |
| Optical window | 10 ϕ- ZnSe window, 125μmϕ low temperature pinhole (option) |




Spectrum of 15 μm CSIP




**Specific detectivity D* of the detector (①、②a-STEP)**
Compared to conventional detectors . Thick solid line: theoretical limit of background limited values at 300K.

## Patent Licensing Available

Patent No.: WO2010/137422, WO2010/137423

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# Radiation Detector using Low-Dimensional Semiconducting Scintillator

Measurement Equipment

Assistant Prof. Kengo SHIBUYA (University of Tokyo)

## 1. Low-Dimensional Semiconducting Scintillator

### Strategy to develop ideal scintillator:

**Conventional Scintillator:**

| *Inorganic:* | *Organic:* |
|---|---|
| *High Scintillation Efficiency* *(Favorable)* | *Low Scintillation Efficiency* *(Unfavorable)* |
| *Relatively long decay time* *(Unfavorable)* | *Short decay time* *(Favorable)* |

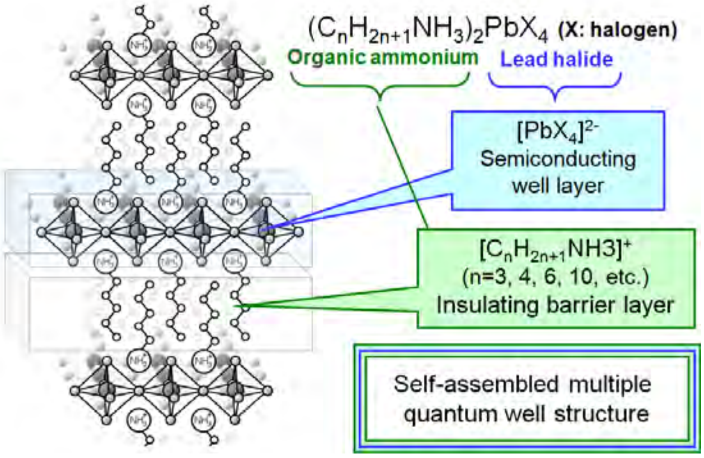
*Quantum Confinement Structure*

*Suppression of Thermal Quenching, realizes*
*1) High Scintillation Efficiency*
*2) Short decay time*

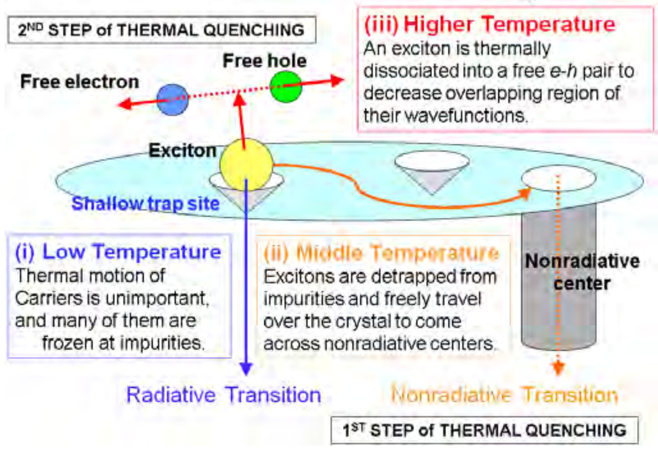
| Material | Density g/cm³ | Emission maximum nm | Relative output % | Decay components ns (%) |
|---|---|---|---|---|
| NaI(Tl) | 3.67 | 415 | 100 | 230 (91%), 150,000 (9%) |
| BGO | 7.13 | 480 | 8 | 60 (10%), 300 (90%) |
| LSO(Ce) | 7.35 | 420 | 75 | 41 (100%) |
| stilbene | 1.16 | 410 | 22 | 4.6 (90%), 15 (10%) |
| $BaF_2$ fast | | 220 | 5 | |
| $BaF_2$ slow | 4.89 | 310 | 16 | 0.8 (20%), 630 (80%) |
| $C_4PbBr_4$ | 2.65 | 438 | 6.5 | 2.8 (40%), 18 (40%), 130 (20%) |
| $C_6PbI_4$ | 2.40 | 558 | 11 | 0.39 (30%), 3.8 (30%), 16 (40%) |

**New Scintillator:**

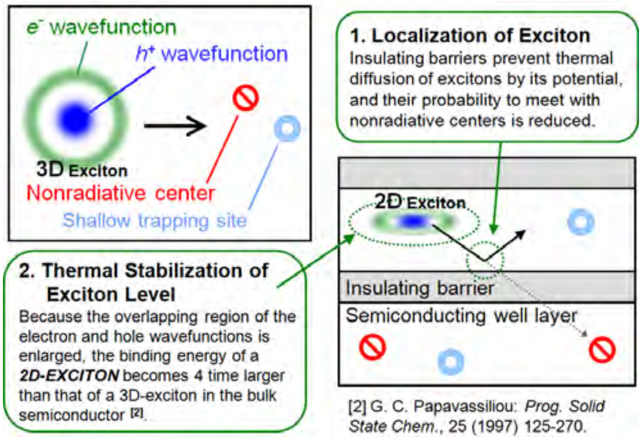
Lead-halide-based Perovskite-type Organic -Inorganic Hybrid Compounds with Quantum Well.




## 2. Suppression of Thermal Quenching by Quantum Confinement Structure



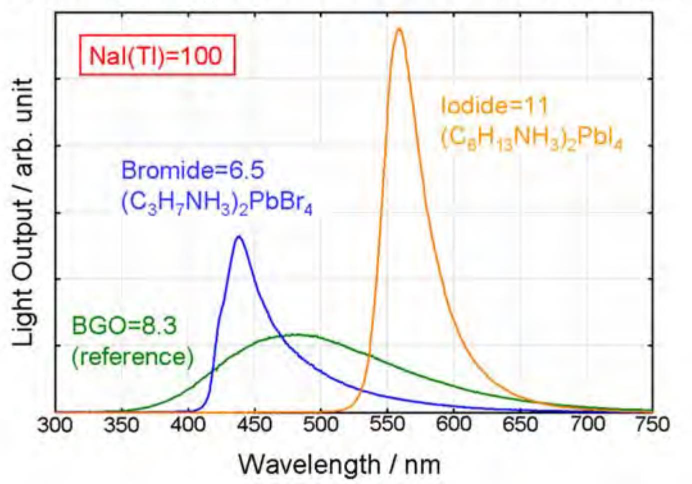

*Thermal Quenching Processes*



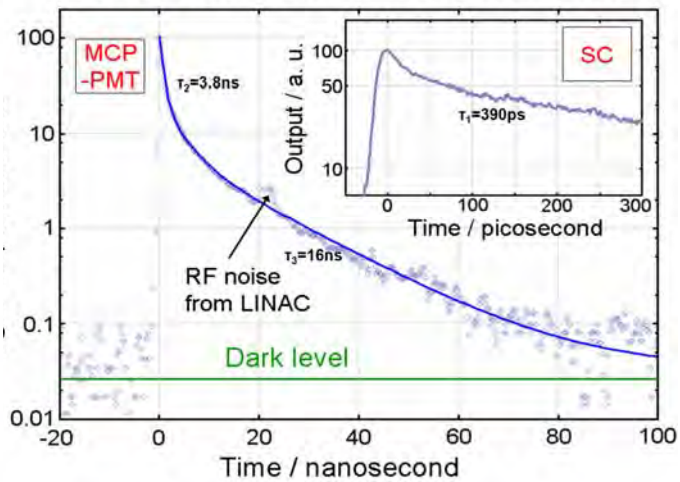

*Mechanism to suppress Thermal Quenching by quantum confinement structures*

## 3. Properties of the New Scintilator

**Scintillation Spectra of the Bromide and Iodide**




**Scintillation Time Profile of the Iodide**




**Patent Licensing Available** Patent No.: WO2002/056056 (JP, US, EP)

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# Measuring Properties of an object with Acoustically Induced Electromagnetic Waves(ASEM)

Measurement Equipment

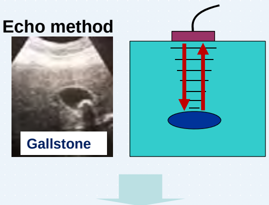
Associate Prof. Kenji IKUSHIMA (Tokyo University of Agriculture and Technology)

## 1. Novel ASEM method

・Conventional:
(Ultrasonic-pulse echo method)

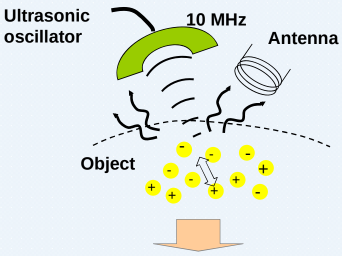
Mechanical Properties { Mass density distribution, Elastic coefficient }

Echo method




Imaging of mechanical properties

・Novel : ASEM
Acoustically Stimulated ElectroMagnetic Method




Imaging of Electromagnetic Properties
(developed by K. Ikushima)

Electromagnetic radiation is generated by temporal modulation of the magnetization or electric polarization via ultrasonic waves in a variety of materials.

Ultrasonic wave ⟶ Tm ⟶ Bj

$$S_m = s_{mn}T_n + d_{jm}H_j,$$

*Sm*: Strain
*Tn* : Stress

$$B_j = d_{jm}T_m + \mu_{ji}H_j.$$

**Assume,** $m(t) = m_0 \sin\omega t$

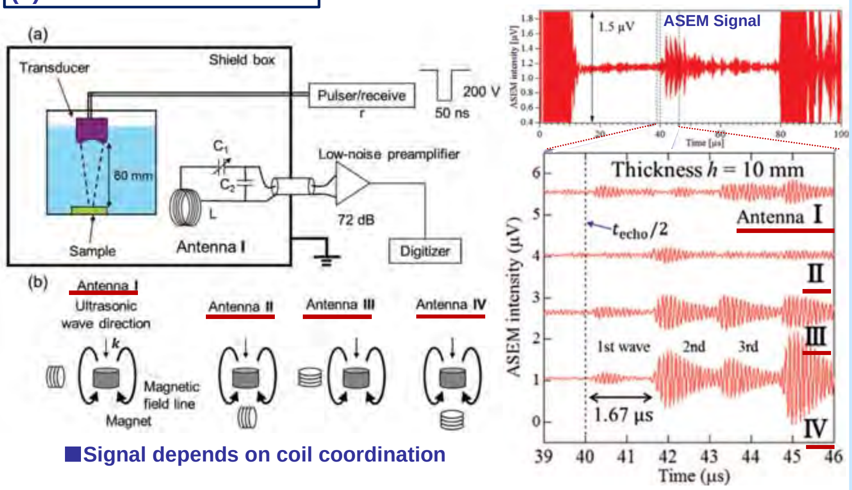
$$B^{\rm near}_{\rm emit}(x,t) = -\frac{\mu_0}{4\pi}\{3(m_0\cdot n_0)n_0 - m_0\}\times\frac{\sin\omega t}{r^3}.$$

We observe $V_{sig}$ ,

$$V_{sig} \propto \{3(m_0\cdot n_0)n_0 - m_0)\omega\cos\omega t\}/r^3.$$

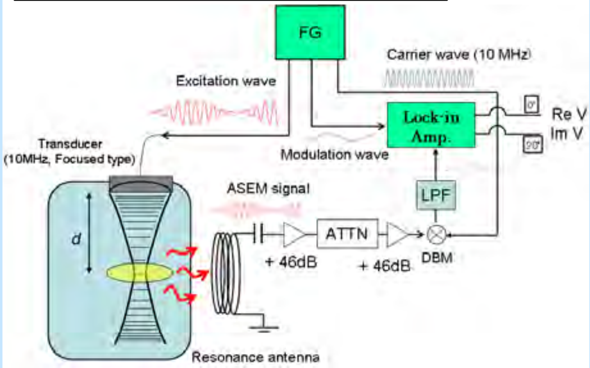
## 2. Measurement & Data

### (1) Pulse – ASEM Method



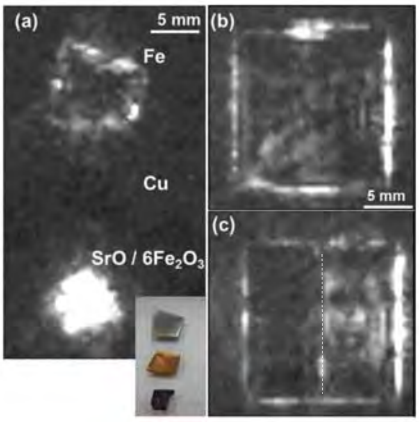

■Signal depends on coil coordination

### (2) AM Modulation – ASEM Method



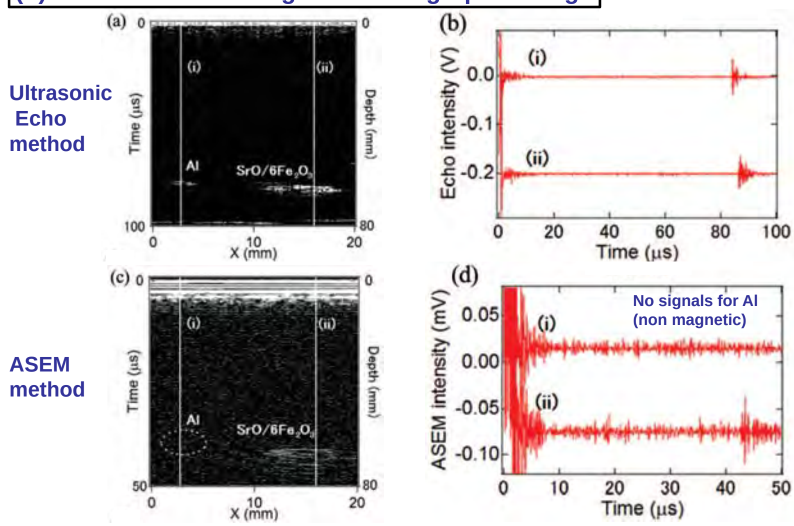

Improvement:
■Large S/N ratio
■Shorter measurement time

### (a) Non destructive 2-D Magnetic Image




ASEM images for magnetic(Fe and SrO/6Fe$_2$O$_3$) and nonmagnetic materials(Cu). Visualization of the stress induced magnetization in an iron foil before(b) and after folding. The new residual stress is observed through the ASEM signals(the white Line in (c) ).

### (b) Non destructive Magnetic Tomographic Image




“For magnetic materials, non destructive hysteresis measurement is also possible.

## 4. Application

・Imaging of materials which electromagnetically responds via the ultrasonic wave.
( piezoelectric, magnetic materials which light doesn’t penetrate )

## Patent Licensing Available

Patent No.: WO2007/055057 (JP, US, EP)

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Cryogenics

# Helium Circulation System (HCS) for MEG

Prof. Emeritus Tsunehiro TAKEDA (University of Tokyo)

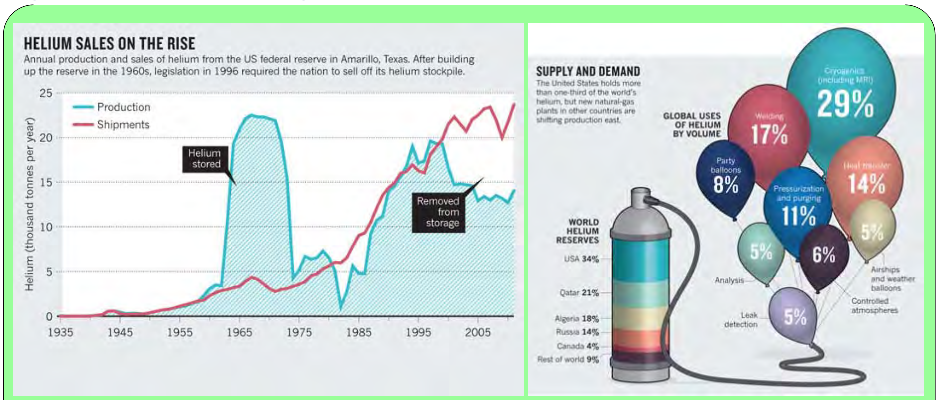
## 1. Helium Problems and MEG (Magnetoencephalography)

### MEG problems

- Large amount of expensive He required (8 - 10l/day)
- Frequent liquid He refilling required (2 times/week)

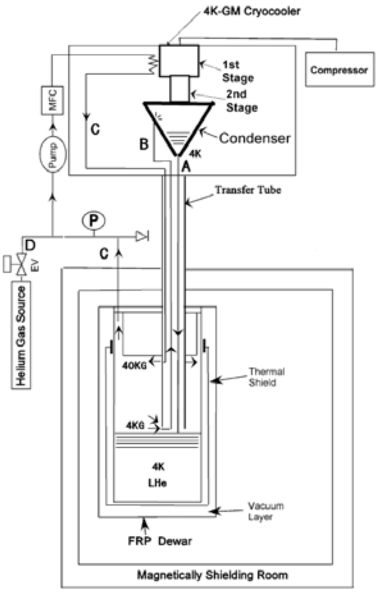
### Required specifications for the HCS for the MEG

- Liquid He circulation: 10l/day
- Continuous Operation: 1 year or more
- No blocking by contaminants ($H_2O$, $N_2$, $O_2$)
- No incremental noise (acoustic/ magnetic) added by HCS




Current Status of Helium production and consumption
(excerpt from Nature, 31 May 2012, Vol 485)

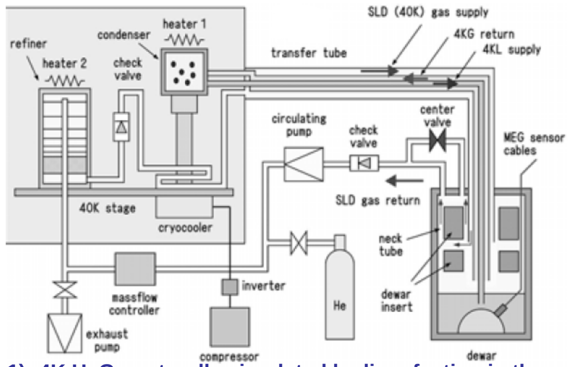
## 2. Newly developed Helium Circulation System




### Basic idea of the new HCS

A: pipe to lead LHe (to cool SQUIDs) from condenser to dewar by gravity
B: pipe to lead lower temperature (4K) HeG from dewar to condenser
C: pipe to circulate higher temperature (40K) HeG (to cool the dewar)
D: pipe to add pure HeG
EV: electric valve
MFC: mass flow controller

- Line B ⇒ A
  The condenser absorbs low temperature gas and liquefies it without raising it up to the room temperature (300K).
- Line D ⇒ C
  40K HeG is flowed into the neck tube of the dewar to cool it.

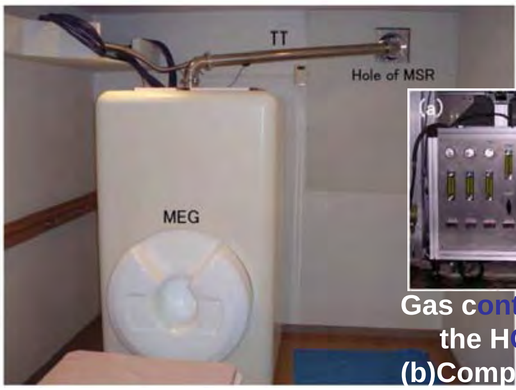


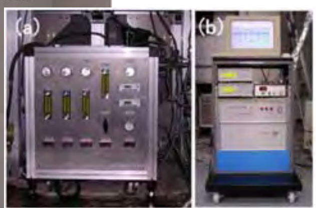

1) 4K HeG : naturally circulated by liquefaction in the condenser
2) 40K HeG (to cool dewar) : circulated by a pump

- Refiner with heater is introduced to prevent blocking by contaminants ($H_2O$, $N_2$, $O_2$).
- Trapped contaminants are automatically exhausted after evaporated by the heater.
- Transfer tube : a newly developed seven concentric TT to reduce the amount of heat flowing into the system

Block diagram of the gas flow

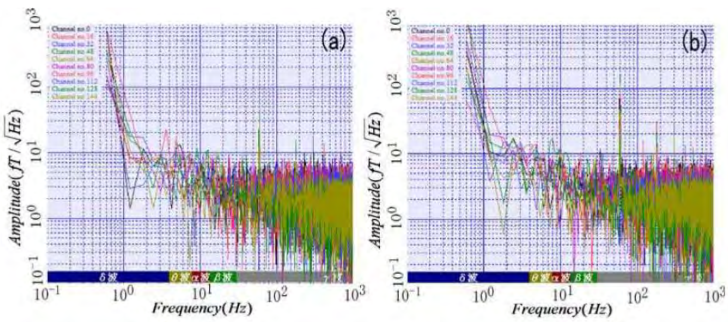
## 3. HCS and MEG in Operation



Gas control system of the HCS
(b)Computer

Multi-pipe TT of the HCS installed on the commercialized MEG




BEFORE HCS installation (b)AFTER HCS installation

Noise amplitude spectra of selected 10 channels of the system

**Advantages:**

1)Helium consumption: reduced to 1/200 of conventional systems.
2)Operation cost: less than 1/10 of conventional systems.
3)Incremental noise: no noticeable noise added by HCS

***This system is already commercialized by Frontier Technology Institute Inc. (JAPAN)***

## 4. Applications in other fields

1)MRI 2)Low temperature science

### Patent Licensing Available

Patent No.: WO2000/039513, WO2004/070296 , WO2004/110269

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Energy

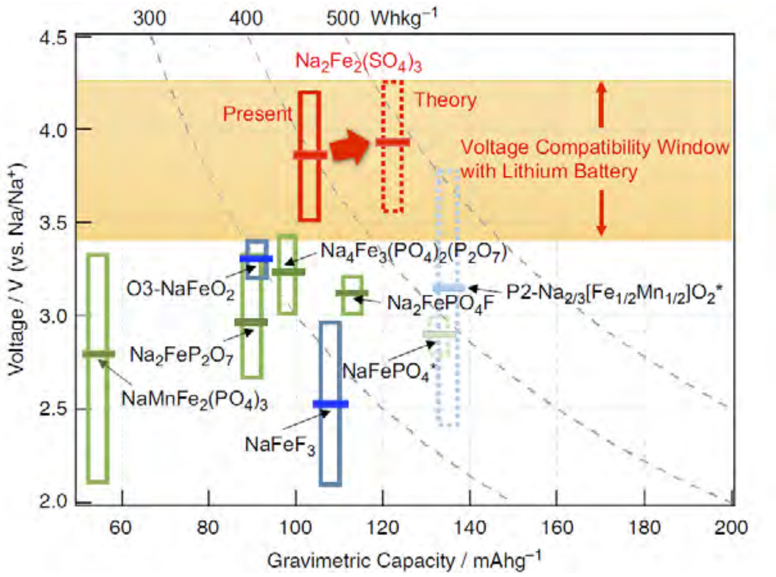
# 3.8 V Earth-Abundant Sodium Battery Electrode

Prof. Atuo YAMADA (University of Tokyo)

- We discovered a novel cathode $Na_2Fe_2(SO_4)_3$ for rare-metal-free Na-ion rechargeable battery.
- $Na_2Fe_2(SO_4)_3$ cathode shows the highest-ever $Fe^{3+}/Fe^{2+}$ redox potential at 3.8 V (versus Na) with more than 100mAh/g.
- $Na_2Fe_2(SO_4)_3$ has a fast (liquid-like) Na transport channel during the charge-discharge reaction.

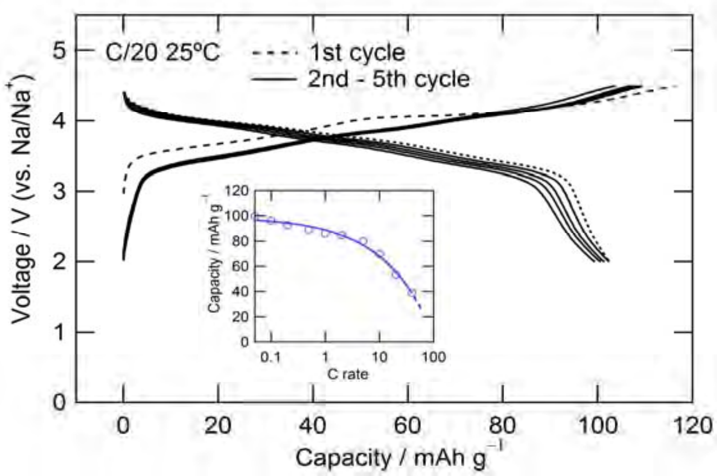
## 1. Novel $Na_2Fe_2(SO_4)_3$ Electrode

- Overall comparison of the Fe-based cathode materials in Na-ion battery system
- $Na_2Fe_2(SO_4)_3$ provides ;
  redox potential : 3.8V (versus Na/Na+)
  current density : ＞100mAh/g
  *energy density* : ＞400Wh/kg
  (theoretical 540Wh/kg)
- The theoretical capacity is higher than those of Li cathodes for present Li battery system.
- It is a entirely new composition and structure with the first alluaudite-type sulphate framework.



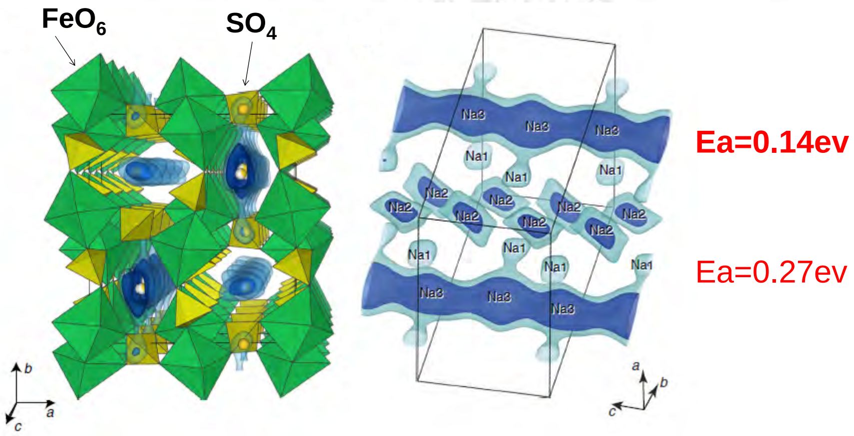

## 2. Electrode Properties of $Na_2Fe_2(SO_4)_3$ in Na Cell

- Galvanostatic charging and discharging profiles of $Na_{2-x}Fe_2(SO_4)_3$ cathode cycled between 2.0 and 4.5V at 25℃
- The initial capacity of 102 mAh/g (theoretical 120mAh/g) is highly reversible over 30 cycles under various current rates C/20(2Na in 20h) to 20C(2Na in 3min).




## 3. Na-ion Diffudion in $Na_2Fe_2(SO_4)_3$

- Ab initio calculations show very low activation energies for Na-ion migration within Na3 channel (Ea=0.14eV; Liquid-like) and Na2 channel(Ea=0.27eV).
- These Na channels show very fast charge-discharge kinetics, and the continuous space of Na3 site acts as a faster Na transport channel.




## Patent Licensing Available

Patent No. : PCT/JP2014/073162

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# Thermochemical Fuel Production by Non-Stoichiometric Perovskites

Energy

Prof. Yoshihiro YAMAZAKI (Kyushu University)

## 1. Thermochemical fuel production

Solar Concentrator

Full solar spectrum usage (using sunlight as heat instead of optical wave)

### Total Reaction

① Water-Splitting Reaction

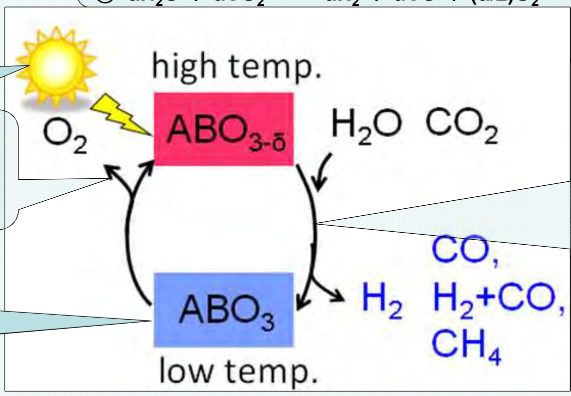
$\alpha H_2O \Rightarrow \alpha H_2 + (\alpha/2)O_2$

② $(\alpha/4)CO_2 + (\alpha/2)H_2O \Rightarrow (\alpha/4)CH_4 + (\alpha/2)O_2$

③ $\alpha CO_2 \Rightarrow \alpha CO + (\alpha/2)O_2$

④ $\alpha H_2O + \alpha CO_2 \Rightarrow \alpha H_2 + \alpha CO + (\alpha/2)O_2$

No $H_2/O_2$ separation required because the reaction is divided into 2 step reaction.




### 1st step reaction

〔High-temperature *Reduction* Step〕

①~④$O_2$ Emission

$ABO_{3\pm\delta} \Rightarrow ABO_{3\pm\delta-\alpha} + (\alpha/2)O_2$

### 2nd step reaction

〔Low-temperature *Oxidation* Step〕

①$H_2$ Generation Reaction

$ABO_{3\pm\delta-\alpha} + \alpha H_2O \Rightarrow ABO_{3\pm\delta} + \alpha H_2$

②$CH_4$ Generation Reaction

$ABO_{3\pm\delta-\alpha} + (\alpha/4)CO_2 + (\alpha/2)H_2O \Rightarrow ABO_{3\pm\delta} + (\alpha/4)CH_4$

③CO Generation Reaction

$ABO_{3\pm\delta-\alpha} + \alpha CO_2 \Rightarrow ABO_{\pm\delta} + \alpha CO$

④Syngas($CO+H_2$)Generation Reaction

$2ABO_{3\pm\delta-\alpha} + \alpha H_2O + \alpha CO_2 \Rightarrow 2ABO_{3\pm\delta} + \alpha H_2 + \alpha CO$

Various Fuel Gas Generation

**No Precious Metal Required**

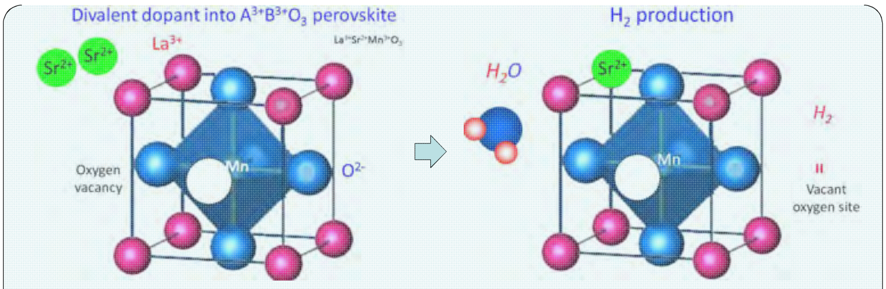
A: Alcali metals, Alkaline earth metals, Rare earth metals

B: Transition metals, Metalloids

## 2. Mechanism of Thermochemical Fuel Production


- Flexible structure

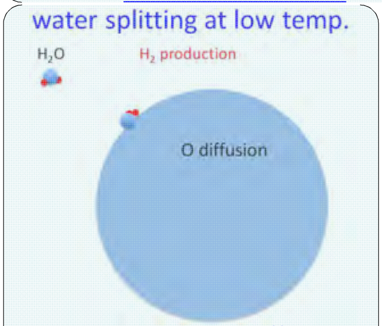
**Basic Structures**



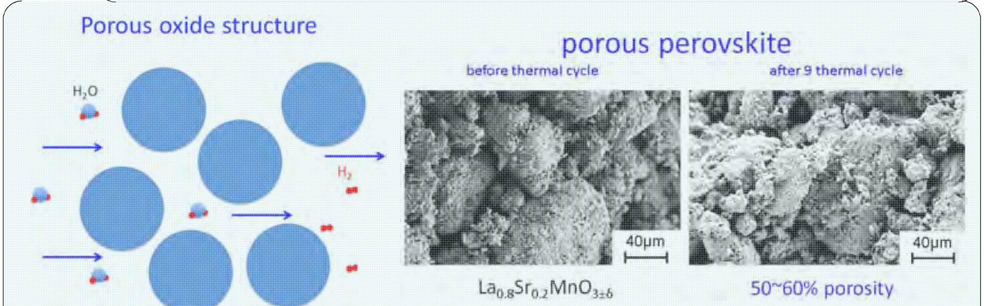

- Large amount of oxygen vacancy

$ABO_{3\pm\delta-\alpha} + \alpha H_2O \Rightarrow ABO_{3\pm\delta} + \alpha H_2$

**Mechanism of water-splitting**

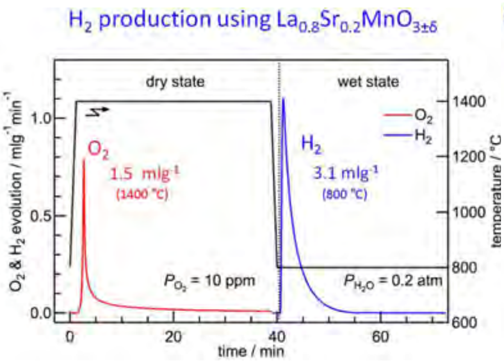


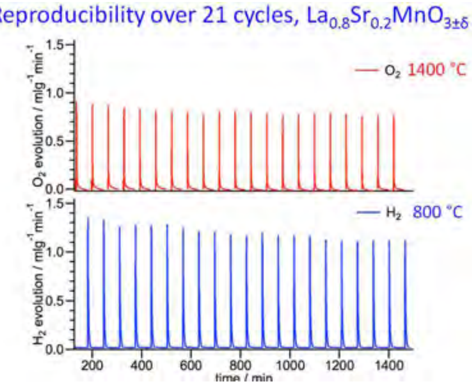

**Fast oxygen ion diffusion**

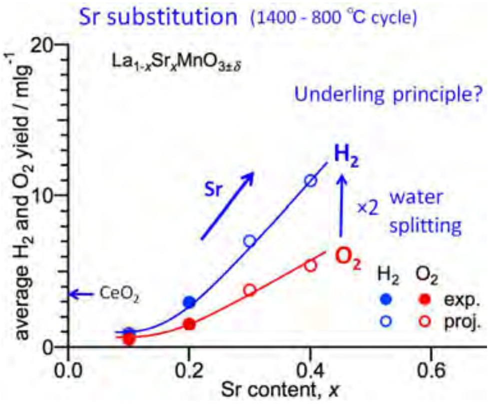



**Porous Oxide Structures**

## 3. Performance of water-splitting




## Patent Licensing Available

Patent No.: WO2013/141385 (JP, US, EP, KR, CN) (JST, Caltech)

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Water

# Safety Disinfection Technique by Plasma Treated Water

Associate Prof. K. KITANO (Osaka University)

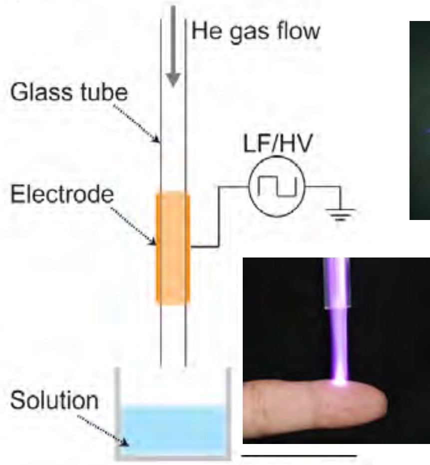
- We have developed a handy type, low cost & safety plasma jet system.
- Exposure to plasma jet and plasma treated water with the reduced pH is significantly effective to kill bacteria of human body.
- The plasma jet system will contribute to plasma medicine as well as plasma sterilization.

## 1. Plasma Jet System

- A schematic diagram of a low-frequency plasma jet generation system
- A plasma is generated in a He gas flowing in the glass tube when LF/HV pulses are applied to a single electrode around the tube.

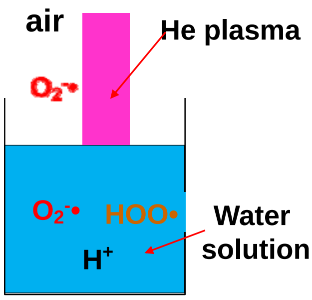
  *LF=10kHz, HV=5～10kV*

  Discharge power : a few watts.

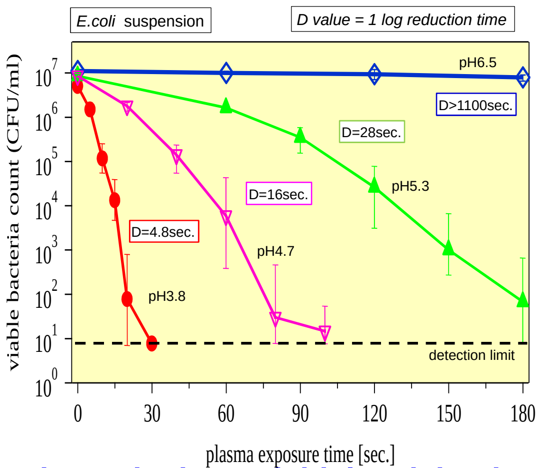



( Handy type ～$10 )

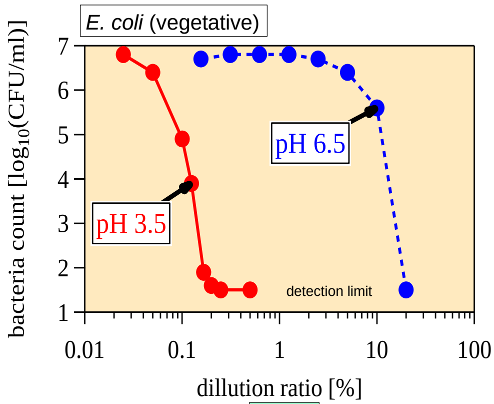
## 2. Physicochemical Property of Plasma Treated Water (PTW) with the Reduced pH




p*K*a = 4.8




Bactericidal Activity of diluted PTW

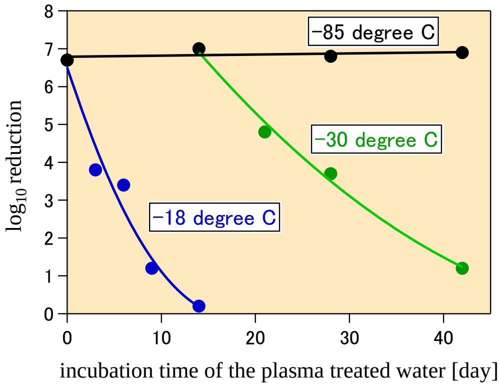



PTW has extremely strong bactericidal activity

- Reducing pH＜4.7 strengthens the bactericidal activity drastically.
- Mechanism
  - ･Plasma generate $O_2^-\bullet$ (superoxide anion radicals).
  - ･When pH is <4.8, $O_2^-\bullet$ is changed to HOO• (hydroperoxy radicals) by acid dissociation, and HOO• directly interact with bacterial cells to inactivate them.
- The presence of $O_2^-\bullet$ is essential for the bacterial inactivation.

## 3. Bactericidal Activity of Plasma Treated Water

- The activity can be preserved for a month by freezing.
- Safety indirect plasma disinfection will be brought by the combination of the plasma treated water and the reduced pH.




## Patent Licensing Available

Patent No. : WO2008/072390,WO2009/041049

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Mission :
We contribute to the creation of innovation in science and technology as the core implementing agency of the fourth phase of the Science and Technology Basic Plan.

Visions :
1. To achieve innovation in science and technology through creative research and development.
2. To maximize research outcomes by managing research resources on the virtual network.
3. To develop the nation's infrastructure for science and technology to accelerate innovation in science and technology.

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# Japan Science and Technology Agency
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