BEANS’
Hetero-functional Integrated Device Technology Development

Bio Electro-mechanical Autonomous Nano Systems

BEANS Laboratory
The University of Tokyo
Kyushu University
Ritsumeikan University
Advanced Industrial Science and Technology

BEANS Project is sponsored by NEDO (New Energy and Industrial Technology Development Organization)
MEMS Future = **BEANS**

- In Japan, we say semiconductor chips are rice for the industry.
- Rice provide energy for the body.

- Beans contain proteins for bio functions, such as eyes for sensing and muscle for actuation. We hope MEMS to be beans for the industry.

**MEMS Technology & Market Development Roadmap**

<table>
<thead>
<tr>
<th>Generation</th>
<th>Devices</th>
<th>Years</th>
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</thead>
<tbody>
<tr>
<td>1st</td>
<td>Individual MEMS devices</td>
<td>2005</td>
</tr>
<tr>
<td></td>
<td>MEMS devices being developed by utilizing micromachining and semiconductor process</td>
<td>2020</td>
</tr>
<tr>
<td></td>
<td>2025</td>
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</table>

2nd Generation: Multifunction devices
- Miniaturization
- High performance
- High reliability

3rd Generation: Hetero Functional Integrated Devices For the Creation of New Lifestyles
- Areas of Applications
  - Environmental
  - Energy Conservation
  - HealthCare
  - Safety/Security
- Focused Process
  - Nano/Bio Integration
  - Large Area
  - Continuous Process
  - 3 Dimensional Nano Structure

US$ 22.0B (2015)
US$ 10.0B (2010)
US$ 4.0B (2005)

FineMEMS
- Highly Integrated and Complex MEMS
- Integrated MEMS
  - Multi-Functional System-on-Chip
  - System-in Package (SIP) MEMS
- Combination with Nano Function

Fujita, Int. Symp. Micromachine/Nanotech ’07
New Lifestyles being Enabled by BEANS

Target of BEANS Project

<table>
<thead>
<tr>
<th>Devices</th>
<th>Environment/Energy</th>
<th>Health care</th>
<th>Safety/Security</th>
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<tbody>
<tr>
<td>Process</td>
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<tr>
<td>Bio-Org</td>
<td>Bio-Org</td>
<td>Health care</td>
<td>Safety/Security</td>
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<tr>
<td>n-Inorg</td>
<td>n-Convergence</td>
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<tr>
<td>3D Nano</td>
<td>3D Nano</td>
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<tr>
<td>Struct</td>
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<tr>
<td>Area/</td>
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<td>DB</td>
<td>Knowledge DB</td>
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Categories & Subjects of BEANS

① Bio/Organic Materials Integration Process
- Nano-scale Interfaces Treatment
- Bio/Organic Integrated Higher-Order Structure Formation

② Novel fabrication technology for 3-D Nano-structures
- Top-down fabrication of monolayer-flat, defect-free 3D structure
- Bottom-up technology for heterogeneous integration of materials and functions on 3-D platform
- 3-D nano-fabrication for aerospace applications

③ Large Area Continuous Process of Micro/Nano Structure
- Non-vacuum large-area deposition techniques of high-quality nano/micro materials
- Continuous nano/micro-machining and integration Process for fiber substrates

④ Building up of Knowledge Database
  in Heterogeneous Technology Convergence Process Development

BEANS Research Initiative

Life BEANS Center
Bio Integration Process
The University of Tokyo

BEANS Laboratory
Project Management Knowledge DB

Life BEANS Center
Kyushu
Organic Materials Integration Process
Kyushu University

3D BEANS Center
Novel fabrication Technology for 3D Nano-structures
Ritsumeikan University

Macro BEANS Center
Large Area Continuous Process of Micro/Nano Structures
AIST

3D BEANS Center Shiga
3D Nano-structures for Aero-Space Applications
Ritsumeikan University

Project Leader: Atsushi YUSA
-A Bio Materials Integration Process: Life BEANS Center

Market, Social Needs, Technology Requirements

Health, Medicine ⇒ Implantable Device, Highly Sensitive Chemical Sensors
Environment ⇒ Energy Harvesting Device
Harnessing Bio and Organic materials for MEMS

Research Overview

- Implantable glucose sensors
- Single molecular Level, Ultra highly sensitive chemical sensors
- Sensors for drug kinetics with minimal load of animal experiments

-B Organic Materials Integration Process: Life BEANS Center Kyushu
Nano-Process Technology Enables Innovative Organic Devices

Process development for Organic Nano-structures

Low-cost, large area and high optoelectronic performance Control of 100nm nano structures

High performance organic Display devices

Organic Solar Cells

Photonics Devices

Present

E-beam, nano-print

Future

Top-down Fabrication

Block copolymers

Nano-dot formation

Molecular orientation

Past

Amazing film forming capability
Novel fabrication technology for 3-D nano-structures: 3D BEANS Center

**Needs**
Sensor network for safe, secured and healthy life  
High-sensitivity sensing, energy harvesting, high-density recording

**Seeds**
A monolayer-flat, defect-free 3D structure (Si, SiO$_2$ etc...)

Surface functionalization by foreign materials and nano-structures

Alignment of nanoparticles on trenches

Supercritical-fluid conformal deposition

Multi-scale & uniform nano-fabrication

Nanopores

μm topology

**Research items**

1. **Top-down fabrication of monolayer-flat, defect-free 3D structure**
   - Neutral beam etching
   - Nano-domain modification by fs-laser

2. **Bottom-up technology for heterogeneous integration of materials and functions on 3-D platform**
   - Supercritical-fluid deposition and coating
   - Assembly of nanoparticles, nanodots and nanotubes on 3-D platforms

3. **3-D nano-fabrication for aerospace applications**
   - Nanostructure imprint on a 3-D microstructure
   - Filters for multi-band selection

**Applications**

Super-capacitors, Ultra-high-sensitivity sensors, Tbit/cm$^2$ recording, nm-resolution high-throughput lithography, Multiband-spectroscopy from space

Large Area Continuous Process of Micro/Nano Structure: Macro BEANS Center

**Needs**

**Seeds**

**Research items**

1. **Large-area energy harvesting devices**
2. **Large-area communication devices**
3. **Large-area display devices**
4. **Sheet-type health-care (monitoring) devices**

**Applications**

To develop new fabrication process which deposits high quality nano/micro materials on meter-size substrate without vacuum process equipment

Non-vacuum large-area deposition techniques of high quality nano/micro materials

Flexible sheet-type devices

To develop new fabrication process that realizes flexible sheet-type large-area devices utilizing micromachining and weaving integration of fiber substrates instead of micromachining of large substrates

Continuous nano/micro-machining and integration process for fiber substrates

Sheet-type health-care (monitoring) devices

Flexible touch sensor

Wearable energy harvesting devices

Smart jackets for safety and security
Outcome of 2008

<table>
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<tr>
<th>Item</th>
<th>Life BEANS Center</th>
<th>Life BEANS Center Kyushu</th>
<th>3D BEANS Center</th>
<th>3D BEANS Center Shiga</th>
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BEANS Laboratory

Established March 24, 2009
Mission
- Executing BEANS Project (Hetero-functional Integrated device Technology Development Project)
- Sending researchers who are assigned from the member companies of BEANS Laboratory to BEANS Centers, and collaborating with researchers of universities and National Institutes

Chairperson: Hisao SAKUTA
Executive Director: Keiichi AOYAGI
Director: Atsushi YUSA (Project Leader)
Members: 20 Organizations (Companies and Institutions) as of July, 2009
- DENSO Corp.
- FUJIKURA Ltd.
- FUJI Electric Systems Co., Ltd.
- FURUKAWA Electric Co., Ltd.
- LINTEC Corp.
- MITSUBISHI Chemical Medience Corp.
- Mathematical Systems, Inc.
- MITSUBISHI Electric Corp.
- MIZUHO Information & Research Institute, Inc.
- OLYMPUS Corp.
- OLYMPUS Information & Research Institute, Inc.
- PANASONIC Electric Works, Ltd.
- SEIKO Instruments Inc.
- TERUMO Corp.
- TOSHIBA Corp.
- TOSHIBA Machine Corp.
- Institute for Unmanned Space Experiment Free Flyer
- Institute of System, Information Technologies and Nanotechnologies
- Japan Resources Observation System & Space Utilization Organization
- Micromachine Center

Number of researchers: 81 (Including affiliates)

BEANS Center Life BEANS Center, 3D BEANS Center: Institute of Industrial Science, The University of Tokyo
Life BEANS Center Kyushu: Center for Future Chemistry, Kyushu University
3D BEANS Center Shiga: Ritsumeikan University
Macro BEANS Center: Advanced Industrial Science and Technology

July, 2009