

electronica 2022

Tohoku Univ. Micro System Integration Center

Leaflet set

Welcome to our exhibition booth.

We introduce research activities of our center and related research laboratories. Please contact to “micro-shien@grp.tohoku.ac.jp”, if you are interested.

We are happy to hear your voice.

No1_ Temperature-fluctuation-harvested Thermoelectric module

No3_ Ultrasensitive resonant acoustic sensors

No4_ Integrated thermoelectric elements

No5_ Ingestible Thermometer

No6_ Micro differential pressure gauge

No7_ Force sensor

No8_ Multi-sensor Platform LSI

No9_ Acupoint Stimulation device using focused ultrasound

No10_ Intravascular Forward-Looking Ultrasound Probe Using Piezoelectric Single Crystal PMN-PT

No11_ Ultra-miniature fiber-optic pressure sensor using white light interferometry

No12_ Measurement of Subcutaneous Biological Substances Using Microperfusion Needle"

No13_ Photofabrication and mounting process on cylindrical structure

No14_ Gyroscope system

No15_ HAL Surface Acoustic Wave device wafer

No16_ Tactile sensor

No17_ SMS(silicon migration seal)

No18_ Magnetic MEMS Actuator for OIS

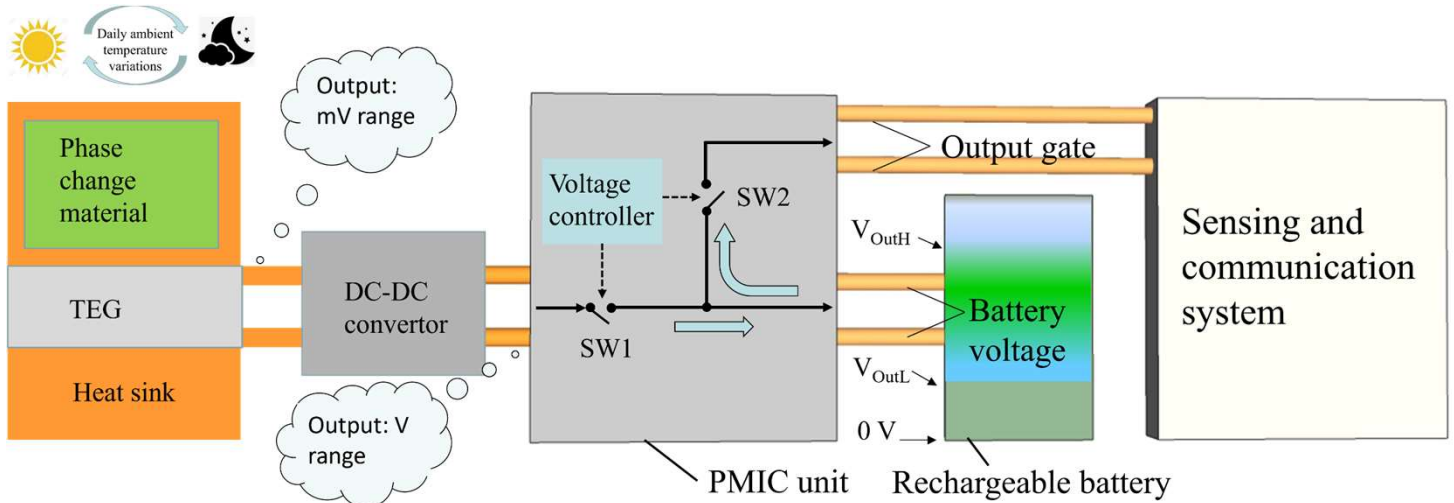
No19_ Low Cost, Scalable Force Sensor by Magnetic Composite Foam

No20_ Tatile Sensor Network System

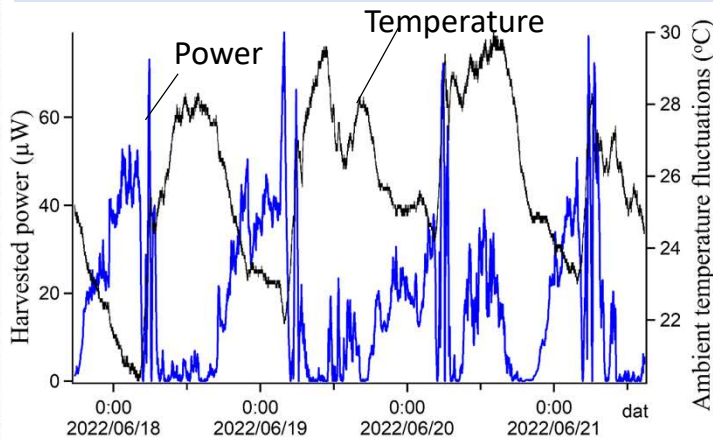
No21_ Piezo-true-MEMS speaker

Leaflet of Tohoku University, Department of Robotics S. Tanaka Laboratory.

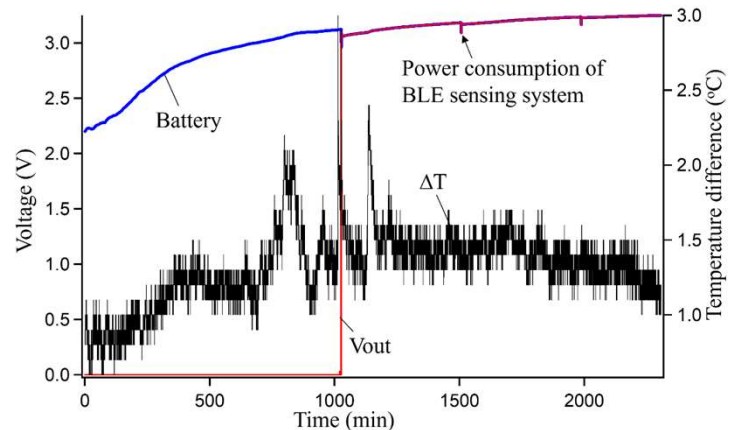
Temperature-Fluctuation-Harvested Thermoelectric Module



Daily ambient temperature fluctuation energy harvesting at anytime and anywhere



Daily ambient temperature has been successfully converted into electricity. The maximum output power reaches 70 μW and the average power is approximately 20 μW .



The output gate of self-powered module has been connected successfully to BLE sensing system which can work continually under time interval of 2 hours.



Dimension: 55 x 55 x 47 mm

Self-powered module

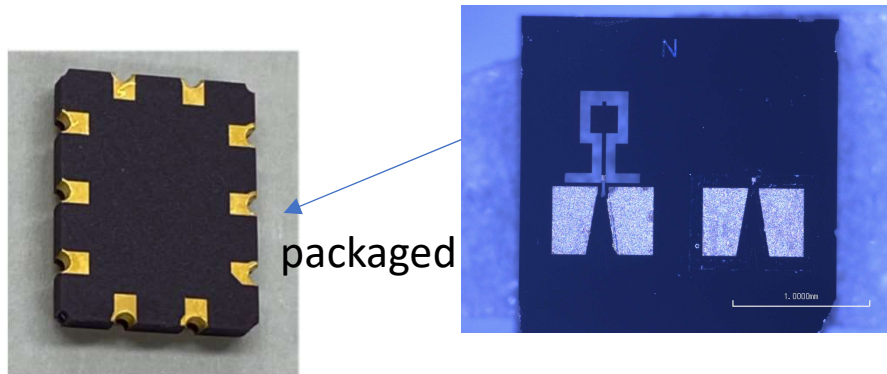
Published:

- . *Energy reports*, **6**, 2022-2029, 2020.
- . *International journal of energy research*, **45**, 15557-15568, 2021.
- . *Applied Energy*, **311**, 118679, 2022.

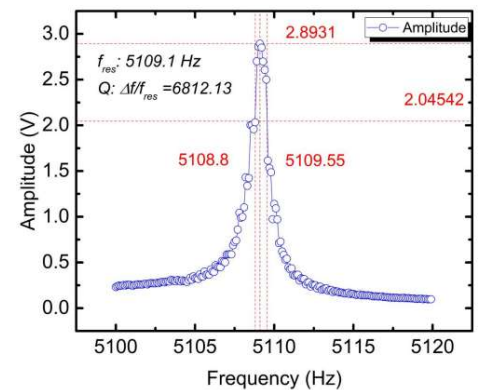
Contact information:

Tohoku University, Micro System Integration Center
Takahito Ono, takahito.ono.d4@tohoku.ac.jp

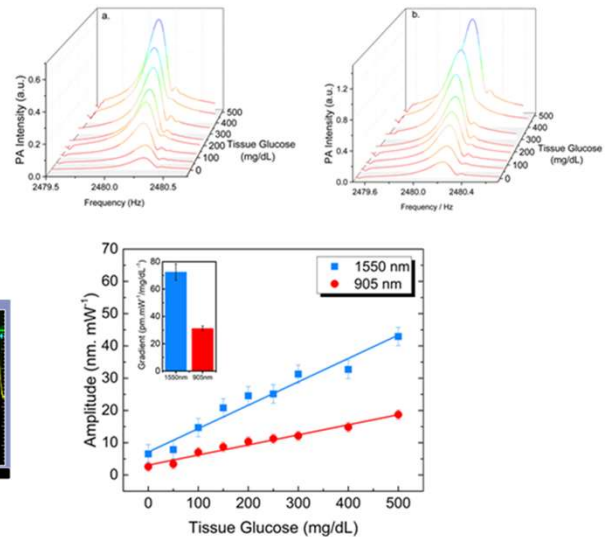
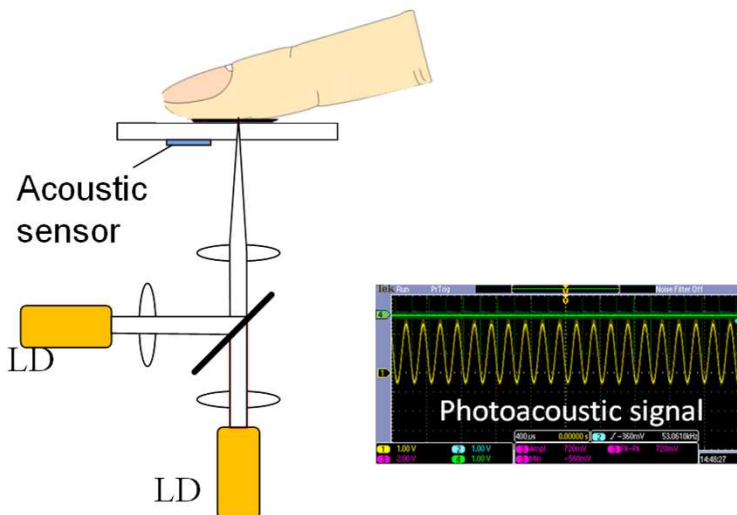
Ultra-sensitive acoustic sensors



packaged



Vacuum-packaged acoustic sensors with piezoresistive readout
Mechanical resonant performance of the typical sensors. Q-factor is 6800.



The sensor is applied to detect the glucose concentration in human body. The photoacoustic signal is detected by the acoustic sensors. Test measurement on a phantom shows linear relationship with glucose concentration.

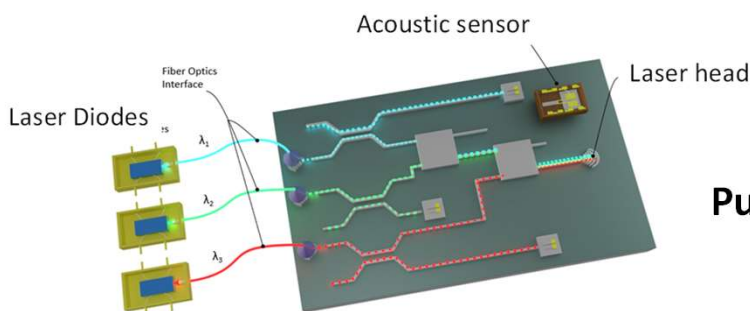


Photo-acoustic inspection device
with the acoustic sensors

There are various applications to
non-destructive inspection

Published:
Photoacoustics, 18 (2020) 100189.

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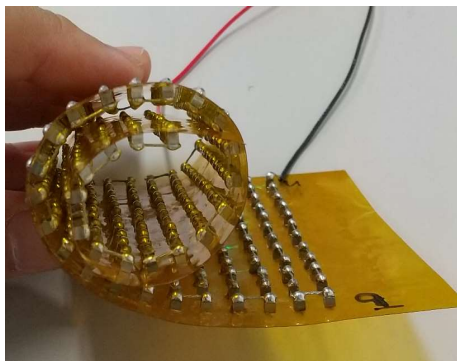
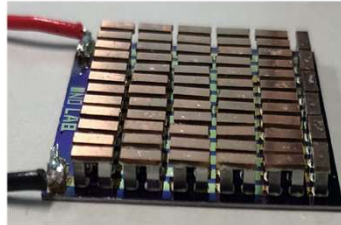
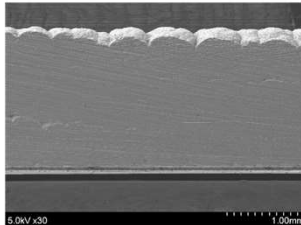
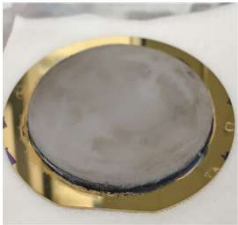
Integrated thermoelectric power generator (TEG)

Material synthesis

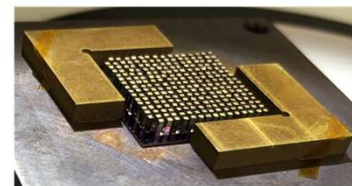
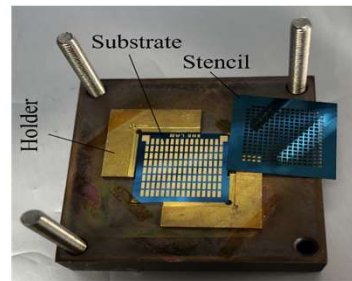
Material evaluation

Device fabrication

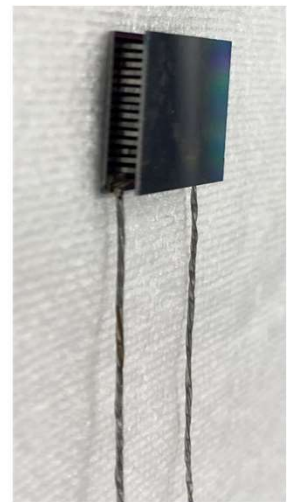
Thermoelectric generators (TEG) are fabricated by the electrodeposited thermoelectric material.



Flexible TEG based polyimide substrate



TEG based assembling technology



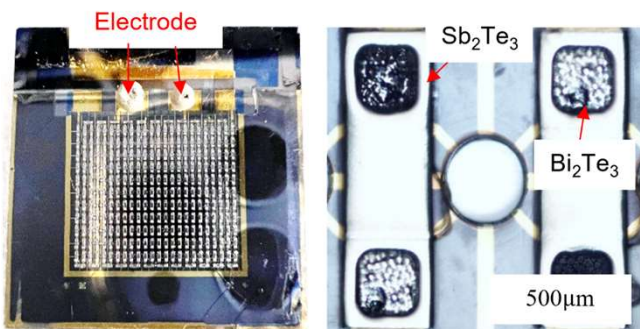
Flexible TEG based rubber substrate

Published:

- . *Energy conversion and management*, **245**, 114571, 2021.
- . *Energy reports*, **8**, 5026-5037, 2022.
- . *Journal of Power Sources*, **536**, 231504, 2022.
- . *IEEE-MEMS 2022*, pp.600-603, 2022.

Contact information:

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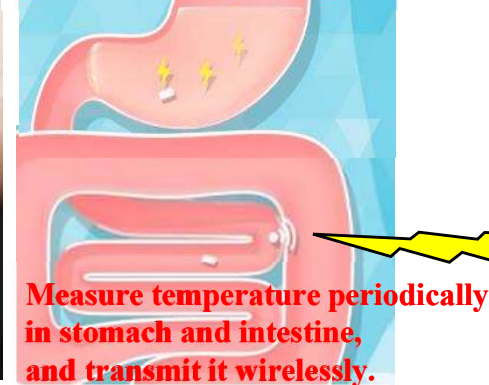


TEG based micro fabrication technology

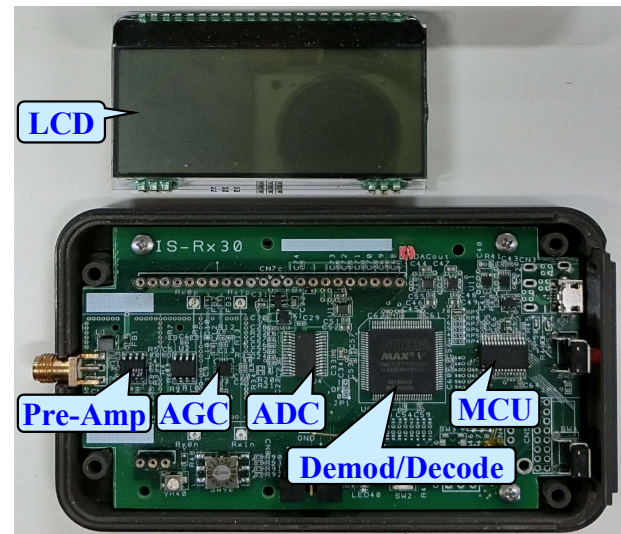
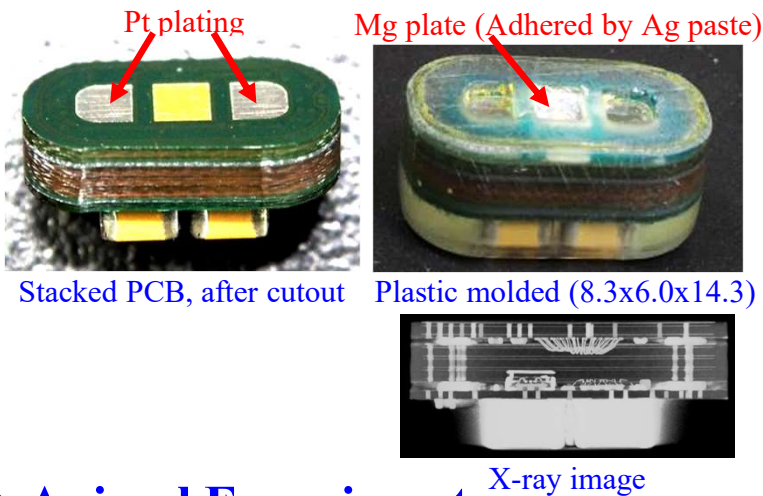
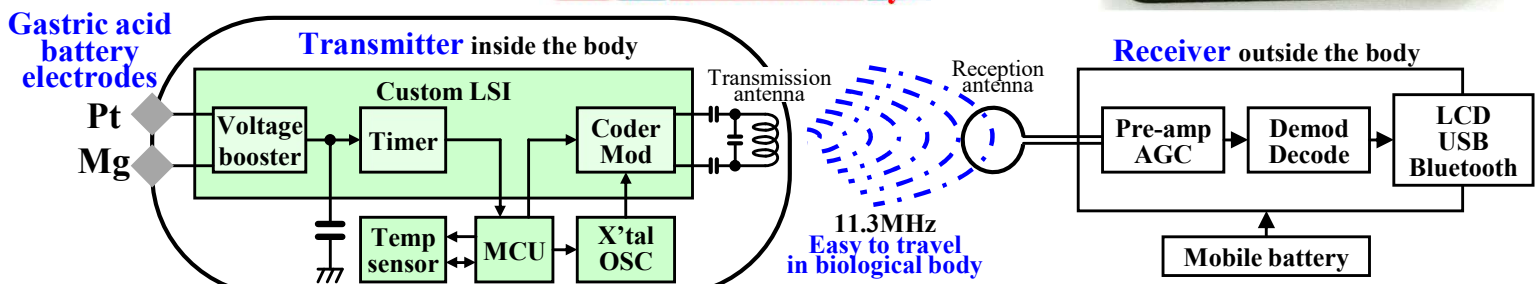
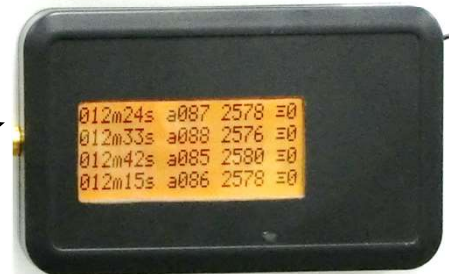
Ingestible Thermometer



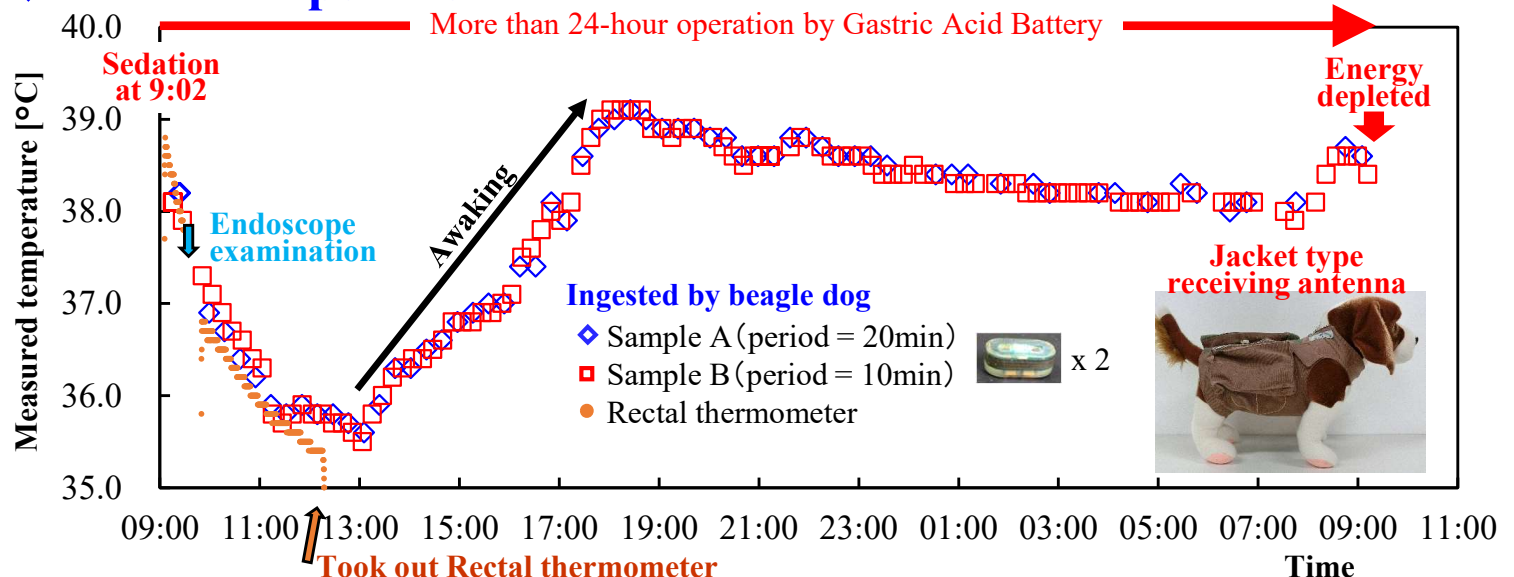
Charge energy into capacitors
by Gastric acid power generation.



Outside the body
Battery operated
Display last four reception
Memorize all reception



Animal Experiment



Please contact to Tohoku University, Micro System Integration Center
Hiroshi Miyaguchi, Hiroshi.miyaguchi.e8@tohoku.ac.jp



The future of Ingestible Thermometer

Now

Existing Thermometers



- ◆ Not precise
- ◆ Burdensome
- ◆ Varied by contact condition
- ◆ Only when measured
- ◆ Difficult to live during measurement

Future

Ingestible Thermometer



- ◆ Precise
- ◆ Burden free
- ◆ Periodical measurement
- ◆ Free to sleep, exercise, etc

➤ Applications

Heat Attack Protection



Maximize Performance



Safety Sports for disabilities



Fertility Treatment



Disordered sleep Treatment



Disease Protection



Depression Treatment



➤ Patents: Four Japanese registered patents, pending at US/EP

QDP33



Incredible “MANOSTAR”

HIGH QUALITY
COMPACT BODY
CLEAR DISPLAY
30mm × 30mm

Equipping the capacitive sensor of in-house development

- ▶ Highly sensitive and precise
- ▶ Correspondence to various micro differential pressure ranges

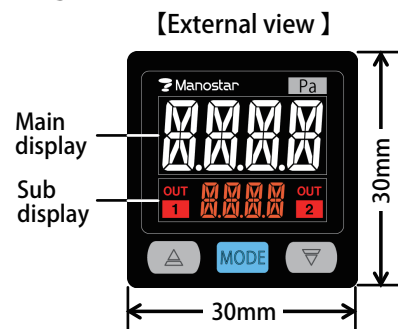
One of the smallest micro differential pressure sensors

- ▶ The body size: 30mm width and 30mm height
- ▶ Capability of close adherence installation

Sophisticated design and visibility

- ▶ High-quality white LCD (main display)
- ▶ Alphanumeric indication in 12 segments

【Installation example】



SPECIFICATIONS

Product code

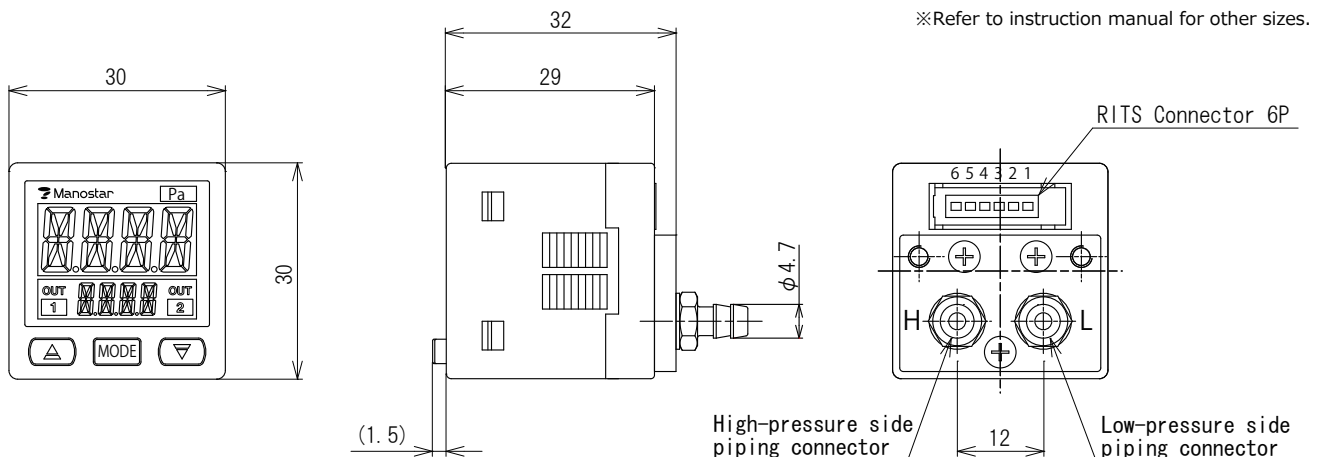
QDP33	N	1	D	200	(example)
					Pressure range code
					Pressure range
					Max. value of scale (Indicate "±" for ± range)
					Unit
					D Pa
					E kPa
					Analog output
					1 4 to 20 mA
					4 1 to 5 V
					Comparison output
					N NPN transistor
					P PNP transistor

Pressure range code	Rated pressure range	LCD display
D 50	0 ~ 50 Pa	0.0 ~ 50.0
D 100	0 ~ 100 Pa	0.0 ~ 100.0
D 200	0 ~ 200 Pa	0 ~ 200
D 300	0 ~ 300 Pa	0 ~ 300
D 500	0 ~ 500 Pa	0 ~ 500
D 1000	0 ~ 1000 Pa	0 ~ 1000
E 1	0 ~ 1 kPa	0.00 ~ 1.00
E 2	0 ~ 2 kPa	0.00 ~ 2.00
D +-50	-50 ~ +50 Pa	-50.0 ~ 50.0
D +-100	-100 ~ +100 Pa	-100 ~ 100
D +-200	-200 ~ +200 Pa	-200 ~ 200
D +-300	-300 ~ +300 Pa	-300 ~ 300
D +-500	-500 ~ +500 Pa	-500 ~ 500
D +-1000	-1000 ~ +1000 Pa	-1000 ~ 1000
E +-1	-1 ~ +1 kPa	-1.00 ~ 1.00
E +-2	-2 ~ +2 kPa	-2.00 ~ 2.00
* D 10	0 ~ 10 Pa	0.00 ~ 10.00
* D 25	0 ~ 25 Pa	0.00 ~ 25.00
* D +-10	-10 ~ +10 Pa	-10.00 ~ 10.00
* D +-25	-25 ~ +25 Pa	-25.0 ~ 25.0

* Expected to release in 2020.

Pressure measuring method	Measuring differential pressure
Gas to be measured	Air or non-corrosive gas (not liquid)
Sensor method	Electrostatic capacitance type
Installation position	On vertical wall only
Medium and ambient temperature	0 to 60 °C (no freezing)
Ambient humidity	35 to 85 % RH (no dewing)
Withstanding pressure of instrument body	10kPa
Withstanding pressure of receiving element	10kPa
Display	Main display 12 segments LCD (White or Red) 4 digits Sub display 12 segments LCD (Orange) 4 digits Accuracy ± 1.0 % FS ± 1 digit (at 23 °C) Temperature characteristic ± 0.15 % FS/°C (zero + span)
Insulation resistance	Between each terminal and case : 10 MΩ or more (500 V DC megger)
Comparison output	Setting method Push type of digital setting Output display Red LCD×2 Output type NPN transistor open collector : Two channels PNP transistor open collector : Two channels
Analog output	Accuracy ± 1.0 % FS (at 23 °C) Temperature characteristic ± 0.15 % FS/°C (zero + span)
Pressure inlet	M5 internal thread Product with metal barb connector Applicable piping : I.D.4
Mass	30g approx.
Connector	RITS Connector 6P (TE Connectivity)
Power supply voltage	12 to 24 V DC ± 10 % (with a ripple 10 % or less)
Connector polarity	Pressure side mark indicated on the pressure inlet that high side is H and low side is L.
Protection degree	Standard IEC60529 IP-code IP 40
Zero adjustment	Push type auto zero (both display scale and analog output adjust zero point at the same time)
Material of the outer case	PBT and polyamide
Conformed standards	RoHS Directive, UL Standards
Accessories	Nil (wiring side connector and attaching parts are sold separately)

OUTLINE



- The specifications and description of the product explained in this leaflet may be subject to change without prior notice because of modification and the like.
- The contents are as of September 2019.

Contact Us

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078-621-7000

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Our website.

<http://www.manostar.co.jp/>

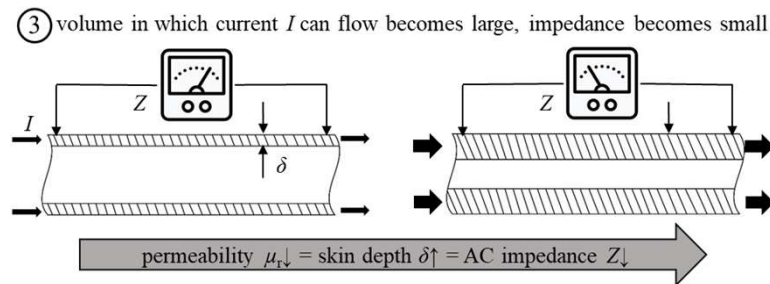
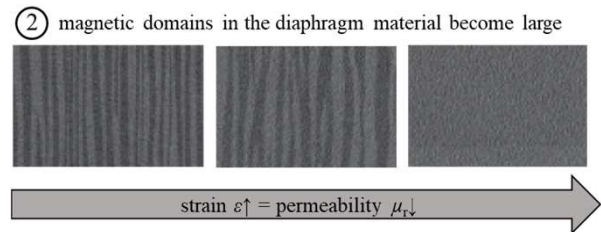
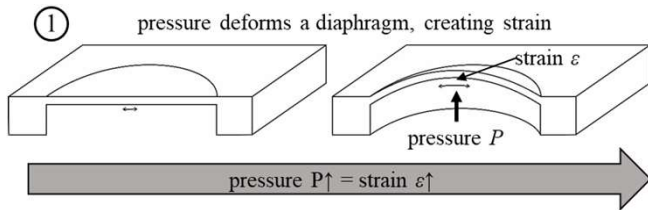
Sole Agent **Manostar CO.,LTD.**

1-2-3, Nishi-shiraike-cho, Nagata-ku, Kobe, Hyogo 653-0031 JAPAN
TEL. +81(78)-621-7000 FAX. +81(78)-621-7788

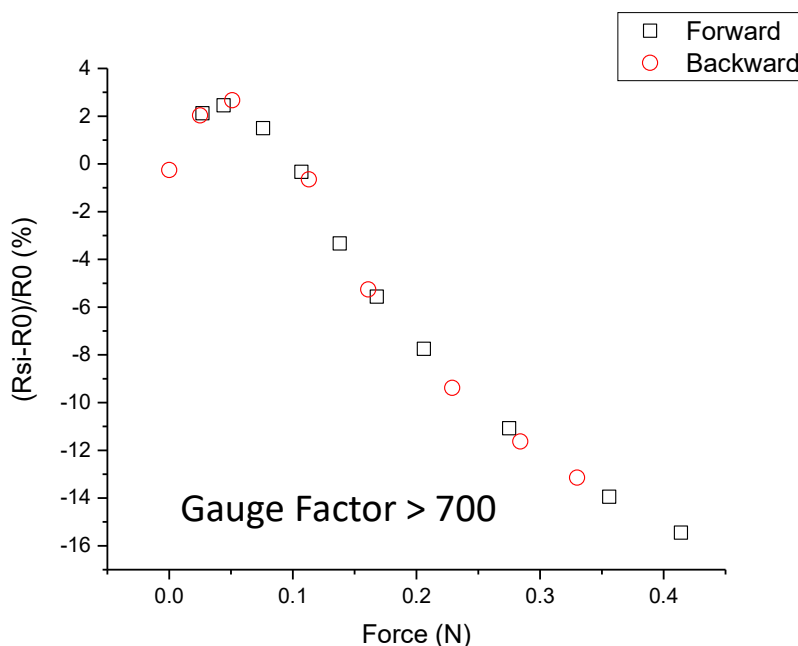
Manufacture **Yamamoto Electric Works Co., Ltd.**

1-2-3, Nishi-shiraike-cho, Nagata-ku, Kobe, Hyogo 653-0031 JAPAN
TEL. +81(78)-631-6000 FAX. +81(78)-631-6020

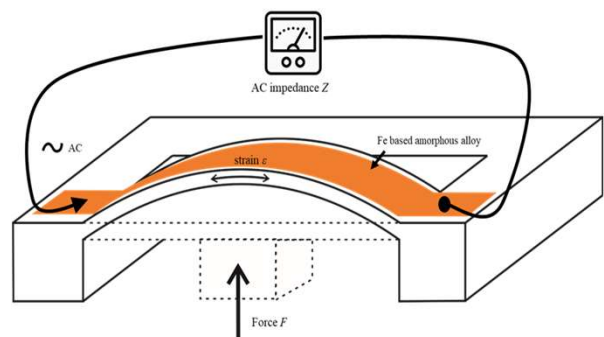
High Gauge Factor Force/Pressure Sensor by using Stress-Impedance Effect



When a tensile stress acts on soft magnetic material, the magnetic permeability (μ_r) increases, and when a compressive stress acts, the magnetic permeability decreases. Further, the depth at which a current flows is affected by the magnetic permeability due to the skin effect, so that the resistance value changes due to the action of stress.



The impedance of a soft magnetic thin film changes when it is under strain → strain gauge for various sensors: force, pressure ...



Contact:

Assoc. Prof. Joerg Froemel

joerg.froemel.e5@tohoku.ac.jp

Froemel, J.; Diguët, G.; Muroyama, M., Micromechanical Force Sensor Using the Stress-Impedance Effect of Soft Magnetic FeCuNbSiB. Sensors, 2021, 21(22), 7578

Multi-sensor Platform LSI

Our original Multi-sensor Platform LSI have 3 basic functions as a platform:

1. Multi-kind and multi-channel sensing

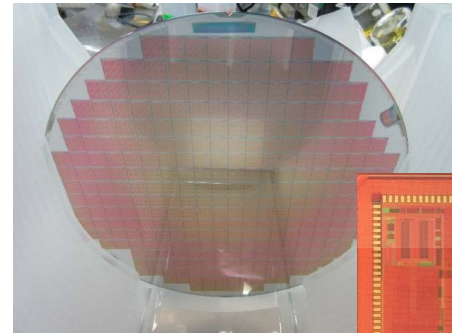
- Cap. and analog voltage output sensor
- Temperature sensor
- 8-multi channel for cap. and analog sensor readout

2. High-efficiency communication

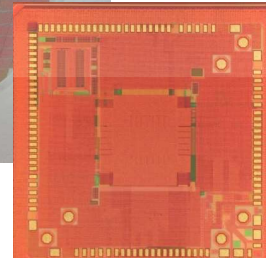
- Max. 256 LSIs / bus
 - Verified 100 LSIs / bus
- Event-driven response
- Differential communication
- Original ASYNC. comm.

3. Integration friendly structures

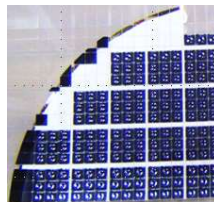
- Bonding area
- Sensor shield
- TSV access pad



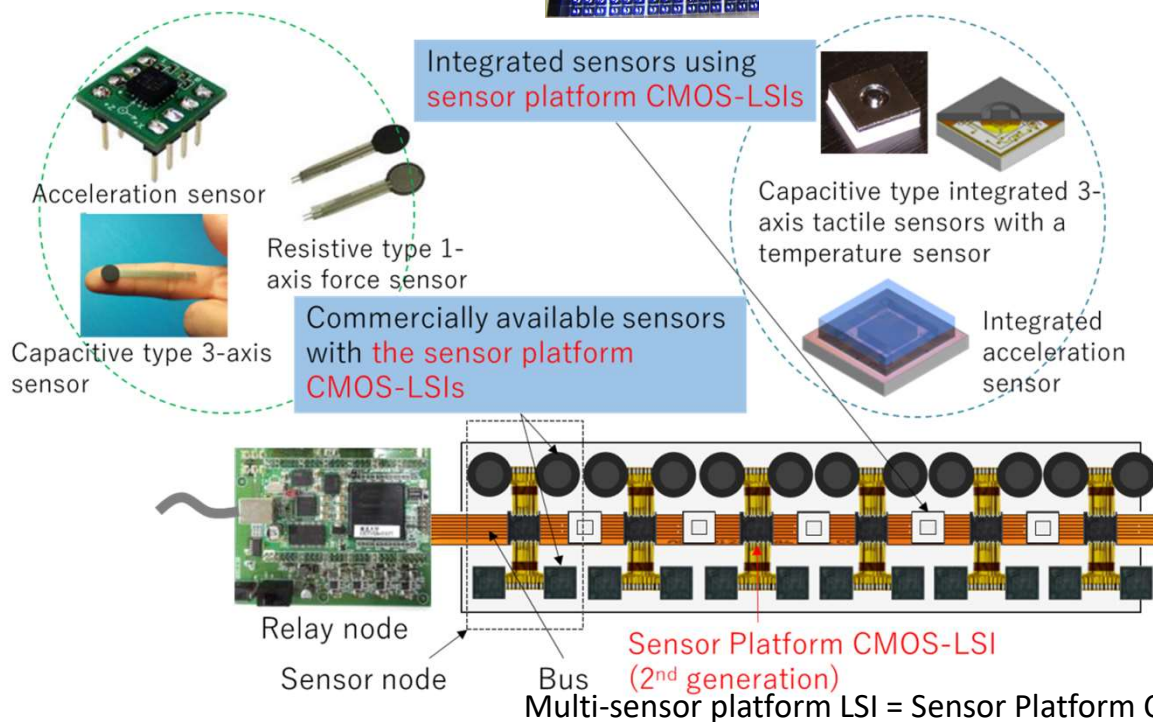
TSMC0.13μm CMOS
8-inch wafer fabrication
2.5mm X 2.5mm size



ASSP(Application Specific Standard Product)



We have wafer-level LSI-MEMS integration and packaging technologies for such as integrated tactile sensor devices



We have some demonstration systems and tools for the multi-sensor platform LSIs

- Tactile sensor module H/W and S/W
- API (Application Programming Interface) for preparing easy and good software

C. Shao, H. Hirano, H. Miyaguchi, M. Nomoto, M. Muroyama and S. Tanaka, "Event-Driven Tactile Sensing System Including 100 CMOS-MEMS Integrated 3-Axis Force Sensors Based on Asynchronous Serial Bus Communication," in *IEEE Sensors Journal*, vol. 20, no. 17, pp. 10159-10169, 1 Sept.1, 2020, doi: 10.1109/JSEN.2020.2991259.

Contact: Visiting Associate Prof. Masanori Muroyama, muroyama@tohoku.ac.jp

Acupoint stimulation device using focused ultrasound

Acupuncture is used widely in oriental medicine. However it is difficult to stimulate continuously or intermittently in daily life with conventional acupuncture. Thus, an acupoint stimulation device using focused ultrasound has been developed (Fig. 1, 2). Because the device size is about 6 mm in diameter, it can be easily put on the skin during daily life. Appropriate stimulation intensity and pattern can be chosen by changing driving voltage and pattern. We stimulated acupoints placed on top of foots with this device and measured the blood flow volume of brachial artery (Fig. 3). As a result, the blood flow volume increased significantly as well as acupuncture (Fig. 4). Because the device stimulate acupoints with intactness of skin, advantages of this device is free from infection, fear and pain by insertion of acupuncture needles.

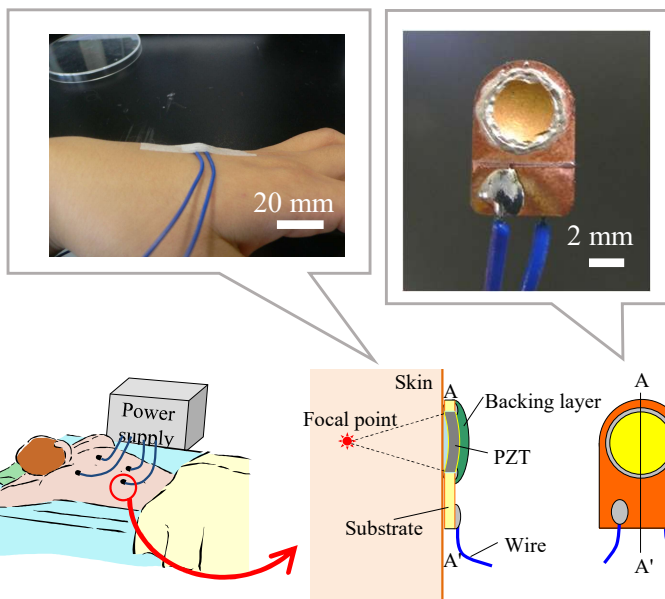
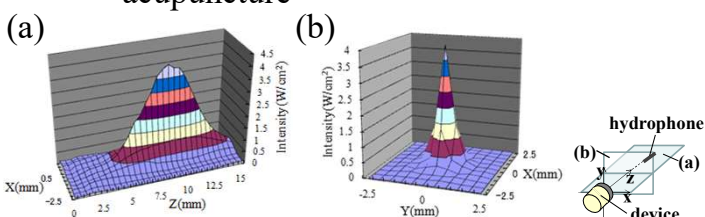


Fig. 1 Schematic view of focused ultrasound acupuncture



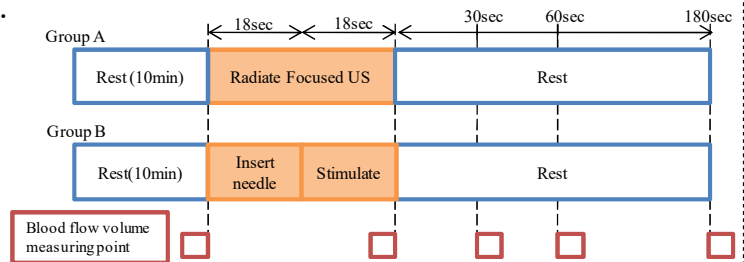
(a) X-Z Plane (Y=0mm), (b) X-Y Plane (Z=9 mm)
Fig. 2 Acoustic field of Fabricated device.

<Reference>

N. Tsuruoka *et al.*, "Brief Effect of Acupoint Stimulation Using Focused Ultrasound," The Journal of Alternative and Complementary Medicine, Mary Ann Liebert, Inc., Vol. 19, No. 5, 2013, pp.416-419.

Contact information:

Noriko Tsuruoka
noriko.tsuruoka@tohoku.ac.jp

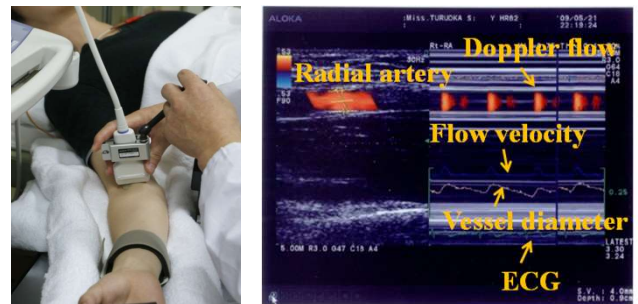


(a) Protocol of the experiment

Group A	Stimulated by focused ultrasound Focal point: 5 mm depth from the skin surface Ultrasound intensity: 1.24 W/cm ² (sine wave)
Group B	Stimulated by conventional acupuncture Stimulation: Rotating the needles manually Needle diameter: 0.16 mm



(b) Stimulation procedure



(c) Ultrasound measurement of brachial artery
Fig. 3 Protocol and experimental setup.

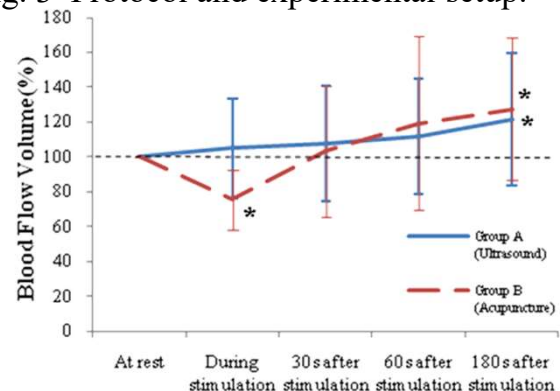


Fig. 4 Percent change of the blood flow volume of brachial artery. *p<0.05.

Intravascular forward-looking ultrasound probe using piezoelectric single crystal PMN-PT

In catheter treatment for vascular lesions such as atherosclerosis, imaging of the lesion will enable treatment secure (Fig.1). Ultrasound measurement is more appropriate than optical measurement because diffuse reflection of light by the blood cells will occur in the intravascular. We develop a forward-looking ultrasound imager able to 3-dimensional imaging of intravascular (Fig.2). We aim for diameter reduction (outer diameter 2.5mm), higher frequency (20MHz), and multi-element (24 elements) of the probe. We use a piezoelectric single crystal (PMN-PT). The device has a structure equipped with a backing material to the short pulse and to reduce vibration in the rear direction (Fig.3). We are using sandblasting, which can be processed into an arbitrary shape PMN-PT (Fig.4).

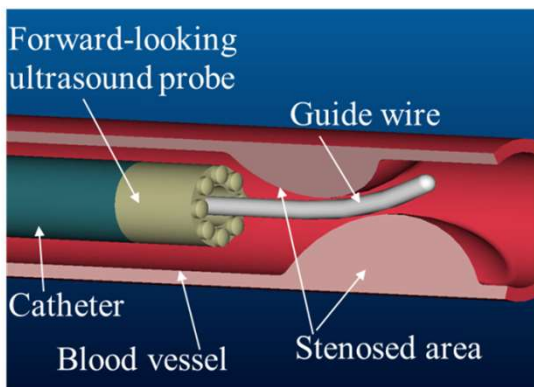


Fig.1 Forward-looking ultrasound probe

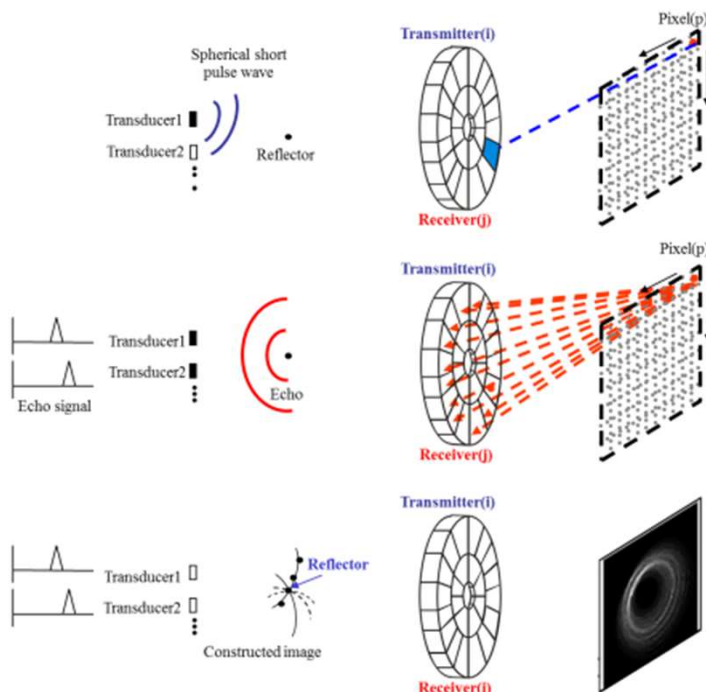


Fig.2 Principle of imaging

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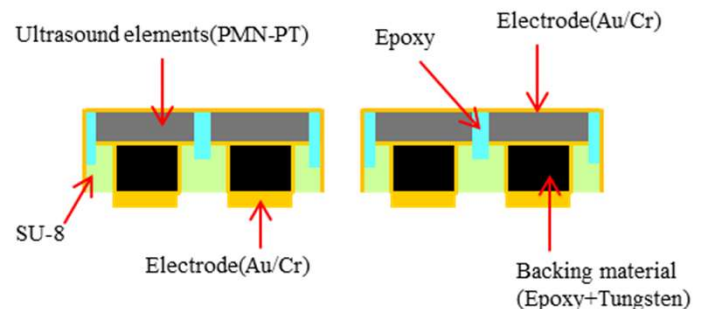


Fig.3 Sectional view of the ultrasound element

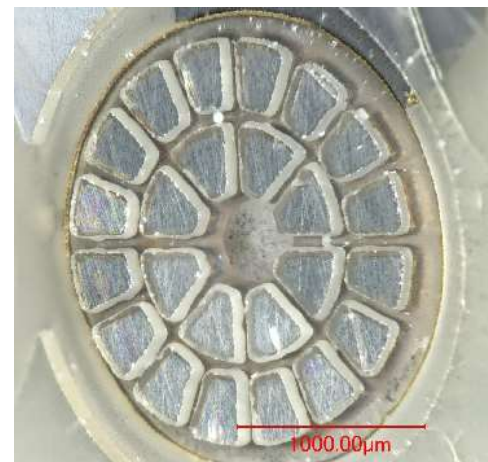


Fig.4 Sandblasting of PMN-PT

<Reference>

J.-J.Chen, R.Kashu, M.Esashi, Y. Haga,
“Forward-looking Intravascular Ultrasound
Probe Using PMN-PT Single Crystal,” The 4th
Asia Pacific Conf. on Transducers and
Micro/Nano Technologies (APCOT 2008), 2008,
pp. 21-24.

Ultra-miniature fiber-optic pressure sensor using white light interferometry

Blood pressure is one of the most important information indicating the condition of the human body among biological information, and abnormalities of heart and vascular system will be reflected sensitively. We have developed an ultra-miniature fiber-optic pressure sensor of 125 μm in diameter by micromachining technology and optical technology. We aim to measure the local blood pressure in intravascular stenosis, microvasculature, children and small animals in catheter treatment (Fig 1). The sensing element, which is composed of a thin diaphragm, is fabricated by micromachining technology on the fiber end, and the diaphragm deformation caused by pressure can be detected by using white light interferometry (Fig2,3). This sensor has various advantages, for example, it can be used in such electromagnetically harsh environments, and it can be produced at a relatively low cost because a lot of sensor chips can be batch fabricated by semiconductor microfabrication technology. The blood pressure of a goat was able to measure by using this sensor (Fig.4).

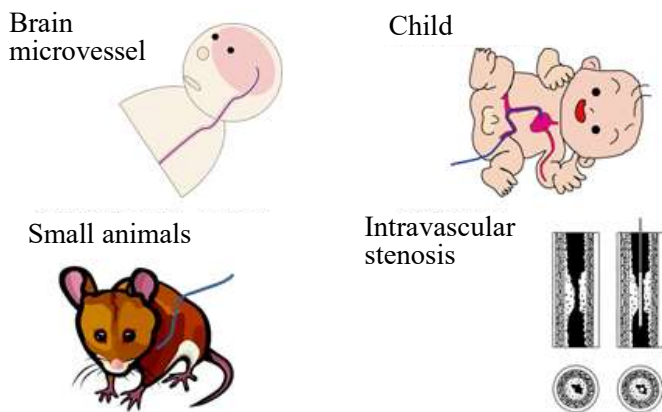


Fig.1 Applications of fiber-optic blood pressure sensor

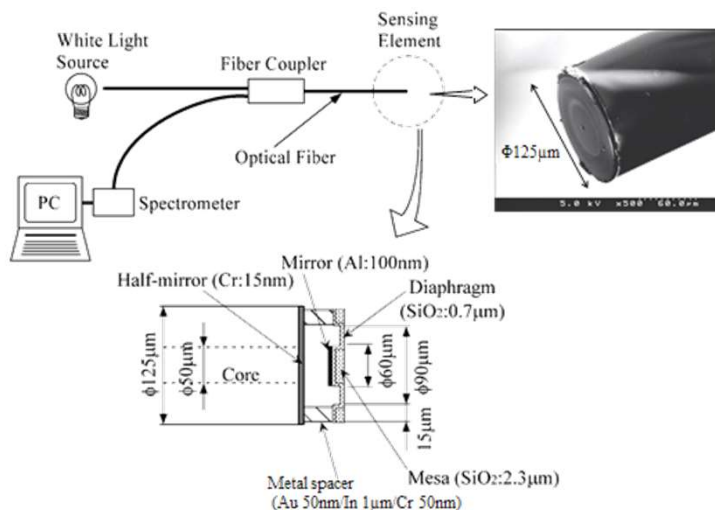


Fig.2 Schematic of sensor system

Contact information:
Yoichi Haga
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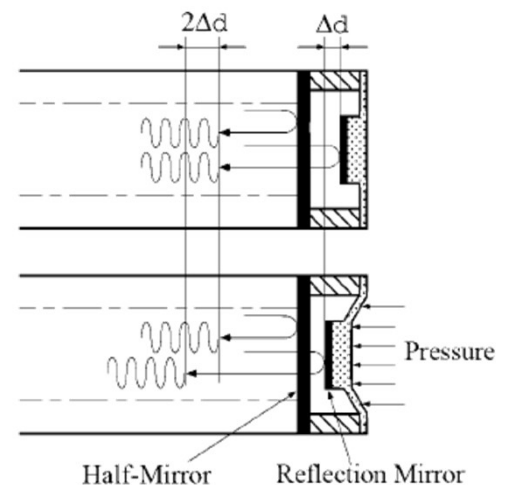


Fig.3 Detection principle of pressure

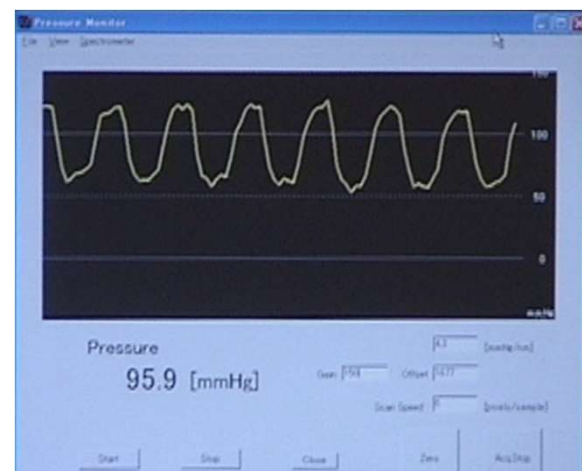


Fig.4 Continuous display of blood pressure

<Reference>

K.Totsu, Y.Haga and M.Esashi, "Ultra-miniature fiber-optic pressure sensor using white light interferometry," *Journal of Micromechanics and Microengineering*, Vol.15, No.1 (2005), pp.71-75

Measurement of subcutaneous biological substances using microperfusion needle

Health management is easy if we can monitor biological substances such as lactate, blood sugar, and stress substances in daily life. We aim to develop a sensor that is minimally invasive, wearable, and does not disturb users in everyday life by MEMS. In this study, biological substances are extracted through a microperfusion system, inserting microneedle under the skin (Fig.1). This device can monitor biological substances continuously because it has a sensor unit outside the body. The perfusion needle is 0.2 mm in diameter and fabricated a flow channel with perforated membrane by non-planar microfabrication technology (Fig.2). It was confirmed that biological substances (lactate, glucose) was collected from under the skin by microperfusion experiments in the back skin of the mice (Fig.3, 4).

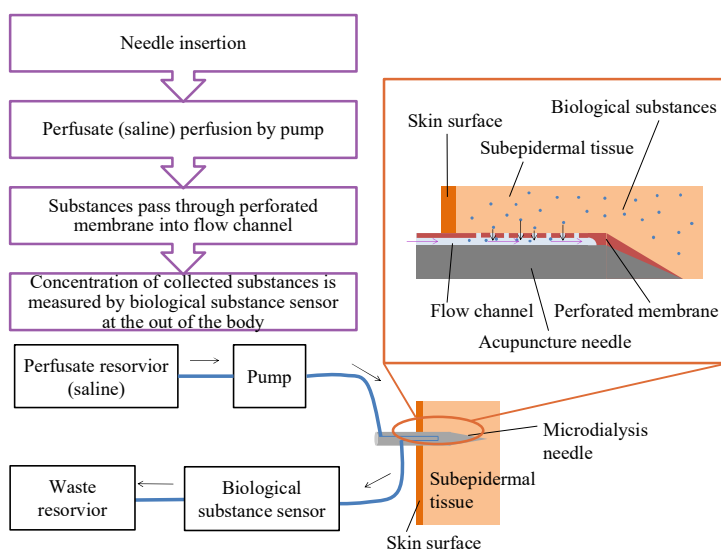
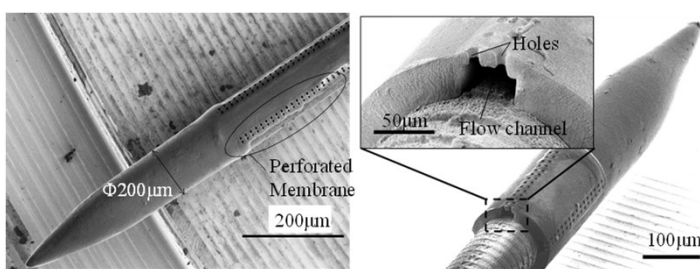


Fig.1 System of measurement of subcutaneous biological substances.



(a) Side view

(b) Cross-section view

Fig.2 Photograph of fabricated microperfusion needle.

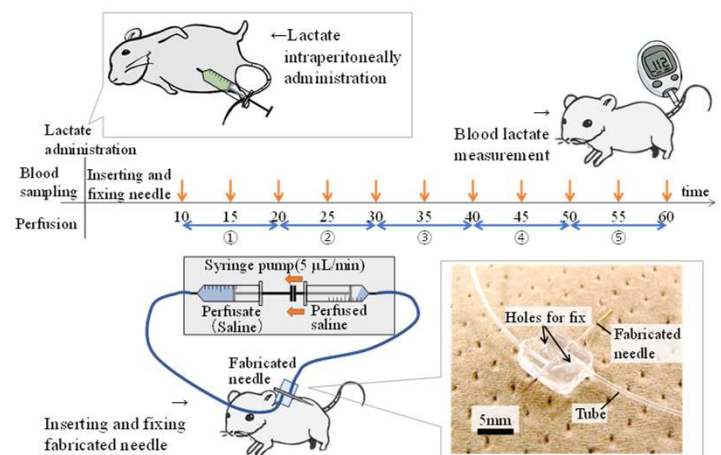


Fig.3 Experimental setup.

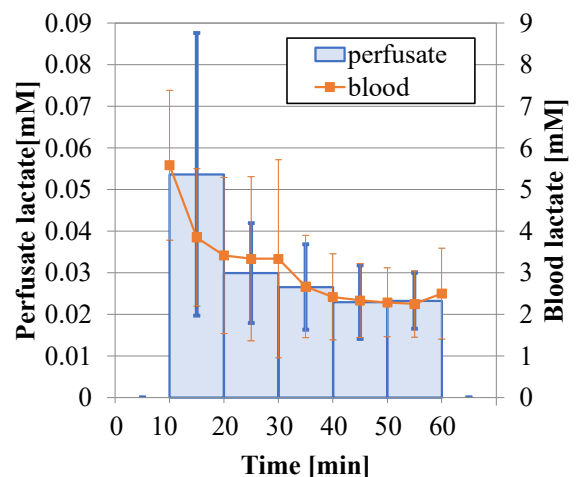


Fig.4 Time change of lactate concentration in blood and perfused solution.

<Reference>

N. Tsuruoka, K. Ishii, T. Matsunaga, R. Nagatomi, Y. Haga, "Lactate and glucose measurement in subepidermal tissue using minimally invasive microperfusion needle," Biomed Microdevices. 2016 Feb;18(1):19. doi: 10.1007/s10544-016-0049-z.

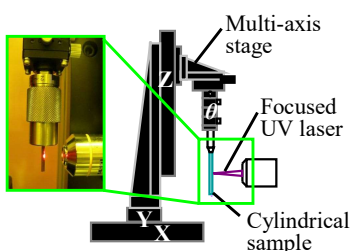
Contact information:
Noriko Tsuruoka
noriko.tsuruoka@tohoku.ac.jp

Photofabrication and mounting process on cylindrical structure

The medical tools inserted or implanted in the human body has many cylinder shapes, such as catheters, endoscopes, etc. Miniaturization, multifunctional capabilities, and high performance are required for these tools. We developed techniques to do micro-fabrication and mounting on cylindrical substances to meet these demands. The highly efficient micro medical tools are developed with thin diameter using this technology.

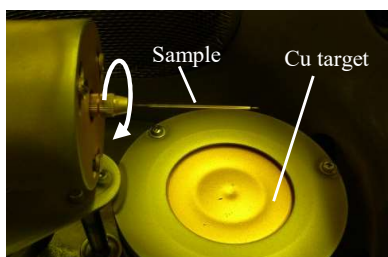
Photofabrication process

Exposure system



This system can expose photoresists on cylindrical shape by uniting laser with an automatic stage.

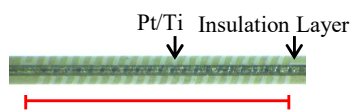
Sputtering system



This system can form thin metal film uniformly on cylindrical shape by rotating sample during sputter.

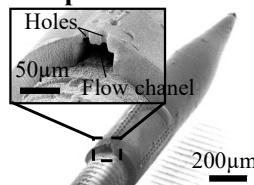
【Examples】

Needle with microheater



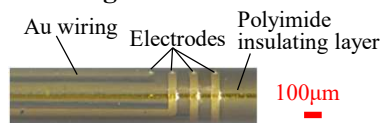
Pt-Ti micro heater was fabricated on acupuncture needle.

Microperfusion needle for subepidermal tissue



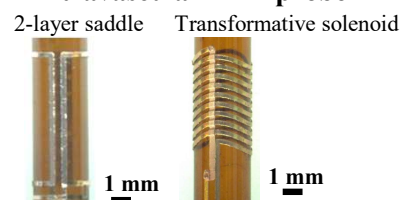
Flow channel with perforated membrane was fabricated on acupuncture needle.

Neural probe with working channel



Recording pad was fabricated on polyimide tube.

Intravascular MRI probe

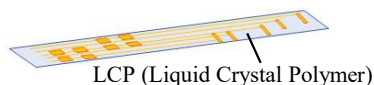


MRI receive coil for the intraluminal application (for example, blood vessel).

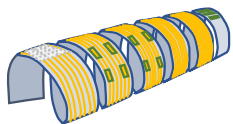
Mounting process

Mounting after coiling

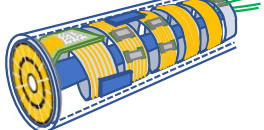
- (1) Patterning on LCP film



- (2) Coiling and heat treatment

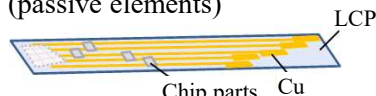


- (3) Mounting parts

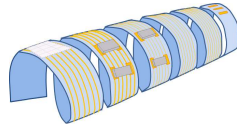


Coiling after mounting

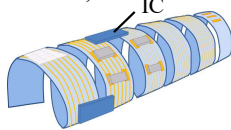
- (1) Mounting chip parts (passive elements)



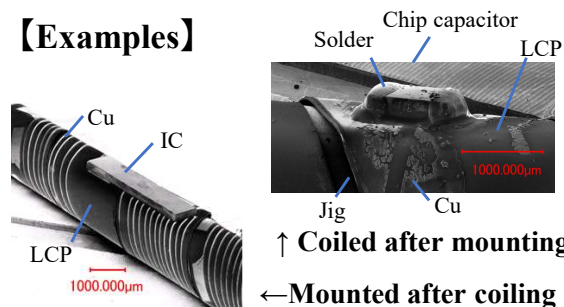
- (2) Coiling and heat treatment



- (3) Mounting IC (Integrated Circuit)



【Examples】

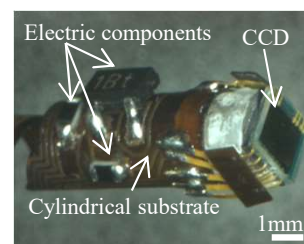


↑ Coiled after mounting

← Mounted after coiling

Direct mounting on cylindrical substrate

Active bending electric endoscope



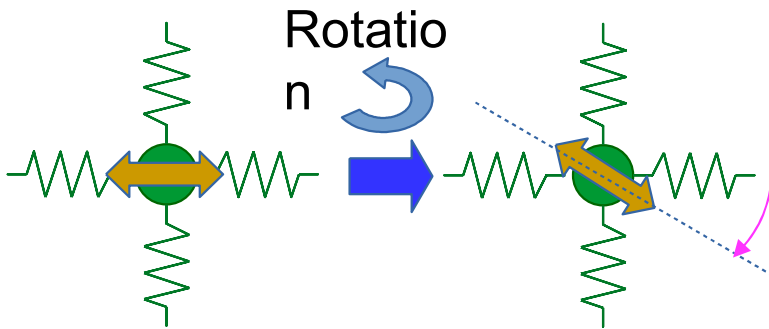
Contact information:
Yoichi Haga
haga@tohoku.ac.jp

<References>

S. Goto *et al.*, Proc. Int. Conf. Microtech. Med. Biol., Okinawa, Japan, 2006, pp. 297–300.
T. Matsunaga *et al.*, Proc. of Japan Institute of Electronics Packaging, 2013, pp.262-265.

Frequency Modulated and Rate Integrating Gyroscope

Rate Integrating Gyroscope (RIG)

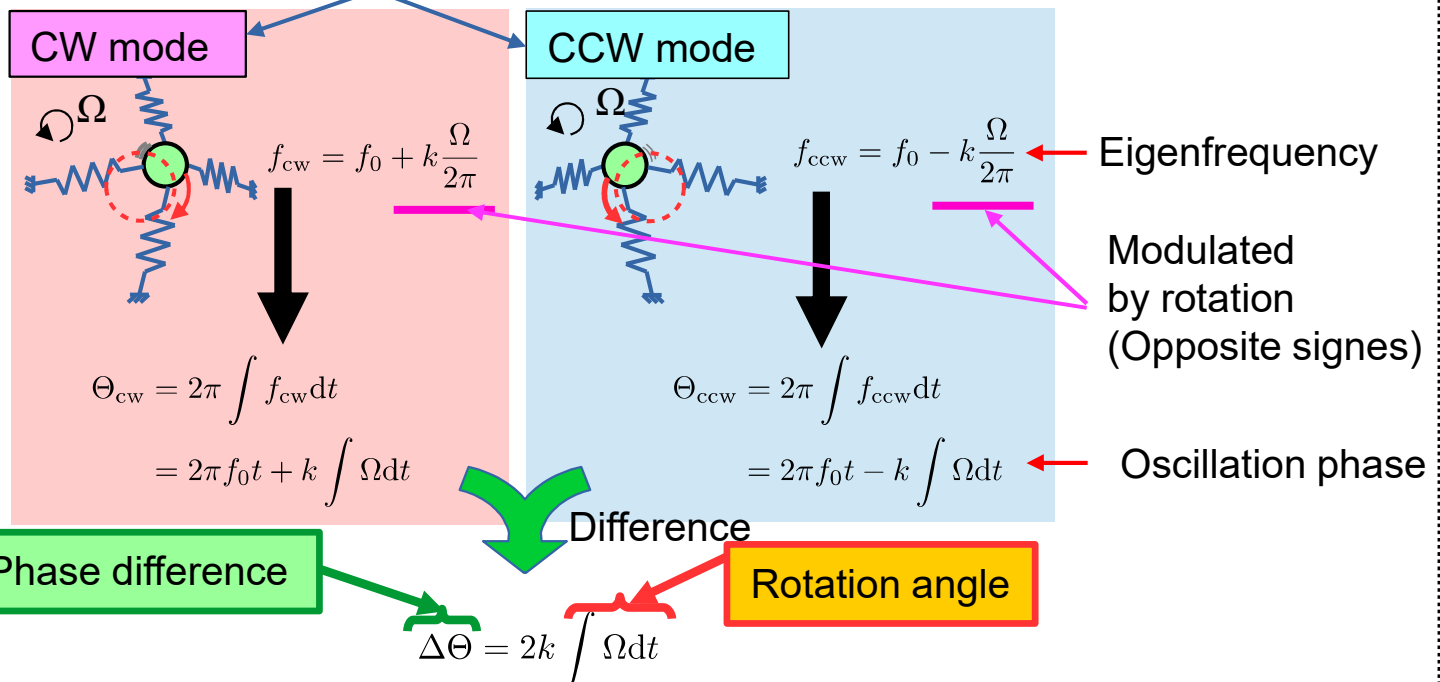


= Foucault pendulum



Principle

Eigenmodes of degenerated resonator



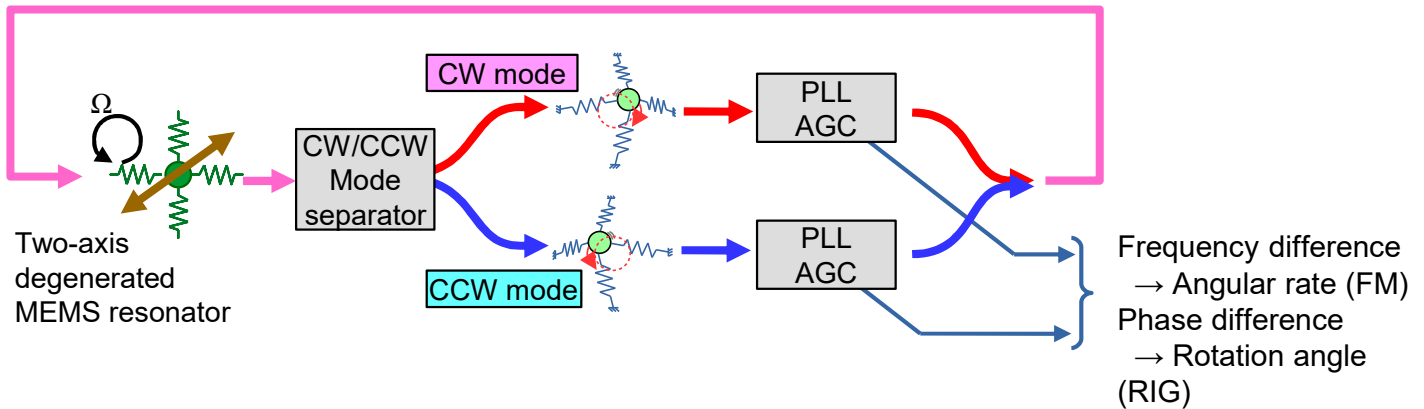
Common-mode disturbance (Temperature etc. → affect f_0) can be completely canceled out

Frequency difference → Angular rate (Ω) measurement
= FM gyroscope

Phase difference → Direct angle measurement
= Rate integrating gyroscope

Frequency Modulated and Rate Integrating Gyroscope

Control technique



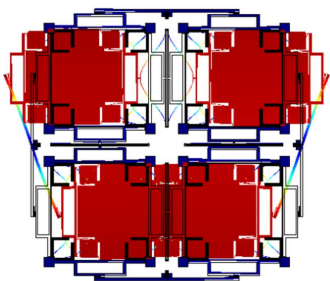
Both CW/CCW modes are **independently** controlled on a **same resonator**.

→ Common-mode rejection becomes perfect !!

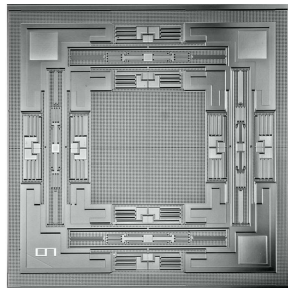
MEMS resonators

Any types of MEMS 2-axis degenerated resonator can be used

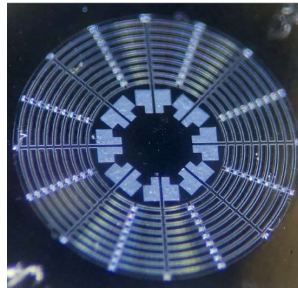
Quad-



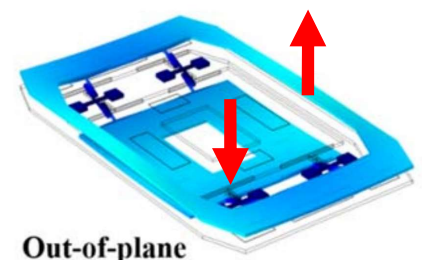
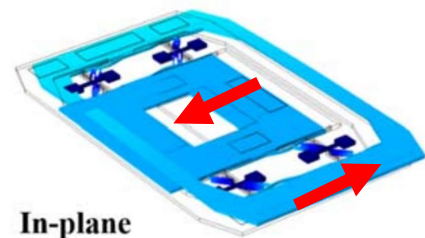
Dual-mass



Ring

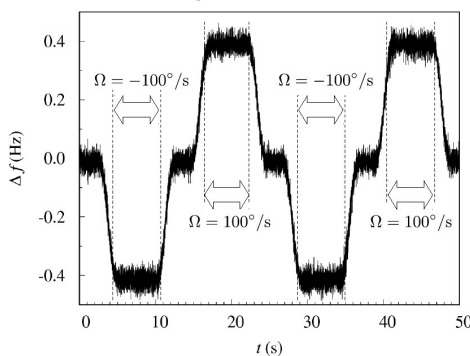


In-plane / Out-of-plane degenerated resonator

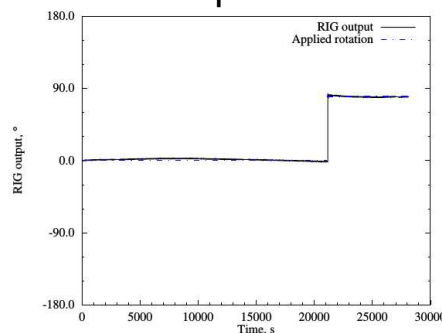


Measurement results

FM-output



RIG-output



HAL SAW Devices

S. Tanaka Lab

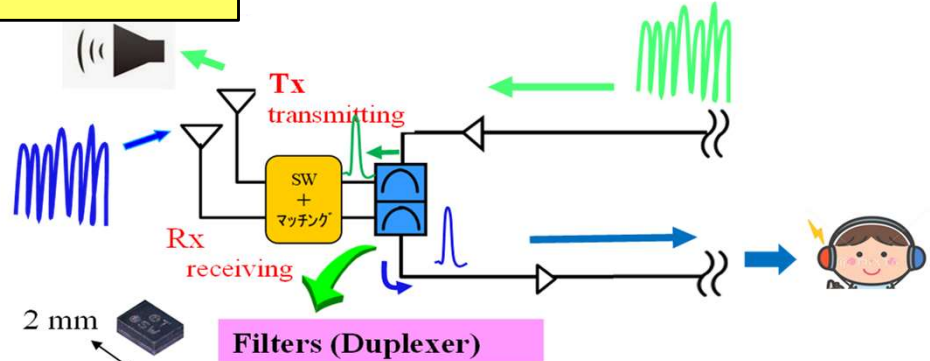
HAL: hetero acoustic layer
SAW: surface acoustic wave

Smart Phone

Many filters are used

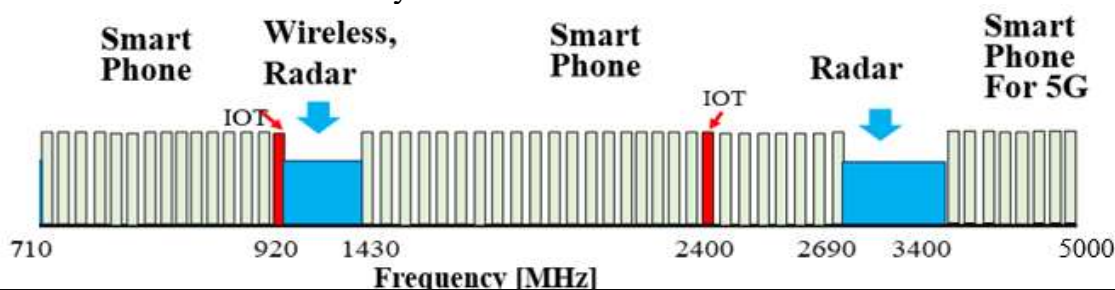


Role of Filter



Current Frequency arrangement 710 to 5 GHz

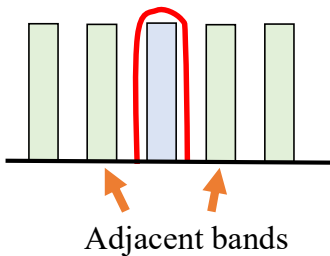
Bands for Smart Phones are busy because of bands more than 80



Following 3 properties are required for filter in addition to size and insertion loss

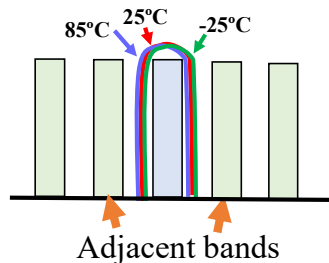
(1) better steepness

No interference from adjacent bands



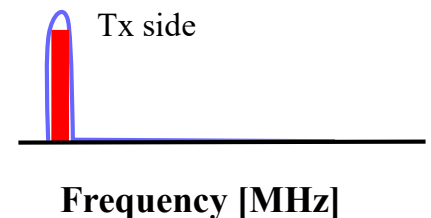
(2) excellent temperature property

No frequency shift due to temperature change

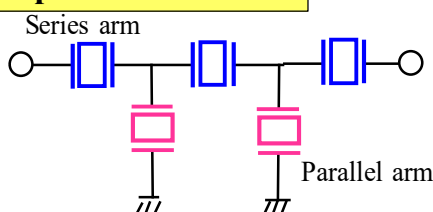


(3) spurious free out of band

No interference from other bands



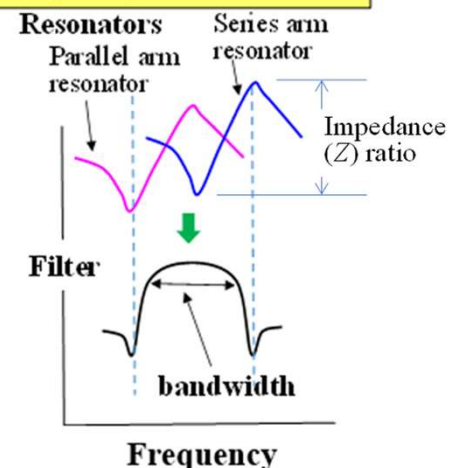
Principle of ladder filter



Factors required for SAW resonator

High impedance (Z) ratio (high Q)
Excellent temperature coefficient (TCF)
Spurious free

Frequency characteristic



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Tohoku University Micro System Integration Center (http://www.mu-sic.tohoku.ac.jp/index_e.html)

519-1176 Aramaki-Aza-Aoba, Aoba-ku, Sendai 980-0845

Phone : +81-22-229-4113 Fax : +81-22-229-4116 e-mail: micro-shien@grp.tohoku.ac.jp



S. Tanaka Lab

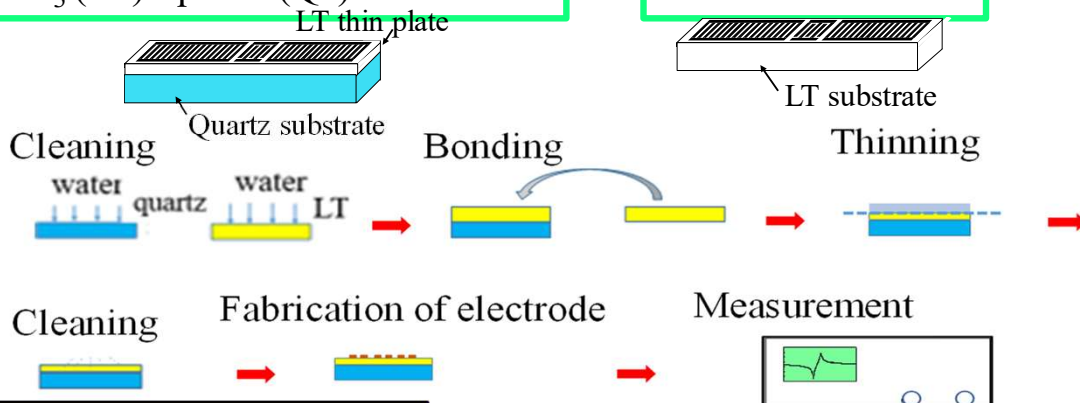
➤ **Patents: 3 patents**

Structure

LiTaO₃ (LT)/ quartz (Qz) HAL SAW

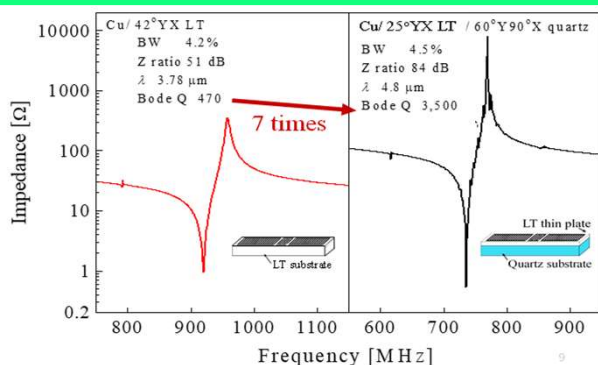
Standard LT SAW

Fabrication process



Frequency characteristics of SAW resonator

33 dB higher Z ratio & 7 times higher Q

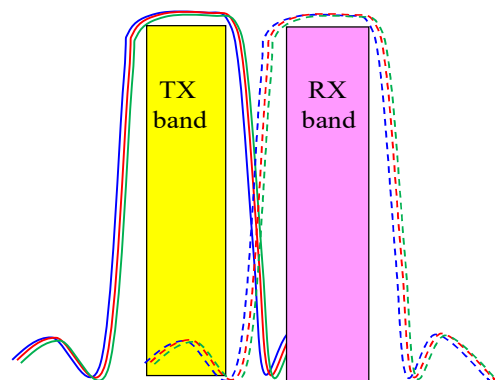


Frequency characteristics of ladder filter

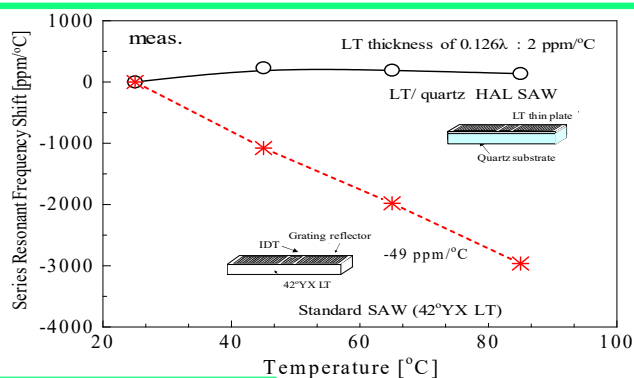
HAL SAW filter

- Low insertion loss
- Steepness
- No frequency shift due to temp. change
- No interference due to adjacent bands

— : 85°C, - - : 25°C, - · - : -25°C



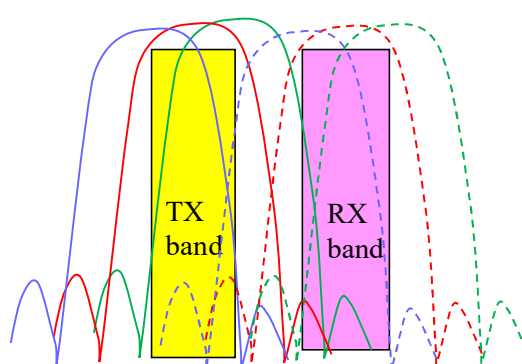
1/ 25 smaller frequency shift (low TCF)



Standard SAW

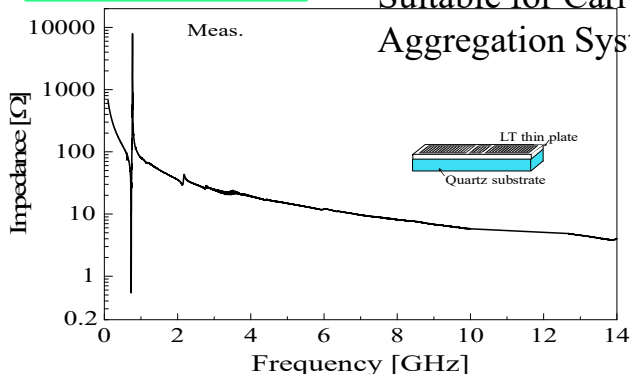
- Large insertion loss
- No steepness
- Large frequency shift due to temp. change
- Large interference due to adjacent bands

— : 85°C, - - : 25°C, - · - : -25°C



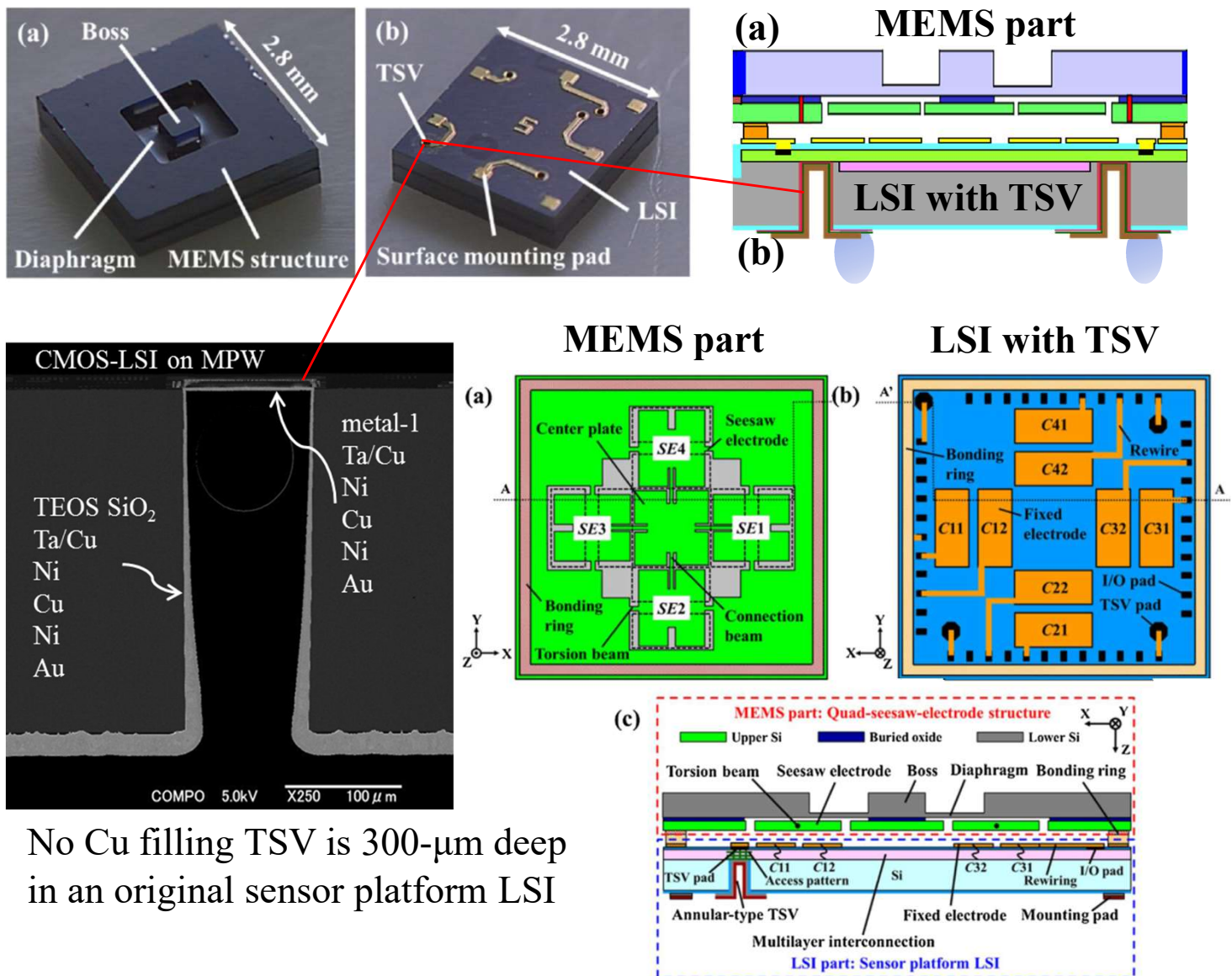
Spurious free

Suitable for Carrier Aggregation System



Integrated 3-axis tactile sensor on LSI with TSV

Tohoku University Tanaka Shuji lab



No Cu filling TSV is 300-μm deep
in an original sensor platform LSI

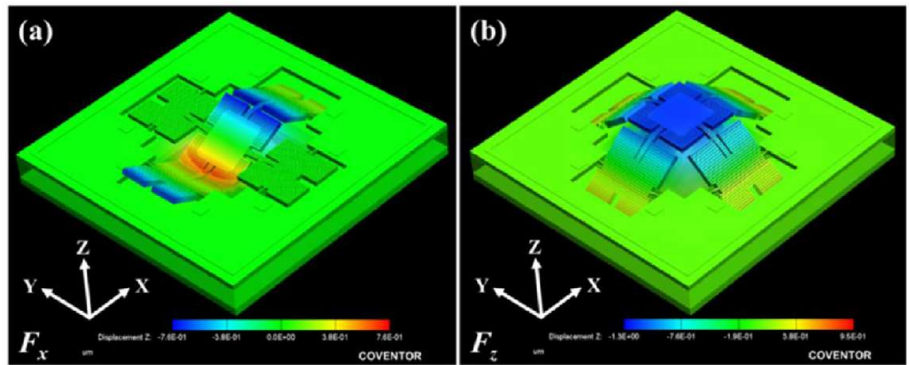
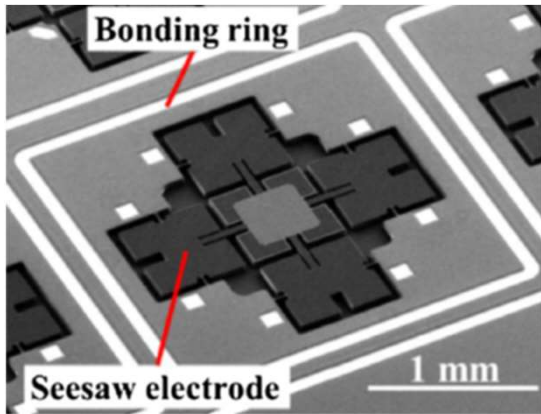
wafer level integrating MEMS and LSI

MEMS-on-LSI integrated tactile sensor that has both fully differential capacitive 3-axis force sensing and signal processing. The MEMS part is composed of a quad-seesaw-electrode structure for fully differential capacitive detection. The LSI part is an original sensor platform LSI(TSMC0.13) that enables signal processing and serial bus communication. The sensor platform LSI was processed for the MEMS-on-LSI integration, the additional processing formed 300-μm-deep annular TSVs, a bonding ring, and sensor electrodes. By Au-Au thermocompression bonding of the fabricated MEMS and LSI parts, a 2.8-mm-square surface-mountable MEMS-on-LSI integrated tactile sensor was completed.

“Tohoku TSV CMOS-MEMS platform” gives many chance for development of surface-mountable CMOS-integrated MEMS.

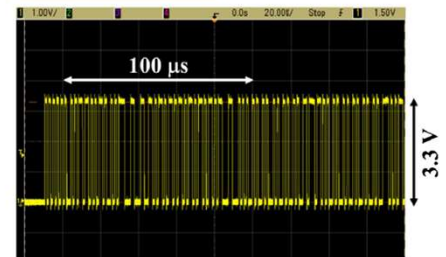
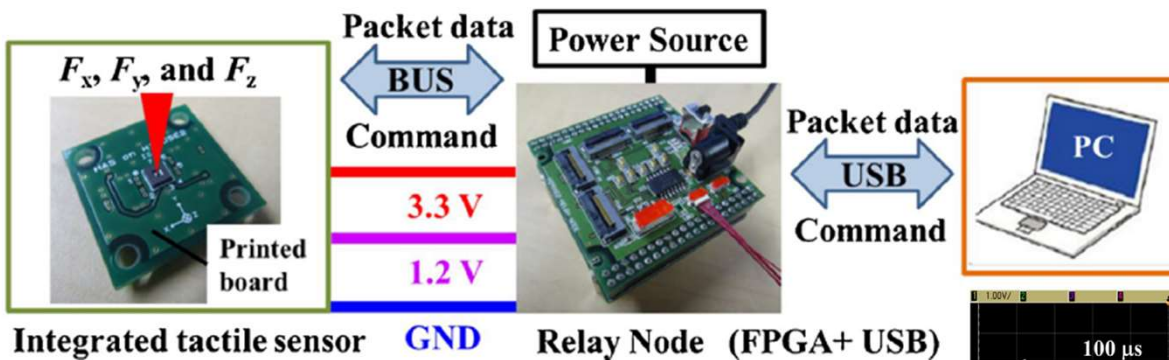
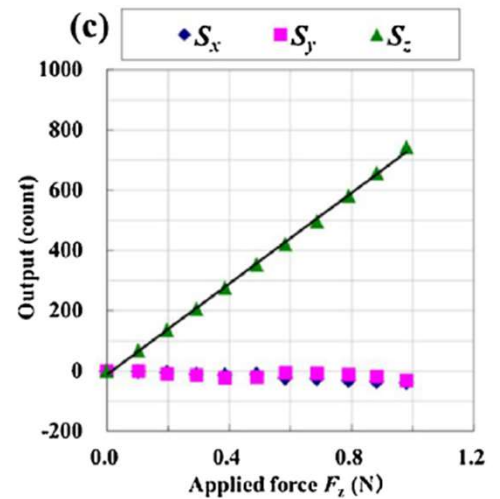
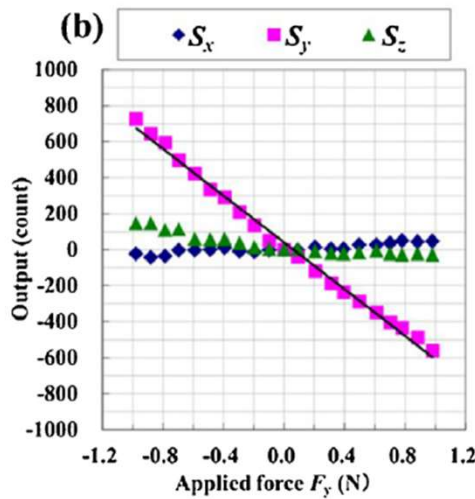
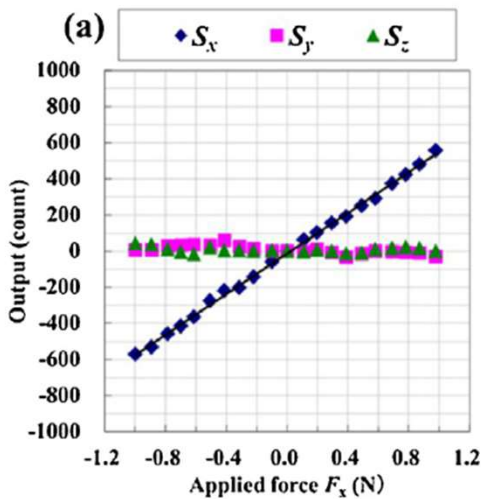


MEMS part



(a) shear force X, Y

(b) normal force Z



A working test demonstrated that digital packet transmission through TSV and confirmed the working principle of 3-axis force sensing with fully differential capacitive detection. A **fully integrated and fully differential 3-axis tactile sensor** was achieved on a single chip with “Tohoku TSV CMOS-MEMS platform” .

(MEMS), 2017, pp. 744-748

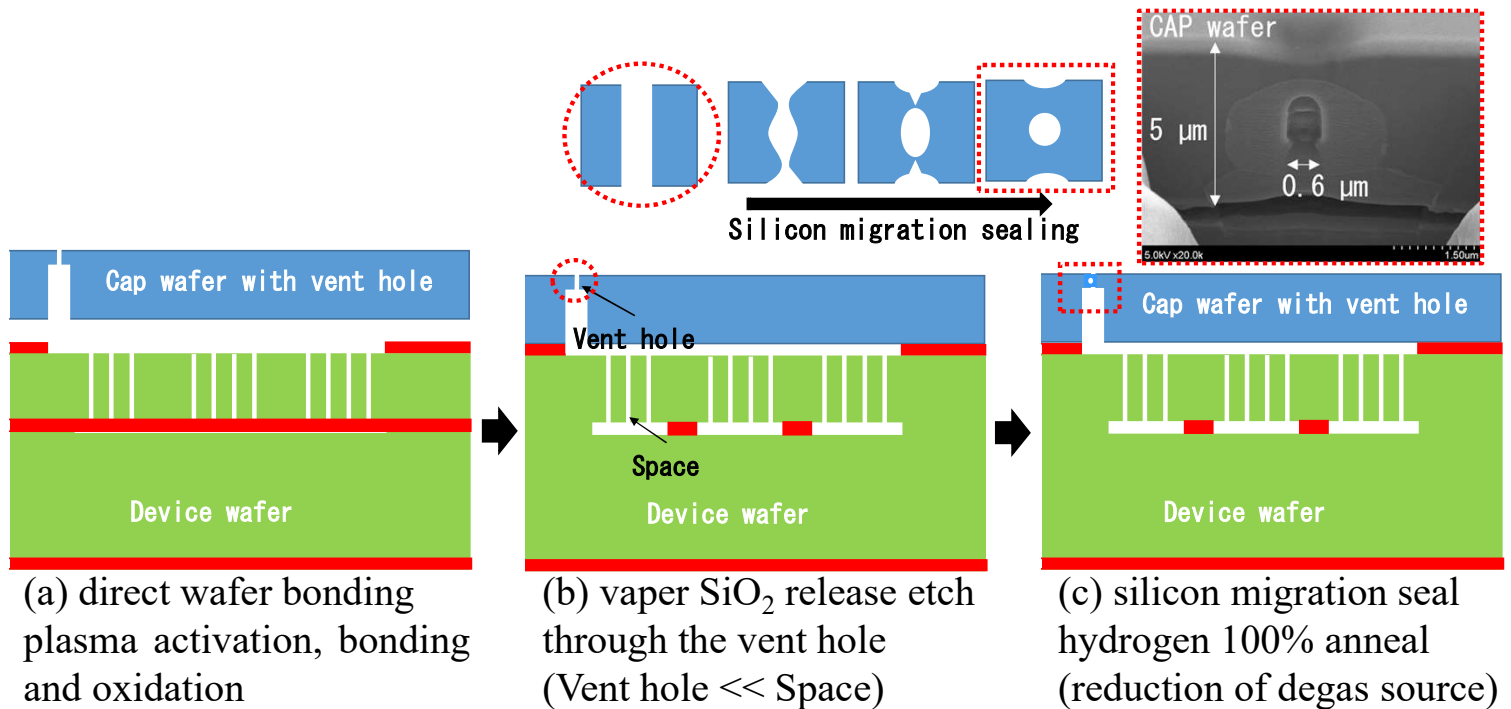
Sensors and Actuators A 273 (2018) 30-41

Tohoku University Micro System Integration Center (http://www.mu-sic.tohoku.ac.jp/index_e.html)
519-1176 Aramaki-Aza-Aoba, Aoba-ku, Sendai 980-0845

Phone : +81-22-229-4113 Fax : +81-22-229-4116 e-mail: micro-shien @ grp.tohoku.ac.jp

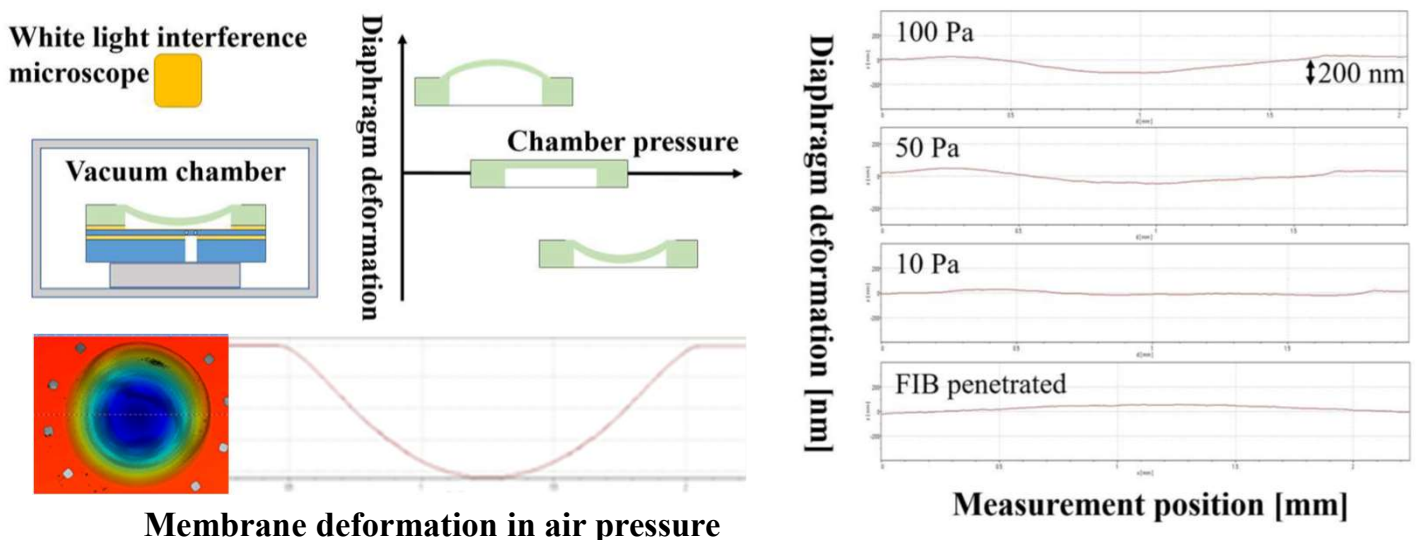
SMS(Silicon Migration Seal) vacuum package

Tohoku University Tanaka Shuji lab



For resonant MEMS, high vacuum sealing is an essential performance factor.

We propose SMS vacuum wafer level package, which not use deposition film and gettering material. Sealing part is made by single crystal silicon. Hydrogen reduction reaction reduces degassing source from the encapsulated MEMS structure during SMS.



The sealing vacuum level was evaluated using silicon diaphragms fabricated in a SMS device wafer. The SMS samples were placed in a vacuum chamber with calibrated pressure gauge to evaluate vacuum level of the sealed cavity. The vacuum level got better than the detection limit of about 10 Pa after few dozen hours annealing in nitrogen, during which hydrogen gas diffused out.

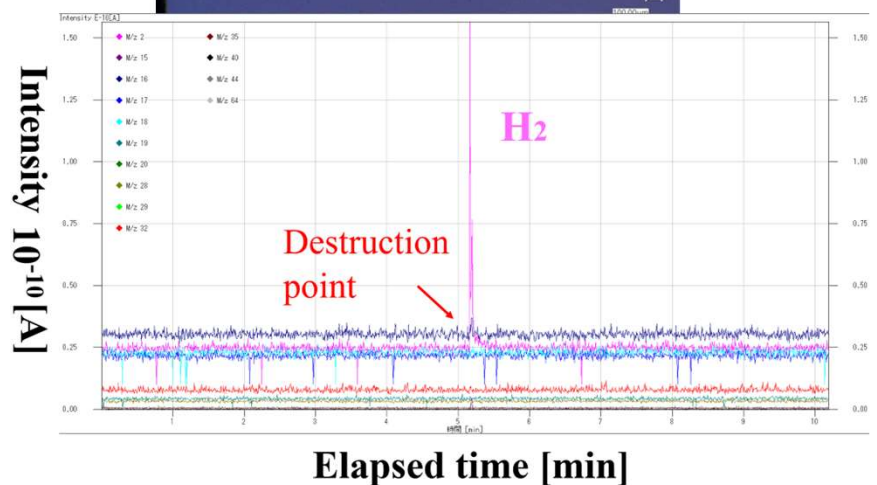
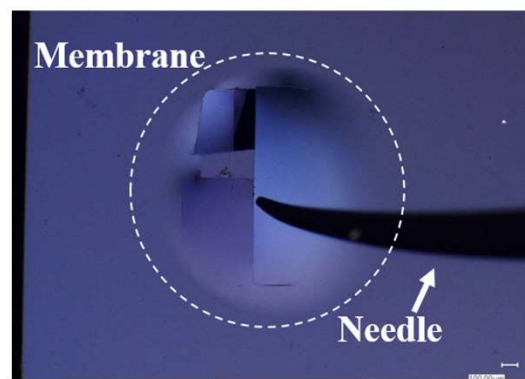
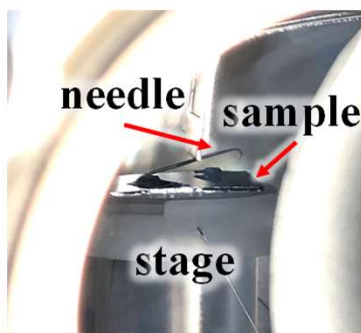
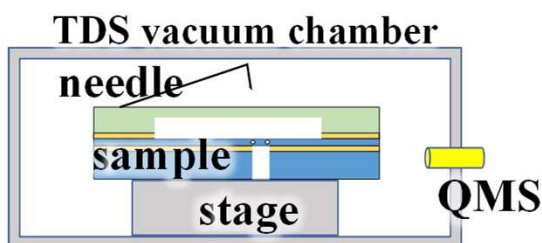


The residual gas inside sealed cavity of the sample was evaluated.

Thermal desorption spectroscopy (TDS) was used for the evaluation to analyze ionic species and their quantities.

A tungsten needle was attached to membrane of SMS sample alignment between tip of needle and membrane center. And the sample was brought into the vacuum chamber of TDS equipment, which has quadruple mass spectrometer (QMS).

First, the vacuum was reduced to the -7^{th} power level. Then, the needle was brought into contact with the sample by pushing it after starting the QMS detection.



The value of M/z_2 was rapidly increased just after the membrane destruction from background level. There was hydrogen gas for residual gas inside sealed cavity. And no other degas was detected.

Higher vacuum sealing can be possible for SMS technologie by efficient hydrogen gas diffusion from sealed cavity.

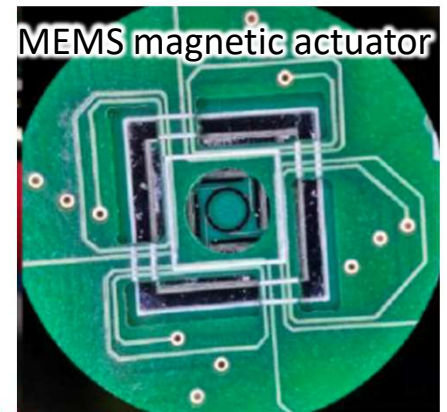
(MEMS), 2022, pp. 565-568

MEMS Actuator with Embedded Magnet and Polymer Spring

Magnetic actuator

- Large displacement $> 100 \mu\text{m}$
- OIS actuator, Haptic device

Key technology: Embedded magnet & Polymer spring (parylene)



Embedded magnet in MEMS structure

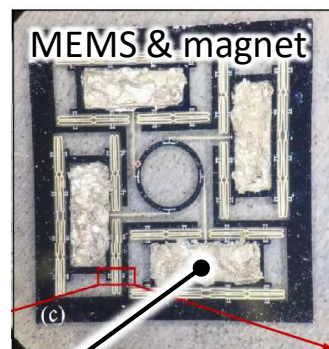
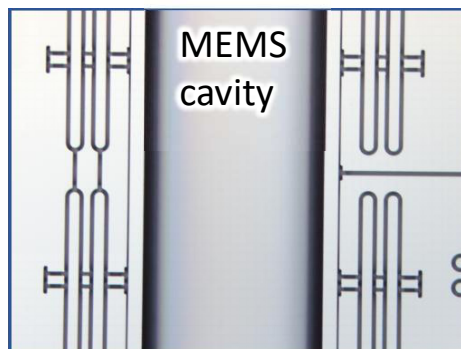
Cavity



Doctor blade coating

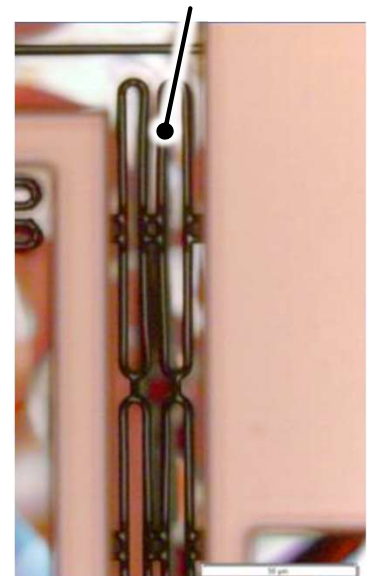


Embedded magnet



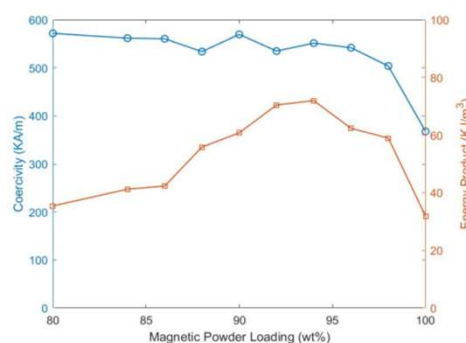
Magnet

Parylene spring Soft & robust



Characteristics of embedded magnet

- Large coercivity
= 500 kA/m
- Large BH max
= 70 kJ/m^3



Year	Material	Fabrication	Coercivity(kA/m)	BHmax(kJ/m³)	Magnet Size
2020	CoPt	Electroplate	1000	77	T100 μm film
2019	NdFeB/Fe	SUS bond	246	<18	$\phi 50 \mu\text{m} \times \text{T}100 \mu\text{m}$
2019	NdFeB	ALD	700	<50	$\text{L}175 \mu\text{m} \times \text{W}175 \mu\text{m} \times \text{T}400 \mu\text{m}$
2019	CoPt	Electroplate	850	56	T60 μm film
2017	NdFeB	Resin bond	772.4	18.4	$\text{L}600 \mu\text{m} \times \text{W}600 \mu\text{m} \times \text{T}200 \mu\text{m}$
2016	NdFeB	Parylene	127~1040	<70	$\text{L}4 \text{ mm} \times \text{W}4 \text{ mm} \times \text{T}400 \mu\text{m}$
2016	CoPt	Electroplate	800	100	T6 μm film
This work	SmFeN	Wax bond	500~560	40~70	$\text{L}3 \text{ mm} \times \text{W}1 \text{ mm} \times \text{T}500 \mu\text{m}$

- Contact: santa@tohoku.ac.jp
mems@tohoku.ac.jp





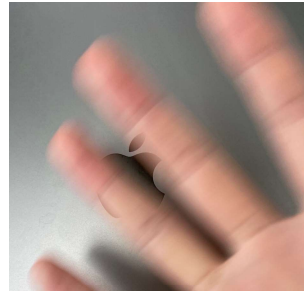
Application 1: Optical Image Stabilization actuator

Optical Image Stabilization

→ Need: in-plane motion with multi-axis displacement

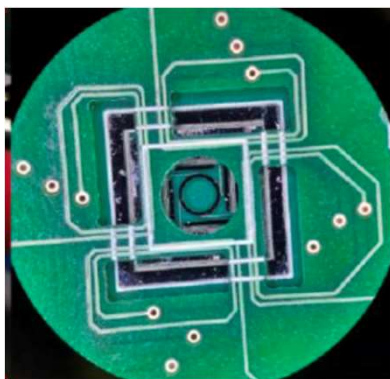


https://join.biglobe.ne.jp/mobile/sim/gurashi/landscape_photographs170207/

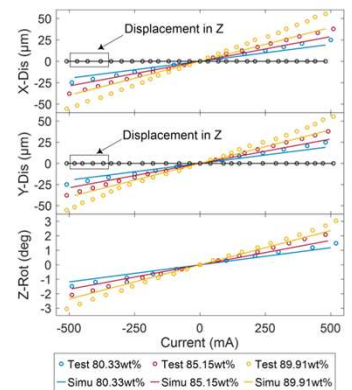
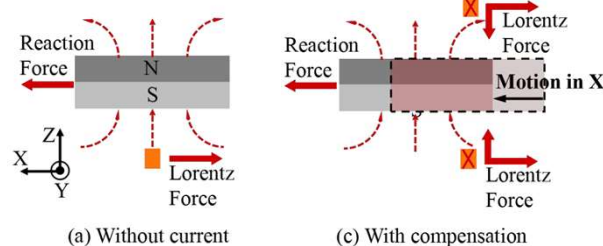


Without OIS
→ blurred photo

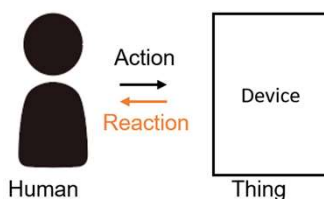
MEMS Magnetic actuator in-plane motion with multi-axis displacement



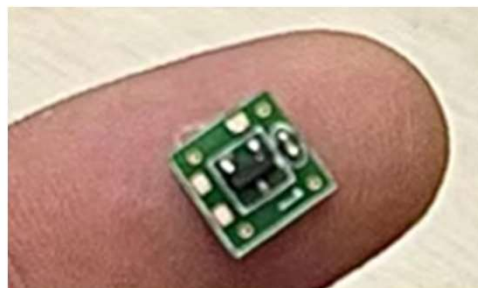
Principle: Lorentz force



Application 2: MEMS haptic device

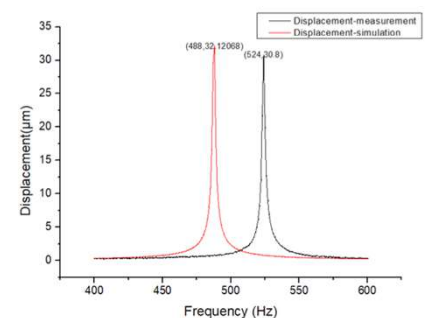


MEMS haptic device



You can feel vibration

Resonance at 488 Hz



Low Cost, Scalable Force Sensor by Magnetic Composite Foam



PolyUrethane (PU) Foams are polymers with high porosity, therefore **strongly compressible**. The Foam is functionalized by inserting strong **magnetic particles**.

The combination of these two properties is perfectly suitable for a **pressure/deformation sensor**. The composite can be **easily deformed up to 80%**. The deformation is sensed by **coils sensible to the magnetic particle displacement**. An **array of coils** will detect the **position of an applied force** on the composite.

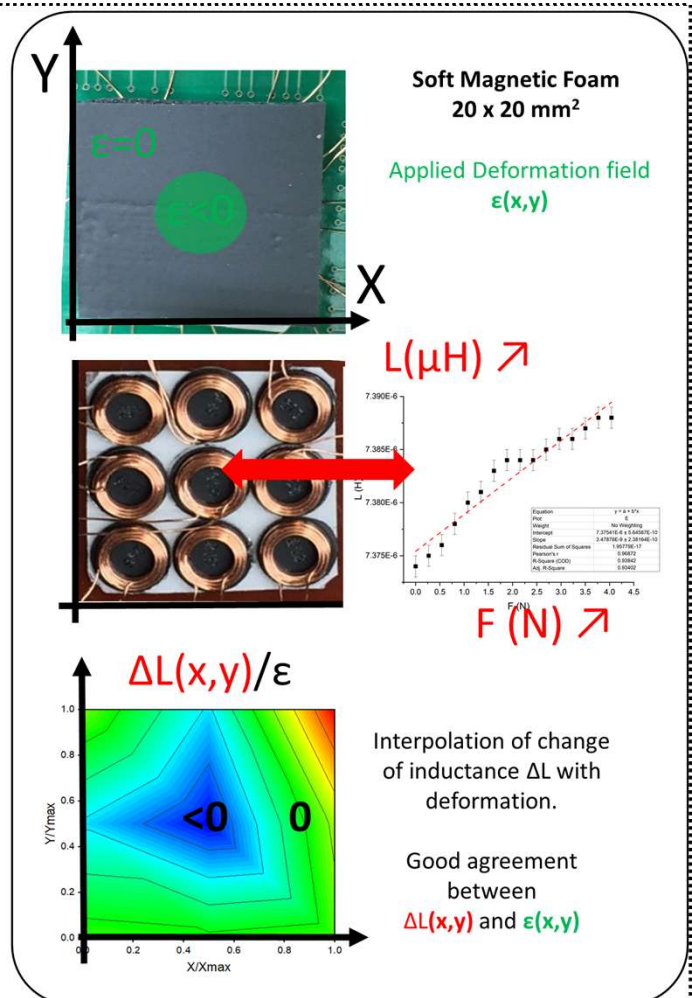
This is new and promising technology: the raw materials are **cheap**, the composite is **easy to process (molding or 3D printed)** and is a **lightweight material**.

Contact:

Assist. Prof. Gildas Diguët

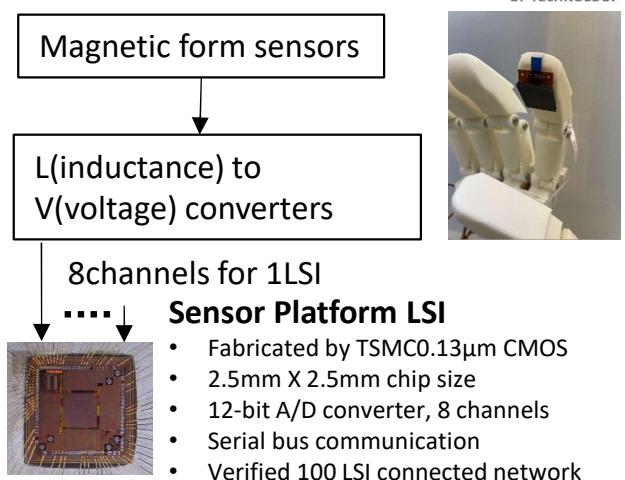
gildas.diguët.d4@tohoku.ac.jp

Diguët, G.; Froemel, J.; Muroyama, M.; Ohtaka, K., Tactile Sensing Using Magnetic Foam. *Polymers*, 2022, 14(4), 834



High Performance Multi Sensor System for Magn. Foam

Large number of pressure/force sensor installation will make new markets such as smart robots, smart furniture, and human motion monitoring. Combination of **original sensor platform LSI** and the magnetic form based pressure/force sensors can make **sensor network systems with large number of sensor installation, small number of wiring, event-driven based fast response and effective sensing data acquisition**.



Contact: Visiting Associate Prof. Masanori Muroyama, muroyama@tohoku.ac.jp

Tactile Sensor Network System

(1) Potential markets having strong pains (needs)

Instead of humans, robots with high-performance multi-sensors will handle various types of things including goods, foods, humans, and virtual ones.



Piece picking at distribution centers, especially EC related ones



Food handling for lunchbox, fruit, vegetable, and so on

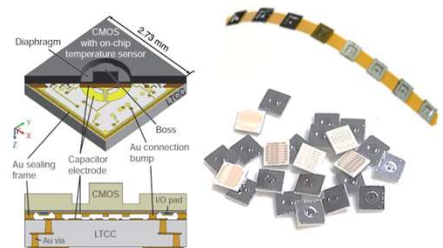
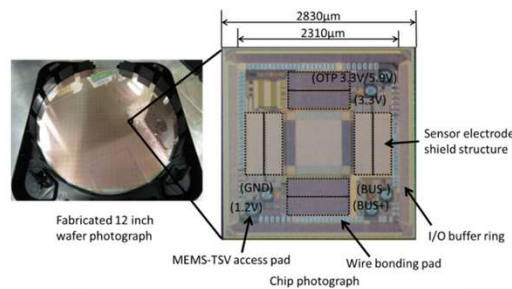
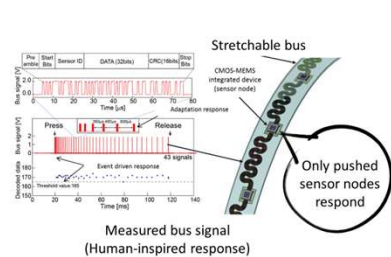


Nursing care and daily life support for comfortable activity of elderly people



Virtual reality and/or mixed reality with new type of human motion sensing systems

(2) Solution by human inspired system with sensor platform CMOS-LSI and MEMS integration technology



Basic concept:

Event-driven response with serial bus communication can realize fast response with small number of wiring for large scale sensor distribution

Patents:

Domestic issued patents: 9
International ones: 11

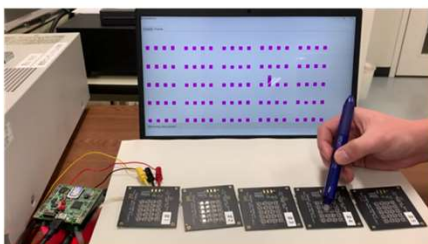
Sensor platform CMOS-LSI:

- Sensor interface as platform Cap./analog sensor 8ch readout circuits
- Communication interface as platform High-reliable clock and data recovery circuit over RS485 differential signaling for 256 sensor connection on 1 bus line
- Integration interface as platform Sensor noise shielding, MEMS integration area, access pads for through Si vias

MEMS integration technology:

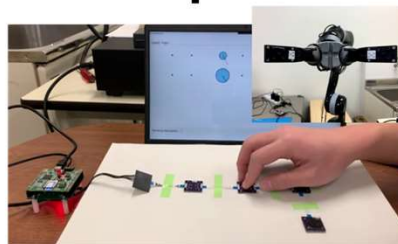
- Flipped CMOS-LSI diaphragm with LTCC interposer, Au bump and Au seal-ring
- 3-axis force sensing with high-sensitivity, low-hysteresis, and digital output
- Embedded temperature sensing for compensation and thermal and force sensing
- 4-inch batch fabrication processing with over 90% high-yield by using our supply chain

(3) Results and future plan



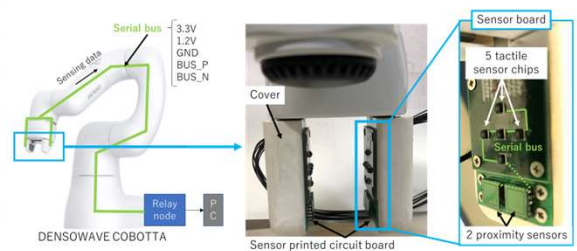
100 integrated chip system:

- 20 integrated chip/PCB × 5 boards
- 100 Z-axis force display S/W



Standard tactile module system:

- 5 chips/board
- Can be assembled like LEGO block
- 3-axis force display S/W
- Can be used for hardness recognition



Prox. + tactile sensor fusion system:

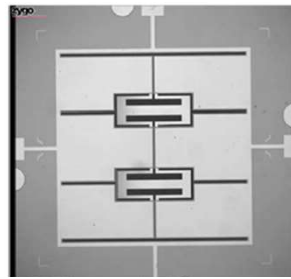
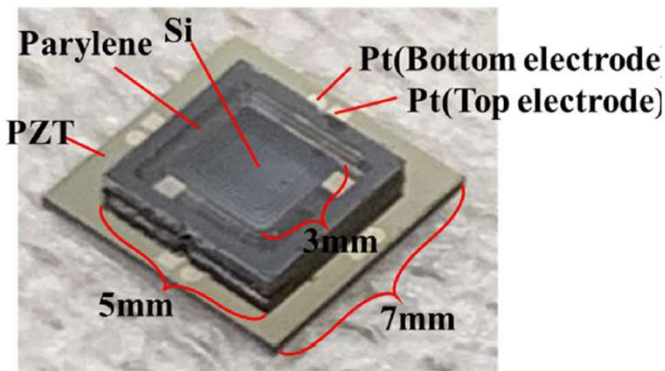
- Proximity sensor array for fine finger alignment
- Soft touch for grasping objects w/ tact. sensors
- Cap. change of the proximity and tactile sensors may be used for object recognition

C. Shao, H. Hirano, H. Miyaguchi, M. Nomoto, M. Muroyama and S. Tanaka, "Event-Driven Tactile Sensing System Including 100 CMOS-MEMS Integrated 3-Axis Force Sensors Based on Asynchronous Serial Bus Communication," in *IEEE Sensors Journal*, vol. 20, no. 17, pp. 10159-10169, 1 Sept.1, 2020, doi: 10.1109/JSEN.2020.2991259.

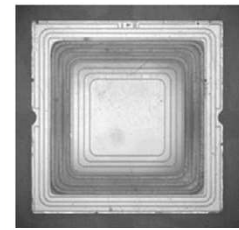
Contact: Visiting Associate Prof. Masanori Muroyama, muroyama@tohoku.ac.jp

Piezo-true-MEMS speaker (for next generation TWS)

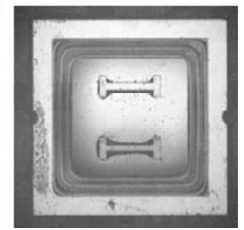
Tohoku University Tanaka Shuji lab



(a) PZT actuator

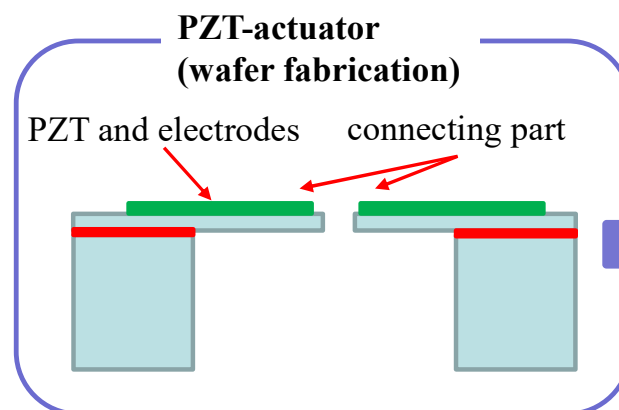
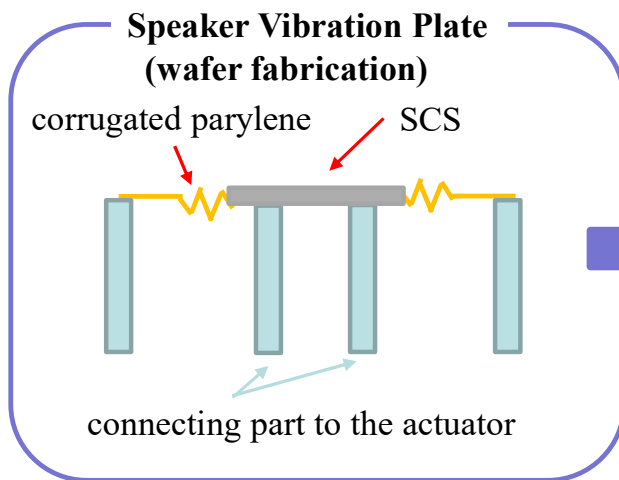


front side

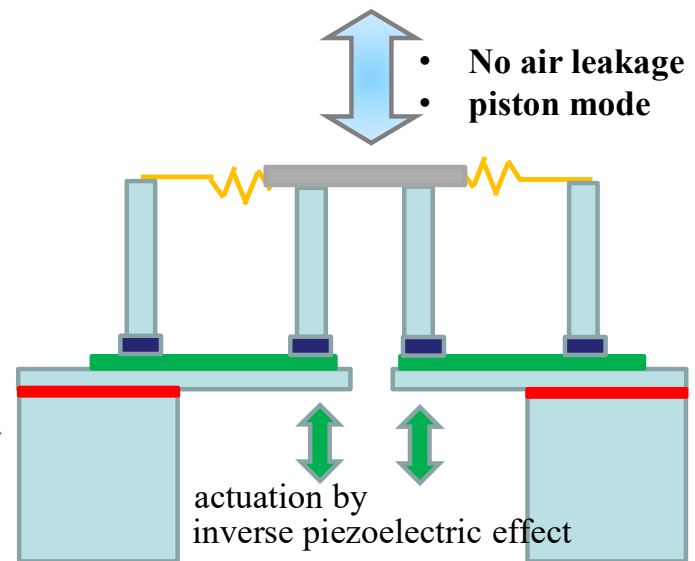


back side

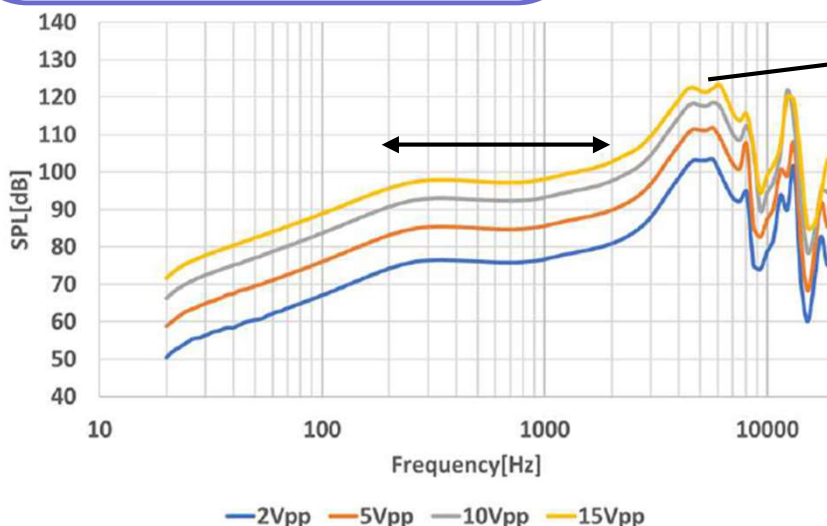
(b) composite vibration plate



integrating

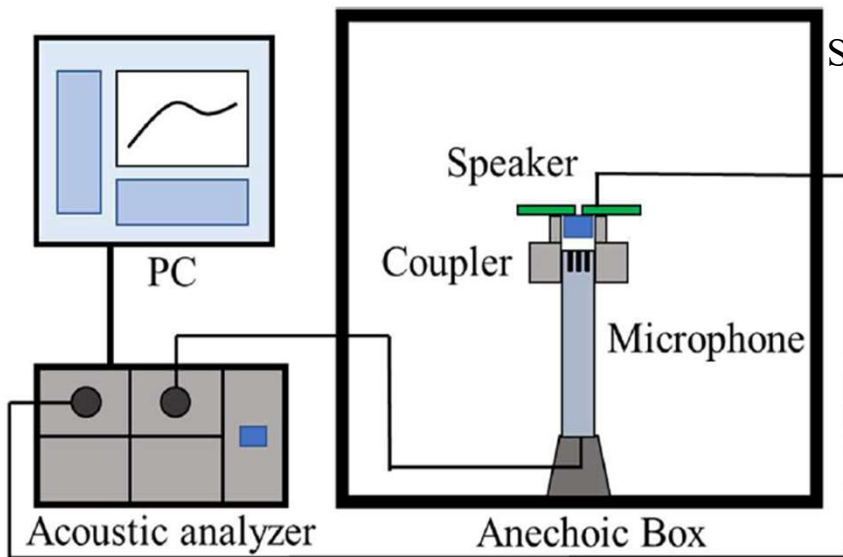


A true MEMS speaker with a Si-parylene composite diaphragm and a PZT actuator. The composite diaphragm is a closed form preventing air leakage and highly deformable by 10 μm thick parylene corrugation. The composite diaphragm and the PZT actuator were integrated.

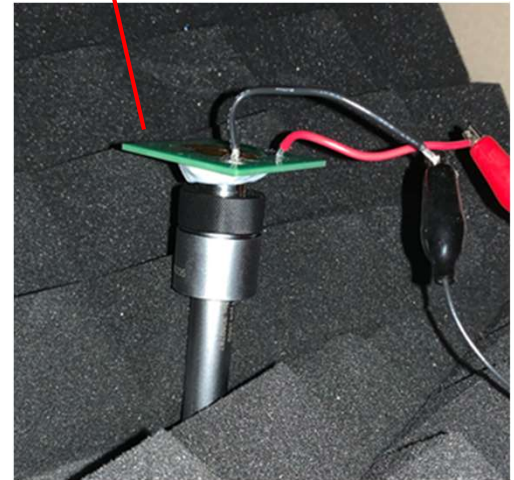


Maximum SPL higher than 120 dB

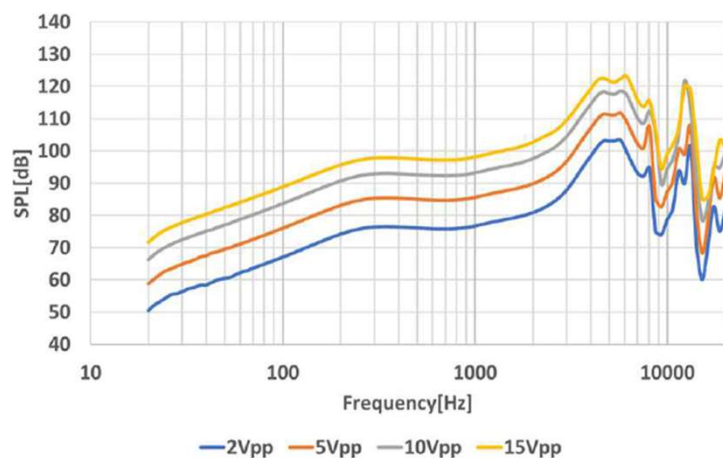
Flat SPL of 85 dB was generated between 200 Hz and 2 kHz



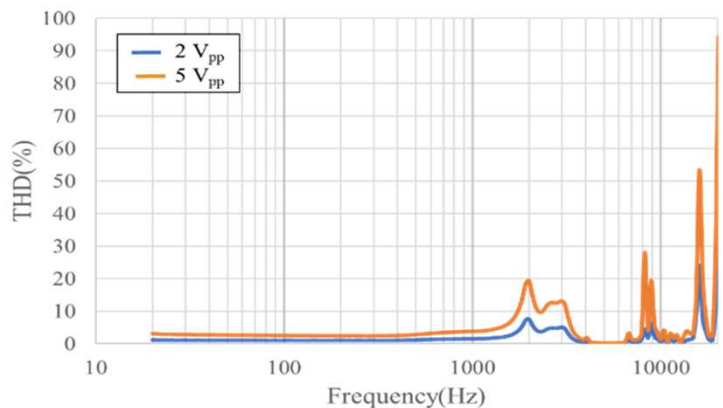
Speaker with PCB



In Ear Simulator Microphone with Ear coupler was attached the speaker. The speaker and the audio analyzer were connected and an AC voltage from the generator and a DC voltage for bias were applied.



(a) SPL (sound pressure level)



(b) THD (total harmonic distortion)

In the ear simulator environment, SPL (sound pressure level) higher than 120 dB was achieved at 4.2 kHz by applying 15 Vpp. And a flat SPL of in the region of 85 dB was generated between 200 Hz and 2 kHz by applying 5 Vpp. THD (total harmonic distortion) is almost smaller than 5% at a driving voltage of 5 Vpp.

(MEMS), 2022, pp. 255-258



Development of MEMS for various applications

Our core competence is MEMS (Micro Electro Mechanical Systems) technology, which is widely used for inertial sensors, pressure sensors, ink jet printers, frequency control devices etc. Recently, MEMS are getting more important for wireless communication, automated control, healthcare, medical diagnosis, energy saving etc. To answer such requirements, we are developing advanced gyroscopes, CMOS-integrated tactile sensors, new acoustic wave filters, microactuators etc. in conjunction with wafer-level packaging technology, piezoelectric thin films and original process tools. We are eager in industrial and international collaboration.

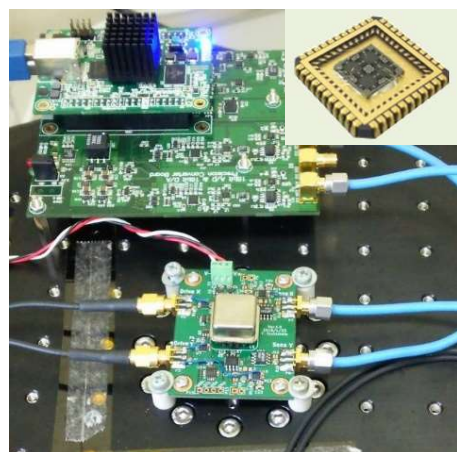


Fig. 1 High performance MEMS gyroscope



Fig. 2 Integrated tactile sensors on robot hand*
*from Prof. Naoki Fukaya, TMCIT

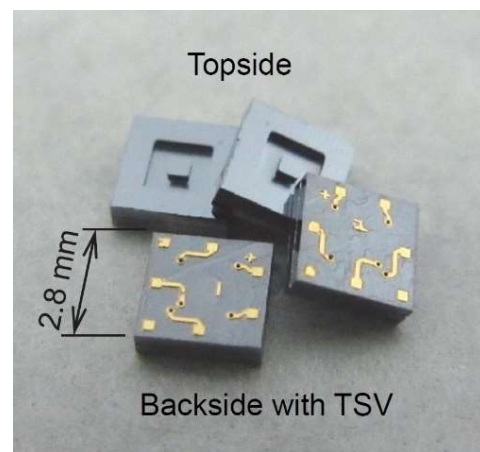


Fig. 3 MEMS-LSI integration platform with TSV

Sensors for robots, automated vehicles and health care systems

Advanced MEMS gyroscopes are developed in device and system levels for automated vehicles and robots (Fig. 1). Integrated bus-network tactile sensors are developed to cover the body of robots (Fig. 2). Ultrasonic range finders for gesture recognition, microactuators for the control of optics and other microdevices are also developed.

Wafer-level hermetic packaging and integration technology

Packaging is a key for MEMS and a source of competitiveness in market. In our laboratory, a variety of wafer-level hermetic packaging and integration technologies (Fig. 3) are ready based on metal-based wafer bonding.

Frequency selection and control devices for wireless systems

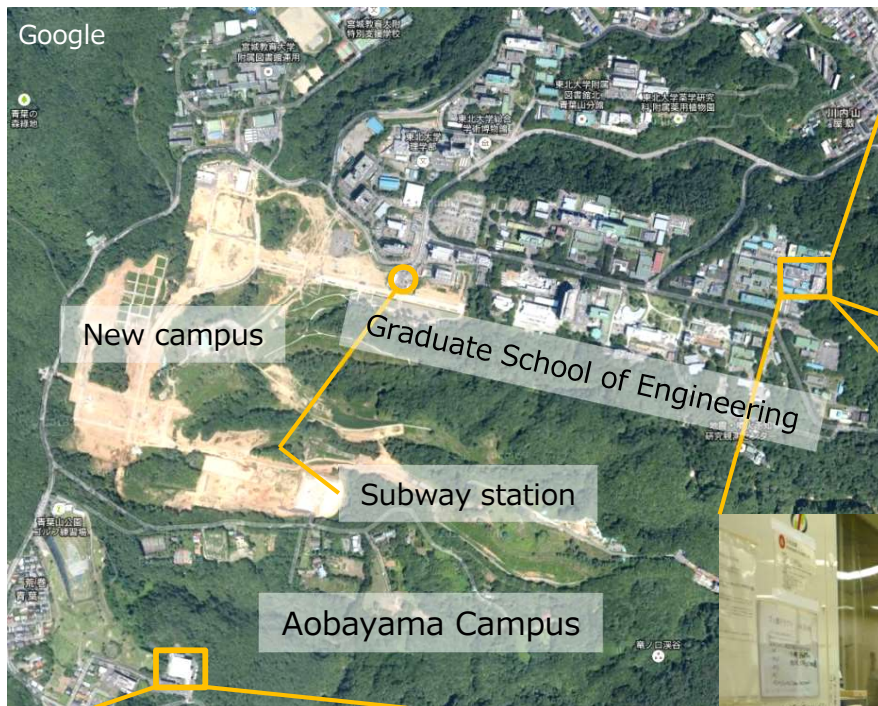
The shortage of frequency resource for wireless communication will be more critical in a coming IoT (Internet of Things) society. Modern frequency selection and control is relying on acoustic wave devices and MEMS. We are developing advanced high-Q, low-TCF SAW and BAW (surface and bulk acoustic wave) devices and RF MEMS switches for the next generation wireless systems.

【Contact】

Department of Robotics, Graduate School of Engineering, Tohoku University
 Shuji Tanaka, Professor
 TEL: +81-22-795-6934
 E-mail: tanaka@mems.mech.tohoku.ac.jp

To industrial customers looking for a MEMS R&D partner

S. Tanaka Laboratory is willing to support MEMS industry in research and development based on a lot of technology, know-how and literature accumulated for a long time in Tohoku University. We can propose multiple styles of research and development, from the proof of concept using small substrates to device prototyping using 4-6 inch wafers, depending on R&D phase in each company. The proof of concept is conducted at the minimum cost and risk mainly using our cleanroom and Micro/Nano-Machining Research and Education Center (MNC). We accept researchers from companies, and they can experience the total process of MEMS development to be experts and key persons in their company's MEMS team. The visiting researcher has a chance to pursue his Ph.D as a graduate student. Prototype devices on 4-6 inch wafers are fabricated mainly in Microsystem Integration Center (Jun-ichi Nishizawa Memorial Research Center). Devices fabricated in our facilities can be commercially used with some reservations. Tools in Microsystem Integration Center can be simply used by visitors based on pay-by-the-hour system ("Hands-on Access Laboratory" system), but we recommend you collaboration with us not to lose time and money in a complacent manner, especially if you are not a MEMS expert. S. Tanaka Laboratory has a lot of experiences about difficult-to-access technologies such as wafer-level packaging, heterogeneous integration and piezoelectric thin films. Consultation about MEMS technology and business are being accepted anytime from companies.



Micro/Nano-Machining Research and Education Center (MNC)



Jun-ichi Nishizawa Memorial Research Center



Cleanroom of S. Tanaka Laboratory

Research Topics in 2022

Advanced inertial sensors for automated vehicles and robots, Tactile sensor system for robots, Frequency control devices for advanced wireless communication (SAW and BAW devices), Piezoelectric thin films and devices, Acoustic and ultrasonic sensors, Microactuators, Heterointegration technology and wafer-level packaging technology, Key technologies for sensors and microactuators, MEMS process tools (ALD tool and wafer bonder) etc.