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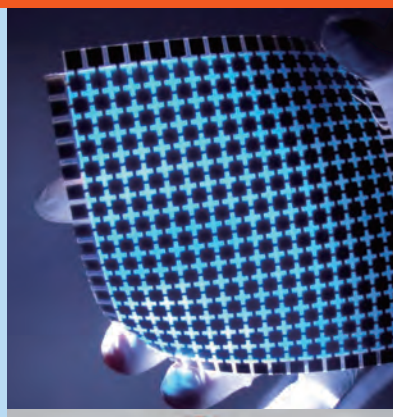
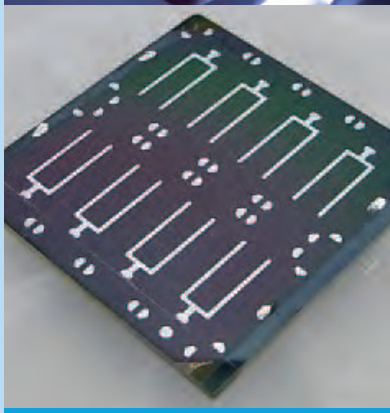




FEATURE

AIST Flexible Electronics Research

Research Hotline

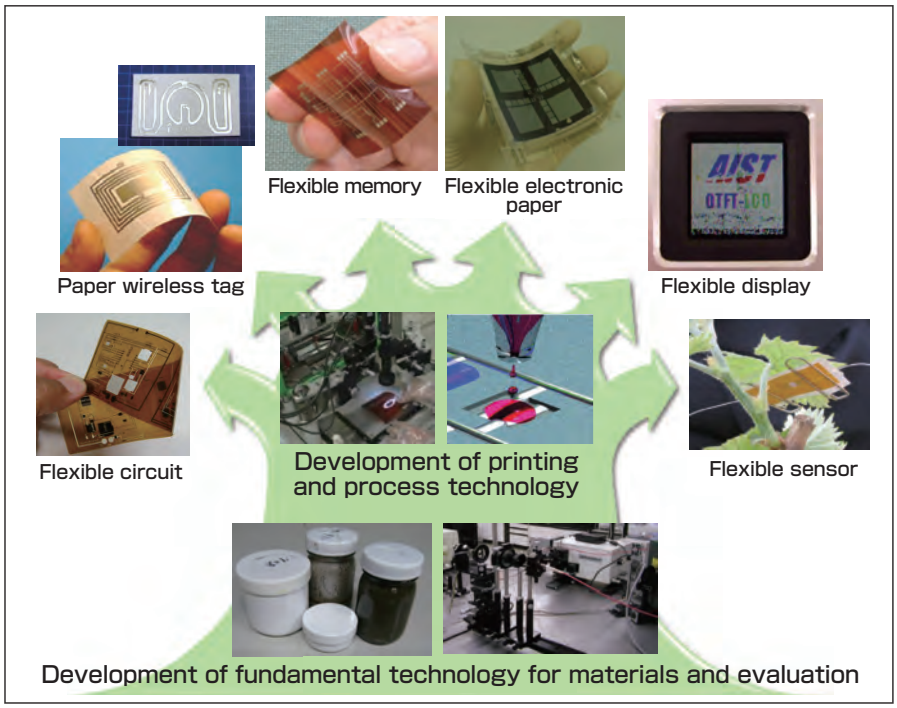
UPDATE FROM THE CUTTING EDGE（July–September 2013）

In Brief

AIST Flexible Electronics Research and Development

Background

In recent years, there has been a drive towards flexible devices as next-generation information terminal devices that are thin, light and adaptable to various shapes, and do not break when dropped. This is set against a backdrop in which there has been widespread adoption of IT technology by the general public, who do not just demand good information communication functionality, but also set a high value on usability. Supporting this great expansion of diversity in the means of information communication that has spread to every corner of society has become a major technical issue, and high-flexibility manufacturing (high-mix variable-volume production) that can easily support diversity has come to be demanded.



Development of fundamental technology for materials and evaluation, printing technology, and device technology aimed at realization of flexible devices for next-generation information terminal devices

AIST initiatives

At AIST, we established a Flexible Electronics Research Center in fiscal 2011 to contribute to the expansion of this technology, and together with the development of flexible devices, we have started to work intensively on device manufacturing technology (printed electronics) to make full use of printing processes that enable highly productive manufacture. Up to this point, we have focused on the input-output capability of new sheet-shaped information terminal devices by developing flexible displays, sensors, memory, wireless devices and the like. In addition, we have developed technology to perform high-precision printing and high-speed low-temperature printing of these flexible devices and fundamental technology for flexible materials. Development has also been carried out of fundamental technology for the evaluation of their performance.

In the future, we will be tackling not only the technology for manufacturing these kinds of devices, but also pioneering new services utilizing them. Such flexible paper-like devices will place a premium on qualities such as “user friendliness,” and have the potential to generate new services to satisfy people’s sensibilities. As a result, there are high expectations for the opening up of new markets. To this end, there has been a recent emphasis on standardization as a means of accelerating market development and strengthening international competitiveness. At AIST, we are contributing to international standardization activities related to printed electronics.

Director
Flexible Electronics Research Center
Toshihide KAMATA

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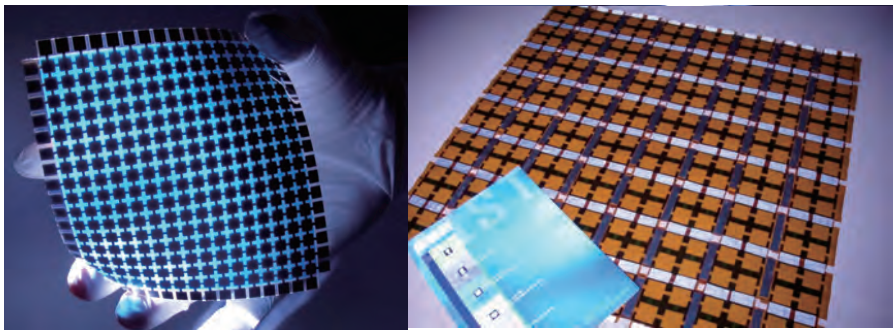
Large-area Fully Printed Flexible Pressure Sensors

Background

With advancements in information terminal devices, a ubiquitous information society in which people can input and output information anywhere anytime is becoming a reality. Moreover, to ensure a safe and secure society, systems should be capable of carrying out information exchange unnoticed using devices such as sensors. Development of devices suitable for this purpose is therefore necessary. For example, in the nursing care field, a network of sensors attached to objects such as floors, walls and beds could be used to gather information that could be collectively analyzed to assess care receivers' health. In such a situation, the sensors must have as free a form as possible so that there is no restriction on their installation location. In addition, low-cost mass production is required together with the ability to flexibly support a wide variety of applications. Accordingly, we have been working towards the development of technology for the low-cost large-scale production of electronic devices such as sensors, and have already succeeded in manufacturing large-area pressure sensors using a printing process.



A 16 x 16 element printed sensor array (left) and an 80 cm x 80 cm large-area sensor array manufactured by gluing together 10-cm-square sensors (right)

Pressure sensor manufacture using a printing process

In such printing processes, electronic devices are fabricated by direct patterning of electrodes, dielectrics, and insulating films on plastic substrates. At the current level of printing technology, problems still exist in certain areas such as achieving sufficient pattern thickness uniformity and surface evenness, and the device design process should take such factors into account. Particularly in the case of forming thin films over printed electrodes, the film can be extremely thin at the edge of the electrode, and leakage currents can become a problem. To tackle this issue, a new structure was adopted in which the electrode edge was covered with an insulating material, and leakage currents have been reduced to a level where they are not a practical problem. This allowed the device yield to be increased from just a few percent to almost 100 %.

Fabricating large-area sensor arrays

Large-area sensor arrays were fabricated using a method that involved gluing together 10-cm-square substrates. Since it uses small substrates, not only does this method offer advantages with regard to handling during manufacturing, it can also lower capital investment risk by reducing the size of the manufacturing equipment. It is hoped that this will allow many companies to enter this field and lead to an improvement in the technology. We have already manufactured an 80-cm-square sensor array using this method, and have demonstrated its operation.

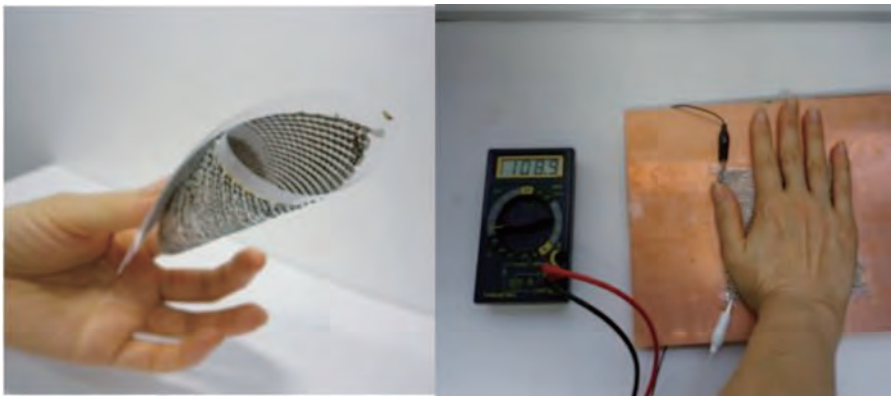
Printed Electronics Device Team
Flexible Electronics Research Center
Sei UEMURA

Press Release
9 Aug. 2012 – “Pressure Sensor Array Made with Polyamino Acid

Printed Flexible Thermoelectric Generators

Research background

Thermal energy, such as waste heat, can be converted into electricity by using thermoelectric generators (TEGs). Because the conventional thermoelectric materials such as bismuth–telluride have high density and minimal flexibility, state-of-the-art commercially available TEGs are rigid and heavy. These characteristics significantly restrict the use of TEGs. Many heat sources have curved surfaces, and they exhaust heat from large surface areas. Conventional TEGs are unfavorable for efficient heat recovery from such heat sources because they are not flexible and their weight makes them unsuitable for use over a large area. This implies that there is a critical need for flexible, and lightweight TEGs.



Flexible thermoelectric generator fabricated using printing process.
Approximately 110 mV was observed when the temperature gradient caused by hand and a plate (approximately 10 °C) was added.

Film-like thermoelectric generators fabricated using printing processs

A simple method of adding flexibility to TEGs is using a flexible film as the substrate. Printing technology enables high-speed production of patterns of functional inks containing thermoelectric materials on large-area flexible plastic films.

Using a composite of carbon nanotubes (CNTs) and insulating polymer, we fabricated a TEG onto a thin plastic film by printing. The printed TEG on a plastic film substrate did not sustain any mechanical damage when it was bent at a radius of curvature of less than 6 mm. The thermoelectric material used in this study, a composite material consisting of CNTs and polystyrene, contained approximately 35 vol% of voids. Because of the reduction in the density of the CNT–polystyrene composite caused by the voids, the TEG was remarkably lightweight (weight per unit area: ~15.1 mg/cm^2). The printed TEG generated approximately 55 mW/m^2 of power at a temperature difference of 70 °C.

Towards commercialization

Due to the high user-friendliness of the printed TEG on a plastic film substrate, we believe that the printed TEG will enable us to develop novel applications such as thermoelectric conversion of body heat. However, improving the performance of the CNT-polymer composite and optimization of device structure will be necessary.

Functional Display Device Team
Flexible Electronics Research Center
Kouji SUEMORI

Glossary

*Stencil printing: A printing process in which an ink pattern is formed on a surface through a plate in which holes have been produced.

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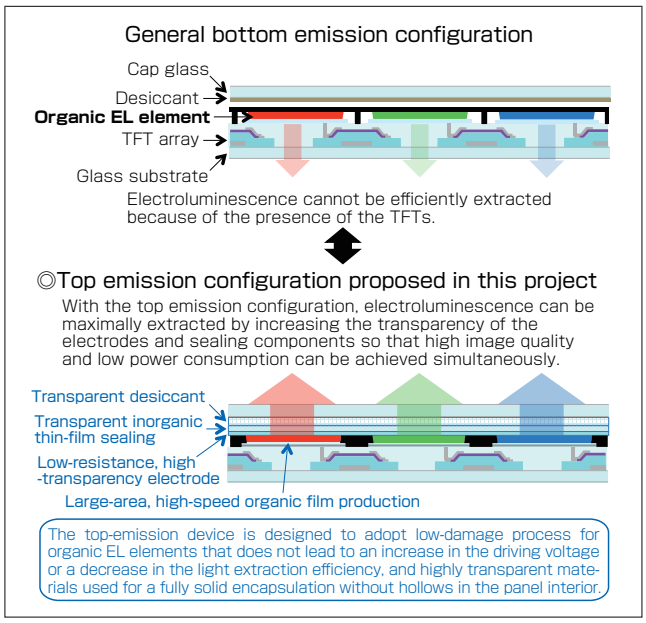
Next-generation Large-Screen Display Technology

Organic electroluminescence display technology

Several years have passed since organic electroluminescence (EL) has been recognized as a next-generation alternative display technology with a superior performance to conventional liquid crystal displays (LCDs) used widely for flat-screen television, personal computers and so on. While small-size organic EL displays have been found in some smart phones and portable game consoles, the television-sized counterparts have not still prevailed in the consumer market. The predominant factor that discourages the dissemination is attributed to the fact that the production technology has still been unestablished for the efficient production of large-screen panels which are superior in image quality and power consumption to the corresponding LCD products.



Conceptual diagram of the conventional bottom emission configuration and the top emission configuration proposed in this project

For the production of large-screen organic EL display panels with superior imaging and energy-saving performance

To satisfy both excellent imaging performance and low energy consumption property at a higher level in organic EL displays, it is necessary to employ a "top-emission" method, which means the display surface is at the opposite side to the thin-film transistor (TFT) substrate for pixel driving. This is because much higher light extraction efficiency is expected for the "top emission" method than for the conventional "bottom emission" configuration, in which the EL extraction is inevitably influenced by the TFT substrate. We are participating in the national project "Development of Basic Technology for Next-generation Large-screen Organic Light-emitting Diode Displays" (Green IT Project) in which industry, academia, and government are working in partnership to establish the technology for commercial manufacturing of the top-emission type large-screen organic EL displays. We are developing and supporting basic technologies such as large-area high-speed organic EL film production, low-damage transparent electrode formation for large-sized top emission displays, and high-transparency solid-encapsulation (transparent inorganic thin-film sealing and transparent desiccant) in concert with materials, equipment, and device makers. This project has a common focus on fabrication processes that do not cause damage to fragile organic EL elements, highly transparent materials for minimizing optical losses, and on large-area, high-speed film production for highly efficient panel production. In a 5-year development time, we have pursued the research and development aiming at establishing the basic manufacturing technology which enables multiple panel production with large-area glass substrates for large-screen organic EL displays, for example, a full-HD 40 inch monitor with low power consumption less than 40 W.

Acknowledgement

This research was supported by the New Energy and Industrial Technology Development Organization (NEDO) as contracted research.

Functional Display Device Team
Flexible Electronics Research Center
Satoshi HOSHINO

Low-temperature-sintering-type Copper Paste

The copper paste problem

In order to reduce the costs of the mounting and manufacturing process for solar cells, a high level of interest is being focused on printing methods for solar cell electrodes and wiring that make use of silver paste. However, the amount of silver currently used for solar cells accounts for approximately 18 % of silver production, and considering the predicted future growth of solar cells, there is a concern that silver supplies will run out. Thus, there is an urgent need to replace silver by another element that can deliver the same performance and for which there are abundant resources. Accordingly, we have focused on copper and have carried out development of a copper paste that can be formed into an electrode by a screen printing method. However, problems still remain, including oxidation of copper and diffusion of copper into the substrate.

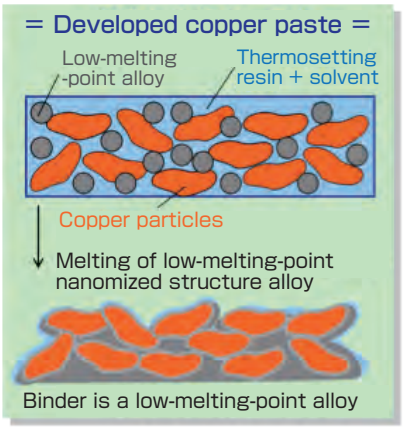


Fig. 1 Developed copper electrode printing method

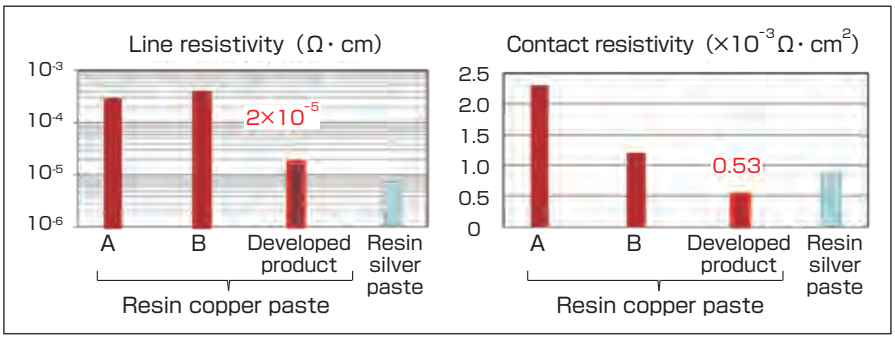


Fig. 2 Electrical properties of the copper electrode

Printing process for copper electrodes with comparable performance to silver electrodes

The oxidation of copper and its diffusion into a silicon substrate was controlled by the use of a copper paste in which a low-melting-point alloy was mixed with copper powder. This paste was used in a low-temperature process to produce copper electrodes that exhibited almost the same performance as those formed using silver paste. The low-melting-point alloy melts at lower than 150 °C, and it diffuses between and into the copper particles and forms metallic bonds by alloying, which improves the conductivity. In addition, due to the fact that this melted alloy covers the copper particles, problems such as oxidation and diffusion of copper into the silicon substrate are avoided. (Fig. 1)

Using this copper paste, a conductor pattern was formed using a screen printing method, and following sintering at 200 °C or lower, the line resistivity was 2×10^{-5} Ω·cm. This is an order of magnitude or more lower than that for commercially available resin-copper pastes and is almost the same as that for commercially available silver paste. It was confirmed that this line resistivity did not markedly change even after 2000 hours at 85 °C and a relative humidity of 85 %. In addition, when a pattern was printed on a transparent ITO electrode used in heterojunction solar cells, which require a low-temperature process, the contact resistivity was lower than that for the silver paste used in current solar cells (5.3×10^{-4} Ω·cm^2) (Fig. 2).

While oxidation of the low-melting-point alloy occurs on the surface layer if it is exposed to high-temperature and high-humidity conditions, almost no oxidation of copper was detected using X-ray photoelectron spectroscopy. In addition,

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no significant diffusion of copper into the silicon substrate was identified by secondary ion mass spectroscopy, even after 6 hours at 230 °C. These results indicate that the alloy is acting as a barrier layer that prevents oxidation and diffusion.

Thus, in terms of the performance required to manufacture solar cells, it is clear that the low-temperature-sintering-type copper paste has high potential as a substitute for the commonly used silver paste.

Future plans

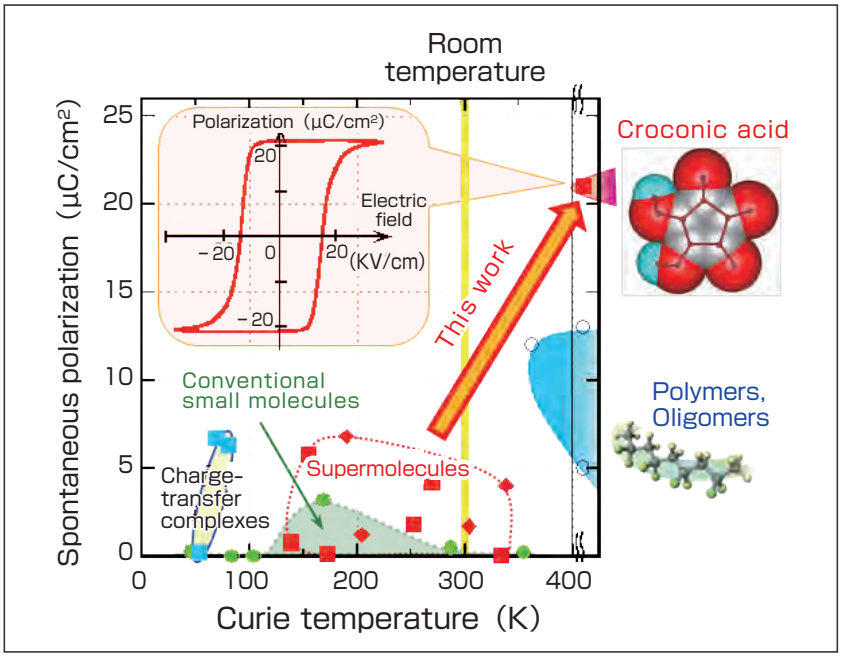
In the future, we will assess the long-term durability and stability of this paste with the aim of early commercialization. In addition, we will evaluate its performance as an electrode material for high-efficiency solar cells in order to achieve low cost and high efficiency.

Printed Electronics Device Team
Flexible Electronics Research Center
Hideo TOKUHISA

Development of Organic Materials that Exhibit High Ferroelectricity

Organic ferroelectrics as potential novel materials

A ferroelectric is one whose electrical polarity can be reversed depending on the direction of an applied voltage, and can maintain its polarity under zero voltage (ferroelectricity). There are a wide range of applications for such materials, including piezoelectric sensors, actuators, capacitors, memory, thermal sensors, and optical elements. Although materials such as $Pb(Zr,Ti)O_3$ (PZT) contain a large amount of toxic lead, they are excluded from the "Restriction of Hazardous Substances in Electric and Electronic Equipment" (RoHS regulations) because of their high ferroelectricity. Nonetheless, the advent of substitute materials is still awaited. Rare metals such as tantalum, niobium and bismuth, for which concerns persist about a future steady resource supply, are widely used in the development of lead-free ferroelectric materials. On the other hand, until recent years, organic ferroelectric materials consisting only of abundant, safe elements have been limited to a few polymers such as polyvinylidene fluoride, and material development has lagged. Today, with the expansion of low-cost, energy-saving printing technology, high-performance novel organic ferroelectric materials suitable for printing processes are in demand, and expectations are rising for new applications that can leverage the large area and shape flexibility.



Comparison of the magnitude of spontaneous polarization and Curie temperature for organic ferroelectric substances
Inset shows polarization properties of croconic acid.

Discovery of organic materials with high polarizability and high operating temperature

We are finding new ways of increasing the ferroelectricity by focusing on

proton or electron transfer mechanisms between molecules, in contrast to past material designs which relied only on the orientational order of permanent dipoles. In recent years in particular, using croconic acid molecules (figure), we were able to realize ferroelectricity with a spontaneous polarization (21 to 22 μCcm^{-2}) approaching that of barium titanate (26 μCcm^{-2}), which is a typical ferroelectric ceramic. The high spontaneous polarization means that the charge density that can be accumulated on the material surface is also high, and not only is this useful for miniaturization of non-volatile memory cells, but it is a starting point for improving the dielectricity (capacitor function), pyroelectricity (sensitivity to heat and temperature changes), and piezoelectricity (ability to convert mechanical and electrical energy mutually). For croconic acid, the phase transition point (Curie temperature) at which the ferroelectricity is lost has not been identified up to 150 °C, and the operating temperature has also increased. As shown in the figure, compared to organic low-molecular-weight ferroelectric substances available until now, both the spontaneous polarization and the operating temperature have been dramatically extended.

Future development

While problems related to processing, including chemical stability, still remain with regard to croconic acid, the same sort of latent functionality has been demonstrated for other organic compounds that have been known for a long time, and materials development to realize the above objective has gained momentum. With the support of the Strategic Basic Research Programs of the Japan Science and Technology Agency (CREST), we are working on the creation of materials that contribute to the development and practical application of material science through evaluation of physical properties, microscopic structural analysis, and material process development.

Flexible Organic Semiconductor Team
Flexible Electronics Research Center
Sachio HORIUCHI

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[1] S. Horiuchi and Y. Tokura: *Nat. Mater.*, 7, 357 (2008).
[2] S. Horiuchi *et al.*: *Nature*, 463, 789 (2010).
[3] S. Horiuchi *et al.*: *Adv. Mater.*, 23, 2098 (2011).

Press Release
March 10, 2010 – “Discovery of Ferroelectricity of Croconic Acid, a Low-molecular-weight Organic Compound, at Room Temperature”

Formation of Organic Single-crystal Thin Film by Inkjet Printing

Printing of thin-film transistors

Printed electronics technology fabricates circuits and elements by printing. One of the main issues with printed electronics is how high-performance thin-film transistors, which are the basic elements of flexible devices, can be fabricated. In particular, for semiconductor layers for which a regular arrangement of atoms or molecules is required to exhibit better performance, a method to control crystallization is needed for forming a highly homogenous crystalline layer by applying microscale ink droplets onto a sheet.

Double-shot inkjet printing technique

By alternate deposition of semiconductor ink containing an organic semiconductor (dioctylbenzothienobenzothiophene) and crystallization ink, we developed a double-shot inkjet printing technique to control the crystallization of semiconductor materials and succeeded in producing a single-crystal thin-film of the organic semiconductor with a molecularly flat surface, which was extremely difficult to realize using conventional printing methods (Fig. 1). By mixing two types of ink on a sheet, the organic semiconductor is immediately in a supersaturated state, and crystal growth gradually starts on the droplet surface. We discovered that by preparing a hydrophilic/hydrophobic surface pattern on the sheet and

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controlling the droplet shape, the direction of crystal growth can be controlled, and a single crystal can be formed over almost the entire region of the thin film. The resulting semiconductor film was quite uniform and had a thickness of 30 to 100 nm depending on the printing conditions. It could be formed with good reproducibility at any position on the sheet (Fig. 2). The process does not require a high temperature or a vacuum process. It can be carried out at almost a room temperature up to about 30 °C, and printing on a flexible substrate such as plastic is also possible.

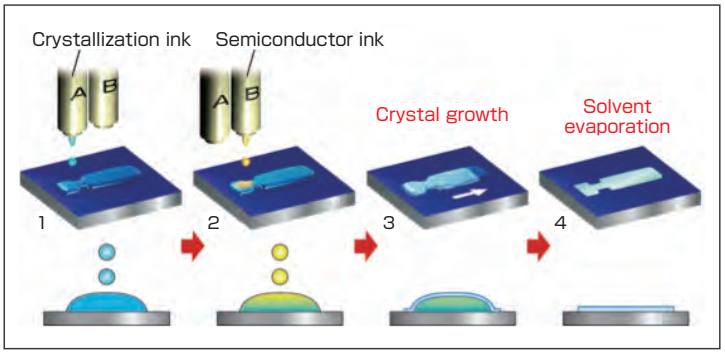


Fig. 1 Conceptual diagram of semiconductor single-crystal thin-film production by the double-shot inkjet printing technique

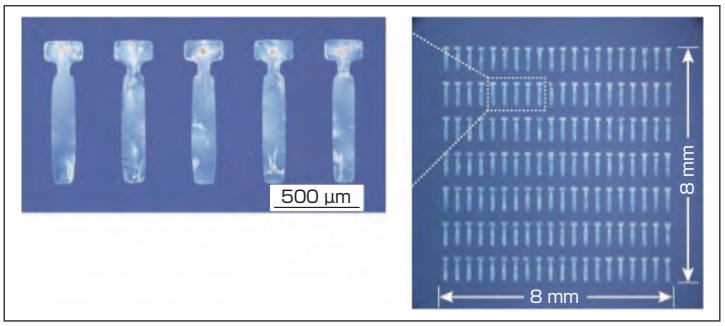


Fig. 2 Fabricated organic semiconductor single-crystal thin-film array

Future development

In the future, we will further optimize the printing conditions, semiconductor materials, and device structure, and improve device performance and stability. In addition, we plan to manufacture high-performance active backplane* with the whole printing process, by combining various printing techniques for metal wires, electrodes and others.

Flexible Organic Semiconductor Team
Flexible Electronics Research Center
Hiromi MINEMAWARI

Glossary

*In a liquid crystal display, the display panel composed of liquid crystal elements is called the front plane, and the panel consisting of drive circuits that control the liquid crystal elements is called the backplane. An active backplane refers to a backplane in which an active element such as a TFT is placed at each pixel and which has an active circuit that can maintain the on or off state even when there is no applied voltage.

References

H. Minemawari *et al.*: *Nature*, 475, 364-367 (2011).

Press Release

August 23, 2011 – "Manufacturing Technology for Single-crystal Thin Films of Organic Semiconductors Using an Inkjet Printing Technique"

Super-Inkjet and Oxygen Pump Technologies for Flexible Electronics

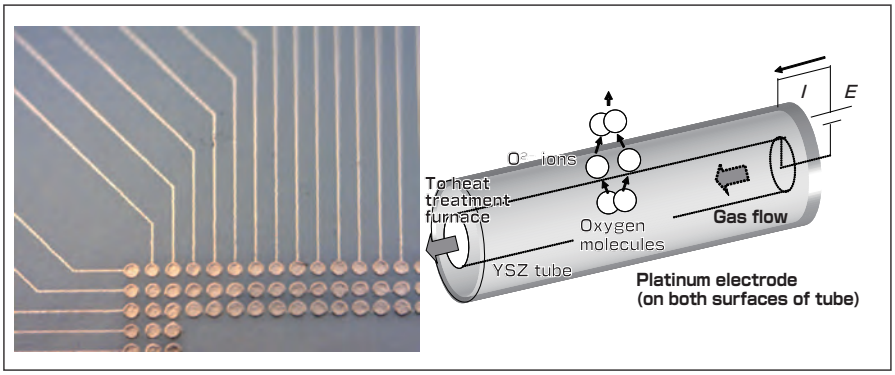
Super-inkjet technology

Instead of high-environmental-load vacuum lithography processes where patterns are formed by milling or dissolving the materials that have been deposited on a substrate, printing methods that make it possible to deposit only the required amount of materials and that can be used under atmospheric conditions

are gaining attention. In particular, inkjet printing is considered a suitable method for large-variety, variable-volume production since it is a maskless printing method and a pattern can be formed simply from a design created on a personal computer.

However, there has been a lower limit of about 1 pL on the droplet volume and the minimum line width has been a few tens of micrometers for the conventional inkjet technologies (piezo and thermal types).

The super-inkjet developed by AIST[1] can discharge droplets with volumes that are 1000 times or more smaller than was previously possible, based on a new electrostatic principle. It has become possible to draw lines with widths of 1 µm or less. Apart from that, inks with viscosities of up to 10 Pa·s can be discharged. In contrast, only low-viscosity, extremely smooth-flowing inks were able to be used in conventional inkjet. In addition, since droplets are so small that drying is almost instantaneous, three-dimensional structures formed by hitting the same spot repeatedly and printing over a step with slanting sides are possible.



Left: Wiring pattern printed on a resin substrate in copper ink by the super-inkjet method
Line width 10 µm.

Right: Schematic diagram showing the operating principle of the oxygen pump
When a voltage is applied across the thickness of the solid electrolyte tube, oxygen is extracted from the gas passing through.

Oxygen pump technology

While minute wiring patterns can be prepared maskless by printing with the super-inkjet technology, it does not necessarily mean that the intended functions will be exhibited merely by putting the material in the right place. We have been attempting the formation of wiring on resin substrates for CPU packages by printing in ink containing dispersed copper nanoparticles. Needless to say, copper is lower in cost than silver, which has been widely used in printed electronics. Copper also has the advantage of having high electromigration resistance when an electric current is passed. We have succeeded in drawing 5 µm line-and-space patterns up to now (figure at left).

However, in the case of copper ink, no conductivity is obtained as printed. This is because the surface of the copper particles is oxidized and hence insulating. To form wiring, it is necessary to reduce the oxidized surface and to sinter the metal particles until sufficient contacts are achieved among them. While there are several methods for reduction sintering, we have investigated a method using an oxygen pump, which is an AIST original technology.

The oxygen pump uses a solid electrolyte known as a fuel cell material. It uses it, however, not as a cell, but instead as a device to extract oxygen by applying an external voltage (figure at right). Copper oxides can be reduced at approximately 200 °C with this technology.[2]

By applying reduction sintering at a low oxygen pressure produced by the oxygen pump to the pattern drawn in copper ink using the super-inkjet technology, a low resistivity of 8 $\mu\Omega$·cm has been achieved.

We are combining the oxygen pump technology with the super-inkjet technology to develop the standard process for fine copper wiring formation by maskless printing.

Functionalizing Process Team
Flexible Electronics Research Center
Naoki SHIRAKAWA

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[1] *Sansoken Today*, 6 (8), 18 (2006).
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Microcontact Printing Method

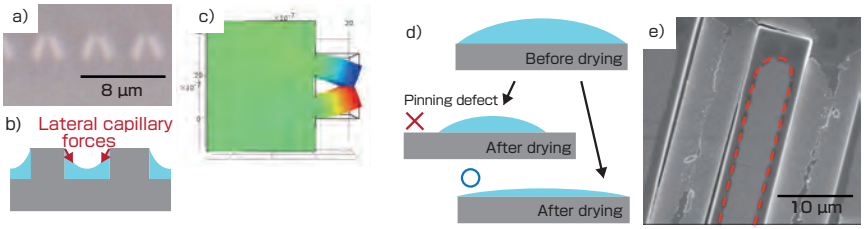
Introduction

We have been conducting various investigations regarding the application of a “microcontact printing method,” which was originally developed for patterning of self-assembled monolayers, as a high-precision patterning method for printed semiconductor devices. To produce patterns finer than 10 μm, we investigated stamp fabrication, inking, and printing processes in which meso-scale interfacial phenomena play important roles.

Meso-scale interfacial phenomena

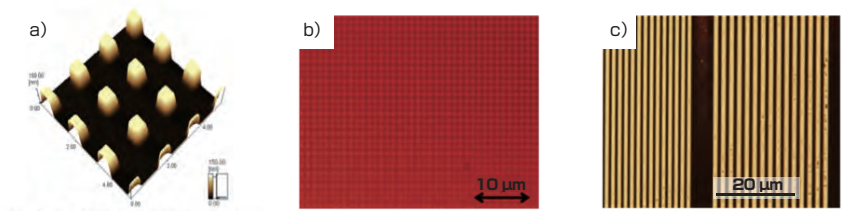
With the microcontact printing method, silicone materials such as Poly(dimethylsiloxane) (PDMS) is generally used as the printing stamp material. Because silicone resin, due to its flexibility, can maintain contact by following the undulations of the substrate surface, it has advantages for large-area electronics applications. However, when the ink dries, lateral capillary forces act at the interfaces of the salient parts of the stamp, which is made of soft silicone resin, and sideways toppling of the salient parts can occur. We have clarified the conditions that suppress print material failures based on the mechanical stability of the stamp material (Figs. 1a, b, and c) and reflected this in the microcontact stamp design guidelines (Figs. 2a and b).

In electronics applications, cross-sectional rectangularity is required even in printed patterns. Generally, the applied ink forms a meniscus (curve formed by interfacial surface tension), and its cross section has a semi-cylindrical shape. In addition, because the ink quantity varies depending on the surface area of the pattern, variations in film thickness are produced. Also, line thinning occurs during drying of the liquid because the ink gathers at the center of the salient part, resulting in poor reproducibility of design dimensions (Figs. 1d and e). We planned to solve these problems by controlling not only the static contact angle, but also the hysteresis angle, dynamic contact angle, and viscoelasticity of the ink, and we have succeeded in printing of 0.8 μm line-and-space patterns using silver nanoparticle dispersed ink (Fig. 2c).



(a) Microscopic image of stamp toppling over
(b) Description of lateral capillary force model
(c) Simulation results
(d) Description of liquid-film pinning defect
(e) Line-thinning of ink pattern on PDMS

Fig. 1 PDMS stamp toppling sideways and line-thinning phenomenon that arise during inking



AFM image of PDMS microcontact stamp made from a silicon wafer mold with a 0.5 μm x 0.5 μm, 0.17-μm-deep dot pattern

A Pattern of rhodamine-B ink printed using a PDMS microcontact stamp (a) (0.5-μm-square dot, 1.0 μm pitch)

A pattern of silver nanoparticle dispersed ink (Left: L/S=0.8 μm, Right: L/S=1.0 μm)

Fig. 2 Rhodamine-B high-precision molecular patterning and silver nanoparticle ink printing by the microcontact print method

Development and applications

We have redefined the microcontact printing method as a printing method that transfers ink without imparting excess printing pressure by controlling wetting phenomena of the stamp surface and soaking dynamics of the ink. We are aiming to expand the applicable scope not only to relief printing but also to gravure, lithography, and a combination of screen printing and lithography. We also plan to manufacture devices such as flexible displays and sensors by high-precision, large-area patterning using the microcontact print method in a manner that saves energy and natural resources, and has a low environmental load.

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Screen-offset Printing Technology

Introduction

Screen printing is a type of stencil printing. Printing is carried out by rubbing ink onto the target object through mesh in a screen mask. Among the various printing technologies, it is the only one that has a track record for mass production of electronics products, and it is used for forming components such as frame electrodes for touch panels. However, as patterns have become finer, problems have arisen such as (i) in the process of ink drying, ink smears occur, and lines become thicker and (ii) irregularities (mesh marks) are left behind on the pattern surface, leading to breaking of the pattern.

Development of screen-offset printing technique

We have developed a screen-offset printing technique to solve the aforementioned problems. An overview of this technique is shown in Fig. 1. First, a highly smooth blanket that absorbs the solvent within the ink is prepared, and a pattern is formed over this by screen printing (Fig. 1(a)). Next, the pattern is transferred from this blanket to the target object (Fig. 1(b)). Figure 2 shows 3-D images of a silver pattern formed by conventional screen printing (a) and by screen-offset printing (b). With screen-offset printing, ink smears are markedly reduced and the rectangularity is maintained. In addition, although not shown in the figure, irregularities in the pattern surface that had been noticeably visible for thin films were flattened by applying pressure during transfer.

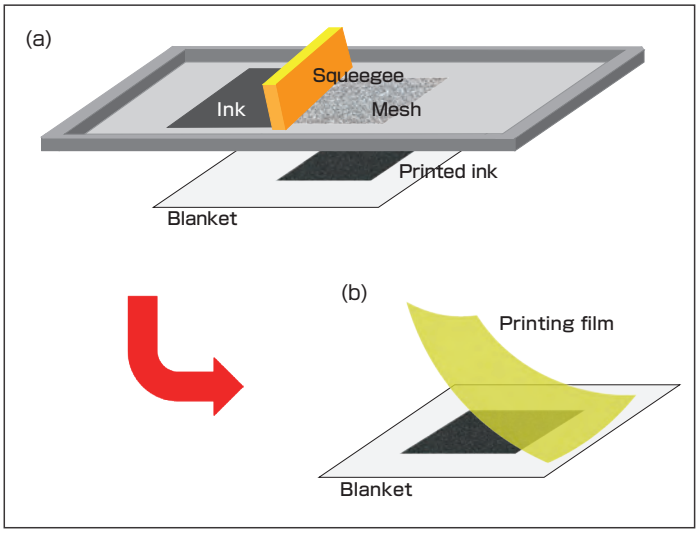

Fig. 1 Conceptual diagram of screen-offset printing

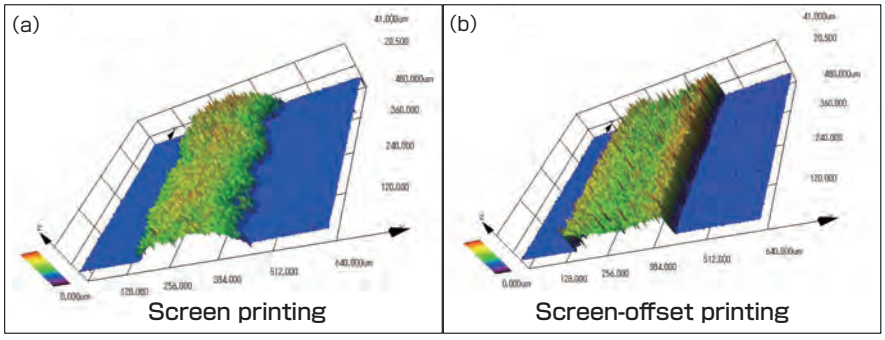

Fig. 2
(a) 3-D image of silver pattern prepared by conventional screen printing
(b) 3-D image of silver pattern prepared by screen-offset printing

Future development

We have introduced screen-offset print technology as a new printing technique that can solve various problems related to screen printing. In the future, we will work on the development of thin, lightweight film-shaped sensors, flexible display elements, and high-precision flexible printed circuit boards using this technique, and contribute to the further development of printed flexible electronics.

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Research Hotline

UPDATE FROM THE CUTTING EDGE

Jul.-Sep. 2013

The abstracts of the recent research information appearing in Vol.13 No.7-9 of "AIST TODAY" are introduced here, classified by research areas.
For inquiry about the full article, please contact the author via e-mail.

Environment and Energy

250 °C switching operation of diamond power diode
Next generation power semiconductor device for energy savings

Diamond is receiving much attention due to its outstanding properties as a power semiconductor material. We have been leading the field of diamond semiconductors from 2005. Recently, we have developed a high performance power Schottky barrier diode (SBD) made of diamond. p type SBD of vertical structure operating up to 1 ampere was developed and mounted in a refractory metal-ceramic type package which can operate in temperatures up to 250 °C. As the device is a "Schottky type" majority carrier device, it can operate at high speed and low loss. Additionally, it can operate at 250 °C that permits the new concept of "cooling system free" operation due to diamond characteritics. We have tested its switching characteristics by using the "double pulse method," and confirmed excellent operation from room temperature up to 250 °C, and also confirmed fast switching of 15 nsec and 60 nJ low loss operation.

For the next step, we are to develop a low defect epitaxial growth technique associated with low defect diamond wafers to confirm actual use over 100 amperes operation.

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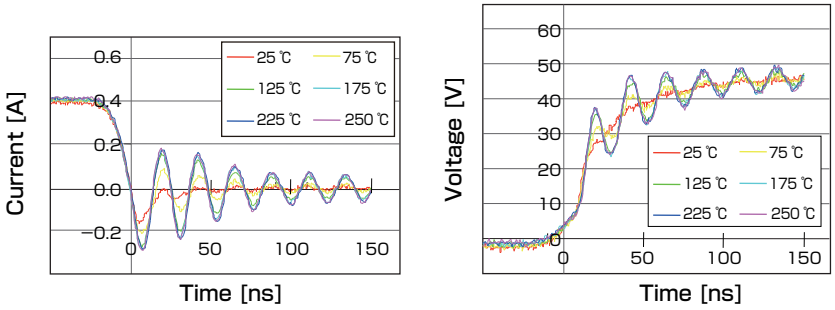

Switching operation of SBD from room temperature up to 250 °C

Development of a new process technology for CIGS solar cells

Toward mass production of CIGS solar cells by all-dry processes

We have developed a new method to fabricate a buffer layer for CIGS solar cells. The new buffer layer is a ZnMgO alloy fabricated by the sputtering method. Advantages of the new method are that (i) ZnMgO is Cd-free and hence is effective to reduce the environmental load, and (ii) the sputtering method is a dry process which is simple compared to wet processes. The conversion efficiency of the CIGS solar cell using the new buffer layer is 17.5 %, which is comparable to that of CIGS solar cells using a conventional CdS buffer layer fabricated by wet processes. This result strongly suggests that we can fabricate high efficiency CIGS solar cells using all-dry deposition processes. We are going to improve our new technology to obtain higher conversion efficiency, and to apply it to large area substrates. These are indispensable for the industrialization.

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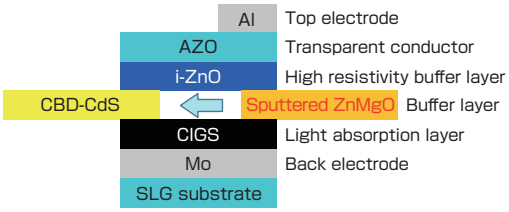
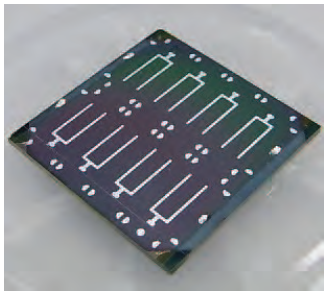


Device structure of CIGS solar cells studied in this work



CIGS solar cell with buffer layer fabricated by sputtering method

Reconstruction of the human evolutionary history using the whole genome sequences

Denial of the interspecies "hybridization" event between humans and chimpanzees

Interspecies hybridization after the speciation between humans and chimpanzees has been a heated controversy in evolutionary biology. Because the whole genome sequences for humans and three great apes are now available, we examined the evolutionary history of the human lineage using a rigid statistical model of genomic sequence evolution. We estimated the products of divergence time and mutation rate for each chromosome between humans and chimpanzees. The estimated values varied significantly among chromosomes, the X chromosome being the smallest value, but the variation could be explained by the variation of mutation rates among chromosomes, not by the variation of divergence times. This means that the speciation between humans and chimpanzees is a single event. In conclusion, we could successfully deny the interspecies hybridization event between humans and chimpanzees.

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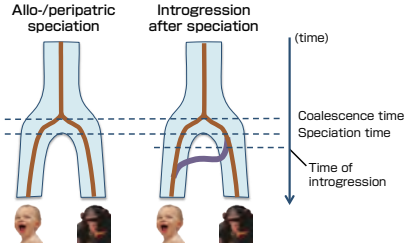
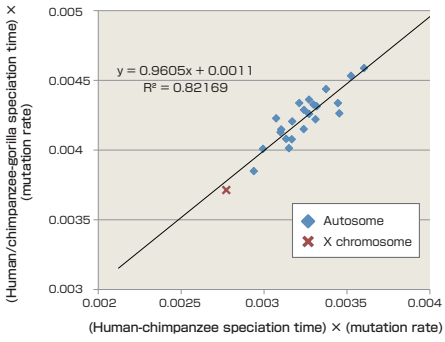


Two contrasting models of speciation between humans and chimpanzees



Products of divergence times and mutation rates correlate among chromosomes

A novel probe for imaging of live human iPS cells

iPS cells can be cultured with monitoring of their quality

In recent years, development of a system to ensure a stable supply of quality controlled iPS cells in large quantities has become important in response to the high expectations held for regenerative medicine. Now, we have developed a highly sensitive lectin probe, rBC2LCN, for iPS cells. rBC2LCN binds to H-type 3 O-glycans on podocalyxin of iPS cells. rBC2LCN allows staining of live iPS cells. This probe shows no-toxicity and can be left in the culture medium, allowing the constant control of iPS cell quality during culture. Moreover, rBC2LCN was successfully used to separate iPS cells from mixed differentiated cells by flow cytometry, suggesting that rBC2LCN would facilitate safe regenerative medicine through removal of residual tumorigenic potential from cells for transplantation. We will evaluate whether transplanting cells treated with rBC2LCN are indeed non-tumorigenic after depletion of iPS cells, aiming at the practical use of the rBC2LCN-based technology in medical treatment.

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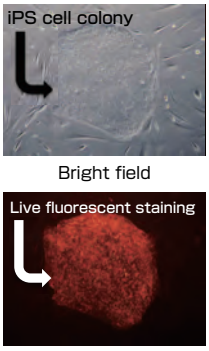
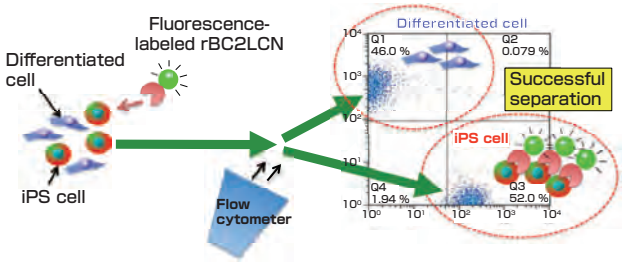


Optical microscope images of live iPS cells stained with rBC2LCN



Separation of iPS cells from differentiated cells using rBC2LCN

Development of handy fuel cell system

A power generator using commercially available LPG cartridges

The developed system employs microtubular solid oxide fuel cells (microtubular SOFCs), and a nanostructure-controlled electrode has enabled the direct use of highly portable general-purpose hydrocarbon fuels, including liquefied petroleum gas (LPG). A prototype handy fuel cell system with a DC 5 - 36 volt microtubular SOFC module was manufactured and demonstrated using a commercially available LPG cartridge. The system was able to drive a DC 5 volt USB device within two minutes. In addition, because only an LPG burner is used for start-up, no external power source is necessary. The rapid start-up and portability of the system mean that it is expected to find application as a power source in emergency and disaster situations and for outdoor use.

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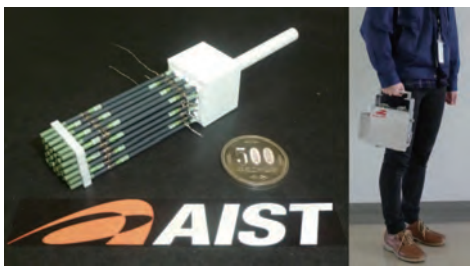
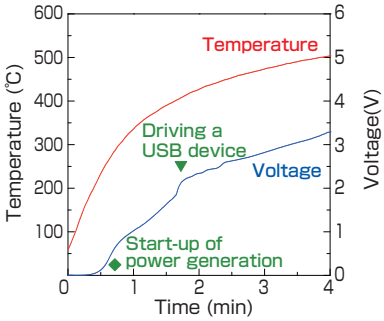


Microtubular SOFC module (DC 5 - 36 volts) (left) and the prototype of handy fuel cell system (right)



Rapid start-up operation with direct butane utilization (When a USB device is connected)

Significant improvement of room-temperature formability of a damping magnesium alloy

Expansion of application range of a magnesium alloy as damping components

We have developed a new rolling process for improving room-temperature formability of a damping magnesium alloy (M1 alloy). In the new rolling process, while a conventional rolling machine is used, the room-temperature formability of magnesium alloys is improved by controlling the annealing temperature and the rolling temperature. The sheet rolled by the new process exhibits excellent room-temperature formability close to that of an aluminum alloy (Erichsen value: 7.9), because the magnesium crystals in the texture of the sheet are less aligned than those of the conventional rolled sheets. The sheet rolled by the new process also exhibits good damping capacity. Thus, it is expected that magnesium alloy products as damping components can be easily processed by press-forming at room temperature.

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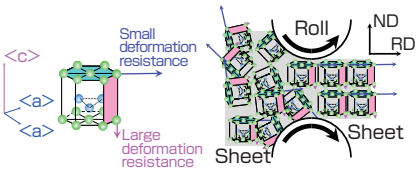
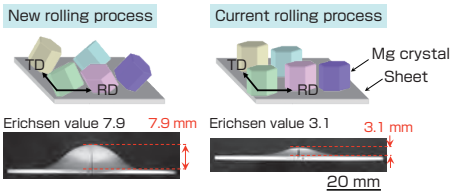


(Left) Anisotropy of deformation resistance of magnesium crystal at room temperature (Right) Texture formation of magnesium during rolling process



(Top) Schematic view of crystal orientation of the M1 alloy sheets processed by the new rolling process and conventional rolling process (Bottom) Results of the Erichsen test for the M1 alloy sheets

Easy-dispersible core-shell type nanoparticles

Expectation for optical film applications

Ceramic nanoparticles attract attention because they are expected to have very unique functions due to their size. Nanoparticles, however, have a big problem that they are easily aggregated, especially in the case of nanoparticles with the size of 50 nm or less. We have developed easy-dispersible core-shell type nanoparticles of which the size is approximately 22 nm. The nanoparticles have a core-shell structure in which the core is cerium oxide with good crystallinity and the shell is a lyophilic polymer, and they can be easily dispersed into water or alcohol.

When the nanoparticles have bad dispersibility, the film including such nanoparticles is generally cloudy. We can, however, obtain highly transparent photo-curing resin films including the core-shell nanoparticles, which have UV cutting property and high refractive index. This film would be used for anti-reflection film. Now we are searching for other applications of the core-shell type nanoparticles.

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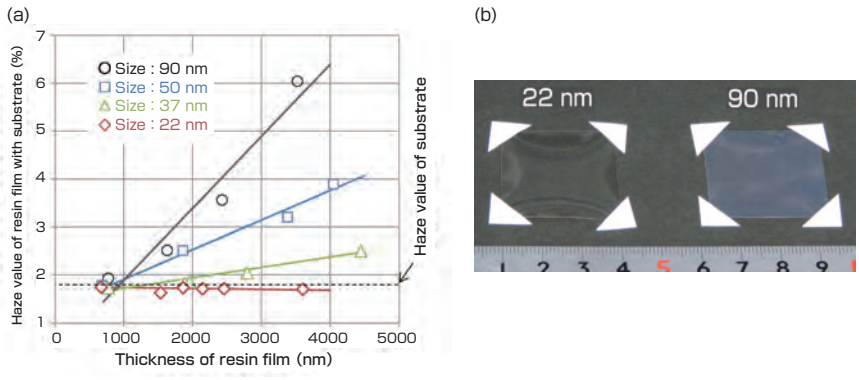

(a) Relationship between thickness and haze value and (b) photograph for photo-curing resin film including 30 wt% core-shell type ceria nanoparticles

Formation of a random laser using submicrometer sized zinc oxide spheres

New application technology using submicrometer sized spheres

We experimentally examined our proposed structure for realizing the control of resonant and lasing properties even in random structures, which was composed of size-mono-dispersive scatterers and intentionally introduced defect regions. In the experiments, we intentionally introduced polymer nanoparticles as point defects into a zinc oxide film composed of mono-dispersive submicrometer spherical particles obtained by laser melting in liquid. We succeeded in the following: drastically improved lasing properties at the defect region compared with those of typical random lasers, suppression of the number of lasing modes, decrease in the thresholds, and limiting the lasing position at the defect. These results suggest the possibility that we can realize single-mode random lasers with well-controlled modal properties even in random structures.

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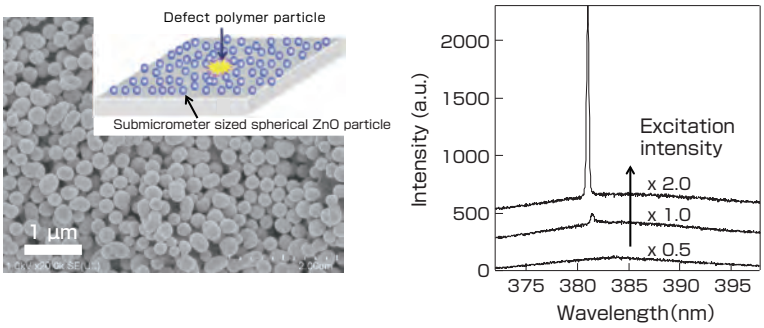

Left: SEM image of thin film consisting of submicrometer spherical ZnO particles
Inset is outline drawing of random laser device using the ZnO particles.
Right: Emission spectra measured at a defect site
The excitation intensities were 0.5, 1.0, and 2.0 times of threshold from bottom to top.

Improvement of metal/plastic adhesion by photo-irradiation

New patterning method for fine metal patterns

We have developed a method for the improvement of metal/plastic adhesion by simple photo-irradiation over metal film formed by electroless plating (ELP). An ELP film coated on a plastic substrate is irradiated with high-intensity pulsed light for a very short time (several hundred microseconds), which causes instantaneous heating of the metal film to a high temperature. As a result, only the interface between the ELP film and the plastic substrate can be heated, thus increasing the adhesion without the damage of the substrate. This method allows us to work with large (over A4-size) metal films in a very short time (order of microseconds). This method also provides a simple metal patterning technique. The irradiation of the pulsed light through a photo mask allows us to produce metal patterns on plastic films. That is, the masked region remains poor in adhesion and can be easily peeled off with adhesive tape.

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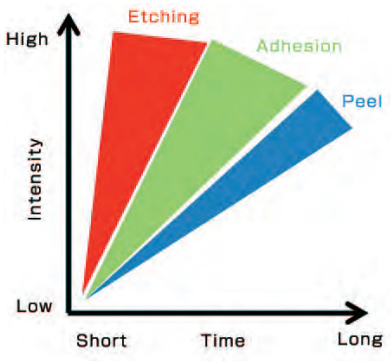

Photo-irradiation condition (intensity and time) for etching, adhesion and peeling of ELP films

Gold film pattern prepared on PET film (top) by the photo-irradiation over a photomask (bottom)

Monitoring of the concentration of radioactive cesium in river water of Abukuma River

Radioactive materials were released into the atmosphere and deposited over wide areas due to the accident at the Tokyo Electric Power Fukushima Daiichi Nuclear Power Plant. Elevated levels of ^{134}Cs and ^{137}Cs have been detected in these areas. It is important to clarify the level of dissolved and total radioactive Cs in environmental water for forecasting the discharge of radioactive Cs from forests and watersheds and assessing the effect of dissolved and particulate radioactive Cs. In this research, we monitored the levels of dissolved and particulate radioactive Cs in river water of Abukuma River using a conventional evaporative concentration method. By monitoring the river waters since September 2012, it was estimated that the levels of dissolved radioactive Cs were less than 0.128 Bq/L and those of total radioactive Cs were less than 0.274 Bq/L in the main stream and branches of Abukuma River in the low suspended solid condition.

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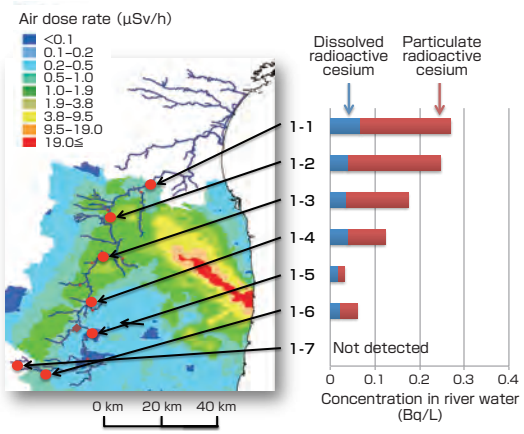

Dissolved and particulate radioactive cesium in the main stream of Abukuma River

Underground permeation of seawater in the 2011 Tsunami disaster areas

Estimation by a helicopter-borne electromagnetic survey

We conducted a helicopter-borne electromagnetic survey over the 2011 tsunami disaster areas in June 2012 to investigate the underground permeation of seawater. This survey revealed that low apparent resistivity layers with resistivity below 20 Ωm, are widely distributed in the shallow underground (depth of approximately 0 to 5 m) over several kilometers from the coastline toward inland areas and that the boundary of the distribution zone almost matches the edge of the tsunami flooding zone. In the deep underground of the distribution zone (depth of 10 m or more), low-resistivity layers resulting from the penetration of seawater from the coast were frequently observed. However, layers of relatively high resistivity were also observed. There is a possibility that fresh groundwater exists near these high-resistivity layers, and this is expected to contribute to the selection of candidate sites for drilling new groundwater wells.

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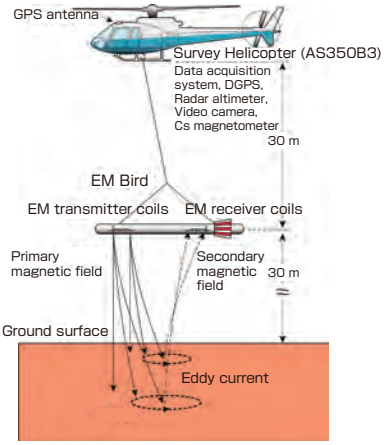


Schematic diagram of the helicopter-borne electromagnetic survey

CNRS-AIST JRL Exhibits at "France-Japan Innovation Ensemble," an Event Organized for French President's Visit to Japan

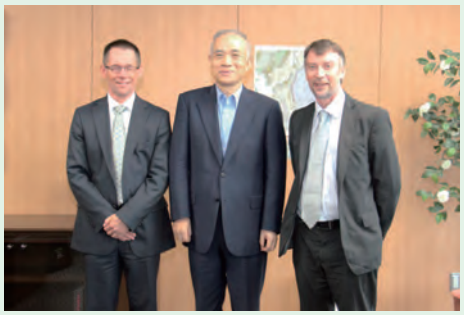
On June 7, 2013, an exhibition, "France-Japan Innovation Ensemble," was held at Shibuya Hikarie Hall on the occasion of the visit to Japan by French President Francois Hollande and his accompanying party. Several international companies and research institutes which are expected to explore innovations through collaborations between France and Japan in the leading-edge fields such as digital robot were introduced at this exhibition. Upon receiving a request of exhibition as a representative successful example of French-Japanese collaborative researches, CNRS-AIST JRL (Joint Robotics Laboratory), UMI3218/CRT took part in this event to show the significance of the collaborative research and gave a demonstration of a humanoid robot.

Minister Fioraso (right) shaking hands with the robot

President Hollande made remarks concerning the importance of further cooperation between the two countries in future industries and service robots. French Minister Genevieve Fioraso responsible for Higher Education and Research and a member of this delegation received an explanation on the achievements of the complementary collaboration presented by AIST Vice-President Kanayama and Director Abderrahmane Kheddar of CNRS-AIST JRL. She stated that much progress is expected from such bilateral collaboration in the future.

AIST Tsukuba Receives Visit from Director Milton of the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, "BIPM")

On July 26, 2013, Director Martin Milton of BIPM and Director Andy Henson of the International Liaison and Communication Department, BIPM, visited AIST Tsukuba to exchange various views with AIST President Chubachi, Vice-President Kawakami and Vice-President Miki.



Director Martin Milton (left), President Chubachi (center), and Director Andy Henson (right)

BIPM is an intergovernmental organization with the administrative office for the Metre Convention and measurement-related research functions located in Sevres, a suburb of Paris, France. It was the first visit to Japan for Director Milton who had been appointed the 13th Director of BIPM in January, 2013. During their talks, President Chubachi expressed his gratitude for BIPM activities and his thoughts on the significance of metrology and measurement science which support industries and innovations. Meanwhile, Director Milton stated his gratitude for the Japanese contribution including that of AIST's technologies and human resources in this field.

Lecture at NMIJ

A lecture, titled "Metrology: Worldwide Achievements and Future Opportunities," was given by Director Milton on the same day at National Metrology Institute of Japan (NMIJ), AIST. A couple of topics were provided during the lecture; the key role of modern metrology originating from the Metre Convention signed in 1875 as a significant techno-infrastructure which supports the modern society, and the redefinition of the SI (the International System of Units) base units along with the innovations of measurement standards. There were active discussions amongst the participants.

Director Milton made a courtesy call on the Ministry of Economy, Trade and Industry on July 29, and left for Korea, his next visiting country.

Cover Photos
Above: A 16 x 16 element printed sensor array (p. 3)
Below: CIGS solar cell with buffer layer fabricated by sputtering method (p. 14)

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