The Best of the AIST

The National Institute of Advanced Industrial Science and Technology is Japan's bridge to nanoproducts.

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THE NATIONAL INSTITUTE OF Advanced Industrial Science and Technology (AIST) is one of the largest public research organizations in Japan with well over 100 years of history, and it has played a significant role to help modernize and spearhead Japanese industry. AIST in its present form (Figure 1), however, is fairly new, since the major reorganization of government-funded labs in 2001. AIST is currently an independent administrative agency, meaning there is a certain degree of freedom from the government, while the majority of the funding is provided by the government as a subsidy through a responsible ministry. AIST reports to the Ministry of Economy, Trade, and Industry (METI).

The Institute is committed to the enhancement of the global competitiveness of Japanese industries and covers virtually all of the industrially relevant fields including life sciences and biotechnology (L&BT); information, communication and computer technology (IC&CT); electronics and photonics (E&P); environment and energy technologies (E&ET); and nanotechnology, materials, and manufacturing (NT&M). Of 2,500 tenured and tenure track research staff,

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FIGURE 1 Main campus of AIST in Tsukuba Science City, a one hour train ride north of Tokyo. The upper twin-peak mountain is Tsukuba Mountain, a symbol of Tsukuba from ancient times.

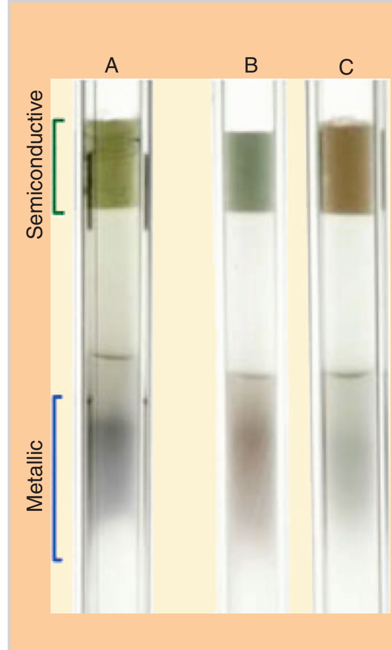

FIGURE 3 Gel electrophoretic separation of semiconductive and metallic single walled carbon nanotubes (SWCNT). (A) SWCNT fabricated by the laser ablation: Diameter = 1.2 ± 0.1 nm. (B) SWCNT fabricated by CVD: Diameter = 1.0 ± 0.3 nm. (C) SWCNT fabricated by the laser ablation: Diameter = 1.4 ± 0.1 nm. Note the difference in color reflecting the SWCNT diameter.

17% are said to be active in the nanotechnology, materials, and manufacturing areas. A caution must be exercised, since nanotechnology and materials are actually becoming a more important basis for all other technologies, thereby making this number a gross underestimate. AIST also has 6,000 temporary research staff such as post-doctoral fellows, visiting researchers from private companies, and graduate students from universities.

Given the interdisciplinary nature and wide range of applications of emerging nanotechnologies, the coverage of AIST is of great advantage to seamlessly bridge nanoscience to nanoproducts. The institute is keen to transfer its proprietary technologies to industry as the number one owner of patents (>10,000) in the public sector. Taking advantage of the wide coverage of technology, AIST is taking a unique approach called "IP inte-

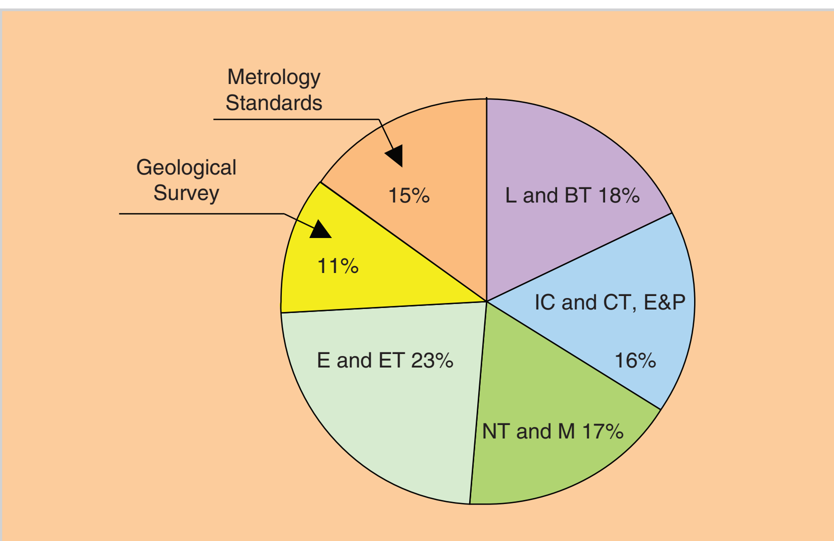

FIGURE 2 Distribution of research manpower in the covered fields. AIST, like the NIST in the United States, is responsible for maintaining and supplying the scientific and industrial standards in addition to its mission to conduct basic and applied research for Japanese industry.

TABLE 1 Research Groups of NRI.

- Nanotheory and simulation
  - Nanomaterials Theory Group
  - Nanosimulation Group
- Nanomaterials
  - Nanostructured Materials Group
  - Molecular Smart System Group
  - Synthetic Nanofunction Group
  - Soft nanosystem Group
  - Self-assembled Nanoelectronics Group
- Nanodevices
  - Superior Nanostructure Group
  - High Temperature Quantum Electronic Group
  - Near-field Nanoengineering Group
- Nanoprocesses
  - Micro- & Nanospace Chemistry Group
  - Nanofluidics Research Group
- Nanomanufacturing
  - Collaborative Research Team of Super Inkjet Technology
- Nanobiomedicine
  - Nanobiomedial Technology Group
- Nanotools
  - Nanoscientific Measurements Group
  - Collaborative Research Team of Mesotechnology

gration" (IP: Intellectual Property) to provide industry in need with a viable solution consisting of the pool of relevant AIST patents as well as current know-how.

The annual research and development (R&D) budget of AIST is approximately US$1 billion, of which some 70% comes from METI as a subsidy, and the competitive grants account for most of the other 30%. Although AIST is strongly committed to promoting collaboration with industry, the commissioned fund from private companies is still 3%.

The R&D structure of AIST consists of 28 research centers and 21 research institutes. A research center is a small- or medium-sized research organization (the number of most tenured staff is less than 30), being operated under the maximum seven-year term basis. Research centers are mission driven and conduct focused research on topics of an urgent industrial, political, or national need such as fuel cells and solar energy (Figure 2). Research institutes are bigger in size, do not have a fixed term, and cover a wider range of research topics from basic science to product development.

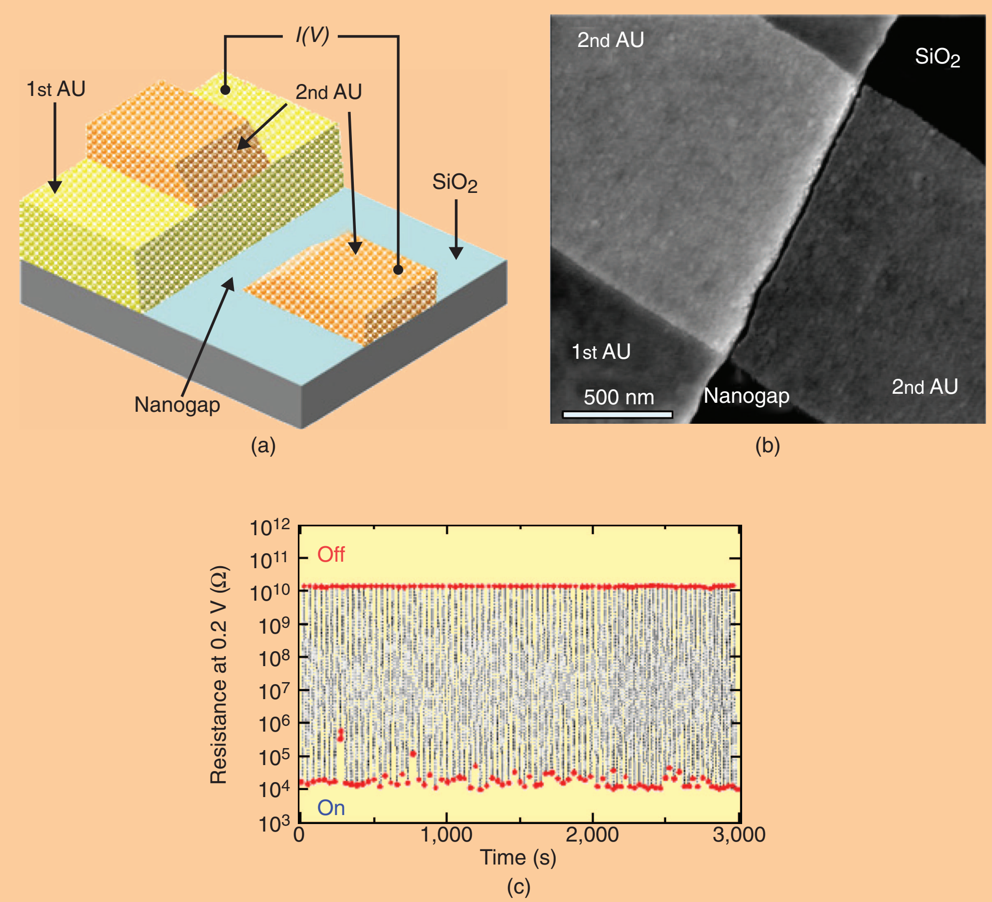

FIGURE 4 (a) Schematic drawing of nano-gap memory device as fabricated by a self-aligning shadow-mask process, (b) SEM image of the nano-gap electrodes, and (c) Switching behavior. The on-off ratio remains stable even after 10,000 cycles.

GET IN LINE

Nanotechnology is one of the prioritized areas in AIST, in line with the government policy set by the Council of Science and Technology Policy (CSTP) in the Second and the Third Basic Plan of Science and Technology. The Nanotechnology Research Institute (NRI) is one of the 21 research institutes in AIST focused primarily on nanotechnology. NRI was established in 2001 at a time of reorganization and doubled its size in the past seven years. It now houses 100 tenure/ tenure-track research staff, with virtually all of them achieving beyond the Ph.D. level, and 200 or more temporary researchers and technicians. The annual research budget relies more heavily on competitive grants than the AIST average, which accounts for over 50% of the total budget of US$20 million. As a consequence of dependence on competitive grants, the R&D budget may largely fluctuate. NRI is committed to the advancement of the wide spectrum of nanotechnology from quantum computing to advanced manufacturing to help industries develop knowledge-based, high-value added, and market competitive products with the highest possible environmental compatibility. Table 1 contains the list of 14 research groups and two collaborative research teams in the NRI, the latter being an ad hoc group with a specific and short-term

> NRI is committed to the advancement of the wide spectrum of nanotechnology from quantum computing to advanced manufacturing.

R&D agenda under a close relationship with private companies.

The NRI operation is not limited to Tsukuba. There is one research group (Micro- & Nano-space Chemistry Group) in Kyushu, the southern big island of the Japanese archipelago, whose R&D is focused on microfluidics. We also have a Synthetic Nanofunction Group in AIST Kansai Center, located near Osaka, the second biggest city in Japan next to Tokyo. There, novel nanomaterials are being developed such as lower dimensional materials for thermoelectric generation, smart inorganic nanocapsules for drug delivery, and organic semiconducting materials with liquid crystallinity.

HIGHLIGHT REEL

The carbon nanotube (CNT) is one of the hottest research areas in AIST's nanotech R&D with over 50 working research staff members in the NRI and the Research Center for Advanced Carbon Materials. Sumio Iijima, its director, discovered CNTs in 1991. Although a wide variety of CNT applications have been anticipated for the past ten years (such as hydrogen storage, fuel cells, high-density capacitors, wires in integrated circuits, and molecular FET along with more conventional uses as reinforcing materials, fundamental materials scientific), issues still remain in terms of the precise control of their structures. Single-walled CNT (SWCNT) can be metallic or semiconductive depending on the chirality, in other words, the way in which the mother graphite sheet is rolled to form the tube. FET applications require only semiconductive SWCNTs, while only the metallic CNTs are good for the integrated circuit wires and transparent electrodes. Unfortunately, there is no method or even a sign of a solution as how to selectively grow either of the metallic or semiconductive SWCNT. Available SWCNT samples, regardless of the growth method, are a mixture of about 1/3 metallic and 2/3 semiconductive nanotubes, and researchers worldwide are searching for an effective, easy, and cost-competitive technology to separate or purify the SWCNT mixtures to get pure metallic or semiconductive SWCNT for their applications.

Hiromich Kataura and Takeshi Tanaka, a group leader and a staff scientist at NRI, recently came up with an ingenious idea that could be an ultimate solution. Figure 3 shows their technique to separate metallic and semiconductive SWCNTs virtually without loss by extending the agarose gel electrophoresis, well-known for its use in DNA analysis. The unique feature of their technology is that the SWCNT solution is not applied to agarose gel as in the conventional gel electrophoresis, but they mix SWCNT and agarose together, and the solution is gelated. Electrophoresis starting with this mixed gel gives rise to a surprising result that only the metallic SWCNT is transported downstream, while the semiconductive SWCNT remains in the gel. A single shot of electrophoresis completes in ten minutes and yields >95% pure metallic and semiconductive SWCNT. There is as yet no explation why semiconductive SWCNT is kept in the agarose gel, but it is easy and it works.

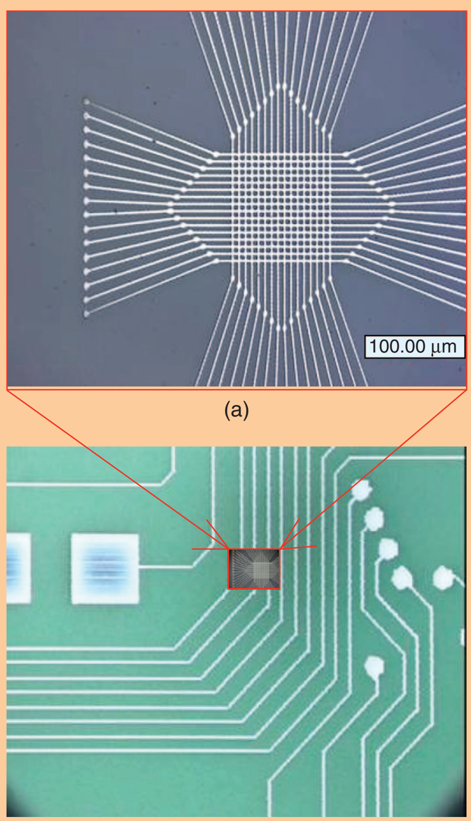

FIGURE 5 (a) 70 μm-wide metal lines fabricated by a (b) conventional inkjet printer in comparison with few-micron wide lines made by the super-fine inkjet.

NANO-GAP RESISTIVE MEMORY DEVICE

"Beyond CMOS" are now the hotly debated keywords in the next generation semiconductor technology, which is ever shrinking the design rule toward 10 nm. Although nobody knows for sure what will be the winning solution, candidates are abundant including the SWCNT FET as mentioned above. Yasuhisa Naito, a member of the research staff of Molecular Nanophysics Group at NRI, developed a truly nanometer scale device consisting of a pair of metal electrodes separated by a narrow gap less than 10 nm. This two-terminal device works as a nonvolatile memory with a low and a high resistance states: The on-off ratio is typically 10^6. Since the gap must be less than 10 nm, the switching is thought to be associated with the voltage-induced protrusion formation and annihilation that drastically modulate the electron tunneling through the narrow vacuum gap. This effect was first observed for gold on silicon dioxide as shown in Figure 4, but later studies showed that almost any kind of metal can be used. The simple structure and ease of fabrication are an especially attractive feature of this device, which should make the nano-gap memory a good candidate of something beyond CMOS.

SUPER-FINE INKJET PRINTING

In line with our efforts to make the manufacturing industry more environmentally sustainable, cost effective, and more flexible, which we call "minimal manufacturing," the so-called printable electronics is an immediate and central target of nanotech R&Ds in AIST. The printable electronics, making the whole electronic products by printing rather than the vacuum deposition, plating, and etching, is believed to pave the way to the use of electronics in a science fiction-like manner such as wearable computers. The realization of printable electronics entails integration of a wide range of disciplines and technologies. Roughly speaking, however, apart from its industrial viability, the development of functional inks and on-demand printing technologies is essential.

Shown in Figure 5(a) is a micrometer-sized metal wire pattern directly fabricated on substrate by our super-fine inkjet printer, which is capable of printing even sub-micron width lines and dots. Figure 5(b) shows a pattern made by a commercially available industrial inkjet printer, showing the drastic difference in the spatial resolution of printed patterns. The super-fine inkjet (SIJ) was invented by Kazuhiro Murata, leader of the Collaborative Research Team of Super Inkjet Technology at NRI. The SIJ rests on the electrostatic ejection of liquid ink drops from an extremely small nozzle aperture. The very sharp apex of the liquid apex results in a strong concentration of electric field that generates a large enough pulling force to counter the surface tension. The SIJ has a number of advantages in addition to the high resolution; the most notable is the lateral precision of deposition, since the electric field can navigate the charge droplets down to the deposition points. Based on this property, the SIJ can be used to create a high aspect ratio or three-dimensional structures as well. After five years of collaboration with major Japanese companies, Kazuhiro Murata created his own start-up company, SIJ Technology, Ltd., in Tsukuba. They started supplying their first model of lab scale super-fine inkjet machines.

The NanoProcessing Facility is providing both external and internal users with state-of-the-art equipment and technical services.

NANO NETWORK JAPAN

Similar to the National Nanotechnology Infrastructure Network (NNIN) in the United States, the Japanese government started the Nanotechnology Support Program in 2002. It ended in 2007 and was followed by a new five-year program entitled Nanotechnology Network Japan. The NanoProcessing Facility (NPF) operated by NRI on the Tsukuba Campus of AIST is one of the 13 core facilities under this program and provides both external and internal users with state-of-the-art equipment and technical services. Figure 6 includes photographs of the NPF with 600 m^2 clean room, which is split into three sections with class 100, 1,000 and 10,000. This is a general purpose facility, where researchers are able to process and characterize virtually any type of materials including those that are organic and biological. There are about 300 registered users with approximately 1/3 of them from industry. Users can register online at http://www.nanoworld.jp/nppp/index_e.htm).

ABOUT THE AUTHOR

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FIGURE 6 AIST NanoProcessing Facility (NPF) in Tsukuba Campus of AIST. AIST NPF is a communal facility equipped with 50 state-of-the-art nanofabrication and nanocharacterization machines, and is open to both AIST researchers and external users virtually free of charge.