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- Future Fusion Technology
- Nano-Science
- Materials Science & Technology
- Intelligent Systems
- Energy & Environment
- Life Science
- Natural Products

KIST is working to turn your dreams into reality



Damian Aguiar, Infinite Time, Infinite Color, Infinite Memory



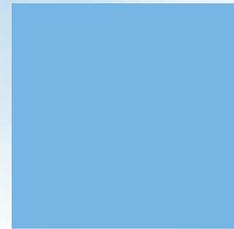
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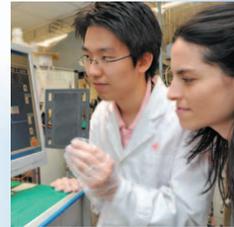
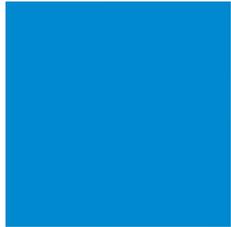
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Leading to the world of tomorrow

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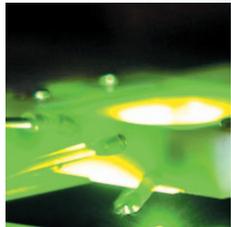


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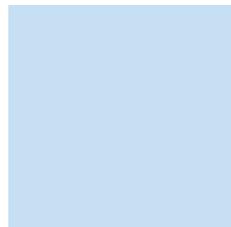
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Foreword



Since its inception in 1966, KIST has played a significant role in Korea's rise to its current position as the 10th strongest economic power in the world. During that time, KIST has emphasized the advancement of fundamental science through the understanding of natural phenomena and built impressive research expertise in materials, nanotechnology, energy, the environment and biotechnology. It is now poised for further distinction as a global research institute responding to the challenges of the 21st century.

KIST believes that the goals set for the new century are best achieved through international cooperation, and as a result, has established relationships with 51 organizations from 24 countries, including the U.S.A., Japan and Germany. Other examples of our global commitment include the opening of KIST Europe over ten years ago in order to promote scientific and technological cooperation between Korea and the EU countries, and the establishment and operation of our own on-site labs at MIT and Carnegie Mellon University in the U.S.A. We are proud of the fact that both the Institut Pasteur Korea and the DuPont Korea Technology Center have selected KIST as a location to perform research in advanced technology.

KIST recognizes the profound benefits of shared knowledge and has been transforming both its site and management system to create a welcoming and supportive environment for foreign scientists. The commitment to cooperative research is further reflected in KIST's education program, known as the International R&D Academy (IRDA), in which skilled scientists from many countries are selected to receive graduate training.

With the launch of *KISToday* we hope to share some of the activities, experiences and achievements of KIST with our global partners and friends. We look forward to keeping you informed of further developments at our institute over the coming years.

July 2008
Dongwha Kum
President

Recent Research on Proton Exchange Membrane Fuel Cells

HYDROCARBON-BASED SULFONATED POLYMERS ARE VERY PROMISING SUBSTITUTES FOR NAFION-TYPE POLYMERS IN FUEL CELL MEMBRANES BECAUSE THEY CAN BE SYNTHESIZED RELATIVELY EASILY AND INEXPENSIVELY.



INTRODUCTION

Much attention has been focused on fuel cells because of their high conversion efficiency and clean operation. Among fuel cell types, proton exchange membrane fuel cells (PEMFCs) show the most promise as a new energy source. This is because they can be operated at reasonable temperatures (5-200 °C) and start-up time is relatively short. Also, performance deterioration as a result of repetitive on/off operations is low compared to other types of fuel cells such as molten carbon fuel cells (MCFCs) and solid oxide fuel cells (SOFCs). Even though PEMFCs outperform other types, there are still some obstacles blocking their successful commercialization. The Center for Fuel Cell Research (CFCR) at KIST has focused on the development of new technologies to address these issues. This review summarizes recent PEMFC research activities in the CFCR. Part I describes the potential for using low cost hydrocarbon-based polymer electrolytes to expand the temperature range at which PEMFCs can operate. ① ② Part II describes the development of a unique way to reduce the degradation of the membrane electrode assembly (MEA) during on/off operations in a PEMFC. ③ Part III addresses water removal techniques for PEMFC operation under subfreezing temperatures. ④ Finally, MEA fabrication for PEMFC operations under non-humidified conditions is presented in Part IV. ⑤

PART I. DEVELOPMENT OF HYDROCARBON-BASED POLYMER ELECTROLYTES FOR FUEL CELL MEMBRANES

The membrane used in an MEA is particularly crucial as it determines the performance of the PEMFC. Perfluorosulfonated Nafion-type electrolyte membranes are commercially available and the most commonly used in PEMFCs owing to their excellent performance and long term stability. However, their application is greatly limited by their high cost and poor performance above 80°C when they suffer conductivity loss through dehydration. Hydrocarbon-based

sulfonated polymers are very promising substitutes for Nafion-type polymers in fuel cell membranes because they can be synthesized relatively easily and inexpensively.

KIST's CFCR has successfully synthesized a new hydrocarbon-based polymer electrolyte for PEMFC operations. This polymer (PES60) contains aromatic ether and sulfone linkages which are relatively stable groups when under hydroxyl radical attack. Figure 1 shows the cell performance of MEAs with commercially available Nafion 112 as compared to PES60. The cell performance of the MEA using the PES60 membrane was 730 mA/cm² of current density at 0.6 V, lower than that of Nafion 112. This could be related to inappropriate interfacial contact between the PES60 membrane and electrodes since Nafion binder was used for electrode fabrication. If better MEA fabrication conditions were established, performance would likely be improved.

Generally, a PEMFC is operated below 90 °C. Above that temperature, the electrolyte membrane loses water, resulting in low cell performance. Instead of sulfonated polymer, however, acid-doped polybenzimidazoles (PBIs) have high proton conductivity above 120 °C. Figure 2 shows the structure of PBI derivatives. High operating temperatures (above 120 °C) are desirable in PEMFC operations because the CO tolerance of catalyst improves at high temperatures. Also, high temperature operations improve thermal management and increase reaction rates by activating Pt catalyst.

The CFCR has developed a unique membrane fabrication method for PBI derivatives. These derivatives are prepared in polyphosphoric acid (PPA) at 200 °C. When polymer mixtures of high molecular weight heterocyclic polymers such as PBI in PPA are cast into films, a transition from a solution state to gel state is observed during the hydrolysis of the solvent from PPA (a good solvent for PBI) to PA (a poor solvent for PBI). The resulting membranes retain high levels of phosphoric acid in the gel structure and exhibit high ionic conductivities and stable mechanical properties at elevated temperatures. The MEA with phosphoric acid-doped PBI for PEMFC operation above 120 °C shows excellent potential for residential PEMFC applications.

The MEA with phosphoric acid-doped PBI for PEMFC operation above 120 °C shows excellent potential for residential PEMFC applications.

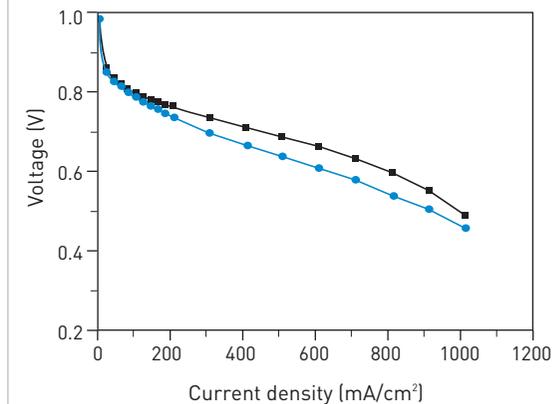
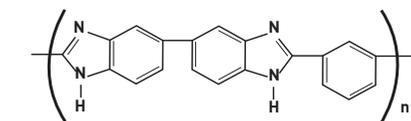
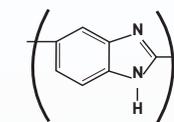


FIGURE 1. Polarization curves for MEAs using PES60 (●) and Nafion 112 (■) with the H₂/air (65-70% relative humidity) at 70 °C under ambient pressure.



PBI (poly[2,2'-(m-phenylene)-5,5'-bibenzimidazole])



ABPBI (poly[2,5-benzimidazole])

FIGURE 2. Chemical structure of PBI derivatives.



For the shut-down process of PEMFCs,

it is best to remove water completely, but this consumes a lot of energy and takes time. In order to reduce energy loss and inconvenience,

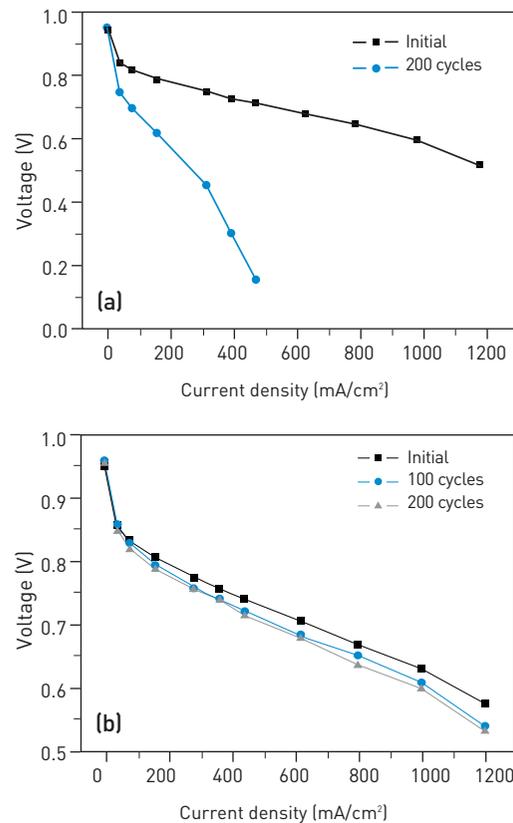


FIGURE 3. Polarization curves with different shut-down processes. (a) open outlets without dummy load and (b) closed outlets with dummy load.

PART II. DEVELOPMENT OF A SHUT-DOWN PROCESS FOR PEMFCs

PEMFC performance degrades as a function of operating time, load (or potential) cycling and on/off repetition. Although the degradation of an electrolyte membrane (Nafion-type perfluorosulfonated polymers) and electrodes (anode and cathode) in MEA have been reported, it is important to note that some of the degradation does not really occur during the actual PEMFC operation in fuel cell vehicles, *e.g.*, operations under a long OCV state or H₂/air potential cycles. If improvements are to be considered for the application of PEMFC to transportation usage, degradation of the MEA during on/off operations should be looked at more closely. It has been reported that the start-up/shut-down process causes the oxidation of carbon support. Research indicates that a hydrogen and air boundary develops at the anode after fuel cell shut-down or during its start-up, thus leading to severe cathode carbon corrosion. In this case, the thickness and catalytic active surface area of the cathode are reduced significantly. The CFCR has investigated several different kinds of situations which could arise during the actual shut-down of a PEMFC, such as the open/closed state of outlets and the application of a dummy load to remove residual hydrogen and oxygen in the electrodes. For the shut-down process of PEMFCs, the CFCR has proposed a better procedure for the shut-down process which lowers the degradation of the MEA in a PEMFC. As shown in Figure 3, the closure of the outlets and application of a dummy load to get rid of residual hydrogen and oxygen in the electrodes are critical elements in mitigating the degradation of the MEA.

PART III. WATER REMOVAL TO IMPROVE PEMFC OPERATION UNDER SUBFREEZING TEMPERATURES

Water molecules in PEMFCs can freeze at subzero temperatures, which makes cold-start capability and long-term durability a great challenge for automotive and outdoor applications. Water produced during fuel cell operation

KIST's CFCR has developed a novel purging technology for measuring residual water in the PEMFC to determine how much should be removed.

forms ice, accumulating in the electrodes, thereby reducing fuel and oxidant diffusion. Therefore, removing the water from PEMFCs is of great importance to improving their start-up ability and mitigating cell degradation when the fuel cells are operated in subfreezing temperatures.

Purging with dry gas at shut-down is one of the simplest and most effective ways to remove water from the fuel cell stack. Research has shown that this purging method is able to prevent cell degradation due to ice formation. Even though it is best to remove water completely, this consumes a lot of energy and takes time. In order to reduce energy loss and inconvenience, a purging method which addresses these two concerns has been a focus of research at KIST. The CFCR has developed a novel technology for measuring residual water in the PEMFC to determine how much should be removed.

Figure 4 illustrates the basic principles of the method for measuring water in a fuel cell stack. In order to measure the total amount of residual water in the stack, a novel method using phase change of liquid water to gas was developed. The main idea behind this method is that the amount of water can be estimated by measuring the change of internal pressure in the stack after all the water in the stack completely evaporates into steam. Two vacuum tanks are used to depressurize the stack; one is for anode, the other for cathode. The tanks are purged with dry nitrogen to eliminate water completely. Then the nitrogen is evacuated from the tanks by a pump. After the fuel cell stack is operated under this specific condition, it is transferred and connected to two tanks, which are kept under reduced pressure, in the climate chamber (Figure 4 (b)). The stack and tanks are maintained at 95 °C for a few hours in the climate chamber to reach an equilibrium state (Figure 4 (c)), and at that point, the pressure of the system is measured. Then, using the ideal gas equation, the residual water amount can be calculated directly from changes in vapor pressure. Using this method, the effects on the residual water amount of several parameters, including purging time, flow rate of purging gas, operation current and stack temperature, are determined.

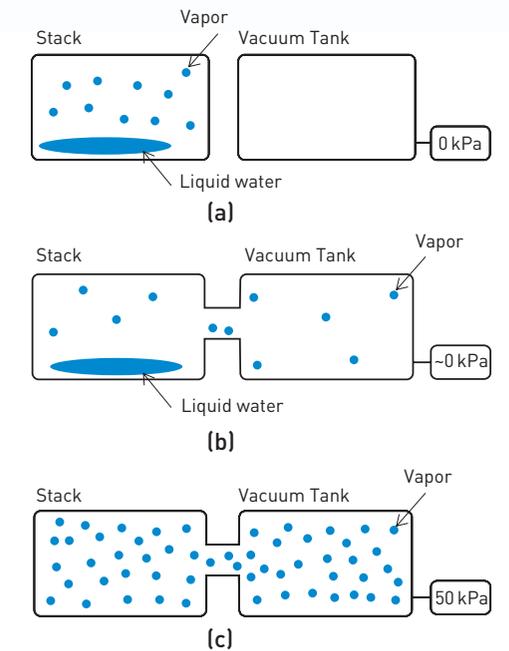


FIGURE 4. Principles of the method using phase change for measurement of residual water; (a) before connecting the stack to vacuum tanks, (b) immediately after connecting and (c) equilibrium state.

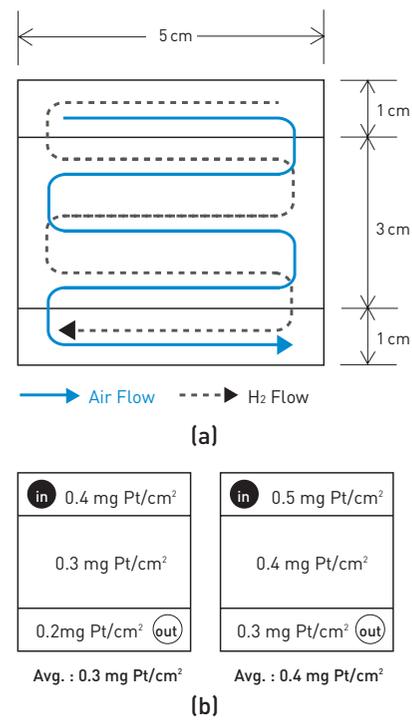


FIGURE 5. The specification of H₂ and air flow (a) and gradient Pt catalyst loading pattern of cathode (b).

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PART IV. MEA FABRICATION FOR PEMFC OPERATION UNDER NON-HUMIDIFIED CONDITIONS

PEMFCs have recently been tested as energy sources in portable electric devices. Since such portable devices impose serious limits on the volume and weight of power sources, it is essential to minimize auxiliary components. Reduction of volume and weight is the major obstacle to commercialization of PEMFCs as portable power sources. One of the most plausible ways for simplifying such a system is to remove the humidifier from a PEMFC system. In general, catalyst is loaded uniformly for PEMFC operation. Therefore, the catalyst loading amount is the same all over the active area of MEA. In reality, however, conditions such as oxygen concentration, relative humidity and the amount of liquid water over the active area are very different. KIST's CFRC has introduced a catalyst gradient coating method which enables MEA to use catalyst more effectively. As shown in Figure 5, a higher amount of catalyst is loaded at the cathode inlet site for gradient catalyst-coated MEA. In this case, more water is generated at the cathode inlet and this water is used to hydrate the MEA, resulting in high cell performance under non-humidified conditions. Therefore, it is possible to operate a PEMFC successfully in portable devices if there is effective water management inside the cell.

CONCLUDING REMARKS

The development of highly efficient and environmentally clean power generation has become a worldwide concern. PEMFCs, which convert the chemical energy of fuels directly into energy, offer tremendous promise as power sources for automotive, stationary and portable power generation in the near future. However, two major factors still stand in the way to the commercialization of PEMFCs. Firstly, the long-term durability of PEMFCs must be increased to at least 5,000 operating hours (including thermal and realistic cycle operation) for automotive applications and 40,000 operating hours for stationary applications. Secondly, the cost of PEMFC components such as electrolyte membranes and catalysts needs to be reduced. As described in this review, the CFRC at KIST has been actively exploring new technologies to meet the durability and cost targets required for PEMFC commercialization. It is now broadening its research scope even further to include the development of a large volume production method for MEA and the fabrication of high performing PEMFC stacks. Other work is being conducted in PEMFC systems which incorporate on-board reformers or hydrogen generators to improve efficiency. These systems would be particularly useful for emergency power supply and military applications.

Nanoparticle Platforms for Molecular Imaging

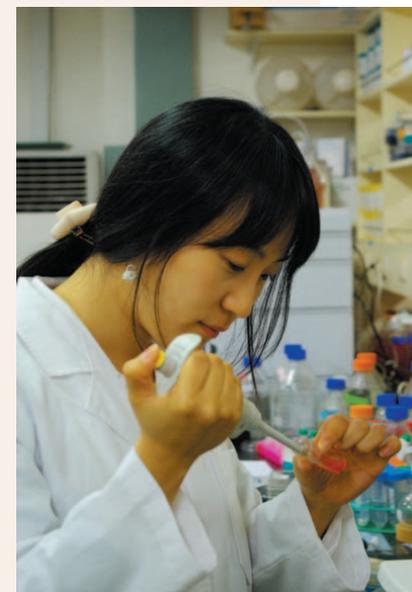


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In 2003, molecular imaging (MI) was introduced by MIT in its *Technology Review* as an emerging technology with profound implications for the identification and treatment of disease. MI enables the non-invasive visualization and tracking of the cellular biological process in living organisms. As a result, MI promises to be particularly effective in the early diagnosis of diseases such as cancer, and in fact, has been touted by the U.S.'s National Cancer Institute as an area of extraordinary opportunity. MI technology also has considerable potential for improving the treatment of disease by optimizing the pre-clinical and clinical evaluation of new drugs.

Recent improvements in imaging instruments and the development of more sophisticated MI probes have expanded the range of the technology still further, allowing researchers to monitor molecular targets in live cells and animals in real-time. Furthermore, interdisciplinary research coupling the imaging sciences to nanotechnology has generated novel imaging probes that exhibit high sensitivity and low background noise for use in living organisms. Among various imaging modalities, the optical imaging technique is particularly well-suited to MI, as fluorescent probes are safe, sensitive and can be specifically applied to small molecules, peptides, and nanoparticles. MI function has seen even greater refinement with advances in polymer and inorganic chemistry which are producing new multifunctional and biocompatible nanoparticle structures. KIST researchers are using their expertise in this area to develop innovative nanoparticle-based imaging probes to improve imaging capabilities.

A number of projects at KIST have involved the study of simple, sturdy, inexpensive and one-step optical fluorescence nanoparticle-based MI probes for use in inhibitor drug screening, detection of target biomarkers, and early detection of disease. Various nanoscale near-infrared (NIR) fluorescence optical imaging probes have been developed by using polymer conjugates,



nanocomplexes, and gold nanoparticles (AuNP) and have been evaluated for their potential applications in biomolecular detection. The imaging probes were designed and prepared by combining biocompatible polymers or AuNP, substrates of target biomarkers (*i.e.*, matrix metalloproteinases (MMPs), protein kinase A, caspase-3), NIR dyes, and quenchers for NIR dyes. These imaging probes demonstrated “no images” in normal conditions owing to the strong fluorescence quenching mechanism, but produced “bright images” by fluorescence recovery when applied to target biomolecules.

Apoptosis is a programmed cell death process in multicellular organisms which plays a key role in the pathogenesis of many disorders like neurodegenerative and cardiovascular disease, and tumor responses to chemotherapy. Because the majority of effective anticancer therapies initiate apoptosis, the use of MI to detect the progression of apoptosis can clinically assist in determining whether a patient’s chemotherapy regimen is working appropriately. The biocompatible NIR fluorescent-activated polymeric nanoparticles developed at KIST have been able to detect early signs of apoptosis in the laboratory. Specifically, apoptosis-sensitive nanoparticles were created by conjugating a caspase-3 (a crucial mediator of apoptosis) cleavable NIR fluorescent dye-peptide substrate to biocompatible polymeric nanoparticles (PEI-DOCA) prepared from a hydrophilic polymer and hydrophobic moiety. It was subsequently confirmed that these polymeric nanoparticles could visualize caspase-dependent apoptosis in living cells (Figure 1). Such an apoptosis-detecting nanoparticle could simultaneously monitor the delivery and apoptotic potential of a drug.

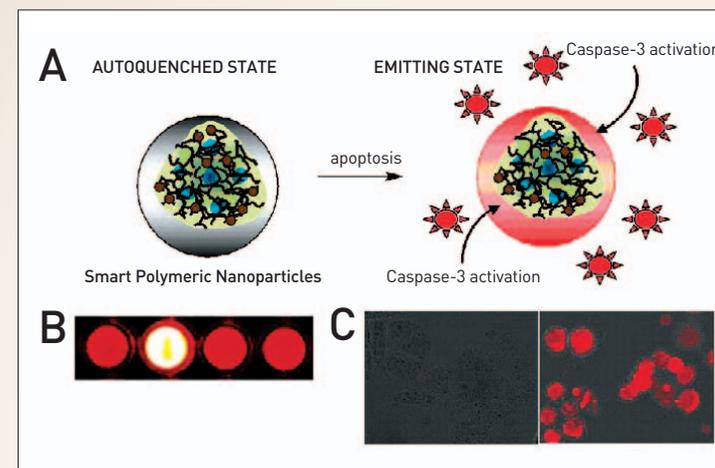
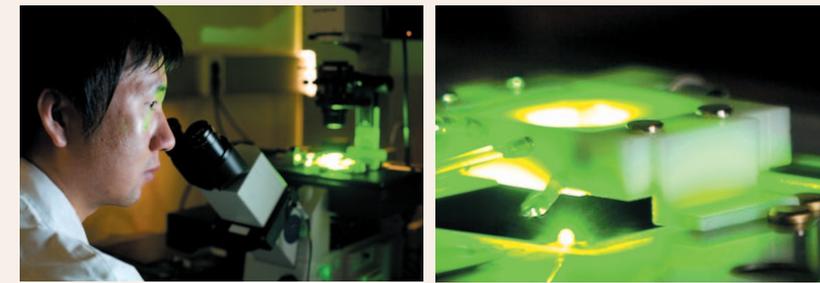


FIGURE 1. (A) Schematic diagram of polymeric nanoparticles for apoptosis imaging. (B) TEM images of nanosized polymeric probes. (C) Fluorescent cellular imaging of HeLa cells incubated with the probe for 1 hour in the presence of TRAIL, a potent inducer of apoptosis. Reprinted with permission from the *Journal of the American Chemical Society*, **128**, 3490-3491 (2006).

The biocompatible NIR fluorescent-activated polymeric nanoparticles developed at KIST have been able to detect early signs of apoptosis in the laboratory.



Protein kinases play pivotal roles in most cell communication and metabolic pathways. Biochemical studies on protein kinases are thus critical to the characterization of signaling disease pathways and the development of therapeutic agents for various diseases, especially cancer. Researchers at KIST recently developed cell-permeable and biocompatible polyion-induced complex (PIC) nanoparticles consisting of a positively charged polymer conjugated to a near-infrared fluorophore (Cy5.5) and protein kinase A (PKA) specific peptide, and a negatively charged polymer. Cy5.5 showed an autoquenched state in the PIC nanoparticle, but the PIC nanoparticle gave rise to strong NIR fluorescence signals in phosphorylated cells (Figure 2). A nanoparticle-based kinases sensor of this type offers considerable potential as an MI probe for detecting protein kinase in single living cells.

Matrix metalloproteinases (MMPs) are a family of zinc-dependent endopeptidases that play key roles in several biological processes including the progression of cancer. As a result, MMPs have been the focus of research associated with new drug development and tumor diagnosis. At KIST scientists have developed biocompatible, cell-permeable gold nanoparticles (AuNPs) that are capable of real-time imaging of tumors in *in vivo* (Figure 3), and by treating them with MMPs, have brought about fluorescent dye release and strong recovery of fluorescent signals *in vitro* systems and tumor bearing mice. These results suggest that the KIST-developed AuNP probe may assist in the simple visual detection of proteases *in vitro* and real-time tomography *in vivo*.

KIST’s work with nanoparticle-based MI probes has demonstrated that multi-quenched smart probes can, through simple visual detection, identify caspase, protein kinase, MMP or inhibitor activity *in vitro* and tomography *in vivo*. Moreover, this platform can be more broadly applied to any target biomolecules. The effectiveness of our unique probe systems in identifying target biomolecules in a rapid and efficient fashion both *in vitro* and in animals highlights the exciting potential of MI probe technology for many important clinical applications.

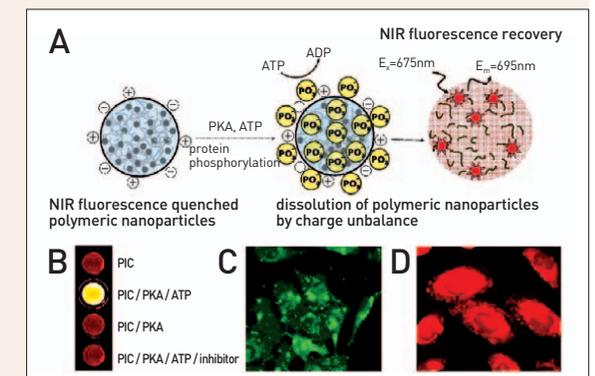


FIGURE 2. (A) Schematic diagram of polymeric imaging probes for protein kinase activity. (B) Fluorescent image from wells containing PIC nanoparticles incubated with PKA stimuli or inhibitors. (C) Cellular uptake of nanoparticles incubated with the probe. (D) Image of the probe incubated in CHO-K1 cells over expressing PKA. Reprinted with permission from *Angewandte Chemie International Edition in English*, **46**, 5779-5782 (2007).

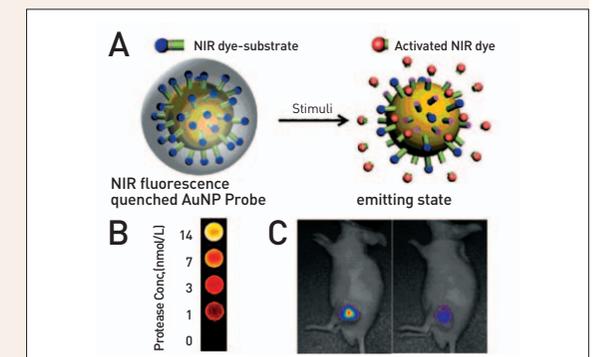


FIGURE 3. (A) Schematic diagram of MMP-activatable AuNP imaging probe. (B) Fluorescent image from wells containing the probe in the presence of various concentrations of MMPs following 2 hours incubation. (C) *In vivo* near-infrared optical imaging of MMP-positive SCC7 xenografts after intratumoral injection of gold probes without (left) or with (right) MMP inhibitor. Reprinted with permission from *Angewandte Chemie International Edition in English*, **47**, 2804-2807 (2008).

Electrochemical Capacitor of Ruthenium Oxide (RuO₂)

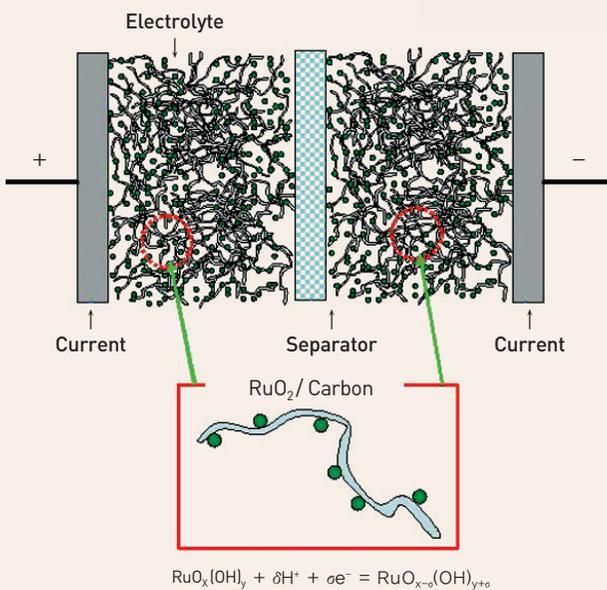


FIGURE 1. Schematic diagram for RuO₂ electrochemical capacitor.

Electrochemical capacitors, sometimes called “supercapacitors” or “ultracapacitors,” are an important research focus at KIST due to their intriguing power and energy density characteristics.

Electrochemical capacitors are symmetrical devices in which an electrolyte is placed between two identical electrodes (Figure 1). While these capacitors can store and deliver charge within seconds, their ability to deliver charge rapidly is dependent on the kinetics of the surface redox (oxidation-reduction) reactions and the combined resistivity of the matrix and electrolyte. Electrochemical capacitors fall into two broad categories: ① double layer capacitors and ② pseudocapacitors that have enhanced charge storage (somewhat similar to a battery) derived from faradaic charge transfer in parallel with the double layer. The double layer, created naturally at an electrode/electrolyte interface, has a thickness of about 10 Å. In order to obtain a high level of stored energy per unit weight or volume, it is necessary to use electrochemically active materials of significantly higher energy content.

The most promising candidates for electrochemical capacitor materials are high surface area-activated carbon and metal oxides, such as RuO₂. KIST research scientists have developed RuO₂ electrodes, made by electrodeposition and spray pyrolysis, which show high capacitance values (Figures 2 and 3, and Table 1)

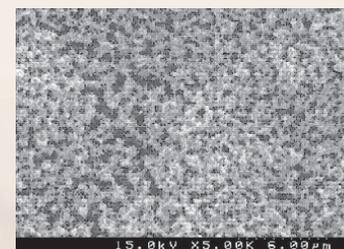


FIGURE 2. SEM images of electrodeposited RuO₂ on Ti substrate (*Journal of Power Sources*, 134, 2004, 148).

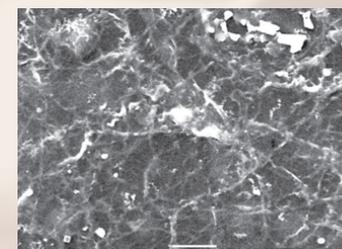


FIGURE 3. SEM images of spray deposited RuO₂ on glass (*Electrochemical Communications*, 9, 2007, 504).

In work performed at the Clean Energy Research Center, MWNT (multi-wall carbon nanotube) was used as a substrate to increase the surface area of RuO₂ (Figure 4).

MWNT was synthesized on a graphite working electrode by chemical vapor deposition (CVD). A solution of 0.05 M Ni(NO₃)₂ · 6H₂O was sprayed on the working electrode which was then dried in an oven for 30 min at 100 °C. Nickel salts on the working electrode were decomposed under argon flow for 2 h at 600 °C and then reduced by hydrogen for 1 h at the same temperature, just before CVD occurred. MWNT was directly grown on an Ni-loaded working electrode via decomposition of acetylene under atmosphere for 3 min at 600 °C in a tubular quartz reactor. RuO₂ was then deposited on the MWNT by a spray method using a ruthenium nitrosyl nitrate solution. Cyclic voltammograms of an MWNT-RuO₂ electrode (2 cm × 0.8 cm) were obtained in a conventional three-electrode system at a scan rate of 10 mV/s with different ratios of RuO₂ to MWNT in weight. (Figure 5 and Table 1)

Results demonstrated that the MWNT-RuO₂ electrode is capable of a higher energy and power density than MWNT alone (Figure 6).

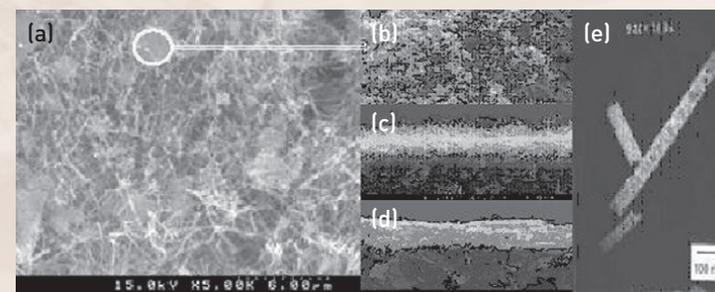


FIGURE 4. SEM images of MWNT-RuO₂: (a) MWNT-RuO₂ electrode; (b) RuO₂ nanoparticles; (c) MWNT layer; (d) MWNT-RuO₂ layer; (e) TEM image of MWNT-RuO₂ electrode (*Journal of Power Sources*, 159, 2006, 1527).

Electrochemical capacitors, sometimes called “supercapacitors” or “ultracapacitors,” are an important research focus at KIST due to their intriguing power and energy density characteristics.

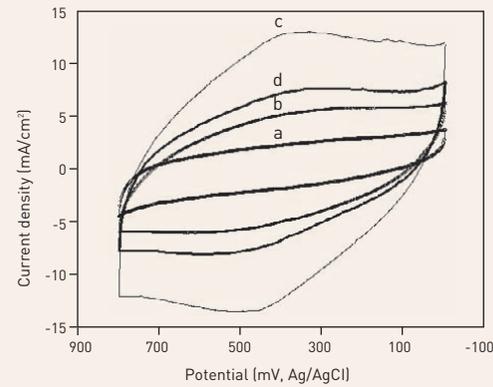


FIGURE 5. Cyclic voltammogram of MWNT-RuO₂ electrode at a scan rate of 10 mV/s. MWNT/RuO₂ = (a) 1.0/0, (b) 1.0/0.5, (c) 1.0/1.0 and (d) 1.0/2.0 (*Journal of Power Sources*, 159, 2006, 1527).

TABLE 1. Specific capacitance of MWNT-RuO₂ electrodes from cyclic voltammograms at a scan rate of 10 mV/s

Weight of MWNT (mg)	Weight of RuO ₂ (mg)	MWNT : RuO ₂	Capacitance (F/g)
1.20	0.00	1.0:0.0	210
0.70	0.35	1.0:0.5	628
2.10	2.10	1.0:1.0	467
1.80	3.60	1.0:2.0	370

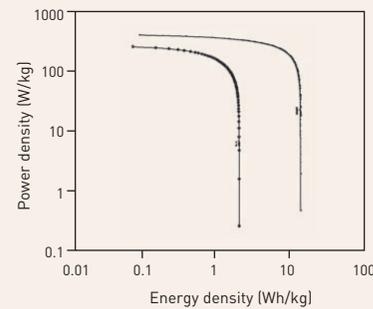


FIGURE 6. Plot of power density against energy density for (a) piranha-treated MWNT and (b) MWNT-RuO₂ electrode (*Journal of Power Sources*, 159, 2006 1527).

TABLE 2. Specific capacitance values achieved with RuO₂ containing thick and thin film electrodes prepared by different methods

Sr No.	Electrode	Method of preparation	Specific capacitance(F/g)
1	RuO ₂ thin film on Ti	Electrodeposition	788
2	RuO ₂ thin film on glass	Spray pyrolysis	551
3	MWNT-RuO ₂ thin film	RuO ₂ impregnated on CVD synthesized MWNT	628

The values of specific capacitances obtained through KIST’s investigation are quite comparable to those obtained with electrodes prepared by other methods (Table 2). However, the electrodeposition and spray pyrolysis methods used for electrode preparation are simpler and more economical than other methods. Since the RuO₂ material is either nanocrystalline or amorphous and has a large surface area, it is ideal for supercapacitor formation. It is thus demonstrated that capacitor properties are strongly related to the preparation method, morphology and material properties of its components.

Tripling Energy Efficiency With Tri-Generation Fuel Cell Systems

Tri-generation is the simultaneous production of electricity, heating and cooling from a single energy unit. Tri-generation systems are also referred to as CCHP systems (combined cooling, heating and power systems). Such systems harness the waste heat resulting from electric generation to produce heat and air conditioning, thus almost tripling energy efficiency compared to more conventional systems that rely on individual energy units to produce separate energy outputs. Tri-generation promises to be an effective technology for coping with high oil prices and for addressing the problem of global warming stemming from excessive energy use.

Combined energy production has already improved energy efficiency with co-generation systems which combine heat and power production. The higher energy efficiency of these systems substantially reduces CO₂ emissions and fuel bills compared to the separate production of energy outputs. However, the high demand for cooling in the summer months seriously offsets the efficiencies gained through co-generation at other times of the year. Thus, the concept of cooling by the utilization of heat energy presents an opportunity to enhance the year-round efficiency of energy generation systems, and tri-generation is being developed to expand the efficiencies gained through co-generation. Up to now, the power generation units adopted for tri-generation systems have been reciprocating engines or turbines, but recently, fuel cells have become a more attractive alternative because they produce significantly lower CO₂ emissions. Among the various types of fuel cells, polymer electrolyte fuel cells (PEFC) and solid oxide fuel cells (SOFC) are showing particular promise for use in future tri-generation systems.

The Energy Mechanics Research Center at KIST is actively researching improvements to tri-generation systems. A fuel cell tri-generation system consists of a fuel cell power



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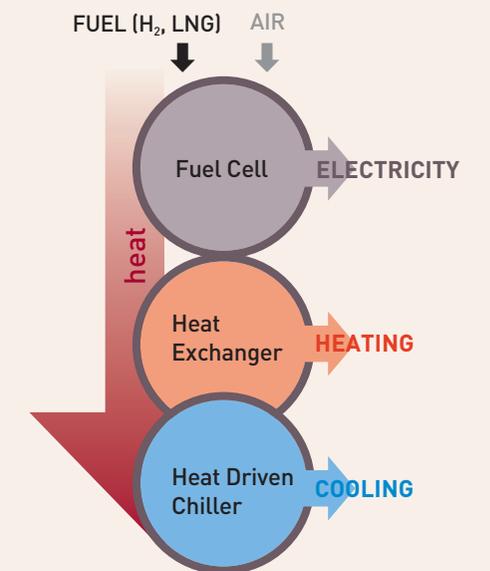


FIGURE 1. Tri-generation fuel cell systems.

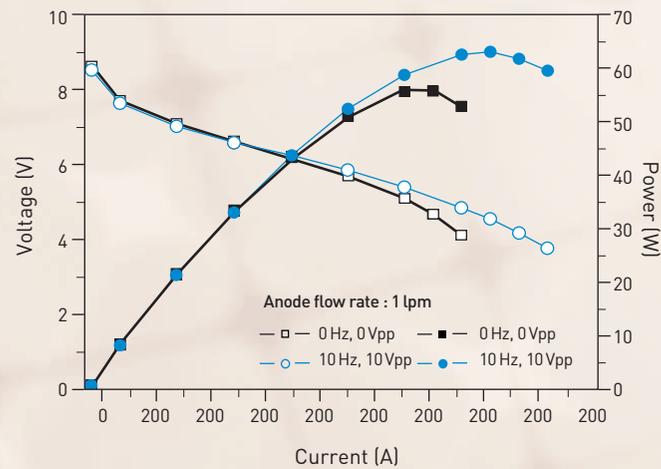


FIGURE 2. Enhanced voltage and power output by the pulse cathode blower.

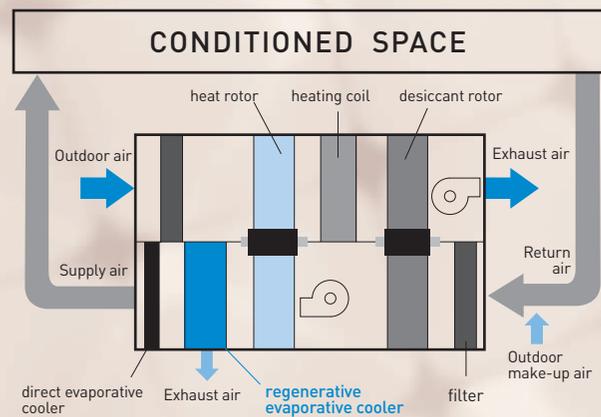


FIGURE 3. Desiccant cooling system.

generating unit, a heating supply unit, and a cooling supply unit, as shown in Figure. 1. The fuel cell power generating unit produces electricity and heat by electrochemical reaction with fuel and air. The byproduct “heat” can be used as a heating source for the heating supply unit. The cooling supply unit also utilizes this heat energy to produce air conditioning.

The fuel cell power generating unit is comprised of a fuel cell stack and a BOP (balance of plant). The fuel cell stack generates electricity. The BOP contains essential components for the reliable operation of the fuel cells including blowers, compressors, pumps, condensers, mixers, gas separators for water and thermal management and electronic circuits for power management. All the BOP components must be systematically integrated for optimum performance of the unit.

The Energy Mechanics Research Center has developed highly efficient BOP components and provided efficient system integration technology for power generating units. One of the outstanding achievements of the Center has been the development of a pulse cathode blower which provides a pulsating air flow into the cathode of the fuel cell. When the pulsating cathode flow is induced with a pulsating frequency of 10 Hz, as displayed in Figure 2, the voltage as well as the power output in the limiting current region dramatically increases, thereby enhancing distribution of oxygen concentration, temperature, and water inside the cathode. The development of such a pulse cathode blower is important for enabling the miniaturization of blowers and the reduction of noise in the power generating unit.

Another important issue for developing efficient tri-generation systems is to produce cooling capacity from heat, such as the waste heat from a fuel cell. Desiccant cooling technology offers a solution to this challenge. In a desiccant cooling system, as shown in Figure 3, air is dehumidified by passing it through a desiccant rotor and then cooling it to the desired temperature using a sensible heat exchanger and evaporative cooler. The heat is applied to the regeneration of the desiccant rotor by desorbing the absorbed moisture in the desiccant rotor. This system works without CFC’s or other similar ozone-depleting chemicals and uses only water as the working fluid.

KIST’s Energy Mechanics Research Center has developed a prototype of a desiccant cooling system which incorporates a regenerative evaporative cooler. Two important components of the system,

the regenerative evaporative cooler and the desiccant rotor, were designed, fabricated and assembled into the system. The regenerative evaporative cooler is able to cool a stream of air using an evaporative cooling effect without an increase in the humidity ratio. It is basically comprised of a pair of dry and wet channels with the evaporation water supplied only to the wet channel. By redirecting a portion of the air expelled from the dry channel into the wet channel, the air can be cooled down to a temperature lower than at intake. The regenerative evaporative cooler was built as shown in Figure 4 by compiling multiple pairs of dry and wet channels. The two channels were separated by a thin flat plate, and metal fins were inserted into both channels to extend the contact surfaces, thereby keeping the cooler compact.

A desiccant rotor was fabricated using a polymeric desiccant newly developed by the Center. To fabricate the desiccant rotor, firstly the polymeric desiccant was prepared by ion modification of the super absorbent polymer and laminated by coating the desiccant on a 0.1 mm thick polyethylene sheet. Then the sheet was corrugated and rolled up into a rotor, as displayed in Figure 5.

Incorporating the regenerative evaporative cooler and the desiccant rotor, a prototype of the desiccant cooling system was built. The exterior dimension of the completed prototype was 700(W) × 800(D) × 1,900 mm(H). The prototype was tested at the standard condition for the performance evaluation of air conditioners. With a regeneration air temperature of 60 °C and a ventilation ratio of 0.3, the prototype showed a cooling capacity sufficient to supply cooling to a floor area of 40 m². The recent achievements of the Energy Mechanics Research Center in the area of tri-generation fuel cell systems is an example of the push KIST is making to develop efficient, clean and sustainable energy systems for the future. This type of innovation will be critical in helping the planet cope with its growing energy needs.

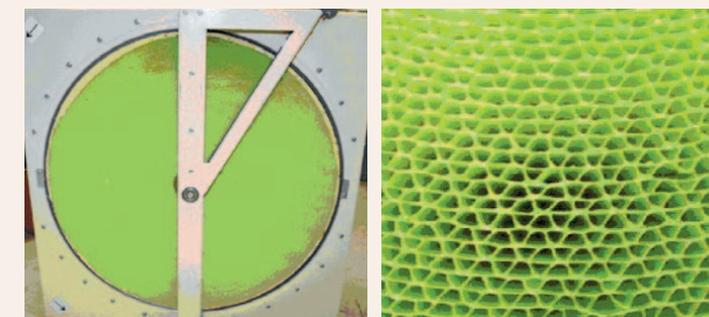


FIGURE 5. Desiccant rotor.

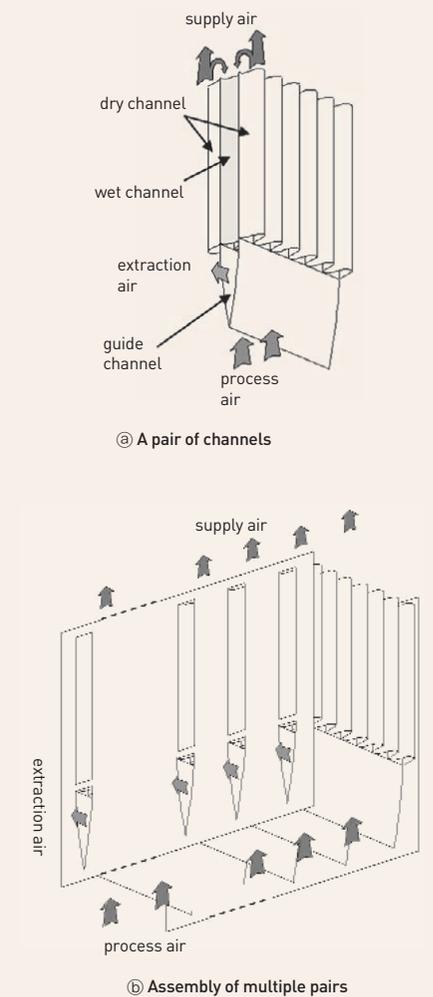


FIGURE 4. Regenerative evaporative cooler.

Understanding Phase-Change



If you want to speed up your PC by replacing only the memory block, Phase-Change Random Access Memory (PRAM), nicknamed “Perfect RAM,” is an excellent option because its speed is 30 times faster than existing flash memory, thousands of times quicker than conventional hard drives and it consumes less power than other forms of nonvolatile memory. Although PRAM has not yet reached the commercialization stage for consumer electronic devices, Samsung has announced the development of a working prototype of 512 Mbit PRAM. A group of researchers, led by KIST’s Dr. Yong Tae Kim, are working with Samsung on breakthrough technologies to make effective prototypes possible.

PRAM’s performance is possible because of the unique switching behavior of chalcogenide glass when heat is applied to the point where the glass is between two states, crystalline and amorphous. All prototype devices make use of a chalcogenide alloy of germanium, antimony and tellurium called GST. This alloy is heated to a high temperature (over 630 °C), at which point the programmable volume in the PRAM [Figure 1] becomes a liquid. Once cooled, it is frozen into an amorphous glass-like state and its electrical resistance is high. By heating the programmable volume of chalcogenide to a temperature above its crystallization point, but below the melting point, it transforms into a crystalline state with much lower electrical resistance. This phase transition process within the programmable volume of chalcogenide can be completed in as little as five nanoseconds. The electrical performance of PRAM is thus dependant on the phase transition mechanism, and PRAM is susceptible to a fundamental tradeoff between unintended vs. intended phase-change. This stems primarily from the fact that phase-change is a thermally driven process rather than an electronic process, which means that it is important to reduce the high programming current density (>10⁷ A/cm²) for Joule heating in the programmable volume. This has led to active areas which are much smaller than the driving transistor area, and different phase-change temperatures. The scaling has forced

KIST’s researchers are working with Samsung on breakthrough technologies to make a new functional PRAM possible.



phase-change memory structures to package the heater, and sometimes the phase-change material itself, in sub lithographic dimensions. In addition, the different phase-change temperatures experienced with GST suggest that non-GST materials would be preferable for use in PRAM.

To address the challenges associated with PRAM, Dr. Yong Tae Kim’s team has investigated tellurium-based binary and ternary chalcogenides, including GST, to discover their phase-change mechanisms and the unknown atomic structures of chalcogenide materials. This article highlights three facets of this research: ① how rapid ovonic switching occurs in GST; ② the identification of unknown atomic structure; and ③ *in situ* observation of a ring-shaped amorphous structure.

It had been thought that the phase change of as-deposited GST proceeds from an amorphous state to a stable hexagonal structure through an intermediate state of metastable face-centered cubic (FCC) during the SET regime of PRAM. However, the micro-structures of once melt-quenched GST devices had not been directly observed. Interestingly, Dr. Yong Tae Kim’s group found that the once melt-quenched GST shows different nucleation phenomena, specifically that the hexagonal structured nuclei exist in the once melt-quenched GST and the hexagonal grain growth is caused by these nuclei, as shown in Figure 2. From this result, it is clear that the melt-quenched amorphous GST changes from an amorphous to hexagonal structure directly, without passing through a meta-stable FCC state. In addition, electrical characteristics show that the ovonic switching voltage decreases from 4.1 to 2.8 V when the as-deposited GST cells are once melt-quenched at 10 V RESET pulse [Figure 3]. The influence of these hexagonal nuclei on crystallization is to decrease the activation energy for nucleation ①.

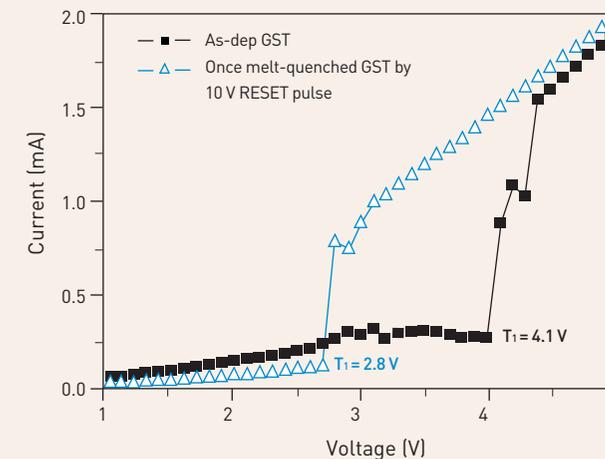


FIGURE 3. Ovonic switching threshold voltage of a once melt-quenched PRAM cell lowered due to the existence of hexagonal nuclei.

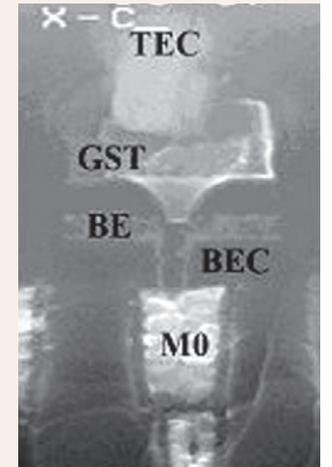


FIGURE 1. Cross-sectional image of the programmable volume of PRAM cell.

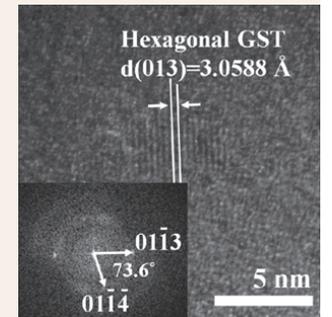


FIGURE 2. HRTEM image and selected area diffracton pattern of the hexagonal nuclei in the once melt-quenched amorphous GST.

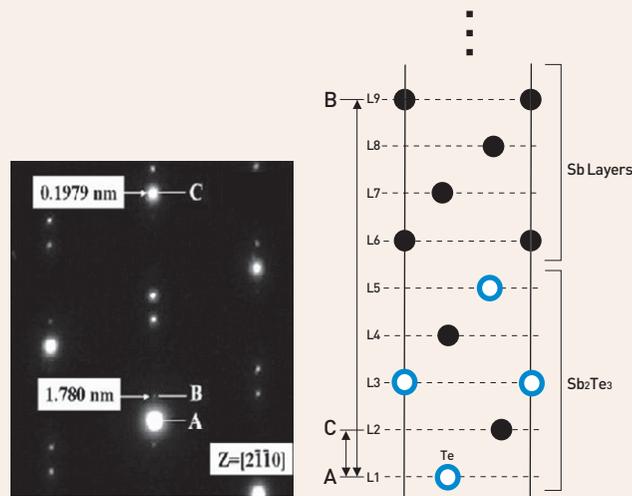


FIGURE 4. Selected area electron diffraction patterns of $Sb_{64}Te_{36}$ and atomic arrangement model of the crystallized δ -phase SbTe alloy with excess Sb.

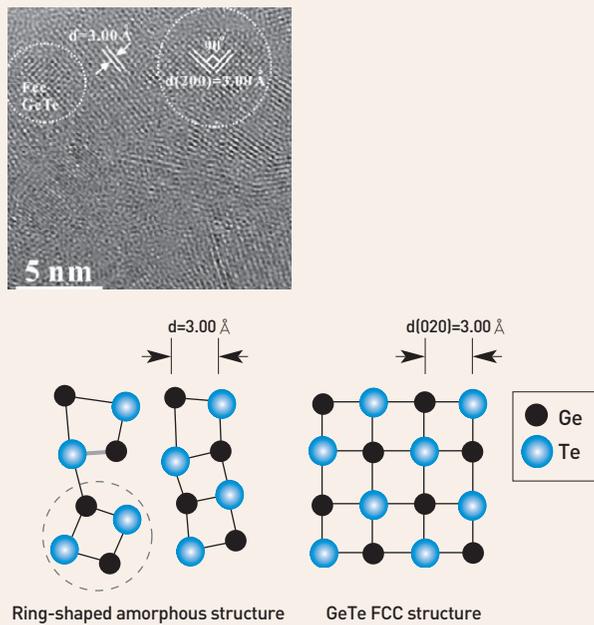


FIGURE 5. HRTEM image of the GeTe thin film *in situ* annealed with High Voltage Electron Microscopy (HVEM) and schematic presentation for the atomic arrangement of the amorphous and the FCC-structured GeTe alloy.

To discover more about the phase-change phenomena of δ -phase SbTe alloys, Dr. Kim's team investigated the unknown atomic structure of δ -phase SbTe alloys with different Sb contents. It was found that as Sb content increases, crystallization occurs with lower thermal activation energy. The observed atomic structure shows that the total number of Sb layers in the unit cell increases as Sb content increases [Figure 4]. Since the bond energy of Sb-Sb is lower than Sb-Te, the phase transition temperature of the δ -phase SbTe alloy can be lower than that of GST without resulting in phase separation ②.

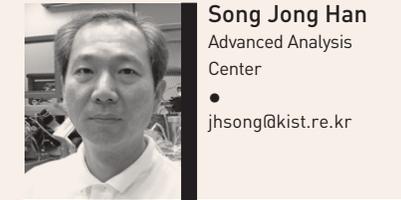
Another achievement of Dr. Kim's group was the *in situ* observation of a ring-shaped amorphous structure. The region close to the FCC-structured GeTe has a ring-shaped structure. Its atomic arrangement is nearly the same as that of the (200) or (020) interplanar spacing of the FCC-structured GeTe, meaning that the FCC-structured GeTe originates from the ring-shaped amorphous structure since it has a similar atomic arrangement to the crystalline state [Figure 5]. The ring-shaped amorphous structure of GST and GeTe, which is very similar to the FCC lattice, accounts for fast crystallization ③.

Through its joint works with Samsung, Dr. Kim's group has developed a new switching mechanism and suggested a new functional PRAM that will become a next-generation non-volatile memory device.

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- ② M. S. Youm, Y. T. Kim, Y. H. Kim, and M. Y. Sung, *Physica Status Solidi [a]*, 205, 1636 (2008).
- ③ E. T. Kim, J. Y. Lee, and Y. T. Kim, *Applied Physics Letters*, 92, 191915 (2008).

Introduction of KIST's 6 MV Ion Accelerator



An ion beam accelerator is a device that uses electric fields to propel electrically-charged particles to high speeds. An ordinary CRT television set is a simple form of accelerator. The early stage of an ion beam accelerator is used for fundamental science such as nuclear and particle physics. As shown in Figure 1, an ion accelerator with a potential of a few MVs is used for ion beam material analysis and property modification, including ion beam engineering.

Ion Beam Analysis (IBA) is based on the interaction, at both the atomic and nuclear levels, between accelerated incident ions and the bombarded material. When a charged particle moving at high speed strikes a material, it interacts with the electrons and nuclei of the material atoms, slowing down through energy loss until it finally stops. This can lead to the emission of particles or radiation whose energy is characteristic of elements in the sample material. Among ion beam analysis techniques, Rutherford Backscattering

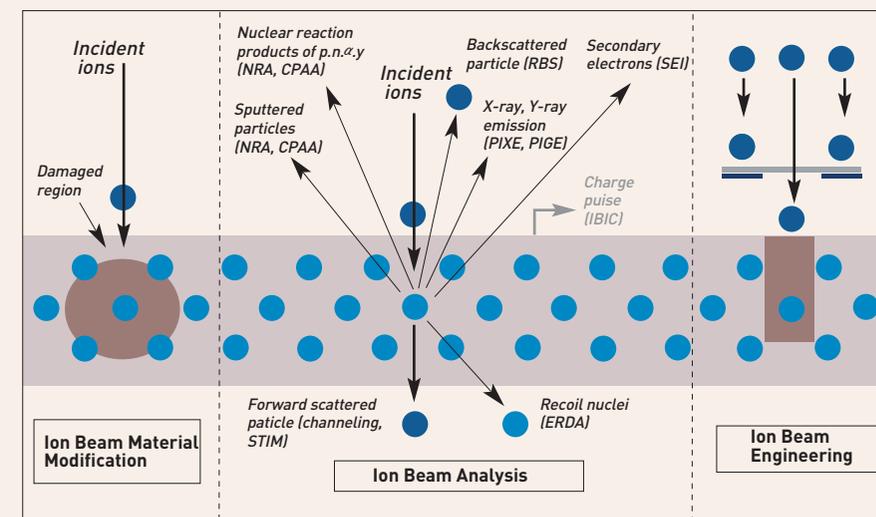
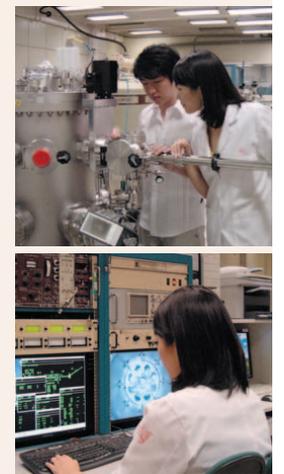


FIGURE 1. Ion beam analysis and ion beam material modification by using a few MVs range ion accelerator.

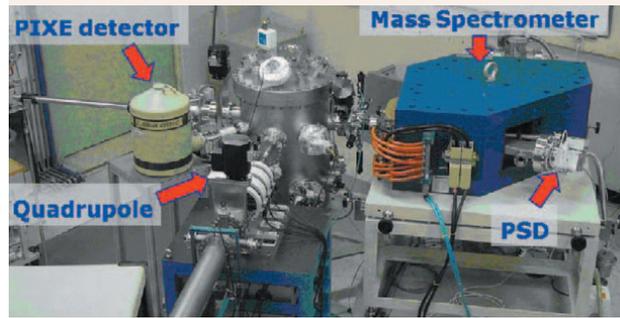


FIGURE 2. High resolution RBS system.

Spectrometry (RBS) and Proton Induced X-ray Emission (PIXE) are the most widely used for surface analysis. Since 1995, KIST's 2 MV ion accelerator has been supporting RBS and PIXE techniques for surface analysis. Currently, a high resolution RBS system is being installed in the 2 MV accelerator to improve depth and spatial resolutions by using a mass spectrometer with a position sensitive detector (PSD) and quadrupole focusing magnet. Figure 2 shows our high resolution RBS system attached to a 2 MV accelerator. Potential depth resolution is less than 1 nm, which is 10 times smaller than that of a normal RBS measurement.

In 2006 with support from the Ministry of Science and Technology's new Basic Research Support Program, KIST launched a 5-year project to construct a 6 MV ion accelerator. A 6 MV tandem machine such as this provides more energy to the ion than does a 50 MeV accelerator. With this high level of energy, new forms of ion beam analysis and material property modification can be done. One of the main applications of 6 MV machines is ERD measurement where unambiguous element identification is combined with depth profiling to give a directly quantitative result. A further advantage to ERD analysis is that it can profile all elements, including hydrogen, simultaneously and with almost equal sensitivities in the ppm range, even if matrices consisting of heavier elements are investigated. Heavy projectile ion ERD is a very powerful analytical technique providing excellent depth and mass resolution for multi-element, multi-layer quantitative thin film analysis.

Another application for a 6 MV ion accelerator is material property modification by using swift heavy ion irradiation (SHI). With the generation of high energy heavy ions from 6 MV accelerators, swift heavy ion beams can be widely used in many fields, particularly for modification of materials through dense electronic excitation following the slowing down of swift heavy ions in material. The passage of SHI through materials mainly produces electronic excitation of the atoms in the materials and causes exotic effects in different classes of materials which otherwise could not be generated by any other means.

A 6 MV accelerator can also be used in Accelerator Mass Spectrometry (AMS). The AMS system, which is a distinct part of a 6 MV accelerator, is shown in Figure 3. AMS differs from other forms of mass spectrometry in that it accelerates ions to extraordinarily high kinetic energies before mass analysis. The unique advantage of AMS as compared to other mass spectrometric methods is its power to separate rare isotopes from abundant neighboring masses ("abundance sensitivity," e.g., ^{14}C from ^{12}C). This method allows complete

Construction of KIST's 6 MV accelerator will be completed in the near future and will become an integral part of the institute's research infrastructure with Pohang KIST's synchrotron beam line and Hanaro KIST's neutron beam line, NMR and super TEM.

suppression of molecular isobars, and in many cases, can also separate atomic isobars (e.g., ^{14}N from ^{14}C). This enables the detection of naturally occurring, long-lived radio-isotopes such as ^{10}Be , ^{36}Cl , ^{26}Al and ^{14}C . Their typical isotopic abundance ranges from 10^{-12} to 10^{-18} . AMS can outperform the competing technique of decay counting for all isotopes where the half life is long enough.

There are many applications for AMS. It is most often used by archaeologists to determine the concentration of ^{14}C , for radiocarbon dating. AMS is preferred over other forms of mass spectrometry because of its insufficient abundance sensitivity, and ability to resolve stable nitrogen-14 from radiocarbon. Due to the long half-life of ^{14}C , decay counting requires significantly larger samples. ^{10}Be , ^{26}Al , and ^{36}Cl are used for exposure dating in geology. ^3H , ^{14}C , ^{36}Cl , and ^{129}I are used as hydrological tracers. In addition, AMS is widely used in biomedical research involving pharmacodynamics, pharmacokinetics, and ADME (absorption, distribution, metabolism, emission) processes by using labeled cells or drugs. AMS is also useful in research related to environmental science such as the investigation of global warming, past environmental change, tracking the sources of gaseous pollutants, and monitoring the soil, atmosphere and water systems in and around nuclear power plants.

The ion beam analysis technique and applications associated with the 6 MV ion accelerator have only been briefly introduced in this article. Much more will be said in the coming years as research with this exciting new technology unfolds. Construction of KIST's 6 MV accelerator will be completed in the near future and will become an integral part of the institute's research infrastructure with Pohang KIST's synchrotron beam line and Hanaro KIST's neutron beam line, NMR and super TEM. These large facilities are expected to produce epochal discoveries in KIST's principal research fields of nano, bio, energy/environment and material science.



FIGURE 3. Picture of AMS system.

RECENT PUBLICATIONS

Polymeric Nanomedicine for Cancer Therapy



Nanomedicine, an offshoot of nanotechnology, refers to highly specific, molecular-scale medical intervention for treating disease or repairing damaged tissues. In recent years, polymer-based nanomedicine, a field that includes the use of polymer-DNA complexes (polyplexes), polymer-drug conjugates, and polymer micelles bearing hydrophobic drugs, has received increasing attention for its ability to improve the efficacy of cancer therapeutics. Owing to their small size and excellent biocompatibility, nanosized polymer therapeutic agents can circulate in the bloodstream for long periods of time, allowing them to reach the target site. In addition, chemical modification of polymer therapeutic agents with ligands capable of specifically binding receptors that are over-expressed in cancer cells can markedly augment therapeutic efficiency. This review highlights the characteristics of cancer that provide nanodrug targeting opportunities and discusses rational approaches for future development of polymeric nanomedicines.

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Journal Title **Progress in Polymer Science**
v. 33, p.113-137

Authors J. H. Park, S. Lee, J. -H. Kim, K. S. Park,
K. M. Kim, I. C. Kwon*

Hollow TiO₂ Hemispheres Obtained by Colloidal Templating for Application in Dye-Sensitized Solar Cells



Hollow TiO₂ hemispheres for application in dye-sensitized solar cells were pre-*pre*-pared by means of RF-sputtering onto colloidal templated substrates. After removing the organic templates by thermal decomposition, quasi-ordered networks of hollow TiO₂ hemispheres were formed. This approach should open up new opportunities for processing material architectures with high surface activity and effective charge transport for high performance photovoltaic and photoelectrochemical cells.

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Journal Title **Advanced Materials**
v. 20, p.1059-1064

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H. -G. Kim, I. -D. Kim*, H. Lee*

Tunneling Anisotropic Magnetoresistance in Multilayer-(Co/Pt)/AlO_x/Pt Structures



We report observations of tunneling anisotropic magnetoresistance (TAMR) in vertical tunnel devices with a ferromagnetic multilayer-(Co/Pt) electrode and a nonmagnetic Pt counterelectrode separated by an AlO_x barrier. In stacks with the ferromagnetic electrode terminated by a Co film, the TAMR magnitude saturates at 0.15%, beyond which it shows only weak dependence on magnetic field strength, bias voltage, and temperature. For ferromagnetic electrodes terminated by two monolayers of Pt we observe order(s) of magnitude enhancement of the TAMR and a strong dependence on field, temperature and bias. The discussion of experiments is based on relativistic *ab initio* calculations of magnetization orientation dependent densities of states of Co and Co/Pt model systems.

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Journal Title **Physical Review Letters**
v. 100, p. 087204

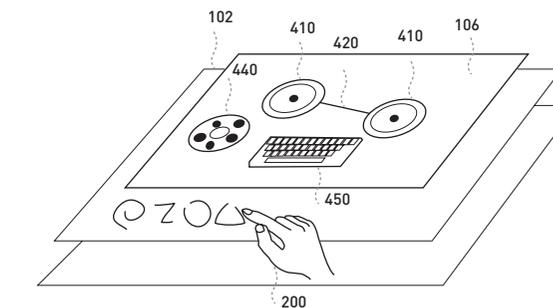
Authors B. G. Park, J. Wunderlich, D. A. Williams, S. J. Joo, K. Y. Jung,
K. H. Shin*, K. Olejnik, A. B. Shick, T. Jungwirth

NEW PATENTS

Graphic User Interface Device and Method of Displaying Graphic Objects



This patented graphic user interface enables users to understand the current items, the associated materials and their relationships without resorting to any complicated exploring procedures.



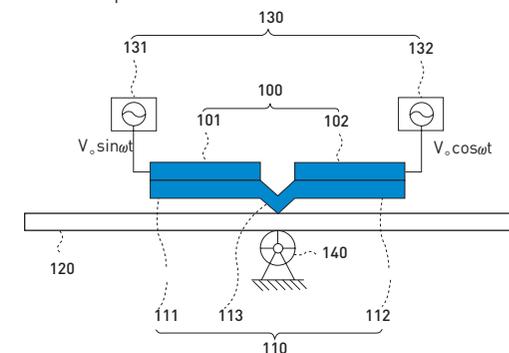
Korea Patent No. **10-0828017**

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Piezo Electric Linear Motor



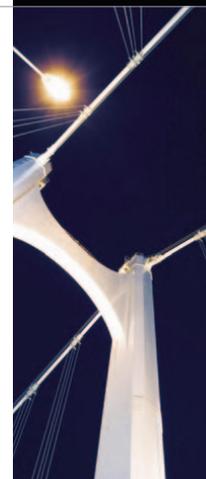
This invention involves a piezoelectric linear motor that functions with relatively low abrasion while allowing accurate linear movement as a result of stationary AC voltages being applied to two piezoelectric elements with a phase difference.



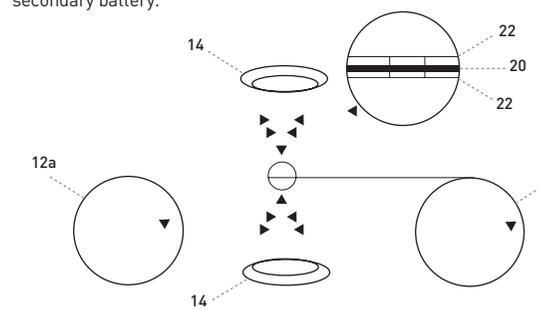
Korea Patent No. **10-0817470**

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Fabrication of a Metal Oxide Electrode Coated with Porous Metal Film and Its Use in a Lithium-Ion Secondary Battery



This patent relates to the development of a metal oxide electrode coated with porous metal film, the method for fabricating this type of metal oxide or carbon film and how such an electrode can be used in a lithium-ion secondary battery.

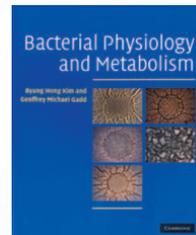


Korea Patent No. **10-0324624**

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DR. BYUNG HONG KIM PUBLISHES MICROBIAL PHYSIOLOGY TEACHING MATERIALS IN ENGLISH

An emeritus research scientist at KIST, Dr. Byung Hong Kim (63), has revised and translated his book, *Microbial Physiology*, to be published by the Cambridge University Press. During 38 years at KIST, Dr. Kim has dedicated his research to microorganisms. In 1988 he published the first edition of *Microbial Physiology* through the Academy-Book Company. After two revisions, he translated and published the book *Bacterial Physiology and Metabolism* along with Professor Geoffrey Michael Gadd of Dundee University, a prominent researcher of microbiology in the U.K. *Microbial Physiology* deals with the diverse metabolism of microorganisms which inhabit various natural surroundings, including extreme environments where higher organisms cannot survive. Information about microbial metabolism and microbial physiology contributes substantively to the rapidly advancing field of microbial dielectric research. It is also used in work related to the environment, biotechnology and the control of pathogenic microorganisms.



KIST-ORNL JOINT SYMPOSIUM



On June 5, 2008, KIST held a Joint Symposium on Energy and Neutron Sciences with U.S.-based Oak Ridge National Laboratory (ORNL). Three representatives from ORNL, including Dr. Thomas Mason, Director of ORNL, and distinguished Korean speakers from various institutes and private companies joined the symposium and shared opinions regarding their research activities. A Memorandum of Understanding (MOU) between KIST and ORNL, as well as two other division-to-division MOUs in the fields of energy resources and neutron sciences, were signed before lunch. The delegation from ORNL also had a chance to visit the Center for Chemoinformatics

Research, the Center for Energy Materials Research, the Center for Fuel Cell Research, and several other labs to observe the research activities of KIST. Dinner was hosted later in the day by President Kum at his official residence.

KIST-JULICH MOU

President Kum paid a visit to Forschungszentrum Julich in Germany on May 5, 2008, to sign a Memorandum of Understanding (MOU) with Chairman Achim Bachem to initiate cooperation in several core research areas. Forschungszentrum Julich is one of three major research institutes under the Helmholtz Association umbrella. KIST and Forschungszentrum Julich have promoted researcher-to-researcher cooperation in neural science, alternative energy research, nano-science and technology, and supercomputers since 2003 through various activities, including the Korean-German Science and Technology Forum. As a result of this formalized MOU, cooperation between KIST and Forschungszentrum Julich is expected to gain momentum. In their discussions, President



Kum and Chairman Bachem agreed to promote concrete research cooperation, including joint research. On the day of the signing, President Kum had a chance to observe some of the research activities of the institute by visiting some laboratories at Forschungszentrum Julich, including the Institute of Bio- and Nanosystems, the Institute of Energy Research, the Institute of Neurosciences and Biophysics, and the Supercomputer Center.

PROF. DR. HANS-JUERGEN WARNECKE HONORED FOR HIS DISTINGUISHED SERVICE IN PROMOTING KOREAN-GERMAN SCIENTIFIC AND TECHNOLOGICAL COOPERATION

Prof. Dr. Hans-Juergen Warnecke, former president of Fraunhofer-Gesellschaft, was awarded the Order of Science and Technology Merit from the government of Korea on April 21, 2008. He received the award at a commemorative ceremony during the 41st Science Day celebration in recognition of his outstanding contribution to the establishment



and growth of KIST Europe in Germany. He was also recognized for his activities in promoting scientific and technological cooperation between Korea and Germany. After receiving this distinguished award, he was invited by President Dongwha Kum to give a commemorative lecture entitled "Innovation and the German Research System." Prof. Dr. Hans-Juergen Warnecke is well known for his help in supporting Korean interests. He has introduced high technology from Germany in areas such as robotics and mechatronics, and been behind many successful technology exchanges. He has provided wholehearted support in critical matters ranging from the establishment of KIST Europe to the recruitment of specialized research scientists and construction of a cooperation network in Europe. In addition, he has used his influence to encourage scientific and technological cooperation not only in Germany, but in the broader region of the EU. Prof. Dr. Hans-Juergen Warnecke has many devoted friends and colleagues in Korea who are prominent in the fields of microsystems and nano-science in this country. He will long be recognized as a special friend to Korea.

KIST HOLDS INTERNATIONAL CULTURAL EXCHANGE (ICE) FESTIVAL

On April 16, 2008, KIST held an International Cultural Exchange (ICE) Festival in which many foreign residents within the science and technology community in Korea were brought together for the day. Invited were nearly 200 guests, including KIST foreign research scientists, International R&D Academy students, and foreign students from neighboring universities. Video clips made by the foreign students, traditional costumes from nine countries, foreign household goods and books were exhibited at the festival. A lecturer from the Korean Language Culture Institute at Korea University even provided a Korean naming service for foreign participants. After the exhibition, there was a performance with traditional dancing and singing. This was followed by special performances from an East Asian musical group and a Mongolian dancer all of whom are foreign students at the Korea National University of Arts.



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