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Cover story. *Various Moving, Various Thinking, Various Voice*

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Leading to the world of tomorrow

contents

Letter from the Editor-in-Chief

Science and technology offer enormous opportunities to enhance quality of life on a global scale, but too often this potential is undermined by public misunderstanding. In recent years scientists and entrepreneurs have become excited about the prospects of what genetically modified organisms (GMOs) can offer. They believe that GMOs can revolutionize agriculture and the food industry by solving the food shortage problem through increases in the quantity and quality of food. So far, however, GMOs have met with only limited success. Consumers are not confident about the safety of GMOs as a food source, and some regard GMOs as "Frankenfood." Lack of communication is blamed for this gap between high expectation on one side and dissatisfaction on the other.

Science and technology are advancing at unprecedented speed. As a result, laymen are unable to keep up with new developments in science and technology, and consequently, are uneasy with products emerging from that development. Even some scientists are hesitant to embrace the implementation of such new ideas. Communication can not only reduce this gap in understanding, but can also serve as a bridge among friends, colleagues and customers.

Here at KIST we believe it is not enough to simply publish esoteric findings in scientific journals. We want to keep our friends well informed about the latest work we are doing and its implications for the future. After all, our alumni remain a valuable network wherever they may be, and the ultimate users of products developed through our research---our customers---are the very reason for our existence. We are not trying to create Frankensteins through our research endeavors, but rather, are searching for viable ways to make the rapid changes so vital to serving the dynamic Korean economy. *KISToday* is one way we are bridging the communication gap and ensuring that our friends and customers are as excited about KIST's scientific advances as we are. We are striving to make *KISToday* a readable journal highlighting remarkable achievements. Through mutual understanding we can make wise choices for the future.

July 2009 **B.Hong Kim**

KIST's Network-based Humanoid *MAHRU*

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INTRODUCTION

As the market for industrial robots has matured and gradually become saturated, attention has shifted to intelligent service robots as a new growth engine for the future robotics market. The idea is to design intelligent service robots to provide useful services for human beings in daily life by providing information and/or labor in the home or office. One representative example of such a product is the vacuum cleaning robot "ROOMBA" developed by iRobot Corporation, based in the United States. iRobot has provided three million vacuum cleaning robots to the world market during the past three years, thus showing that a robot can be mass produced as a good consumer product.

In order to successfully commercialize intelligent service robots, it will be necessary to market them at a cheap enough price to appeal to a wide range of consumers while offering as many benefits as possible to users. Currently however, it is almost impossible to reduce the price of a robot enough to appeal to a mass market because the many functions for control, intelligence, and service contents require a computer cluster inside the robot itself. To address this dilemma, a new concept for a network robot, known as a URC (Ubiquitous Robotic Companion) has been proposed as a business model. This model was envisioned to decrease the cost of a robot by using external server computer systems connected through a wireless network, thereby removing the high-level and costly computing system from inside the robot. The control system within a network robot controls basic and reactive motions, captures sensor information, and transmits sensor data to an external computer system through a wireless network. External server computer systems provide higher level functions like recognition, reasoning and decision-making, planning, intelligence, service content, etc.

When it comes to intelligent service robots, most humans prefer robots whose shape is similar to their own, so humanoid robots are expected to be the most popular type of service robot in the future. So far, several humanoids have been developed, including *ASIMO* from Honda Co. Ltd., Japan [1][2], *Johnnie* from TUM, Germany [3], *HRP* from AIST, Japan [4], *QRIO* from Sony Co. Ltd., Japan, *HOAP* from Fujitsu Co. Ltd., Japan, *COG* from MIT, USA, *H7* from the University of Tokyo, Japan [5], *HUBO* from KAIST, Korea [6], and a number of others.

This article describes a network-based humanoid, *MAHRU*, developed at KIST by combining the concept of a URC with a humanoid robot design. Previous research on humanoid robots has been focused mainly on the hardware platform and enabling the motion of biped walking, but our research has delved into the basic core technologies for *MAHRU* to become a useful working humanoid.

NETWORK-BASED HUMANOID *MAHRU*

MAHRU was introduced on January 1, 2005, as the world's first network-based humanoid. Core research has continued since that time in order to endow *MAHRU* with working capability through physical interaction in contact environments like the home or office. A brief specification of *MAHRU* is shown in Fig. 1 while the distributed control architecture will be introduced in the subsequent section.

Name	MAHRU
Body	150 cm, 67 kg
Degree of Freedom	35 (Leg 12, Arm 12, Hand 8, Neck 2, Waist 1)
Sensors	Stereo Camera, Force/Torque Sensor, Pose sensor, Microphone
Natural Moton	• Omni-directional biped walking (1,2 km.h) • Human-like dancing with walking • Manipulate 3-D objects in home environments
Distributed Intelligence	• Real-time recognition of faces. voices, gestures, and 3-D objects • Learning Human task & skills • Cooperation between multiple humanoids • Real-time motion imitation and remote control

FIGURE 1. Network-based humanoid *MAHRU* and brief specifications

NETWORK-BASED CONTROL ARCHITECTURE

By adopting network-based control architecture, it is possible to endow a humanoid with various capabilities for perception, human-friendly interaction, intelligence, and service content. Each humanoid has an internal control system while multiple humanoids share an external server computer system equipped with various intelligence software modules as shown in Fig. 2

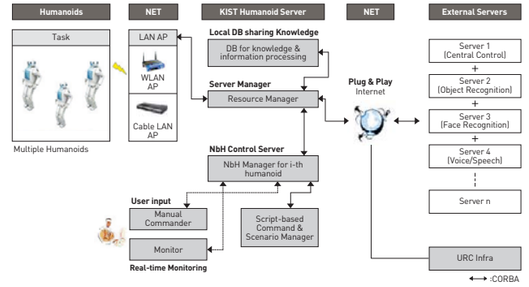

FIGURE 2. Network-based control architecture

The external computer system provides services for multiple network-based humanoids by using multi-tasking capability. All servers are integrated with CORBA middleware while software components in each server are modularized by using CORBA interface. A central control server is the final decision maker of the external computer system and is responsible for real-time data transmission and action command generation after analyzing the commands from the other service servers. It also selects the appropriate servers to provide a service to a network-based humanoid and sends requests for these services to the selected servers. Object recognition and face recognition servers track and recognize the faces and bodies of human beings, recognizes three-dimensional objects, and makes a three-dimensional model of environments. A voice/speech service server recognizes human words and synthesizes human voices. Fig. 3 shows an experimental screen image in which four humanoids are connected to service servers simultaneously.

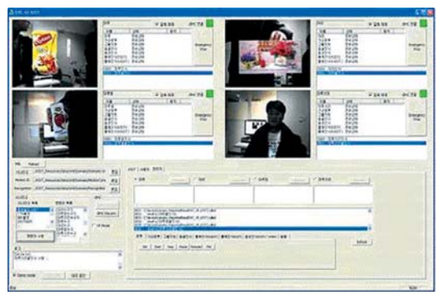

FIGURE 3. Integrated interface of network-based control system

WHOLE BODY CONTROL BY MECOM JACOBIAN

The high mobility required of a humanoid makes it difficult to generate natural whole body motions and to interact with environments in real-time. Real-time motion generation is critical to effect complicated, smooth and agile motions. It is also desirable to include dynamics to improve the stability of a humanoid. The center of mass (CoM) for a humanoid was adopted as a simple alternative to robot dynamics which requires a large amount of computations.

In order to use the CoM in motion generation, the CoM Jacobian was firstly proposed as a numerical method by Kagami, *et al*, in 2000. An analytic formulation of the CoM Jacobian was proposed by Sugihara, *et al*, in 2002, but real-time motion generation was impossible because of the heavy computational load in optimization.

To address this complication, we proposed a motion-embedded CoM (MECoM) by including joint motions and Cartesian motions to generate humanoid motions in real-time by reducing the computational load in whole body balancing and motion generation [7]. The load was lowered drastically by decreasing the dimension of the CoM Jacobian. The overall calculation procedure is shown in Fig. 4. The typical motion inputs used for humanoids are the motion-captured joint data of the upper body and the act of walking for the Cartesian motion of the lower body.

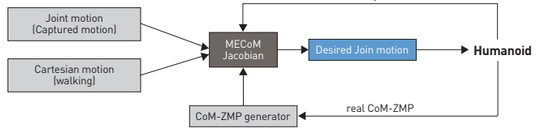

FIGURE 4. Resolution of MECoM Jacobian

Finally, the whole body control makes it possible for *MAHRU* to execute natural arm/hand motions during biped walking and to execute many tasks in contact environments by decoupling motion generation and balancing since balancing is executed automatically by the MECoM Jacobian.

DYNAMIC BIPED WALKING

Since the legs of humanoids must have high degrees-of-freedom to mimic human walking, it is not easy to design a controller for this function nor analyze stability. So, we simplified the walking-related dynamics of humanoids as an equation of motion for a point mass at the CoM and proposed a rolling sphere model for dynamic walking as shown in Figs. 5 and 6. Based on this model, we developed a new biped walking controller which integrated whole body control, shown in Fig. 7. The walking controller consists of a ZMP (Zero Momentum Point) and CoM controller, vibration controller, and body orientation controller. The ZMP and CoM controller minimizes discrepancies between the actual ZMP and desired ZMP and between the actual CoM and desired CoM. The vibration controller eliminates the sustained oscillation of the humanoid due to un-modeled system uncertainty while the body orientation controller reduces error in the body posture of the robot.

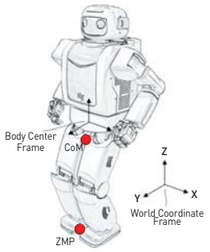

FIGURE 5. Coordinate frame

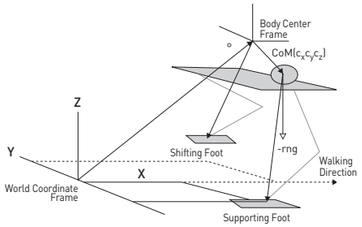

FIGURE 6. Rolling sphere model for dynamic walking

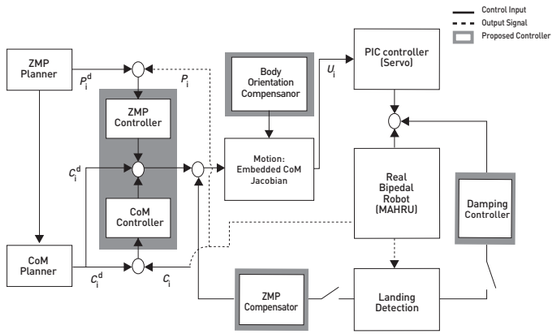

FIGURE 7. Walking controller

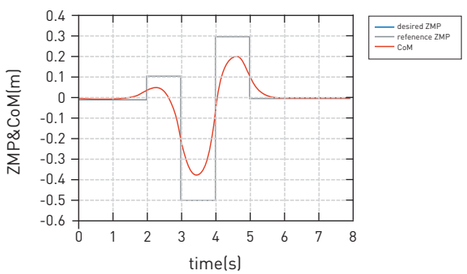

FIGURE 8. Desired ZMP trajectory

To provide stability as the robot walks, the walking patterns of ZMP and CoM at each supporting phase were predetermined as shown in Fig. 8, based on the ZMP equation. In this figure, the desired ZMP trajectory is first determined from the robot's foot prints. To achieve the desired ZMP and generate a stable ZMP and CoM trajectory, the method used to establish a walking pattern utilized a pole assignment method and pole zero cancellation by the series approximation method (PZCSA). PZCSA makes the transfer function of the system including the pole assignment method to approximate one, indicating that the transfer function is stable. As a result, the trajectory of the reference ZMP becomes almost the same as the trajectory of the desired ZMP such that it overlaps with the green line in Fig. 8.

COMPLIANT MANIPULATION IN A CONTACT ENVIRONMENT

Unlike conventional industrial robots, many tasks assigned to a humanoid will involve interactions with human beings or environments. For example, when a humanoid opens a drawer, contact will be made between the robot hand and handle of the drawer since the robot has to grasp the handle to open the drawer. Since these types of physical interactions cannot be predicted with certainty, it is hard to develop a safe motion planning method based on time. If an arm is impeded as it moves along a pre-planned trajectory by conditions in the environment or the responses of human beings, both of which are unpredictable, the arm may eventually break, or worse yet, damage the source of the impediment. In order to avoid these unsafe situations, an event-oriented motion planning was conceived for motion and manipulation. All commands assigned to the arm were considered as competing force events with one another. For example, the arm can be moved by: 1) the motion required to execute a task; 2) an unpredictable external contact; and 3) external force. The way the robot ultimately moves its arm is determined by a combination of these three factors and the relative dominance of each factor. The priority or influence of the three factors is represented as a ratio which can be changed by the operator to achieve intended goals.

Fig. 9 shows examples of event-oriented motion planning. In this example, the humanoid is moving its upper body as directed by the motion capture system, but a human then interferes with that motion by arbitrarily moving the robot's arm. These two motions are clearly in competition. For safety purposes, human interference is given a high influence ratio, and as a result, the arm motion of the robot adjusts to follow the human motion. If human interference is removed, the arm reverts to the motion dictated from the motion capture system. In this experiment, the balancing of the humanoid is guaranteed by the whole body control system.

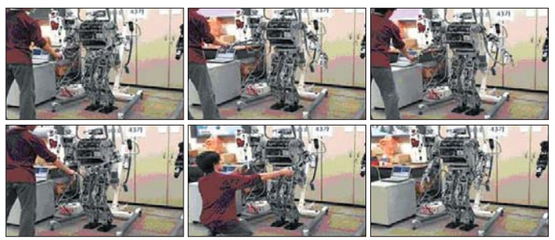

FIGURE 9. Example of event-oriented motion planning

HUMAN-LIKE MOTION IMITATION

When a humanoid works with a person, interaction through gestures is very useful but must be non-threatening. The gestures performed by the robot need to look human-like. Therefore, the humanoid needs to be able to imitate the meaningful, artistic, and creative motions of human beings as closely as possible while maintaining the original intent behind the motions.

A new methodology was developed to generate dynamically stable whole-body motions for humanoid robots based on human motion capture data. This methodology consists of kinematic and dynamical mappings for human-likeness and stability, respectively. Kinematic mapping involves the transformation of whole body motions from human actors into motions of humanoid robots, and the scaling of human foot and Zero Moment Point (ZMP) trajectories considering the geometric differences between a robot and a human. The dynamic mapping process modifies the humanoid pelvis motion to ensure movement stability of whole-body motions.

To imitate the upper-body motion of a human actor, the kinematic mapping method reported by Kim *et al.* [8] was used. Geometric differences in arm length were resolved by scaling the arm length of the humanoid with the arm length ratio between the humanoid and the actor. Then the imitation of the actor's arm motions was formulated as an optimization problem in order to minimize the error between the actor's captured arm motions and the robot's approximated arm motions in relation to the bounding joint position and velocity. The kinematic mapping of lower-body behaviors mostly corrects motions involving the foot and pelvis by scaling pose trajectory and detecting the contact phase of each foot against the ground. In order to locate the ZMP trajectory of a humanoid within a safe supporting area during locomotion, a stable zone for the ZMP trajectory was determined from the foot trajectory scaled through mapping lower-body motions as shown in Fig. 10.

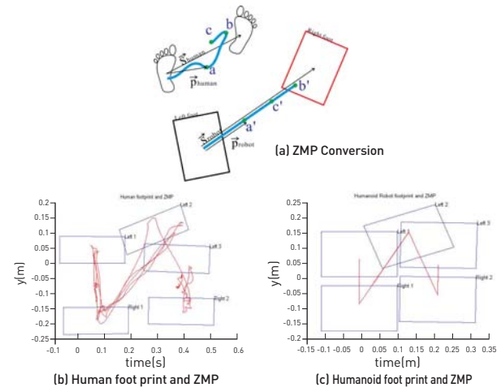

FIGURE 10. Human and humanoid ZMP conversion

The desired ZMP trajectory for a humanoid robot obtained from kinematic mapping, however, may be inconsistent with real lower- and upper- body motions of the robot since no constraints on robot dynamics is considered. So, a new approach to maintain dynamic stability of a real robot was proposed by enhancing the two-dimensional pelvis position to satisfy the CoM trajectory extracted from the desired ZMP trajectory as well as the trajectories for upper-body motion, foot motion, pelvis orientation and the height of pelvis position which was obtained by the kinematic mapping process.

The methodology described above made it possible for KIST's *MAHRU* to successfully imitate human dancing in time to the popular Korean song "Tell me" as shown in Fig. 11.

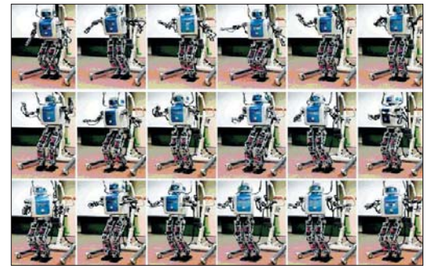

FIGURE 11. Human dancing motion imitation by MAHRU

NETWORK-BASED PERCEPTION

To apply visual processing capability to robots, visual processing algorithms have to be especially powerful in order to account for illumination variation and the geometrical variation of objects. This is important because even under the same light, single-colored objects have different color distributions due to irregular brightness which also affects the viewing geometry of the camera system. A color segmentation scheme which ignores the luminance component suffers from the fact that chromatic color distribution does not take into account the significant effect of brightness changes. While some methods have been proposed to cope with brightness changes by using the shape of the color histogram, difficulties remain with adaptation to abrupt changes in brightness and initial segmentation under various brightness conditions.

We have proposed a new approach by extending Kim and You's idea [9] to achieve a compactly parameterized color model which is able to represent all chromatic color distributions with respect to effective brightness range. Since the proposed Gaussian-cylindrical color model, shown in Fig. 12, can explain the variability with respect to all brightness values, it can provide an effective cue for object tracking when faced with irregular and abrupt changes in brightness. Using this model as a starting point, we introduced a mean-shift iteration utilizing the Gaussian-cylindrical color model and a simple and efficient method for finding the optimal bandwidth of the kernel density function since bandwidth selection in the mean-shift algorithm is critical to robust and effective mean-shift iteration. The optimal bandwidth maximizes the lower bound of the log-likelihood of the tracking target. Experimental results are shown in Fig. 13 with the rectangle showing the detected face location.

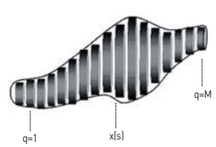

FIGURE 12. Gaussian-cylindrical color model

FIGURE 13. Face tracking under various illumination conditions

Fig. 14 shows experimental results for the tracking, detection and recognition of multiple human faces. The associated names of the recognized persons are shown above the face identification rectangles.

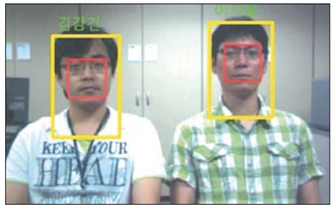

FIGURE 14. Face recognition

In order for a humanoid to provide services in home and/or office environments by handling and manipulating three dimensional objects, robust real-time detection and tracking of three dimensional objects are very important. Even though the particle filter method has been used successfully for the detection and tracking of two dimensional objects, problems remain for real-time application to three dimensional objects since the search procedure in this method involves a long computational time to find the solution. In response to this drawback, we developed a back-projection-based sampling approach to significantly reduce the search space by back-projecting image points with depth information into the parameter space. Fig. 15 shows the effect of the back-projection-based sampling. If particles are generated in three dimensional spaces directly, the search space forms a hexahedron, but the search space becomes surface patches by using the back-projection-based sampling. Fig. 16 shows experimental results on the detection of various types of three dimensional objects in daily life, including (from left to right in the figure) an electronic oven, the door-open push button on an electric oven, a drink can, a drink pack, and the handle of a pot. These can be detected and tracked successfully using the back-projection-based sampling approach.

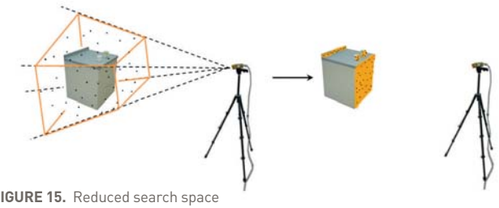

FIGURE 15. Reduced search space

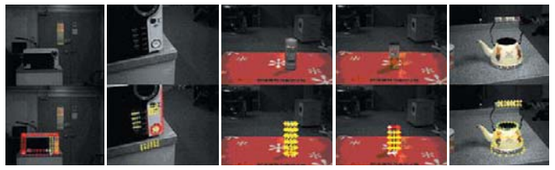

FIGURE 16. Detection and tracking of various 3D objects

CONCLUSION & FUTURE DIRECTION

This article has described the world's first network-based humanoid, *MAHRU*, and the basic core technologies underlying its whole body control, dynamic biped walking, compliant manipulation in contact environments, human-like motion imitation, network-based perception, and network-based control architecture.

We believe a network-based humanoid should not just be a walking or running machine, but rather, an intelligent service robot providing useful services in daily life. As a consequence, our future research will be focused on the development of a working humanoid like a housemaid or butler, capable of physical interaction with human beings and environments. This will involve the integration of cognitive models for self-learning and self-development to enable improved task skills and intelligence.

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Atomic Scale Simulation to Understand Interfacial Phenomena During Thin Film Deposition

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Nanotechnology should be based on the atomic or molecular scale understanding of phenomena and manipulation of the atomic configuration in materials. In spite of considerable progress in developing experimental tools to observe nanometer scale phenomena (e.g., scanning probe microscope, high resolution transmission electron microscope), none has yet been developed which is adequate for observing atomic configuration or understanding the kinetics in atomic scale resolution. Nonetheless, the significant developments in supercomputing technology, which have made computing speeds 25,000,000 times faster over the last 25 years, have enabled atomic or subatomic computer simulation to become another tool in nanotechnology if applied with sufficient care to interatomic potentials and simulation conditions. This article discusses an example of atomic scale computer simulation that has increased our understanding of interfacial phenomena during thin film deposition [1-5].

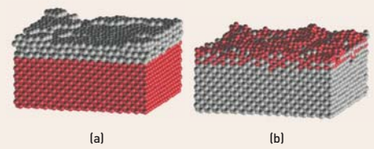

FIGURE 1. Snapshot of the simulated surface of (a) Al deposition on Co (001) and (b) Co deposition on Al (001) surface. (Gray atom : Al, Red atom: Co, reprint from ref. [1])

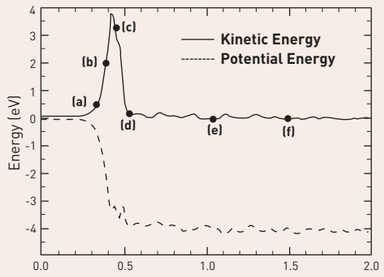

FIGURE 2. Time evolution of the kinetic and potential energy of the deposited Co atom on the hollow site of the Al (001) surface. (reprint from ref. [3])

Thin multilayer structures are widely used in current devices and sensors such as spintronics devices utilizing tunneling magneto resistance (TMR) or giant magneto resistance (GMR) phenomena. In these devices, the electro-magnetic properties are largely dependent on the interface structure between thin ferromagnetic and nonmagnetic layers [6]. Because of the short coherence length of spin polarization, electric spin phenomena can only occur across a few nm-thick ordered thin films. It should also be noted that spin injection from a ferromagnetic electrode to a semiconductor channel is known to be strongly dependent on interfacial structure [7, 8]. Atomic scale control of the interface is thus the prerequisite for these devices, which requires a firm understanding of surface intermixing behavior during deposition in both theoretical and experimental ways. In the present work, we investigated the intermixing behavior of a Co-Al system in both a molecular dynamic simulation using semi-empirical EAM potentials and by using experimental methods such as coaxial impact collision ion scattering (CAICISS) and a vibrating specimen magnetometer (VSM).

Atomic scale deposition behaviors were simulated with a perfect single-crystalline substrate at 300K and with the initial kinetic energy of the deposited atoms fixed at 0.1 eV. We used the EAM potential developed by Pasianot and Savino for Co-Co [9], Voter and Chen potential for Al-Al [10], and Vailhe' and Farkas for Co-Al [11]. Details of the simulation conditions have been reported previously [3]. The Al (001) or Co (0001) slabs were set to $6a_0 \times 6\ a_0 \times 4a_0$, where a_0 is the bulk lattice parameter of the substrate. Film deposition and CAICISS experiments were performed at room temperature in an ultra-high vacuum chamber of

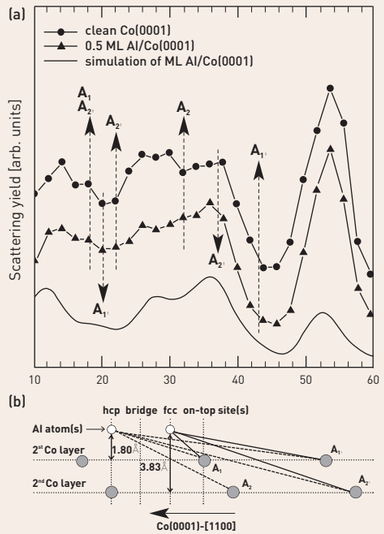

FIGURE 3. (a) Polar scan curves of the He yield backscattered by Co atoms along the (1100) direction for a clean Co (0001) surface (solid circle data), a 0.5 ML Al deposited Co (0001) surface (solid triangle data) and the simulated scattering curve when the deposited Al atoms are placed on the hollow sites at a height of 1.8Å from the first layer of Co (solid line curve). (b) Side view along the (1100) direction of the model structure when the deposited Al atoms are placed on both the fcc and hcp hollow sites of the Co (0001) surface. (reprint from ref. [4])

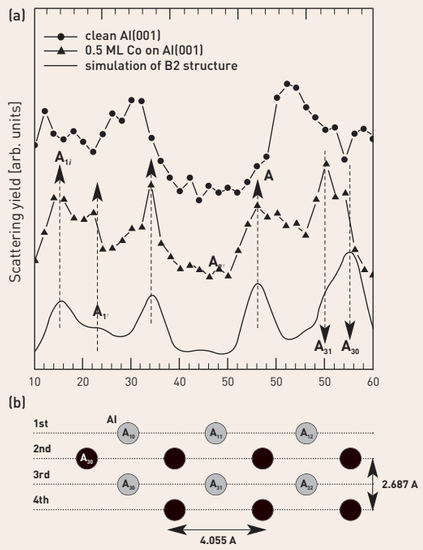

FIGURE 4. (a) Polar-scan curves of the He yield backscattered by Al atoms along the (100) direction for a clean Al (001) surface (solid circle data), a 0.5 ML Co deposited Al (001) surface (solid triangle data) and the simulated scattering curve of CoAl B2 structure with an Al top layer (solid line curve). (b) Side view along the (100) direction of a CoAl B2 structure with an Al top layer. (reprint from ref. [4])

base pressure less than 1×10^{-10} Torr. One side mirror-polished Co (0001) and Al (001) single crystals were used as the substrate. A half monolayer of Al (3.4×10^{14} cm^{-2}) was deposited by evaporation using a heated tungsten filament [4]. VSM measurement of Co/Al multilayers was carried out at room temperature. The Co/Al multilayers were prepared by a well controlled electron beam evaporation system. The prepared samples were Co layer on Si (Co(30Å)/Si), Al layer deposited on the Co layer (Al(30Å)/Co(30Å)/Si) and Co layer on a thick Al layer (Co(30Å)/Al(840Å)/Si). To protect against contamination and prevent oxidation, all samples were capped by Cu film. Magnetization of the multilayer film was measured with an applied magnetic field varying from -1,000 to 1,000 Oe.

The most significant observation in the molecular dynamics simulation related to the asymmetric interfacial phenomena as shown in Figure 1. When Al atoms were deposited on a Co (0001) surface, an atomically sharp interface formed between the film and the substrate. On the other hand, severe intermixing was observed when Co atoms were deposited on an Al surface. Composition, radial distribution function and lattice parameter observed in the simulated interface evidently showed that 3 ML of a CoAl-B2 compound layer formed at the interface between Co and Al. The simulation also showed that the surface intermixing occured by dynamic penetration of the deposited atoms into the substrate, which suggests that the intermixing should be understood in terms of the kinetics for the atomic penetration.

The advantage of computer simulation was markedly demonstrated when we monitored the energy of the deposited atoms during simulation, as shown in Fig. 2. The initial kinetic energy of the deposited atom was 0.1 eV with zero potential energy. As the deposited atom approached the substrate at or about 1.4 ps after starting simulation, the kinetic energy increased very rapidly to 3.8 eV. This increase in the kinetic energy or acceleration to the substrate was accompanied by a rapid decrease in the potential energy. Local acceleration near the substrate is natural in most systems where the potential energy curve between the deposited atom and the substrate has a minimum at the equilibrium distance. The magnitude of acceleration is proportional to the slope of the potential curve with respect to atomic distance, i.e., the attracting force between the deposited atoms and substrate atoms.

Local acceleration has not been considered in conventional models of the thin film process. However, observation of local acceleration helps to resolve what has been the puzzling phenomenon of significant intermixing under low-energy deposition conditions such as thermal evaporation or molecular beam epitaxy. Even if the energy barrier to atomic penetration into the perfect substrate is larger than the initial kinetic energy of the deposited atoms, the local acceleration of the deposited atom in the vicinity of the substrate surface can provide enough kinetic energy to overcome the energy barrier to atomic penetration. A kinetic criterion can be inferred from the simulation results: surface intermixing occurs if the sum of the initial kinetic energy of the deposited atom and the local acceleration is larger than the energy barrier to surface intermixing.

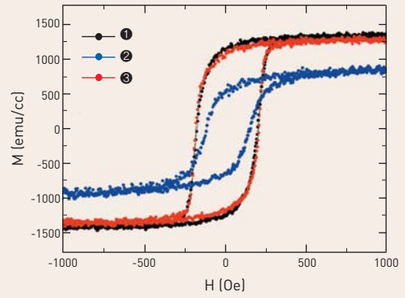

FIGURE 5. VSM measurement of Co-Al multilayers.
❶Cu capping/Co(3nm)/Cu buffer/Si sub.
❷Cu capping/Al(3nm) /Co(3nm)/Cu buffer/Si sub.
❸Cu capping/Co(3nm)/Al(84nm)/Si sub.

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The predicted asymmetry in the atomic scale intermixing was experimentally confirmed by both CAICISS and VSM measurement. Figure 3 shows the polar scan spectrum of 3KeV He^+ particles scattered by substrate Co atoms along the [1$\bar{1}$00] direction when Al was deposited on the Co substrate. The spectrum is almost identical to that of the pure (0001) Co surface, except for the peak at the incidence angle of about 37°. The observed spectrum agrees very well with the calculated one based on the assumption that the deposited Al atoms are placed at a distance of 1.8Å from the top Co layer on either the fcc or hcp site with the same probability. This result clearly shows that no intermixing occured between the deposited Al atom and the Co substrate. First principle calculations of the adsorption energy of Al ad-atoms on a Co (0001) surface support the experimental observations. The calculated adsorption energy of hcp and fcc hollow sites are 3.557 and 3.548 eV, repectively. Al atoms can thus occupy both hcp and fcc hollow sites at room temperature with approximately the same probability. Equilibrium height of the Al ad-atom from the surface Co layer was calculated to be 1.87±0.01Å, which is comparable to the observed value, 1.8Å. Figure 4 shows the polar scan spectrum scattered by substrate Al atoms along the [001] direction when a 0.5 monolayer of Co was deposited on the Al (001) surface. Due to the Co deposition, the spectrum was significantly changed from that of the pure Al (001) surface. However, the calculated spectrum of a CoAl-B2 structure fits very well with the observed spectrum, which shows that the deposited Co atoms significantly induced the CoAl-B2 layer.

Figure 5 shows the hysteresis curves measured by VSM of the Co/Al multilayers. The hysteresis loops of Co(30Å)/Si and Al(30Å)/Co(30Å)/Si are identical. However, the saturated magnetization of Co(30Å)/Al(840Å)/Si is much smaller than that of Co(30Å)/Si and Al(30Å)/Co(30Å)/Si samples. These behaviors can be explained by the formation of a nonmagnetic CoAl-B2 interlayer resulting in reduced thickness of the magnetic Co layer when Co was deposited on the Al surface. We also observed VSM hysteresis loops for various thicknesses of Co thin film on Al(840Å)/Si substrate. Hysterisis loop could not be observed when the thickness of Co was smaller than 10Å. It can thus be said that the thickness of the nonmagnetic CoAl-B2 layer is 10Å or 3 atomic layers, which agrees well with the MD simulation results.

ACKNOWLEDGEMENT

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A Locomotive Capsule Micro-Robot for the Gastrointestinal Tract

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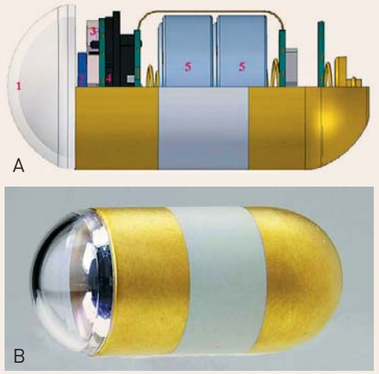

FIGURE 1. A: Schematic diagram of capsule endoscope: optical dome (1) lens (2), LEDs (3), image sensor (4), battery (5). B: Photograph of MiRo

FIGURE 2. Motion of paddling a canoe

Flexible endoscopy is a useful procedure for detecting and treating abnormalities in the gastrointestinal tract. The conventional push-type flexible endoscope is the most commonly used type of endoscope used in hospitals today. Unfortunately, this conventional endoscope is quite stiff when pushed, which can cause pain and discomfort in patients depending on the skill of individual operators. Moreover, its reach does not extend to the small intestine.

Wireless capsule endoscopes (CEs) were developed to address these problems and commercialized by Given Imaging Inc. (Israel), Intromedic (Korea), and Olympus (Japan) [1,2,3]. MiRO, developed by IMC (Intelligent Microsystem Center: http://www.microsystem.re.kr), is an example of one of these wireless capsule endoscopes. It has dimensions of 11 mm in diameter and 24 mm in length and consists of a CMOS camera, a communication module, illuminating LEDs, and a battery, as shown in Figure 1. When a patient swallows the wireless CE, the pain and discomfort often experienced with conventional endoscopes is reduced, and it is possible to view the small intestine for diagnostic purposes. The device also transmits wireless still images (2~3 frames/sec) from the gastrointestinal tract.

The wireless CEs currently on the market have great advantages over conventional options, but at present, are limited to applications in the small intestine and esophagus. Although the small intestine is a unique area that conventional endoscopes cannot reach, the majority of clinical cases involve the stomach, colon, or rectum. Current CEs are designed to move passively by the natural peristaltic motion in the digestive tract, but this passive movement is often not appropriate for diagnostic and therapeutic purposes. A wireless CE device with active locomotion at a regular velocity would better suit most diagnostic and therapeutic purposes as well as expand the application areas. Development of a device with a locomotive mechanism is extremely challenging, however, because the intestinal tract has a harsh environment consisting of soft and locally deformable tissues which have very slippery surfaces as a result of mucous secretion.

Studies of robots capable of locomotion have focused on legged robots [4,5,6]. However, a legged mechanism is difficult to apply to a capsule and is not easy to miniaturize. Nonetheless, one example of a legged locomotive mechanism for the gastrointestinal tract has been proposed which is based on active multiple legs with independent degrees of freedom [7]. Since this locomotive mechanism uses multiple legs, it needs multiple actuators and controllers. Therefore, it has drawbacks in terms of power consumption and miniaturization.

At KIST we have developed a locomotive mechanism which could become one of the most important components of a future CE. We have proposed a new paddling-based locomotive mechanism, a concept designed to mimic the motion of canoe paddling, as shown in Figure 2. The canoe-type paddles function as the legs of our micro-robot and the linear actuator, which is composed of a reliable commercialized micro-motor and a lead screw, acts as the "canoeist."

The locomotive mechanism of the proposed micro-robot is presented in Figure 3. Step (1) shows the initial state of the capsule-type micro-robot, which is inserted into the intestine. Step (2) shows the legs, which are protruded, and clamp onto the intestinal surface when the actuator moves the inner cylinder backward. Step (3) shows the legs, which are retracted, when the actuator moves the inner cylinder further. At this point, the outer body of the micro-robot advances forward. Step (4) shows the end of the stroke of the actuator. Step (5) shows the legs, which are released and folded into the robot body after being fixed to the intestine, when the actuator moves the inner cylinder forward. Finally, step (6) shows the legs and the inner/outer cylinders, which move forward without any movement of the micro-robot body. After these steps, the robot can begin again with the same configuration as step (1). Using this locomotion principle, our proposed capsule-type micro-robot can be easily moved inside the intestinal tract.

Figure 4 is a photo of the locomotive mechanism developed in our labs at KIST. This prototype uses a conventional micro step motor as an actuator and a lead screw for linear motion. The outer body of the prototype micro-robot is designed as a capsule with a diameter set to about 13mm. The outer body of the micro-robot, the inner cylinder and the outer cylinder are made of stainless steel. The legs are fabricated with SUS 304, manufactured by wire EDM (Electrical Discharge Machining). The total length is 43 mm and the stroke of the legs is determined by the slits on the robot body. To accommodate the components but keep size to a minimum, the maximum weight of the prototype is kept to 5.2 grams. To actuate and control the micro-robot, there is a control circuit to signal position and velocity change as well as switch direction of the legs [8].

For the feasibility test, *in vitro* experiments were performed using small intestine obtained from a live pig. The intestine was spread on Styrofoam forms with radii of about 25, 30, and 40mm. Our micro-robot was inserted into the small intestine and propelled along both straight and curved paths.

Eventually, *in vivo* animal tests were carried out at Yonsei Medical Center which has laboratories and medical facilities for animal tests. In this *in vivo* locomotion test, the capsular micro-robot was inserted into the porcine anus using an overtube. The overtube was about 15mm in diameter and guided the micro-robot to the large intestine. A C-arm mobile X-ray system monitored the motion of the capsular micro-robot. Figure 5 shows the still images from the X-ray movie of the moving capsular micro-robot.

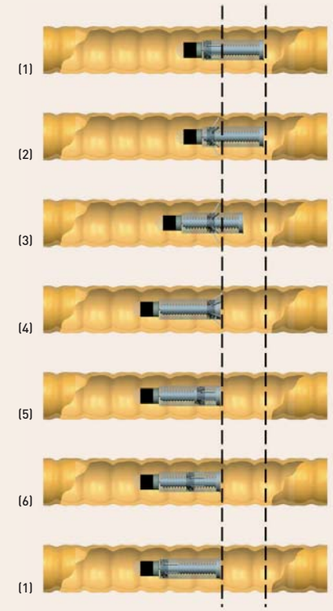

FIGURE 3. Locomotion principle of our proposed capsule-type micro-robot

FIGURE 4. Fabricated legged micro-robot

FIGURE 5. *In vivo* test and still image captured from X-ray movie of moving capsular micro-robot in large intestinal tract

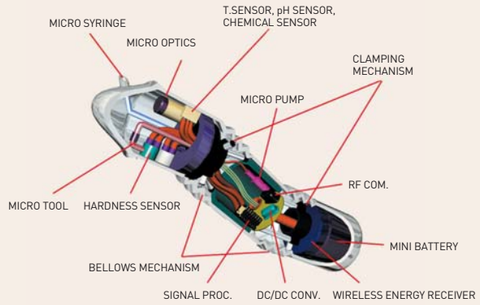

FIGURE 6. Conceptual diagram of future capsule endoscope to examine entire gastrointestinal tract

Throughout this *in vivo* test, our capsular micro-robot capably moved along the large intestinal tract. Specifically, the micro-robot traveled through the sigmoid pass, ascending tract, and gamma loop of the pig's colon. In the *in vivo* experiments, the locomotive capsule had a mean velocity of 17cm/min in the total length of 40cm. Based on these results, it is clear that the micro-robot we developed has feasible locomotive performance in the intestinal tract.

Although the *in vivo* results indicate that the paddling-based locomotive endoscopic capsule can successfully perform automatic locomotion in the large intestine of a living pig, several problems remain before the locomotive endoscopic capsule can be applied to the human body. First, the human large intestine has four major obstacles for an endoscopic capsule to pass through, including the junction of the rectum and sigmoid colon, junction of the sigmoid and descending colon, and the splenic and hepatic flexures. By contrast, a pig's large intestine does not have this type of structure, but rather, an overlapping spiral shape.

In the porcine large intestine, peristalsis decreases or disappears under anesthesia. Another research group developed a new endoscopic capsule to resist peristalsis and allow anchorage to the intestinal wall at a desired location [9]. However, in this study, mucosal injury caused by the paddles of the endoscopic capsule was observed. After manual retrieval of the paddling-based capsule endoscope, a colonoscopy revealed several pinpoint erythematous lesions on the intestinal mucosa, which suggested trauma from the end tip of the paddles. Since then, there have been investigations of new materials and surface designs of paddles to prevent mucosal injury. Recently, there was a feasibility study of a legged locomotive endoscopic capsule advanced in the gastrointestinal tract [10]. In this study, a well-designed *ex vivo* phantom model was used which simulated the structure of the human colon using porcine large intestine. Also, in the *in vivo* test with a living pig, the capsule was able to travel against peristalsis. However, the average velocity was only 3 cm per minute and it took about 50 minutes to examine the entire human colon of approximately 1.5 meters.

To recap, while our locomotive mechanism successfully traveled inside a large intestine, further study and development are needed to reduce the potential for injury and minimize risk. Future technologies will need to build on existing ones. They need to be capable of both diagnosis and treatment, and consequently, the capsule-type endoscope is an ideal prototype for these applications. To address the most important issues, the following functions and outcomes would be required:

- development of a locomotive mechanism for the gastrointestinal tract
- development of specialized capsules for different regions of the human body
- development of micro tools for biopsy and drug injection
- development of wireless power transmission technology
- integration of a bi-directional communication module for capsule control
- development of multi-functional sensor integration into the capsule
- development of merged ASIC

Our concept of a future endoscopic capsule equipped with all the functions listed above is illustrated in the diagram rendered in Figure 6.

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Flexible Electronics

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In 1983, Motorola introduced the world's first commercial cellular phone called DynaTAC. This represented one of the most significant technological breakthroughs in human communication. Although DynaTAC was too large and heavy for portable service (1.3kg, 127×228×45 mm, see left image of Fig. 1), it still became a status symbol. Only a few wealthy individuals ever owned one. A few years later in 1988, SKT, a Korean mobile service company, started a mobile communication business. Now, after only 20 years, most people over the age of 15 use cell phones for voice calls as well as other functions including games, message transfers, and video clips. We can't imagine our lives without cell phones and their associated services. Since such significant progress in cell phone technology, from brick-like to light, slim, and multi-functional, has been achieved in such a short time, the question arises, "What will happen in the next 20 years? Or even 10 years?" The exponential development of the technology related to cell phones is bound to lead to more big changes in the ways we communicate.

FIGURE 1. Evolution of Cellular Phones

Since 2003 KIST has conducted research related to the development of materials for flexible electronics. In Particular, we have focused on low voltage operating flexible thin film transistors.

What do we want from our cell phones?

In order to predict the future of the industry, the author conducted a brief survey a few years ago in which the primary question was, "How would you like your cell phone to be in the future?" The summary conclusion was that the respondents wanted their future phones to be thin, beautiful and multi-functional. These features are paramount in today's market and are expected to remain so for the near future. Current phones on the market are now as thin as one centimeter or less. Beautiful phones such as the i-Phone and Prada phone are attractive to consumers even though they are very expensive. In addition, smart phones, in which many functions such as GPS, Bluetooth, a camera, Wifi and DMB are incorporated in one device, are popular. With ever expanding functions, it appears that the cellular phone may one day become a substitute for the notebook computer.

Nonetheless, there are two major obstacles to overcome before the cellular phone can emerge as a substitute for the notebook computer. The first one is the display and the other is the input device. Since the cellular phone should be designed for easy carrying in clothing or carry-on bags, it should not be bigger than a wallet. On the other hand, having a large display and input device is important for convenience. Touch panels can be a good solution to this dilemma. With touch panels, display and input devices can share the same space resulting in a larger area than if they were placed in individual dedicated spaces.

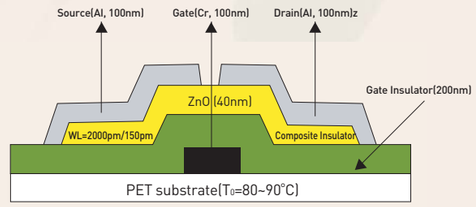
FIGURE 2. A flexible cellular phone concept from Nokia: the Morph.

Recently, Nokia proposed a concept phone called "the Morph," illustrated in Fig. 2. The main feature of this phone is that it is foldable and bendable. With this flexible form, a larger display area and space for the input device are possible while retaining a carriable size. This is the future concept of flexible electronics even though many technical breakthroughs must first be made to realize this concept.

Flexible Transistor

Since 2003, KIST researchers, including this author, have conducted research related to the development of materials for flexible electronics. We have classified flexible electronics into four categories: active material, passive material, substrate and integration. In particular, we have focused on low voltage operating flexible thin film transistors.

A transistor consists of metallic electrodes, semiconducting active materials and dielectric materials. Conventional transistors use silicon as an active material and silicon oxide as a dielectric material. Conventional transistors are not bendable because they consist of brittle ceramic materials. The substrate on which the transistor is fabricated should also be flexible. Polymers are excellent for this purpose because they are functional up to 200°C and exhibit soft characteristics. In order to make a bendable transistor, researchers have focused on organic semiconducting and dielectric materials. However, so far these materials have demonstrated poor performance compared to conventional ceramic transistors. To implement stable flexible transistor operation, it is important to achieve a fabrication process with higher permittivity (K) gate dielectric and high field effect mobility at room temperature. A traditional Poly-Si semiconductor's mobility is as high as 50~150 cm^2/Vs; however, if it is deposited on plastic substrates, the substrates become distorted. Traditional silicon-based transistors use SiO_2 gate insulators with a dielectric constant of 4. An SiO_2 gate insulator, which requires a deposition temperature of 200~300°C, exhibits limited growth on plastic substrates. In addition, organic dielectrics have low dielectric constant characteristics (dielectric constant 3~4), causing a transistor's driving voltage to be high.



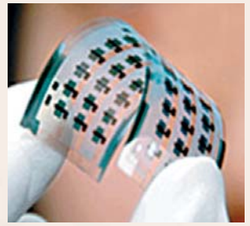


FIGURE 3. KIST's Flexible Transistor (mobility 65)

At KIST we fabricated a bendable transistor on a polymer substrate by depositing ZnO as a semiconducting material and BiZnNb (BZN) as a dielectric material. The thicknesses of the two ceramic layers were thin enough to make a bendable transistor. Deposition was carried out at room temperature in order to prevent the thermal degradation of the polymer substrate. A gate dielectric with a higher permittivity (K) constant induced large capacitance values between the semiconductor layer and gate dielectric enabling the manufacture of transistors capable of operating at less than 5 V operation voltages. We found that using high K dielectrics with adequate thickness (〉200 nm) improved the suppression of pinhole formation and breakdown dielectric characteristics. To date, we have achieved a field effect mobility of 65 cm^2/Vs.

In ongoing research we are pursuing new types of next-generation applications such as wrist handsets and wearable computers as well as flexible displays. Research into the key technical infrastructure behind flexible electronics is on-going based on flexible displays. According to Display Search, transistor manufacturing technologies with high mobility/high stability will generate a market of US $20 billion by 2015. If high field-effect mobility, long-term lifetime stability and a high on/off ratio is implemented in the future, flexible transistors can be utilized in flexible logic circuits, micro chips and memory transistors. Furthermore, low voltage operations will contribute to cost savings by enabling the use of lower cost driver electronics making them particularly suitable for portable applications, e.g., in laptop computers, the most rapidly growing segment of the computer industry. Flexible transistors will also be useful for large scale macro-electronics such as electronic paper as well as flexible and wearable electronics.

Lithium Secondary Batteries as High Efficiency Energy Storage Devices

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FIGURE 1. Lithium secondary batteries and electrode materials developed at KIST.

Batteries, first invented in the late 18th century and commercialized a century later, set mankind free from the wall outlet. Even though early models of batteries did not perform as well as modern ones, the technology still enabled the production of small portable electronic devices such as wrist watches, calculators, flashlights, etc. Batteries also made it possible for devices that consume electricity to be cordless. Since its initial development, battery technology has progressed slowly but steadily. Various types of batteries produced with different chemical materials have been introduced into the market and have evolved into rechargeable types known as secondary batteries.

In 1991 Sony introduced lithium secondary batteries which have become the state-of-the-art battery system. The working principle of lithium secondary batteries is that lithium ions shuttle between the cathode and anode. Thus they are often referred to as lithium ion batteries (LIBs). Because LIBs have much larger capacities than Ni-Cd and Ni-MH batteries, previously the most advanced batteries on the market, electronic devices which consume considerably more electricity have been designed and commercialized, dramatically changing lifestyles around the world. Devices such as cellular phones, laptop computers, camcorders and digital cameras are some of the electronic devices which have benefited the most from the introduction of lithium secondary batteries.

Japan has been the world leader in market share and developmental technology of lithium secondary batteries since their initial commercialization, but Korea has made a concerted effort since the mid-90's to become a major player in the field. It now holds the second largest global market share and has achieved comparable technological advances in terms of battery manufacturing. Korea is still investing heavily in the development of principal technologies related to the electrode materials used in lithium secondary batteries, and KIST is at the forefront of this process.

The Battery Research Center at KIST was established to meet national long- and mid-term R&D goals related to secondary battery industries. The Battery Research Center conducts basic and applied research in electrochemical science covering a wide range of topics such as electrochemical processes, energy conversion/storage systems, and many others. These research areas represent crossover technology combining electrochemistry, nano, and processing technologies. The

Center's research focus currently includes electrode materials for energy conversion/storage systems, electrolytes, thin film secondary batteries, thin film processes, and other related research topics.

The Center's main research areas include:

- Core technologies for next-generation lithium secondary batteries.
- High performance cathode and anode materials and electrolytes for batteries.
- Nano-structured materials for batteries and control of surface structure.
- Integrated systems for secondary batteries and solar cells.
- Novel battery systems.

The Battery Research Center at KIST has been devoting most of its efforts to developing advanced cathode and anode materials for lithium secondary batteries. Recently we have transferred technologies involving high capacity and high safety cathode materials, fluorination technology for natural graphite anode materials, high-performance lithium polymer batteries, and thin-film batteries.

Fig. 2 shows the SEM image of a high density cathode material, $LiMn_xNi_yCo_zO_2$, with uniform morphology, a material developed by KIST. We have developed the processing technology for the synthesis of cathode materials using a co-precipitation method. We have also developed a surface treatment technology to coat the surface of cathode particles with metal oxides or fluorinated compounds. The surface coated $LiMn_xNi_yCo_zO_2$ has shown about a 25% improved capacity, cycle life, and rate performance characteristics compared to conventional $LiMn_xNi_yCo_zO_2$.

Fig. 3 shows a comparison of the cycle life of different $LiMn_xNi_yCo_zO_2$ cathode materials. M-LMNC3 and M-LMNC4 are the cathode materials synthesized and surface-treated using the technology developed at KIST. They retain more than 80% of their initial capacity after cycling 500 times, a very superior cycle performance compared to previously commercialized cathode materials.

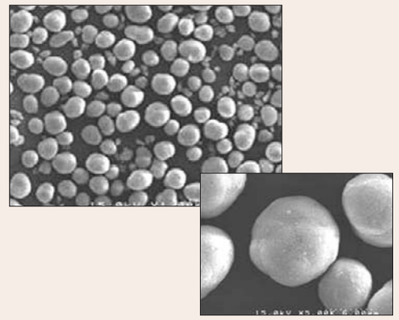
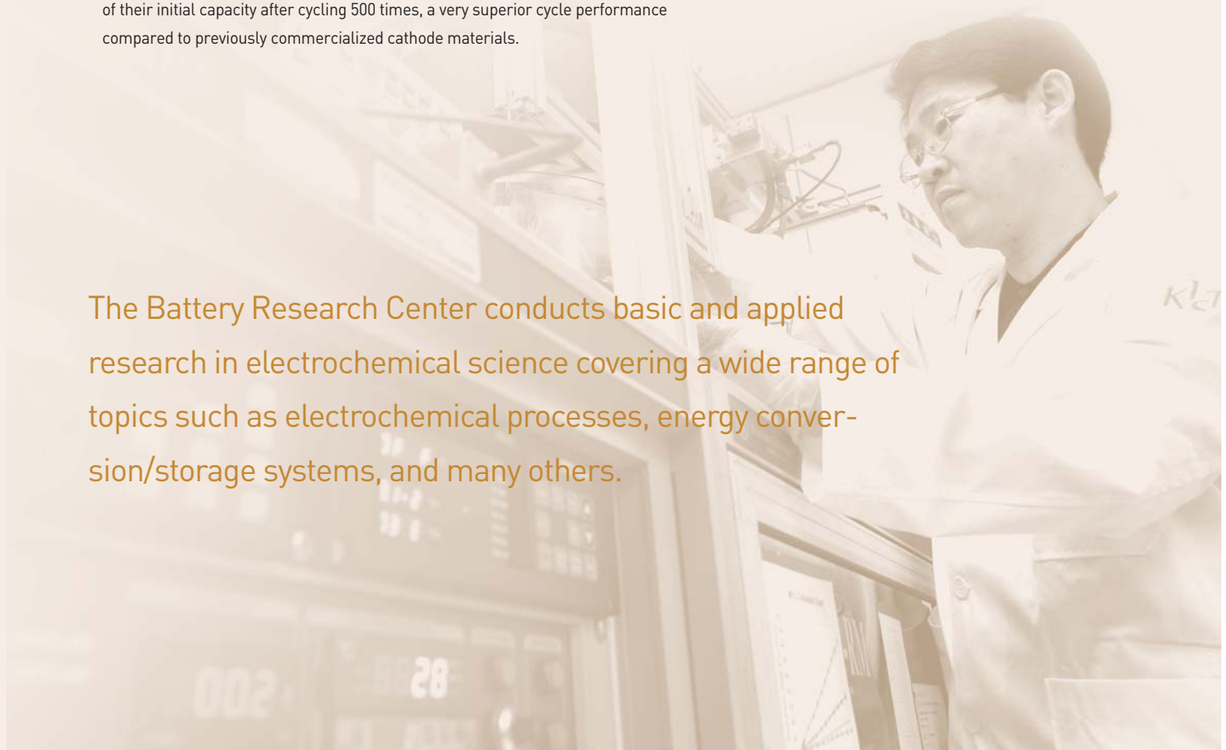


FIGURE 2. SEM image of high density cathode material with uniform morphology.



The Battery Research Center conducts basic and applied research in electrochemical science covering a wide range of topics such as electrochemical processes, energy conversion/storage systems, and many others.

Fig. 4 shows the cycle performance of natural graphite anode materials. Even though natural graphite has the advantage that it costs much less than synthetic graphite, its poor electrochemical performance has hindered it from being used as an anode material for lithium secondary batteries. We have developed a surface treatment technology using a fluorination method. By fluorinating the surface of natural graphite particles, a stable SEI (solid-electrolyte interface) layer is formed which protects the natural graphite particles from deteriorating. As a result, the cycle performance of the natural graphite anode is improved dramatically (Fig. 4, ST-Gr) as reflected in an initial capacity of more than 350 mAh/g and a retention of more than 80% of its initial capacity after cycling 500 times at 1C rate. This fluorination technique will enable natural graphite to be used in high quality lithium secondary batteries.

The Battery Research Center is constantly developing advanced cathode and anode materials for lithium secondary batteries. One of the current studies underway at the Center involves research into novel materials with high capacities that meet the demands of plug-in hybrid electric vehicles. In the near future, the Center is planning to expand its research scope into even more challenging areas. For example, research is about to begin on bio-compatible batteries and flexible lithium secondary batteries which can be used in implantable medical devices, E-books, wearable computers, etc. Advanced research of this type, performed and envisioned at KIST, will undoubtedly advance the technology level of the Korean lithium secondary batteries industry.

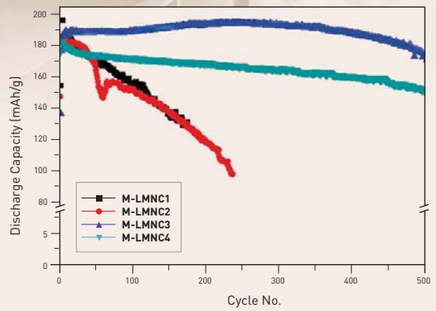


FIGURE 3. Cycle performance comparison of different $LiMn_xNi_yCo_2O_2$ cathode materials.

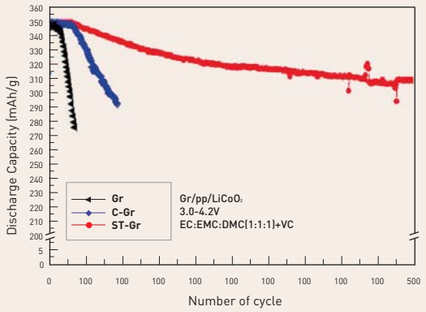


FIGURE 4. Cycle performance of surface-treated natural graphite anode materials compared to untreated ones.

Tissue Engineering and Regenerative Medicine: Mechano-active Scaffolds for Bio-Organs

Soo Hyun Kim
Biomaterial
Research Center
•
soohkim@kist.re.kr

Dramatic advances in the fields of biochemistry, cell and molecular biology, genetics, biomedical engineering and materials science have given rise to the remarkable new cross-disciplinary field of tissue engineering and regenerative medicine (TERM). As the average age of the population increases, age-related "wear-and-tear" conditions as well as traumatic injury or disease have also become more common. TERM promises a more permanent treatment option for these conditions than that currently offered through healthy donor organs which are typically in short supply. Tissue engineering emerged in the 1990's, and since then, certain techniques have been clinically applied for articular cartilage lesions, as well as diseases and injury involving the corneal epithelium and epidermis. Nevertheless, the clinical opportunities for tissue engineering are still limited, despite a greater need for treatment in societies with declining birthrates and growing proportions of the elderly. The latest and most advanced technologies in material/biological science, three dimensional molding methods, promise to become an important field for developing structures that are morphologically and functionally similar to those of a living body.

Mechanical stimulation regulates the specialized structures and functions of mammalian cells, tissues, and organs. Mechanical stimulation also increases collagen production and induces the phenotype of cells in engineered tissues to be more consistent with a contractile, differentiated phenotype. To engineer any tissue under conditions of mechanical strain (mechano-active tissue engineering), it is necessary to utilize soft but elastic scaffolds (mechano-active scaffolds).

In our work we have synthesized very elastic biodegradable poly(glycolide-*co*-ε-caprolactone) or PLCL [poly(L-lactide-co-ε-caprolactone)] scaffolds. Those scaffolds exhibit very flexible but rubberlike elastic properties and retain recovery even under cyclic loading in culture media for up to an initial 2 weeks. For efficient tissue engineering, scaffolds should maintain their mechanical stability for an initial period, but then degrade at an appropriate time to be replaced by new tissues. PLCL scaffolds with 90% porosity have shown 100% recovery at near 100% strain. In addition, these PLCL scaffolds have demonstrated excellent compatibility. They can be used in conjunction with a mechano-active bioreactor to deliver mechanical signals to cells adhering to the scaffolds during mechanical strain application. Some of the recent advances in mechano-active tissue engineering, focusing on blood vessel and cartilage regeneration, are described below.

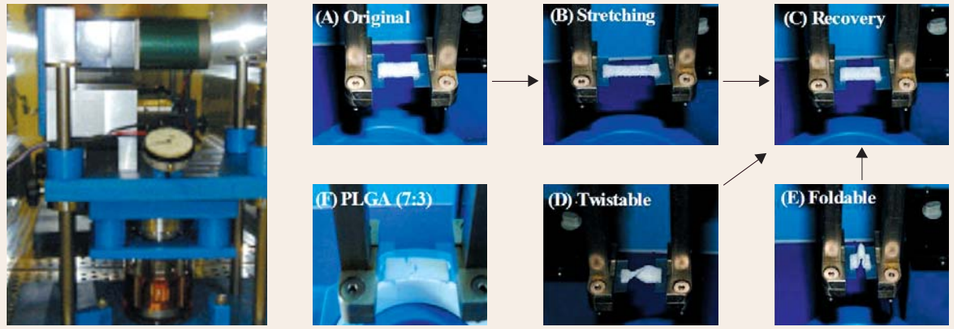


FIGURE 1. Bioreactor and elastic behaviors of PLCL scaffolds. PLCL scaffolds (A) were extended to 250% of their initial length (B) with 3MPa for 5 sec and recovered (C) by releasing the load. The scaffolds were twisted (D) and folded (E) via cyclic strain apparatus. PLGA (F) was broken at 20% strain.

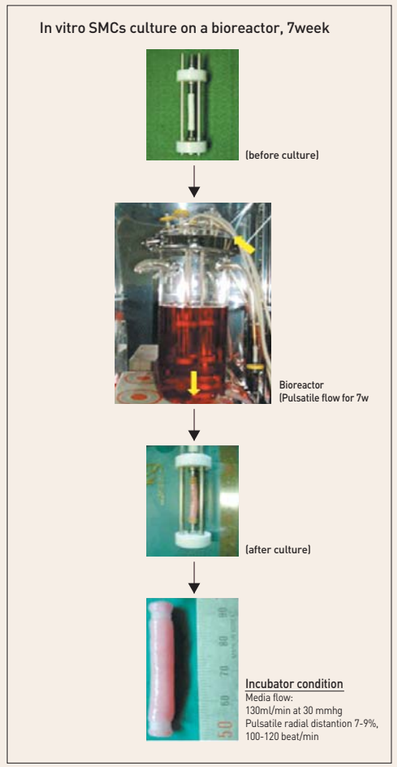


FIGURE 2. In vitro pulsatile flow system (bioreactor); insert shows a connecting sleeve between a perfusion tube and a scaffold.

A small diameter blood vessel can become blocked easily because the smaller diameter slows blood velocity and can lead to blood coagulation. Consequently, the use of a bioreactor for tissue engineering technology is valuable in preparing a mature and functional artificial blood vessel. Our work with rubberlike elastic PLCL scaffolds involved the regeneration of blood vessels subjected to a repeated expansion-contraction mechanical stimulus in pulsated fluid similar to the human blood stream. PLCL scaffolds were subjected to pulsatile strain and shear stress by culturing them in pulsatile perfusion bioreactors for up to 7 weeks. As control experiments, vascular smooth muscle cells (VSMCs) were cultured on PLCL scaffolds statically. The pulsatile strain and shear stress enhanced the VSMCs proliferation and collagen production. In addition, significant cell alignment in a direction radial to the distending direction was observed in VSM tissues exposed to radial distention, similar to that of native VSM tissues *in vivo*, whereas VSMs in VSM tissues engineered in a static condition exhibited random alignment. Importantly, the expression of SM α-actin, a differentiated phenotype of SMCs, was up-regulated 2.5 times more in VSM tissues engineered under the mechano-active condition than in VSM tissues engineered in a static condition. This study demonstrates that the engineering of VSM tissues *in vitro* by using pulsatile perfusion bioreactors and elastic PLCL scaffolds leads to the enhancement of tissue development and the retention of differentiated cell phenotype.

Research involving large diameter blood vessels aims to find a method for the regeneration of 6mm scale large diameter blood vessels by using scaffolds made through a novel gel spinning technology. To withstand expansion-contraction stress under high pressure within a fast blood stream environment, a scaffold with high strength and elasticity must be used. Using a gel molding technique developed to make a micro-fiber structured scaffold, we were able to produce a biocompatible and biodegradable scaffold having appropriate porosity, high

mechanical strength, and cell injection efficiency. Moreover, we have developed a practical tissue engineering technology using autologous bone marrow stem cells and mechano-active scaffolds.

We fabricated tubular, macro-porous, fibrous scaffolds using biodegradable PLCL in a gel-spinning process. PLCL scaffolds showed good mechanical properties and porous structures. For *in vivo* study, fibrous scaffolds were implanted into a canine aorta and subsequently removed and examined when the dog was sacrificed after 6 months. On the basis of this study, PLCL scaffolds show good patency and considerable promise as vascular tissue grafts for clinical applications in the future.

Due to the lack of self-healing capacity of avascular and aneural tissues, even minor cartilage defects can result in mechanical joint instability and progressive damage, and cartilage damage is notoriously difficult to treat and cure. Although many studies have explored cartilage regeneration using techniques associated with tissue engineering and cell therapy (e.g., autologous chondrocyte implantation and marrow stimulation), these approaches have not adequately addressed certain problems in cartilage regeneration, such as fibrocartilage formation and lower mechanical strength of implants relative to that of native cartilage. Articular hyaline cartilage is subjected to particularly complex loads that affect its development and maintenance in the body. Hence, mechanical stimulation associated with normal physiological movement is crucial in properly re-forming articular cartilage through tissue engineering. The successful generation of functional, engineered cartilage will require a mechano-active scaffold that can transmit mechanical signals to adherent cells in the physiologically dynamic *in vivo* environment. To deliver the required mechanical signals associated with the surrounding biological environment of cartilage, we fabricated a sponge-type microporous scaffold from elastic PLCL copolymer by a gel-pressing method.

To evaluate the suitability of microporous PLCL scaffolds for mechano-active cartilage tissue engineering, chondrocyte-seeded PLCL scaffolds were cultured for 10 days under continuous compressive deformation of 5% strain at 0.1 Hz using a compressive-mode bioreactor as well as under control static conditions. These scaffolds were subsequently implanted subcutaneously into nude mice. The collagen and GAG content of mechanically stimulated scaffolds increased significantly over 10 days in culture compared to that in static-cultured scaffolds. Histological analysis showed that the mechanically stimulated implants formed mature and well-developed cartilaginous tissue, as evidenced by the presence of chondrocytes within lacunae and the abundant accumulation of S-GAGs.

Tissue engineering scaffolds play a crucial role in delivering mechanical stresses from the extracellular environment to the cells responsible for tissue formation. PGCL and PLCL are rubber-like, elastic, biodegradable polymers that have been developed as key materials for mechano-active tissue engineering. In both *in vitro* and *in vivo* studies, these scaffolds have sustained SMC phenotype and chondrogenic differentiation in vascular tissue engineering and cartilage tissue engineering, respectively.

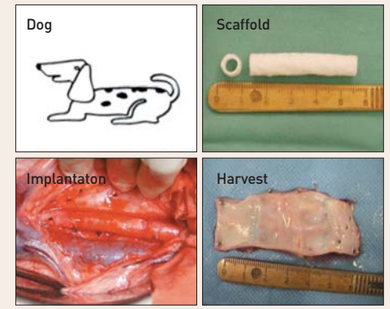


FIGURE 3. In vivo canine study: fibrous scaffold implantation and harvest after 6 months.

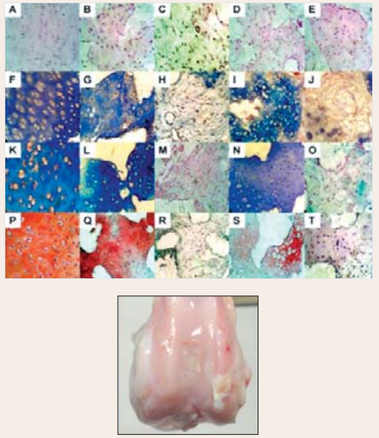


FIGURE 4. Histological studies of implants at 8 weeks and photograph of rabbit knee articular cartilage defects immediately after creation with PLCL scaffold at 12 weeks. The sections were stained with H&E (A-E), Masson's Trichrome (F-J), Alcian Blue (K-O), or Safranin O (P-T). Articular cartilages of rabbits were stained as the positive controls (A, F, K, P). The other images are of the constructs stimulated mechanically for 10 days (B, G, L, Q) or 24 days (D, I, N, S) and of the constructs not stimulated for 10(C, H, M, R) or 24 days (E, J, O, T).

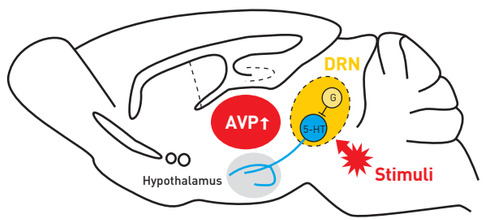
PUBLICATIONS

1 Deletion of N-type Ca^{2+} Channel $Ca_v2.2$ Results in Hyperaggressive Behaviors in Mice

The Journal of Biological Chemistry, 284, 2009, 2738-2745

Chanki Kim, Daejong Jeon, Young-Hoon Kim, C. Justin Lee, Hyun Kim, and Hee-Sup Shin

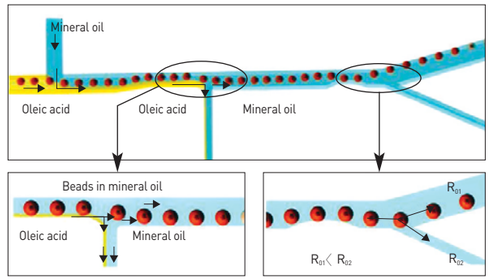
Voltage-dependent N-type Ca^{2+} channels play important roles in the regulation of diverse neuronal functions in the brain, including neurotransmitter release. Using N-type Ca^{2+} channel $Ca_v2.2$ deficient mice, we demonstrate that N-type Ca^{2+} channels at the dorsal raphe nucleus (DRN) have a key role in the control of social aggressive behaviors. Our results suggest that the role of N-type Ca^{2+} channels in GABA transmission in the DRN is required for the suppression of aggression. The deletion of this N-type Ca^{2+} channel function led to an increased firing activity of serotonin (5-HT) neurons in the DRN and elevated level of arginine vasopressin (AVP) hormones in the brain, resulting in enhanced aggression in the $Ca_v2.2$ mutant mice. These results may provide us with a new insight into the neurobiology underlying aggressive behaviors in animals and humans.

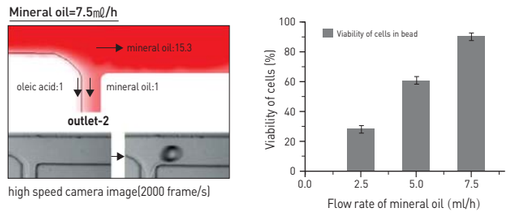


2 Rapid Exchange of Oil-phase in Microencapsulation Chip to Enhance Cell Viability

Lab on a Chip 9, 2009, 1294 ~ 1297

Choong Kim, Kang Sun Lee, Young Eun Kim, Kyu-Jung Lee , Soo Hyun Lee, Tae Song Kim and Ji Yoon Kang





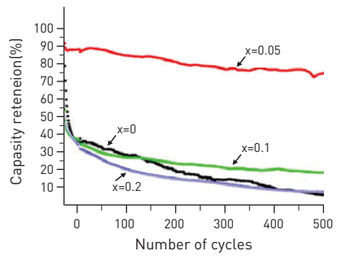
This paper describes a microfluidic device for the microencapsulation of cells in alginate beads to enhance cell viability. The alginate droplet including cells was gelified with calcified oleic acid, using two-phase microfluidics. The on-chip gelation had generated monodisperse spherical alginate beads, which could not be readily obtained via conventional external gelation in a calcium chloride bath. However, the prolonged exposure of encapsulated cells to the toxic oil phase caused serious damage to the cells. Therefore, we proposed the formulation of a rapid oil-exchange chip which transforms the toxic oleic acid to harmless mineral oil. The flushing out of oleic acid after the gelation of alginate beads effected a dramatic increase in the viability of P19 embryonic carcinoma cells, up to 90%. The experimental results demonstrated that the cell viability was proportional to the flow rate of squeezing mineral oil.

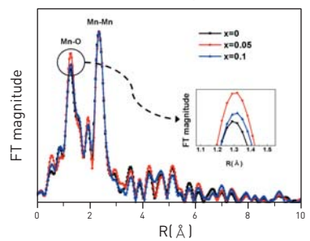
3 XPS/EXAFS Study of Cycleability Improved LiMn2O4 Thin Film Cathodes Prepared by Solution Deposition

Electrochemistry Communications 11, 2009, 695-698

Dong Wook Shin, Ji-Won Choi, Won-Kook Choi, Yong Soo Cho and Seok-Jin Yoon

The influence of Sn substitution in $LiMn_2O_4$ thin films used as cathodes was studied via solution deposition to improve the electrochemical performance of thin film lithium batteries. Improved performance was highlighted by the higher capacity retention of 77% after a 500 cycling test for $LiSn_{0.025}Mn_{1.95}O_4$ thin films, compared to 12% for pure $LiMn_2O_4$ thin films. This promising result is believed to relate to the increase in the average Mn valence state and the decrease in $[MnO_6]$ octahedral distortion in spinel structure. Beyond the optimal composition of $LiSn_{0.025}Mn_{1.95}O_4$, further Sn substitutions ($x \geq 0.10$ in $LiSn_{x/2}Mn_{2-x}O_4$) led to insignificant influence on the cycling performance accompanying apparent precipitation of SnO_2 and SnO after the cycling test. The non-monotonous effect of Sn substitution in $LiMn_2O_4$ thin films on electrochemical performance was investigated by focusing on the probability of replacing Mn by Sn according to the valence states of Mn and Sn, as well as Sn content. This was analyzed by several techniques including XRD (X-ray diffraction), XPS (X-ray photoelectron spectroscopy), and EXAFS (extended X-ray absorption fine structure).

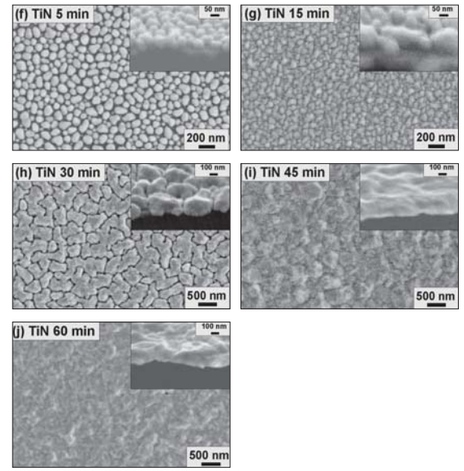




4 Deposition of Copper Particles and Films by the Displacement of Two Immiscible Supercritical Phases and Subsequent Reaction

Chemistry of Materials 21, 2009, 913–4924

Jaehoon Kim, Douglas Taylor, James DeYoung, James B. McClain, Joseph M. DeSimone and Ruben G. Carbonell



Copper (Cu) films have been extensively investigated as substitutes for aluminum (Al)-based interconnects in microelectronic devices due to increased demand for high packing density. Current Cu film deposition techniques, such as chemical vapor deposition (CVD), physical vapor deposition (PVD) electroless deposition, and electrodeposition, have drawbacks including poor gap-filling and conformality, creation of voids, possible incorporation of impurities into the film, complexity of the deposition process, and generation of environmentally harmful waste. In this research, we demonstrate that a supercritical carbon dioxide ($scCO_2$)-based Cu film deposition technique can result in highly pure Cu films, thanks to the gas-like transport and zero interfacial tension properties of $scCO_2$ and the inherent solvation of organic by-products into the $scCO_2$.

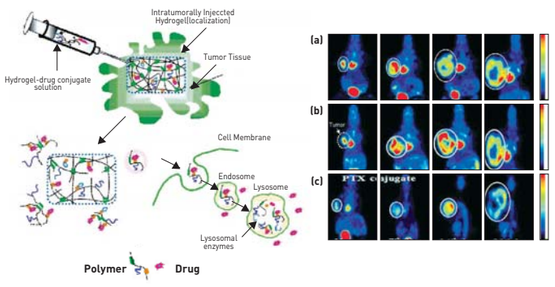
5 Thermosensitive Poly(organophos-phazene)-Paclitaxel Conjugate Gels for Antitumor Applications

Biomaterials, 30, 2009, 2349-2360

ChangJu Chun, Sun Mi Lee, Sang Yoon Kim, Han Kwang Yang, Soo-Chang Song

A thermosensitive polymer-paclitaxel (PTX) conjugate was designed with the aim of developing a local injectable drug delivery system that could increase the therapeutic efficacy of PTX via a controlled and sustained release of PTX at target tumor sites while decreasing systemic side effects. We developed the injectable, *in situ*-forming, biodegradable, and thermosensitive poly(organophosphazene)-PTX conjugate through a covalent ester linkage between carboxylic acid-terminated poly(organophosphazene) and PTX. The aqueous solution composed of the poly(organophosphazene)-PTX conjugate existed in an injectable fluid state at room temperature but immediately formed a hydrogel at body temperature. The polymer-PTX conjugate hydrogels, after local injection at the tumor site, were shown to inhibit tumor growth more effectively and longer than PTX and saline alone, indicating that the tumor-active PTX from the polymer-PTX conjugate hydrogel was released slowly over a longer period of time and effectively accumulated locally in the tumor sites.

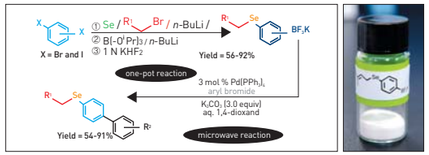
This suggests that the poly(organophos-pha-zene)-PTX conjugate holds promise for use in clinical studies as a single and/or combination therapy. Using the injectable and thermosensitive poly(organophosphazene)-drug conjugate hydrogel described in this study, it may be possible to develop a drug delivery system that can locally deliver the drug through an intratumoral injection, not requiring surgery, to maximize tumor inhibition at the tumor sites over a prolonged period and to minimize the systemic side effects since the polymer-drug conjugates would remain localized.



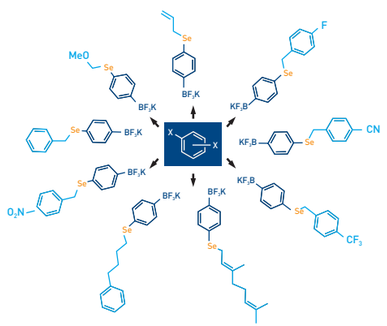
6 A Facile One-Pot Preparation of Organoselanyltrifluoroborates from Dihalobenzenes and Their Cross-Coupling Reaction

Organic Letters, 11, 2009, 361-364

Hong Ryul Ahn, Young Ae Cho, Dong-Su Kim, Jungwook Chin, Young-Soo Gyoung, Seokjoon Lee, Heonjoong Kang, and Jungyeob Ham



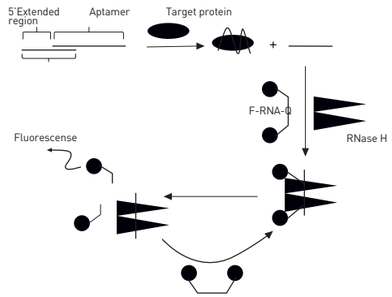
In recent years, interest in synthesis of selenium-containing compounds has increased because of their interesting reactivities and potential biological activities. Thus, a simple and economical method for the preparation of selenium-containing organoboron compounds for use in palladium catalyzed cross-coupling reactions remains a highly desirable goal. In this communication, we report initial results to develop a convenient preparation of potassium organoselanyltrifluoroborates in good yields via a simple one-pot, multicomponent reaction involving dihalobenzenes, electrophiles, and selenium powder. Additionally, using the resulting organoselanyltrifluoroborates, we successfully performed microwave-promoted Suzuki-Miyaura cross-coupling reactions with aryl- and alkenyl bromides in the presence of 3.0 mol% of $Pd(PPh_3)_4$ catalyst. From the results, we expect that these novel selenium-containing potassium oranotrifluoroborates would appear to be very useful precursors for the Suzuki-Miyaura-type cross-coupling reaction.



PATENTS

METHOD AND KIT FOR DETECTING A TARGET PROTEIN USING A DNA APTAMER

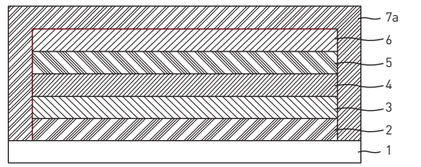
Patent No. 10-0896987 Contact Info. **Ahn, Dae-Ro** (drahn@kist.re.kr)



This patent discloses a method and kit for detecting a target protein in a sample using a signal amplification strategy. The signal amplification strategy is established for the aptamer-based molecular recognition of a target protein with concomitant release of single-stranded DNA (G-DNA) which binds complementarily to a single-stranded RNA comprising a fluorophore and a quencher ("F-RNA-Q").

INORGANIC THIN LAYER AND ELECTROLUMINES-CENCE DEVICE COMPRISING THE SAME

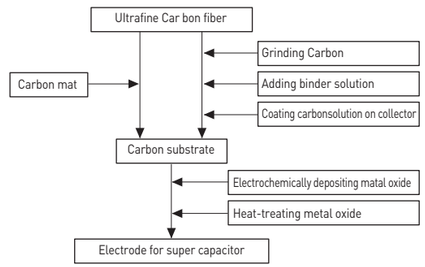
Patent No. 10-0540179 Contact Info. **Kim, Jai-Kyeong** (jack@kist.re.kr)



This patent discloses (1) an inorganic thin layer which is moisture and oxygen proof and composed of an inorganic composite containing at least two kinds of inorganic materials; (2) an organic electroluminescence device including the inorganic thin layer as a passivation layer; and (3) a fabrication method thereof.

ELECTRODE FOR SUPERCAPACITOR HAVING METAL OXIDE DEPOSITED ON ULTRAFINE CARBON FIBER AND THE FABRICATION METHOD THEREOF

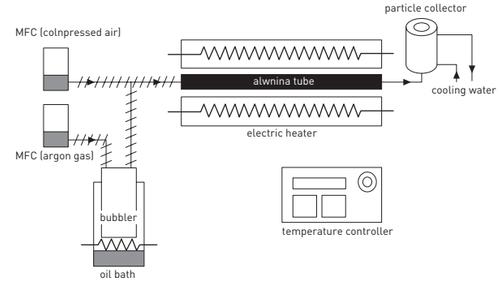
Patent No. 10-0894481 Contact Info. **Kim, Dong Young** (dykim@kist.re.kr)



This patent discloses an improved electrode for a supercapacitor. The electrode is comprised of: (1) a collector; (2) a carbon substrate disposed on the collector consisting of ultrafine carbon fibers having a specific surface area of at least 200 m 2/g (BET) and a d 002value of 0.36 nm or less; and (3) a metal oxide thin layer formed on the carbon substrate.

METHOD FOR THE PREPARATION OF VANADIA-TITANIA CATALYST HAVING A NANO STRUCTURE FOR DEGRAD-ING CHLORINATED ORGANIC COMPOUNDS BY USING A SOLVOTHERMAL SYNTHESIS PROCEDURE

Patent No. 10-0887249 Contact Info. **Jurng, Jong Soo** (jjurng@kist.re.kr)



This patent discloses a method for preparing a vanadia-titania catalyst having a core-shell structure. This catalyst is highly active in decomposing chlorinated organic compounds such as dioxin present in the exhaust of an incinerator.

KIST NEWS

2009 Korea-EU Joint Workshop (March 17~18)

The 2009 Korea-EU Joint Workshop, organized by KIST Europe and the Korea Industrial Technology Foundation (KOTEF), was held on March 17~18, 2009. Among the participants were President Dongwha Kum of KIST, Chairman Yong-Geun Kim of KOTEF, and Ambassador Brian McDonald of the European Commission Delegation in Korea. Over 400 Korean and international participants from industrial, academic and research sectors attended the workshop where information was provided on recent developments pertaining to environmental regulations in the EU, plans for R&D cooperation, and green technology. There were enthusiastic in-depth discussions on core issues such as the EU Framework Program, renewable energy, and REACH (Registration, Evaluation, Authorization and Restriction of Chemicals). The workshop was a valuable forum for reinforcing industrial technology cooperation between Korea and the EU countries.

Hybrid Computational Science Lab Opens in the Computational Science Center of KIST (March 25)

A signing ceremony was held on March 25, 2009, to mark a Memorandum of Understanding between the Computational Science Center of KIST, the Nano and Micromechanics Laboratory at Brown University and the Computational Nanomaterials Laboratory of Seoul National University to establish a Hybrid Computational Science Center at KIST. The members of this joint collaborative laboratory at KIST consist of top notch research scientists in their respective areas. The Computational Science Center of KIST, led by Dr. Kwang-Ryeol Lee, is a leading research group in Korea in computational nano-bio technology. Professor Kyung-Suk Kim of Brown University and Professor Jisoon Ihm of Seoul National University are world renowned scholars in the field of nanotechnology. Novel techniques to maximize the surface area of polymer materials and amorphous carbon materials will be developed for application in renewable energy and clean environment technologies, such as hydrogen storage materials, nano-catalysts, filters for cleaner environments and CO2 absorbents. The KIST researchers will focus on developing a new surface modification technology through both atomic scale simulation and experimental approaches. The research group at Brown University will develop a new multi-scale surface modeling technology, and the team at Seoul National University will use quantum mechanical calculations to optimize the atomic structure of materials for efficient hydrogen storage.

The 2nd Annual ICE (International Cultural Exchange) Festival 2009 (April 30)

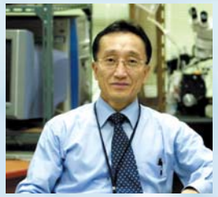
KIST commemorated National Science Month on April 30, 2009, with the ICE (International Cultural Exchange) Festival 2009 in which foreigners at KIST made presentations about the traditions and culture of their respective countries. Under the slogan "Enjoy ICE before it melts!" the event was attended by about 150 foreign scientists and students from 20 countries who are involved in research activities at KIST. The participants presented their respective research activities through posters, and organized displays of their national food, costumes, and traditional cultures. This event was also open to foreigners at nearby institutions such as Korea University, Kyung Hee University, Hankuk University of Foreign Studies, Korea National University of Arts and the Korea Development Institute, thus making it a representative international event in the Hongneung neighborhood. Some of the outside participants not only attended the event, but also helped prepare for it with their friends from KIST. The ICE Festival is one of several events hosted each year by KIST in honor of its international staff and student population. Another is "Foreigners Day," held every year around Chuseok, for foreign scientists and IRDA (International R&D Academy) students, and their family members.

Dr. Kum Attends Universitas 21 Symposium & Annual General Meeting 2009 (May 21)

The Universitas 21 Symposium & Annual General Meeting 2009, which this year explored the theme of "The Role of the University in Influencing Public Policy," was held over three days beginning May 20, 2009. At a symposium session on May 21, Dr. Dongwha Kum, President of KIST, gave a presentation entitled "Progress of Science & Technology and the Role of Academia in Korea" in which he addressed the influence that science and technology play on domestic and foreign economic policy. The co-speaker with Dr. Kum was John Casteen III, Chair of Universitas 21 and President of the University of Virginia. Universitas 21 was launched in 1997 for the purpose of establishing networks between world-renowned research-oriented universities. There are 21 member universities representing 14 countries. Korea University is the only member from Korea.

Dr. Hee-Sup Shin Elected a Foreign Associate of the National Academy of Science (April 30)

Dr. Hee-Sup Shin of KIST's Center for Neural Science, an authority on brain research, was elected a Foreign Associate by the National Academy of Sciences (NAS), U.S.A., on April 30, 2009. The NAS announced that eighteen Foreign Associates from 15 countries had been elected during its 146th annual meeting. Membership in the NAS is considered one of the highest honors that can be accorded to a scientist or engineer. A formal nomination can be submitted only by an existing Academy member. Election is based on the candidate's achievements in research, subject to voting at the annual meeting of the Academy. With the new election, the total number of Active Members is now 2,150 and that of Foreign Associates, 404. It is only the second time that a Korean has been elected to be an NAS Foreign Associate. The first was the election of Dr. Ho-Wang Lee in 2002, who is famous for his discovery of the "hantavirus" which causes hemorrhagic fever with renal syndrome. Dr. Shin is acclaimed for having raised Korea's neural science to the world level through numerous seminal research findings. His research accomplishments include development of a number of genetically engineered mice to study cognition and consciousness using the gene-knockout technology. One of his pioneering works was the identification of T-Type calcium channels as the key mechanism that controls consciousness and unconsciousness states. He then went on to lay a foundation for developing breakthrough therapies for controlling sleep, epilepsy and pain.



Awards

- **Dr. Bum-Jae YOU, Center for Cognitive Robotics Research**
  - Scientist of the Month (Korean Science Foundation, February 17, 2009)
- **Dr. Tae Song KIM, Intelligent Microsystems Center**
  - Young Engineer Awards (The National Academy of Engineering of Korea, March 9, 2009)
- **Dr. Chang Ho KIM, KIST Europe**
  - Order of Science and Technology Merit / Jinbo Medal (Ministry of Education, Science and Technology, April 21, 2009)
- **Dr. Hwa Sup LEE, Center for Energy Materials Research**
  - Order of Science and Technology Merit / Ungbi Medal (Ministry of Education, Science and Technology, April 21, 2009)
- **Dr. Hyeon Ok YANG, Natural Products Research Center**
  - Presidential Citation (Ministry of Education, Science and Technology, April 21, 2009)
- **Dr. Eric FLEURY, Advanced Functional Materials Research Center**
  - Presidential Citation (Ministry of Education, Science and Technology, April 21, 2009)
- **Dr. Yunje KIM, Center for Environmental Technology Research**
  - Prime Minister's Citation (Korea Food & Drug Administration, May 14, 2009)
- **Dr. Sang Bae LEE, Intelligent System Research Division**
  - Cavaliere dell'Ordine della Stella della Solidarieta Italiana (Italian Government, June 2, 2009)
- **Dr. Nam-Gyu PARK, Solar Cell Research Center**
  - KIST Staff of the Year 2009 (KIST, February 10, 2009)
- **Dr. Cheolju LEE, Biomedical Research Center**
  - The Won Hee Park Award (KIST, February 10, 2009)
- **Dr. Seok Jin YOON, Thin Film Materials Research Center**
  - Song Gok Science & Technology Award (KIST, February 10, 2009)
- **Dr. Yoon Pyo LEE, Energy Mechanics Research Center**
  - KIST Staff of the Month (KIST, April 9, 2009)
- **Dr. Yong Seo CHO, Center for Chemoinformatics Research**
  - KIST Staff of the Month (KIST, May 6, 2009)

A Sign of the Times!

In the modern era, science and technology have played a vital role in the economic development of nations and the well-being of its citizens. In addition, the advancement and innovation that result from achievements in science and technology are often a gauge of national power and influence. When Korea was struggling with reconstruction, modernization and the building of a self-supporting economy during the post-war years, the concept of an institute devoted to research and development in support of national economic priorities was hatched. In 1966 this concept became a reality when the Korea Institute of Science and Technology (KIST) was officially founded. From its very start, KIST has been of the utmost importance to the Korean government.

Since Korea was still an underdeveloped country at the time KIST was dedicated in 1969 and communication was poor, a method had to be found to inform the Korean people about this bold new initiative for helping the nation. A stamp was issued by the Ministry of Communication (now the Ministry of Information and Communication) to commemorate and advertise the launch of KIST. One million stamps were printed, each with a value of 7 Won (approximately 2.5 U.S. cents at the exchange rate of that time).

In sharp contrast to our own times, when such a move would never be considered for health reasons, the Office of Monopoly also distributed and sold cigarettes as a method of announcing the event. Two million packages of Sintanjin cigarettes, the finest brand then sold, were distributed nationwide with the slogan, "KIST: Research and Development of Industrial Technology is a Shortcut to Economic Development," printed on every package.

The issuance of the stamps and distribution of the cigarettes reinforced the importance of KIST to the nation and its priority for the government.

Although other means of communication gradually replaced stamps and cigarette packets as tools to disseminate information to the public, the Ministry of Information and Communication continued to use stamps to honor KIST. A commemorative stamp was issued in 1976 to mark the ten-year anniversary of the institute's founding. Yet another stamp was issued in 1996 for the 30th anniversary. The values of these stamps were 20 Won and 150 Won, respectively.

The rapid growth of the Korean economy, spurred in part by the remarkable developments conceived at KIST, seemed to be reflected in the increasing values assigned to the anniversary stamps and the complexity of their designs. Although the achievements of KIST and its role in national economic development are now more likely to be communicated via the internet, TV and other emerging forms of rapid communication, **the new form of announcements still make it clear that KIST continues to play a key role in the development and prosperity of the nation**.

Alumni Update

I am currently working as a Product Specialist for Research Biolabs, a subsidiary of QIAGEN, a German-based company. This has been my first job and I've been with the company for 2 ½ years now. The range of experiences I had while studying at KIST has really helped me to handle this job.

Of course, a big part of the KIST experience was academic. KIST provided the best lecturers in their own respective areas. During lectures I appreciated the very warm and interactive communication between students and lecturers. For me, this interaction was the best way of learning. Also, performing my research was so convenient because the KIST labs were so well equipped. Because of that, I had a lot of flexibility in conducting my experiments. Perhaps some may think that KIST students are too tied up with work---even on weekends. That's what I thought too at first; I was worried about having "to spend my life living in the lab." But as time went by, I got used to it and adapted to the hardworking Korean culture.

Well, of course, I did not spend those 730 days all alone. I made a bunch of lovely Korean and international friends at KIST. Those friends were what filled my days with colors and memories. I have never met anyone as friendly, unselfish and extremely helpful as the Korean people. My lab mates were my favorite Korean friends. I can't say "thank you" enough for what they did to make my stay a memorable one. A very special thanks to Dr. Kim Byung Hong, my immediate supervisor, who not only guided me with my experiments, but also molded my character in those 730 days and whose influence I still feel. Thank you to all.

Another group of special friends I made were from Costa Rica, Nigeria, Indonesia, Vietnam, Rwanda, India and China. My housemates, especially, were so supportive. We kept encouraging each other in those painful nights when we felt all alone away from our homelands. I used to believe that I could never make true friendships with people I knew for less than three years. But amazingly, I made many buddies and built many true friendships while at KIST, even after only two years. The friends I made while at KIST have a very special spot in my heart. All our laughter, joy and shared tears will last eternally in my heart.

Apart from doing research, I also managed to do some sight-seeing while at KIST. Korea is such a beautiful country with its magnificent scenery---the mountains and the buildings. But of course, having known the people, the food, the language and its culture is what really matters and makes it all completely breath-taking.

I not only graduated academically from KIST, but I started a whole new chapter of life while I was there. I'll remain forever enriched by the experience.

Pamela Choo
(M.S.Program at IRDA 2004.9~2006.8)

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