JANUARY 2014

Energy Outlook

International Institute for Carbon-Neutral Energy Research

Key technologies for a Carbon-Neutral Society

～ Carbon Capture and Storage (CCS) technology as the best prospect for carbon reduction ～

Special Interview

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Key technologies for a Carbon-Neutral Society

～ Carbon Capture and Storage (CCS) technology as the best prospect for carbon reduction ～

Global carbon dioxide (CO_2) reduction has become a pressing topic in recent years as changes in the climatic system have made abnormal weather and severe natural disasters more common; these phenomena are likely explained as impacts of climate change throughout the world. In 2007, the Intergovernmental Panel on Climate Change (IPCC) released its 4th assessment report, declaring that global warming was incontrovertible. Moreover, in its 5th assessment report, released in September of last year, the IPCC asserted almost categorically that human influence has been the dominant cause of the observed increase of CO_2 in the atmosphere since the middle of the 20th century. A potential solution to this problem is offered by carbon capture and storage (CCS), which holds considerable promise. As such, the challenge moving forward is to figure out how to promote the deployment of this technology as a key tool for CO_2 reduction.

CCS as the key to CO_2 reduction

Kenshi Itaoka: The world's attention is currently focused on CCS as a key technology in achieving a carbon-neutral society. What role will CCS play in tomorrow's world?

Toshifumi Matsuoka: CCS is a technology for separating and capturing CO_2 from facilities that emit large amounts of it, such as thermal power plants, and safely-storing it deep underground in saline aquifers or exhausted oil or gas fields in a supercritical form, which is a state between a liquid and a gas. It's a revolutionary technology that promises big CO_2 emission reductions.

Itaoka: There has been a lot of talk about setting up CCS in conjunction with coal-fired power plants.

Matsuoka: Yes, if we look at sources of energy over the past 200 years, we've gone from wood to coal, then to oil. From now on, there needs to be a shift in developed countries toward energy sources that generate low CO_2 emissions, like natural gas; but developing countries will no doubt continue to rely primarily on coal-fired power plants.

Itaoka: I understand that in the United Kingdom, no large scale coal-fired power plant development proposals will be approved unless the design incorporates CCS.

Matsuoka: Yes, the British government has ruled in line with the EU's CCS directives that all new large scale coal-fired plants must, by law, be "CO_2 Capture Ready." The EU focuses on CCS in anticipation of future introduction of legal requirements for its adoption and economic promotion policies by making sure that facilities are CCS compatible. One example of CCS leadership is the project in Sleipner West, Norway, where in 1996, the world's first fully operational CCS facility was established to capture CO_2 emissions from underwater gas field production. This project is now widely known and considered a pioneering and successful example of CCS.

Itaoka: I understand that today, Sleipner is still storing about 1 million tons of CO_2 every year at the site where CCS operations first began.

Matsuoka: That's right, and finding more sites suitable for CCS like Sleipner will help accelerate the widespread adoption of CCS.

Expectations of CCS in Japan

Itaoka: At Sleipner, they extract natural gas from a gas field and inject CO_2 separated from gas back to the saline aquifer above it. But it seems to be difficult to find a similarly appropriate CO_2 storage site in Japan, which has no large scale depleted gas or oil fields. What sort of storage sites would be considered if CCS was to be implemented in Japan?

Matsuoka: The Japanese archipelago is a very complex structure, riding on the Eurasian and the North American plates with the Philippine and the Pacific plates pushing into it from the south. This means there could well be geological problems at storage sites. However, this doesn't imply a lack of places to store CO_2. A demonstration experiment for CCS has already taken place in aquifers in Nagaoka city of Niigata prefecture, and even when the Mid Niigata Earthquake struck during that experimental period, there were no problems.

In addition, although not large scale, there are oil and gas fields in Niigata and Akita prefectures. Depleted oil and gas fields have already been proven capable of storing oil and gas for a long period of time, so the risk of leakage of stored CO_2 is small, which enforces the idea that they are suitable as CO_2 storage sites. In other words, even in Japan, the use of depleted oil and gas fields is a future possibility.

Itaoka: I see. So Japan, too, can put its depleted oil and gas fields to practical use even if they're not large scale. Are there any other candidates?

Matsuoka: Deep offshores sites are another possibility. And if the CO_2 were to mineralize, that would be ideal.

Itaoka: Yes, CO_2 mineralization at hot springs cause ongoing mineral encrustation, which can lead to pipe clogging and eventually necessitate pipe replacement. However, such ossification of CO_2 is an ideal CCS technology.

Matsuoka: That's right. Guaranteeing safety after storage is a point of discussion when it comes to storing CO_2 in saline aquifers, but one potential solution is mineralization. Mineralization of underground CO_2 takes place after about 10,000 years of storage, so we should be thinking about how this time span might be shortened.

Toshifumi Matsuoka

Kenshi Itaoka

Cost: the key to CCS implementation

Itaoka: Then there's the issue of cost of CCS, which demands a solution, doesn't it?

Matsuoka: Yes, cost really is a difficult problem. Until now, technology development in Japan has started with basic seed funding from universities, and implementation is carried out with business sector cooperation. However, businesses are reluctant to cooperate on CCS technology development because the costs of implementation still outweigh the benefits. Nevertheless, currently in Japan, the Ministry of Economy, Trade and Industry and the Ministry of the Environment have put together a budget to start projects for CCS storage site searches and demonstration experiments. In the United States, the government is working on setting up a CCS taskforce for projects that will demonstrate commercial viability.

Itaoka: Is that because government funding is considered essential to the promotion and implementation of CCS?

Matsuoka: Well, sharing the costs of climate change has become a very real issue. For example, the Ministry of Land, Infrastructure, Transport and Tourism is considering revising the infrastructure standards for structures such as embankments.

Special Interview

We expect further climate change in the future, so if rainfall is going to go from tens to hundreds of millimeters an hour, then we will need to strengthen the infrastructure to be able to handle such levels of rainfall, and this entails extra costs.

Itaoka: So here we're comparing the cost of CO_2 emission reduction initiatives, such as CCS, against the cost of preventing natural disasters brought about by climate change. In other words, we're looking at the cost of adapting to climate change.

Matsuoka: One other point is the commercialization of CCS. In terms of technology, CCS has pretty much already been proven to be safe in terms of separating CO_2, capturing it, and transporting it to the storage site. What remains to be validated is monitoring; so looking at the technological aspects, you may say we're mostly ready. In other words, we have to plan for the operational costs arising from commercialization and widespread adoption.

Itaoka: Monitoring is connected to cost, as well. The research team at I²CNER is led by Associate Professor Takeshi Tsuji, who is the lead principal investigator of the CO_2 Storage Research Division. The team is working on ground breaking research that involves such things as the development of monitoring techniques utilizing microseismic noise, which would enable low cost operational monitoring.

Matsuoka: I expect great contributions by Associate Professor Tsuji and his group too. And I feel that it won't be long before the issue of cost will have been mostly solved.

Itaoka: If that happens, what other issues remain?

Matsuoka: For CCS, the biggest issue is that, to date, there is not a single case in the world of storage that has been completed, and that includes Sleipner. In other words, there is no scientific agreement on how long ongoing monitoring would be required at a storage site once storage is complete.

Itaoka: That period of time could be decades, or perhaps much longer.

Matsuoka: CCS is currently being considered for ISO standardization; however, we need to get an accurate picture of what CCS entails, including management methods and sharing of the costs incurred.

What should we expect from I²CNER?

Itaoka: What kind of role should we expect I²CNER to play in the issue of CCS throughout Japan?

Matsuoka: I²CNER has a number of world leading researchers from various fields, so the first thing we can expect is scientific breakthroughs that can impact the technology of CCS. For example, progress is being made in using molecular dynamics to investigate the movement of CO_2 and inject it more efficiently into porous rock. Such technologies that take into account the properties and the behavior of CO_2 in porous rock are important. Also, the processes of separation and capture of CO_2 amount to more than half of the overall CCS cost, so we can also expect the development of science that will enable cost reduction in these processes. And with mineralization, we have to approach the issue from the reactions at the molecular level; this will need the effort of research institutes such as I²CNER.

Itaoka: In order to come up with such breakthroughs, the development of human resources and the supply of brilliant minds is extremely important.

Matsuoka: Absolutely. Achieving a carbon-neutral society requires a sustained effort. And for that,we will most definitely need the talent of young people.

Itaoka: So what kinds of things should students be looking to study if they're to excel in energy-related fields?

Matsuoka: The University is just a checkpoint in life. Compared to the few years one spends at the university, one's working life continues for another 30 years or so. Therefore, for a student to become a resource sought by society after graduation, they should keep on learning, both throughout their time at the university and also into the future. I expect great things will come out of I²CNER, a place where brilliant scientists are convening and young researchers can launch their successful careers.

Toshifumi Matsuoka

Professor, Graduate School of Engineering
Department of Urban Management,
Division of Geo-Management
Kyoto University

Matsuoka graduated in 1973 from the Department of Physics, Faculty of Science and Technology, Tokyo University of Science, and then completed the master's program at the same university's Department of Physics in the Graduate School of Science and Technology in 1975.
In 1995, he received his engineering doctorate from the School of Engineering, the University of Tokyo. After working as a researcher at Japan Petroleum Exploration Co. Ltd., in 1998 he became an associate professor of the Faculty of Engineering, Kyoto University, and has been employed in his current position since 2001.

Kenshi Itaoka

Professor, Acting Division Leader of Energy Analysis Research Division
International Institute for Carbon-Neutral Energy Research (I²CNER),
Kyushu University

After graduating from the Department of Aesthetics and Art History, Faculty of Fine Arts, Tokyo University of the Arts in 1984, Itaoka completed the master's program at the Department of Industrial Design, Faculty of Engineering, Chiba University in 1986. Later he completed the master's program at the Department of Urban and Regional Planning, Faculty of Natural Resource Development and Planning, University of Wisconsin-Madison in 1992. In 2011, he received his doctorate from the School of Engineering, the University of Tokyo. After working at Fujitsu General Limited and the Mizuho Information & Research Institute Inc., he joined the International Institute for Carbon-Neutral Energy Research (I²CNER) at Kyushu University in 2013. He accepted his current position in I²CNER in November 2013.

Research Highlights

1 A family of oxide ion conductors based on the ferroelectric perovskite $Na_{0.5}Bi_{0.5}TiO_3$

Ming Li, Martha J. Pietrowski, Roger A. De Souza, Huairuo Zhang, Ian M. Reaney, Stuart N. Cook, John A. Kilner, Derek C. Sinclair

Nature Materials (2013) DOI: 10.1038/nmat3782

Oxide ion conductors are the active components in many electrochemical devices used in clean energy technologies such as solid oxide fuel cells and electrolyser cells. The most well known of these is yttia stabilised zirconia (YSZ) discovered by Walther Nernst in 1899. Since then few materials have been discovered that can compete with YSZ in terms of conductivity and stability. In this work a new family of oxygen ion conductors has been discovered based on an unusual perovskite composition, $Na_{0.5}Bi_{0.5}TiO_3$ (NBT), which is a lead free piezoelectic material, but one that shows a high leakage conductivity. This leakage was thought to be due to either the sodium or the oxygen being mobile. Oxygen isotopic diffusion experiments conclusively proved oxygen to be the mobile species and by substituting magnesium for titanium produced a highly conductive material. The two figures on the right show an oxygen diffusion profile for the magnesium substituted material (Figure1) and a plot of the low temperature conductivity of NBT and YSZ showing the superior conductivity of the new material at low temperatures (Figure2) .

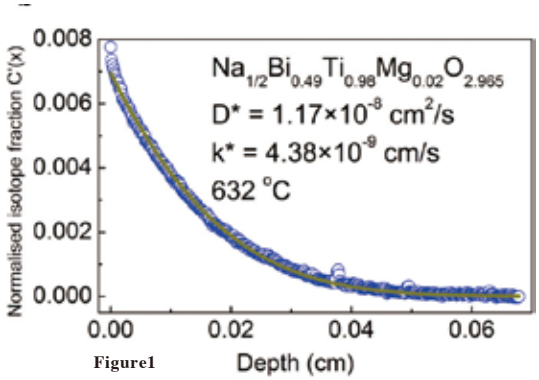


Figure1

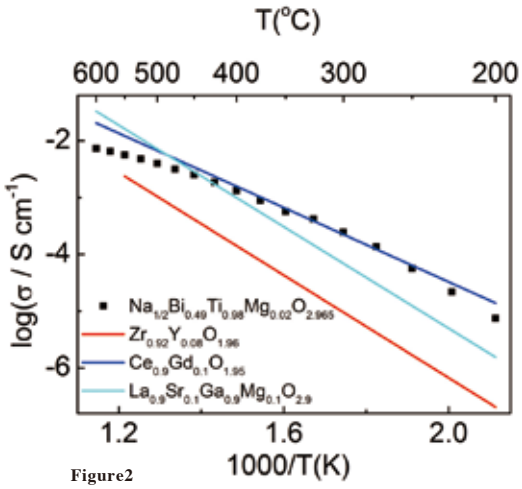


Figure2

2 Adsorption Isotherms and Heat of Adsorption of Difluoromethane on Activated Carbons

Ahmed A. Askalany, Bidyut B. Saha, Kutub Uddin, Takahiko Miyazaki, Shigeru Koyama, Kandadai Srinivasan, Ibrahim M. Ismail

Journal of Chemical & Engineering Data, Vol. 58, P.2828-2834 (2013) DOI: 10.1021/je4005678

Difluoromethane (HFC-32) is a hyrdofluoroocarbon refrigerant that has been used either as a pure fluid for low temperature refrigeration or as an ingredient of 400 series non-azeotropic refrigerants for packaged air conditioning applications. Adsorption data on HFC-32 are expected to be beneficial for two distinct applications, namely, for possible thermal compression when used as a pure component and separation of the mixtures at the end of the life cycle. Experimental adsorption data of HFC-32 over a range of 25 to 75°C and pressures up to 1400 kPa on activated carbon powder (Figure1) and fiber are reported. The data are fitted to Tóth and Dubinin-Astakhov isotherm equations. Adsorbed phase volume is derived from the data. Isosteric heats of adsorption are extracted and its dependence on relative loading and relative pressure is analyzed (Figure2). These data are essential in designing adsorption cooling, heat pump, and storage systems.

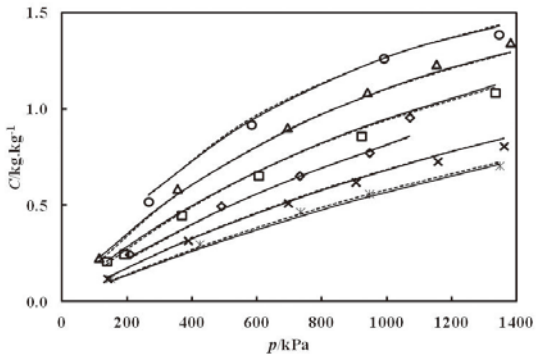


Figure1:Adsorption uptakes C of activated carbon powder/HFC-32 with Tóth and D-A equations with adsorption pressure p.

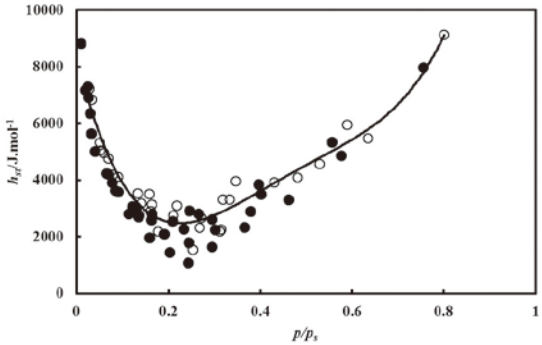


Figure2:Relative pressure p/p_s dependence of heat of adsorption h_{st} of activated carbon powder/HFC-32 and activated carbon fiber/HFC-32.

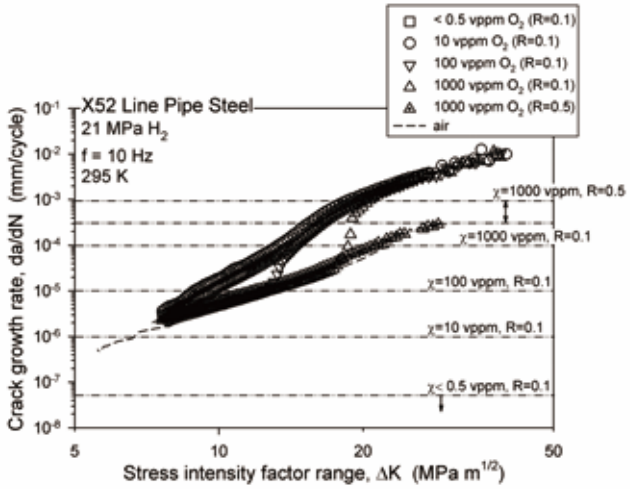
Research Highlights

3 Elucidating the variables affecting accelerated fatigue crack growth of steels in hydrogen gas with low oxygen concentrations

B.P. Somerday, P. Sofronis, K.A. Nibur, C.San Marchi, R. Kirchheim

Acta Materialia, 61, 16, P.6153-6170 (2013) DOI: 10.1016/j.actamat.2013.07.001

Hydrogen gas can dramatically accelerate fatigue crack growth rates in ferritic steels, including lower-strength steels that are technologically favored for hydrogen production, storage, and distribution components. Evidence indicates that such accelerated crack growth can be inhibited by trace concentrations of oxygen in the hydrogen gas. However, this inhibition has not been systematically quantified as a function of the environmental and mechanical variables that govern cracking. In this study, a physics-based model was developed to account for the inhibition phenomenon, resulting in an analytical expression that predicts the onset of hydrogen-accelerated crack growth as a function of inert-environment crack growth rate, load cycle frequency, mean stress, and oxygen concentration.



The measured onset of hydrogen-accelerated crack growth (symbols) is reliably predicted (dashed lines) as a function of oxygen concentration (χ) and mean stress (R).

4 Mechanism of activation of TiFe intermetallics for hydrogen storage by severe plastic deformation using high-pressure torsion

Kaveh Edalati, Junko Matsuda, Makoto Arita, Takeshi Daio, Etsuo Akiba, Zenji Horita

Applied Physics Letters103, 143902 (2013) DOI: 10.1063/1.4823555

TiFe, a potential intermetallic for solid-state hydrogen storage, does not absorb hydrogen without a sophisticated activation process because of severe oxidation. This study shows that nanostructured TiFe becomes active by high-pressure torsion (HPT) and is not deactivated even after storage for several hundred days in the air. Surface segregation and formation of Fe-rich islands and cracks occur after HPT. The Fe-rich islands are suggested to act as catalysts for hydrogen dissociation, and cracks and nanograin boundaries act as pathways to transport hydrogen through the oxide layer. Rapid atomic diffusion by HPT is responsible for enhanced surface segregation and hydrogen transportation.

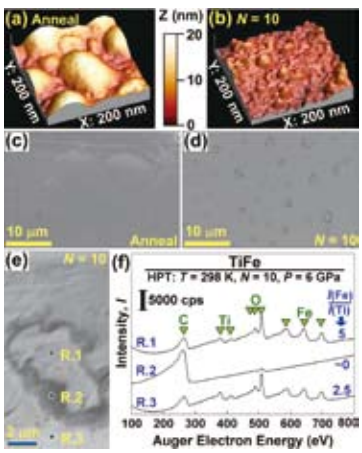


Figure1: AFM, SEM, and AES results for annealed sample (a, c, f) and sample processed by HPT for N=10 turns (b, d, e, f).

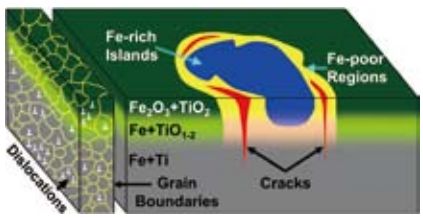


Figure2: Schematic illustration of activation mechanism by HPT.

5 Effect of the phase-separated structure on CO_2 separation performance of the poly (amidoamine) dendrimer immobilized in a poly (ethylene glycol) network

Ikuo Taniguchi, Shuhong Duan, Teruhiko Kai, Shingo Kazama, Hiroshi Jinnai
J. Mater. Chem. A, 1, P.14514-14523 (2013) DOI: 10.1039/c3ta13711b

The Poly (amidoamine) (PAMAM) dendrimer is stably immobilized in a poly (ethylene glycol) (PEG) network upon photo-crosslinking of PEG dimethacrylate (PEGDMA) in the presence of the dendrimer. Structural analysis of the resulting polymeric blend by laser scanning confocal microscopy reveals polymerization-induced phase separation on a micron scale and the formation of a bicontinuous structure of PEG-rich and PAMAM dendrimer-rich phases.
The average dendrimer domain size is determined to be 2.2-2.8 μm depending on the PEG length when the dendrimer content is 50 wt%. The resulting membrane displays excellent CO_2 separation properties over H_2 under highly humidified conditions. The CO_2 separation properties are associated with the dendrimer domain size. The mechanism of preferential CO_2 permeation is elucidated. The polymeric membranes hold potential for pre-combustion CO_2 capture.

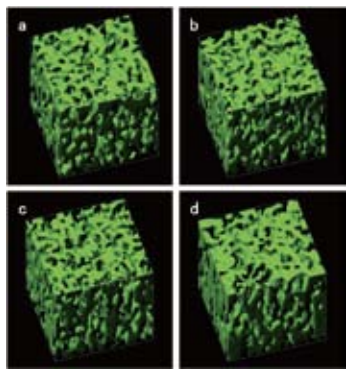


Figure1:
Reconstructed fluorescent 3D images of the PAMAM dendrimer in a PEG network with various PEG lengths. The average EG unit of (a) 3,(b) 9,(c) 14, and (d) 23. The images of 20×20×20mm are displayed, which show only the PEG-rich phase labeled with fluorescein and the dendrimer-rich phase was left empty. The dendrimer content was 50 wt%.

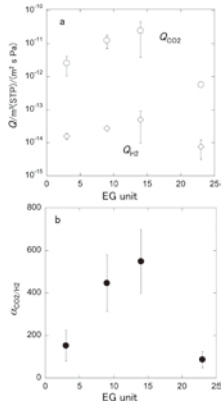


Figure2:
Effect of the PEG length on the CO_2 separation properties of the polymeric membrane using a gas mixture of CO_2/H_2(5/95 by vol) at 80% relative humidity and 298 K: (a) gas permeance and (b) selectivity. The PAMAM dendrimer content was 50 wt%. Error bars denote standard deviation. (n = at least 3).

6 Empirical Prediction of Electronic Potentials of Single-Walled Carbon Nanotubes With a Specific Chirality (n,m)

Yasuhiko Hirana, Gergely Juhasz, Yuhei Miyauchi,
Shinichiro Mouri, Kazunari Matsuda, Naotoshi Nakashima
Scientific Reports 3, 2959 (2013) DOI: 10.1038/srep02959

The determination of the electronic states of single-walled carbon nanotubes (SWNTs) with a specific chirality has been a central issue in the science of SWNTs. We have established the empirical equations with fitting parameters for the determination of the reduction and oxidation potentials of SWNTs for a wide range of diameters and chiral angles. We discovered that the reduction potentials of the SWNTs showed a distinct chirality family dependence, while the oxidation potentials did not show such family pattern dependence. This difference is explained by the chirality family dependence of the work functions of the SWNTs, and also confirmed by the theoretical calculations. Finally, we would like to emphasize that the present study provides information on the fundamental properties of the SWNTs and graphene. This will lead to a deep understanding of their electronic states, which is essential for developing applications of these nanomaterials. Our finding is very basic and is useful for many studies using carbon nanotubes as a material.

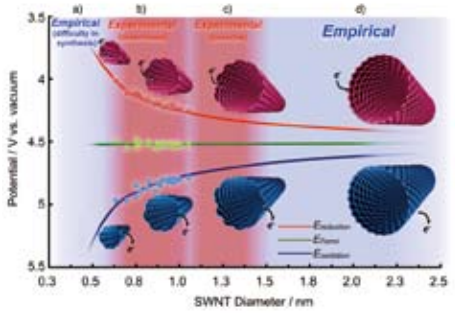


Figure1: Electronic potentials of SWNTs as a function of their diameters

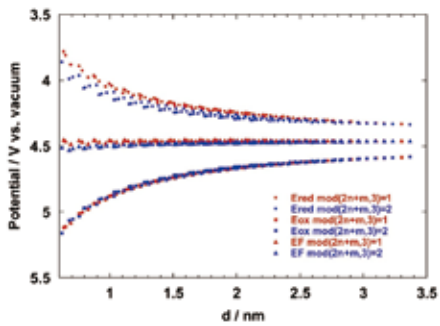


Figure2: Electronic potentials of SWNTs determined by the presented empirical equations. d= diameters of SWNTs.

Event Information

I²CNER & ACT-C Joint Symposium

~ Advanced Molecular Transformations for Sustainable Energy Future ~

International Institute for Carbon-Neutral Energy Research (I²CNER) of Kyushu University and the Advanced Catalytic Transformation Program for Carbon utilization (ACT-C) of Japan Science and Technology Agency (JST) will hold "I²CNER & ACT-C Joint Symposium" to represent research outcome. Prof. Ei-ichi Negishi of Purdue University, 2010 Nobel Prize Laureate in Chemistry, and Prof. Benny D. Freeman of University of Texas at Austin will be joining Symposium as Plenary Speaker, and many other researchers in related field are invitied to share their findings. We welcome all participants in related field.

Date: January 30 (Thu), 2014 9:30 – 20:00
Venue: I²CNER Building, Ito Campus, Kyushu University, Fukuoka, Japan
URL:http://i2cner.kyushu-u.ac.jp/symposia2014/en/index.eng.html

Upcoming events

I²CNER Symposia 2014
Date: January 30 (Thu) – 31(Fri), 2014
Venue: Ito Campus, Kyushu University
URL:http://i2cner.kyushu-u.ac.jp/symposia2014/en/program.eng.html

International Conference on Hydrogen Production 2014
Date: February 2 - 5 (Sun-Wed), 2014
Venue: I²CNER Hall, Ito Campus, Kyushu University
URL:http://ceram.material.tohoku.ac.jp/ich2p2014/

AWARDS

The 10th Asian Thermophysical Properties Conference "Significant Contribution Award"

Prof. Xing Zhang
(Principal Investigator of Thermal Science and Engineering Research Division)

Prof. Zhang received the "Significant Contribution Award" at the 10th Asian Thermophysical Properties Conference for his accomplishments in Asian Thermo physical Properties Research. (Oct. 3, 2013)

The 10th Asian Thermophysical Properties Conference Young Scientist Award

Asst. Prof. Naoya Sakoda
(Thermal Science and Engineering Research Division)

Asst. Prof. Sakoda received the "Young Scientist Award" at the 10th Asian Thermophysical Properties Conference for his notable contributions to Asian Thermophysical Properties Research as young researcher. (Oct. 3, 2013)

The 23rd Japan Institute of Metals and Materials Young Researcher Award(Microstructures)

Asst. Prof. Nobuo Nakada
(Hydrogen Materials Compatibility Research Division)

Asst. Prof. Nakada received the 23rd Japan Institute of Metals and Materials Young Researcher Award (Microstructures) for his significant work in metal materials engineering and related fields. (Sep. 17, 2013)

The IIJIMA Prize

Assoc. Prof. Tsuyohiko Fujigaya
(Fuel Cells Research Division)

Assoc. Prof. Fujigaya received the IIJIMA prize from the Fullerenes, Nanotubes, and Graphene Research Society for his work on "Highly Durable Polymer Electrolyte Fuel Cell Electrocatalyst based on Carbon Nanotube." (Sep. 5, 2013)

The Japan Society of Mechanical Engineers, Micro-Nano Science & Technology Division "Excellent Paper Award"

Assoc. Prof. Shintaro Ida
(Hydrogen Production Research Division)

Prof. Tatsumi Ishihara
(Associate Director, Lead Principal Investigator of the Hydrogen Production Research Division)

Assoc. Prof. Ida and Prof. Ishihara, along with their master' s course student who has now graduated, received the JSME Micro-Nano Science & Technology Division excellent paper award for their work on "Development of photocatalyst for water splitting using two-dimensional semiconducting nanocrystals," which they presented in the 4th Micro-Nano Science & Technology Symposium. (Sep. 8, 2013)