FINAL REPORT
For Japan-Korea Joint Research Project

AREA	1. Mathematics & Physics (2) Chemistry & Material Science 3. Biology 4. Informatics & Mechatronics 5. Geo-Science & Space Science 6. Medical Science 7. Humanities & Social Sciences

1. Research Title:

Highly efficient dye-sensitized solar cells through modification of their TiO2 films with silicon

2. Term of Research: From July 1, 2009 To June 30, 2011

3. Total Budget

a. Financial Support by JSPS: Total amount: 2,400 thousand yen

1st Year 600 thousand yen 2nd Year 1,200 thousand yen

3rd Year 600 thousand yen

b. Other Financial Support : Total amount: 0 thousand yen

4. Project Organization

a. Japanese Principal Researcher	
Name	Dr. Hironori Arakawa
Institution / Department	Department of Indstrial Chemistry, Faculty of Engineering, Tokyo University of Science
Position	Professor
b. Korean Principal Researcher	
Name	Dr. Kang-Jin Kim
Institution / Department	Department of Chemistry, Korea University
Position	Professor

c. List of Japanese-side Participants (Except for Principal Researcher)

Name	Institution/Department	Position
Dr. Takeshi Yamaguchi	Dept. of Industrial Chemistry, Faculty of Engineering, Tokyo Univ. of science	Assistant Professor
Dr. Hironobu Ozawa		Assistant Professor
Mr. Takahiko Ono		Ph.D. Student
Mr. Kazuki Kuroda		M.S. Student
Mr. Hideaki Sudo		M.S. Student
Miss. Megumi Awa		M.S. Student
Mr. Kyohei Noguchi		M.S. Student
Mr. Shohei Oura		M.S. Student
Mr. Tomoya Kaneyasu		M.S. Student
Mr. Hiroki Hayashi		M.S. Student
Mr. Ryosuke Yoshizawa		M.S. Student
Mr. Yu Okuyama		M.S. Student
Mr. Hiroki Kawaguchi		M.S. Student
Mr. Shunsuke Honda		M.S. Student
Mr. Kazutaka Mita		M.S. Student
Mr. Naoya Watanabe		M.S. Student

d. List of Korean-side Participants (Except for Principal Researcher)

Name	Institution/Department	Position
Dr. Sathia Priya	Dept. of Chemistry, Korea University	Postdoctor
Mr. Young Sam Jung		Ph.D. Student
Mr. Chang Ho Kim		M.S. Student
Mr. Tae Kyong Lee		M.S. Student
Mr. Yong-Sun Choe		M.S. Student
Miss. Eunsung Ha		M.S. Student
Miss. Seung Ju Lee		M.S. Student
Mr. Kyu Hak Park		M.S. Student
Mr. Hyung-Kyun Lee		M.S. Student
Mr. Kang-Woo Lee		M.S. Student

5. Number of Exchanges during the Final Fiscal Year*

a. from Japan to Korea

*Japanese fiscal year begins April 1.

Name	Home Institution	Duration	Host Institution
Dr. Hironori Arakawa Dr. Hironobu Ozawa Mr. Yu Okuyama Mr. Hiroki Kawaguchi Mr. Shunsuke Honda Mr. Kazutaka Mita Mr. Naoya Watanabe	Dept. of Industrial Chemistry, Faculty of Engineering, Tokyo Univ. of science	June 23 to 26	Dept. Chemistry, Korea University
For Final Fiscal Year(FY2011) Total: 7 persons		For Final Fiscal Year(FY2011) Total: _____ man-days	
Numbers of Exchanges during the past fiscal years			
FY2009: Total 7 persons FY2010: Total 7 persons			

b. from Korea to Japan

Name	Home Institution	Duration	Host Institution
For Final Fiscal Year(FY2011) Total: 0 persons		For Final Fiscal Year(FY2011) Total: _____ man-days	
Numbers of Exchanges during the past fiscal years			
FY2009: Total 4 persons FY2010: Total 0 persons			

6. Objective of Research

Dye-sensitized solar cell (DSC) is recognized as one of next-generation solar cells because of its relatively high efficiency and its estimated low production cost. Therefore, extensive studies have been made all over the world for its industrialization in this two decades. The light-to-electric energy conversion efficiency of DSCs has been gradually increased, and more than 11% conversion efficiency was recently achieved. However, present efficiency is not sufficient for wide distribution of DSC modules into our society. 15% conversion efficiency is the final target for the large scale industrialization of DSC modules. In order to improve the conversion efficiency, drastic improvement of both the short-circuit photocurrent (J_{sc}) and the open-circuit voltage (V_{oc}) of DSC are essential.

For the improvement of J_{sc}, light absorption range of the dye-sensitized TiO_2 photoelectrode must be expanded into near IR region. In addition, the light harvesting efficiency at this wavelength range must be increased. On the other hand, both negative shift of the conduction band energy of TiO_2 and suppress of the electron leakage from the conduction band of TiO_2 to the I_3^- in the electrolyte are essential for the improvement of V_{oc}.

In this international collaboration research, the studies on the improvement of J_{sc} was mainly carried out in Prof. Kang-Jin Kim's group in Korea University, and the researches for increasing V_{oc} was done in our group (Prof. Arakawa's group in Tokyo University of science). Since effective method for the improvement of J_{sc} or V_{oc} has been already established in each group, dramatic enhancement of the solar cell performance of DSCs is expected to incorporate each technique. We can prepare high performance black dye based DSCs exhibiting more than 10.5% conversion efficiency. Therefore, the objective of this international collaboration research is the achievement more than 11% conversion efficiency by adapting the method which improves J_{sc} value developed in Prof. Kan-Jin Kim's group to our black dye based DSCs. The other objective is to give the international experiences for students, such as visiting a foreign country, communicating with foreigner and making presentation of their research in English. Such experiences must be of great benefit for them.

7. Methodology

(1) Improvement of J_{sc}

Silicon nanoparticles have a conduction band with slightly higher energy than that for TiO_2, and can absorb the visible light strongly up to 750 nm. Therefore, they can serve as a sensitizer of TiO_2 nanocrystalline DSCs. In this study, NH_2 functionalized silicon nanoparticles (Si-NH_2) have been prepared to employ them as a co-sensitizer for DSCs. Effective enhancement of J_{sc} for N719 based DSCs has been already obtained in Prof. Kang-Jin Kim's group, and the conversion efficiency was also improved. Preparation of a more efficient Si-NH_2 and optimization of the experimental conditions for our black dye system were main subject for this term.

(2) Improvement of V_{oc}

As mentioned above, to suppress the electron leakage from the conduction band of TiO_2 is essential for the improvement of V_{oc}. In order to accomplish this requirement, surface modification of TiO_2 photoelectrode by metal-oxide thin overlayer has been conducted. Such a thin overlayer can serve as a blocking layer for the electron leakage, therefore, V_{oc} is effectively improved. For example, Al_2O_3 and Nb_2O_5 are reported to serve as an effective blocking overlayer for N719 based DSCs. In this study, screening of various metal oxides was carried out to find suitable metal oxides as a blocking thin overlayer for our black dye based DSCs. Then, optimization of the experimental conditions was done to achieve higher conversion efficiency.

(3) Enhancement of the performance of DSCs

In order to achieve 11% conversion efficiency, each result obtained in Korean side and Japanese side was incorporated. This collaboration experiments were carried out in Korea at June 23-25 in 2011. DSC preparation was done in Prof. Kan-Jim Kim's laboratory at Korea University, and the cell performance was measured in Korea Institute of Science and Technology (KIST).