**WMRIF 3rd Young Scientists Workshop 2012 – prize research visits**

As winner of the first prize at the 3rd Young Scientists Workshop in Bangkok, Thailand in August 2012, I was given the fantastic opportunity to make research visits to two of the participating materials research institutes. This report gives a summary of my two visits, for which I chose VTT in Finland, and NIMS in Japan.

**Research Visit to VTT (Technical Research Centre of Finland), Espoo, Finland**

**2-13 September 2013**

The first of my two visits was hosted by Dr Jari Ihonen in the fuel cell research department of VTT in Espoo, Finland, close to Helsinki. The focus of my current research at NPL is on performance diagnostics and in situ measurement for polymer electrolyte membrane (PEM) fuel cells, and so it was very instructive for me to see the extent of the facilities at VTT, where around 40 researchers work on both PEM and solid oxide fuel cell (SOFC) technologies, including some industrial-scale testing of systems. A fuel cell is an electrochemical energy conversion device based on an ion-conducting electrolyte separating fuel and oxidant gases. These react on the surface of catalysed electrodes, generating useful electric current. They have the potential to be a highly efficient low carbon energy source if used with hydrogen from renewable feedstocks, and can have zero emissions at the point of use. However, several materials and measurement challenges have to be overcome in order to bring down the cost and improve durability of this technology.

Dr Ihonen kindly welcomed me into his group where they were in the process of setting up a test stand with the capability of on-line gas sampling during operation of a cell. The idea is to reproduce the mode of fuel cell operation used commercially where the fuel is recirculated through the cell, with the exhaust closed. As fuel is consumed it is replaced with fresh fuel via a pressure regulator on the inlet – this enables more efficient fuel consumption by minimising the fuel that is wasted in the exhaust. The research challenge is to understand how impurities in the fuel are enriched by the recirculation process, and how that might affect the durability of the electrocatalyst materials in the fuel cell. I helped to commission the new experimental setup for sampling the recirculated gas which would then be analysed by gas chromatography (GC). I also learned several new skills for assembly and operation of PEM fuel cells, and learned about the unique facility developed at VTT for parallel testing of cells within a single stack – a so-called “multi-single-cell”.

I was also fortunate to have been present for the first testing of a new 30kW pilot plant which was being commissioned by Timo Keranen for a cogeneration project at a chlor-alkali factory, as well as a several kW solid oxide fuel cell testing facility – an opportunity to see the technology working on an industrial scale. I am hugely grateful to Dr Ihonen and his researchers Luis Perez and Pauli Koski for giving me so much of their time, and also for introducing me to some nice cafes and bars in Helsinki.

**Research Visit to NIMS (National Institute of Materials Science), Tsukuba Science City, Japan**

**17-28 Feb 2014**

The second of my trips was to the Global Research Centre for Environment and Energy based on Nanomaterials Science (GREEN) at the National Institute for Materials Science (NIMS) in Tsukuba, Japan. This is a new research centre at NIMS aimed at promoting nanotechnology in materials science research for the purpose of achieving green innovation in Japan. The GREEN research centre is based in state-of-the-art new laboratories in Tsukuba Science City, with a suite of advanced facilities for materials synthesis and characterisation. I was hosted by Dr Tsuyoshi Takata of the Photochemical Energy Conversion group, who works on catalyst materials for photocatalytic water splitting as a renewable source of hydrogen from sunlight and water. This is a research topic we are interested in developing in the electrochemistry group at NPL.

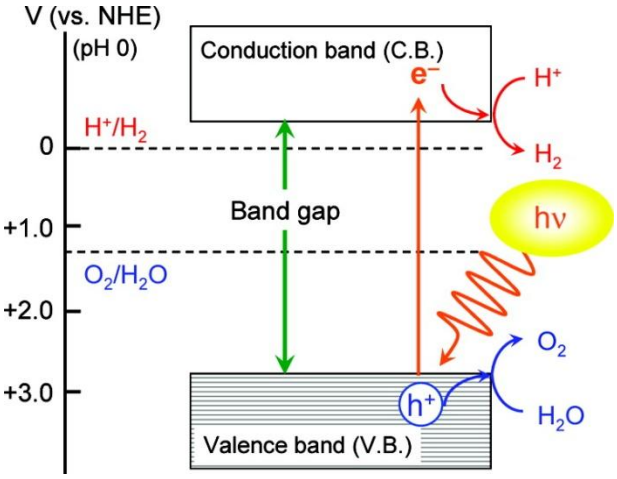


**Figure 1. Basic principle of overall water splitting on a heterogeneous photocatalyst.**

The principle of photocatalytic water splitting is illustrated in Figure 1. Photoexcitation of a semiconductor material dispersed in water generates an electron/hole pair, which can then migrate to the particle surface where the electron reduces protons to generate hydrogen and the hole oxidises water to generate oxygen. The main materials challenges lie in designing a material with a suitable bandgap for absorption in the visible light range as well as tailoring the energy levels to overlap the electrode potentials of the $H^+/H_2$ and $O_2/H_2O$ electrochemical redox couples. The catalyst must also minimise both electron/hole recombination and $H_2/O_2$ recombination. The latter is usually achieved by the use of a co-catalyst in the form of nanoparticles decorating the surface of the photocatalyst particles. Dr Takata and his research group at University of Tokyo, led by Prof. Kazunari Domen, have developed a $RuO_2/CrO_2$-based co-catalyst system that is effective at preventing recombination due to the $CrO_2$ forming a barrier that is permeable to water but impermeable to $O_2$.

I was given instruction on synthesis of two photocatalyst materials, the first based on a well-established perovskite material, $SrTiO_3$, doped with 5 at% Na and using the $RuO_2/CrO_2$ cocatalyst. This material is a semiconductor with a bandgap that absorbs light mainly in the near-UV but is reasonably active. The other material I made, $LaMg_{0.33}Ta_{0.67}O_2N$, is similarly a

perovskite-type crystal-structure but with some of the oxygen sites replaced with nitrogen. This lowers the bandgap so that there is absorption at longer wavelengths, well into the visible range. However, the activity of this material is not so high, and in my experiment it evolved some nitrogen as well as hydrogen. Development of such oxy-nitride materials to be highly active under visible light irradiation is the main area of Dr Takata's research.

As well as learning about photocatalysis, Dr Takata also arranged for me to meet the director of GREEN, Dr Kohei Uosaki, and other researchers in the GREEN centre, including several groups researching various aspects of Li-ion battery materials (another potential future research area for my group at NPL), and some of the fuel cell researchers, which may lead to some productive collaborations. I was very honoured to be invited to give a seminar on my own research during the second week of my stay, which I am pleased to say was well received.


Dr Takata was a generous host, taking me to sample traditional Japanese cuisine as well as a party with the other researchers from GREEN. Whilst in Tsukuba, I also met with one of the other Young Scientists from the 2012 WMRIF workshop, Akira Takahashi, who is a researcher at AIST, located close to NIMS. During the weekend he took me for some sightseeing in Tokyo, which was made all the more memorable due to the Tokyo Marathon coinciding with my visit. My visit was filled with new experiences, being my first time in Japan, and I greatly enjoyed learning about Japanese culture and traditions, and tasting interesting food and drink.

I am immensely grateful to Dr Takata and his coworkers in GREEN for such an informative visit, to Johsei Nagakawa and Kana Uchiyama for making all the travel and accommodation arrangements to NIMS.

Finally I would like to thank the WMRIF awards committee for giving me the wonderful opportunity to make these two exciting and educational research visits.

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