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A conference report for UKNC

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Summary

SPIE Optics and Photonics is the largest multidisciplinary meeting in optical sciences and technology in North America. The meeting covers a broad range of topics across the field of optics and photonics with over 3,000 technical presentations in four broad areas. The breadth of topics covered gives an interesting oversight into the recent advances in optics and photonics while the specific symposiums provide opportunities to discuss specific topics and networking events to all researchers within their chosen fields. The 70 symposiums include far reaching topics from organic semiconductors, metamaterials and particle technologies.

The focus of my research has been nitride materials for solar hydrogen production and therefore the majority of my time was spent at the 9th Solar Hydrogen and Nanotechnology symposium. There were 26 presentations including 6 keynote talks, 9 invited and 11 contributed talks. Of this, in addition to my own presentation on nitrides there was a further contributed talk and one keynote talk on nitrides in water splitting.

Plenary Sessions

The plenary sessions highlighted the advances in three distinct areas of optics and photonics research including bringing star power to Earth, the potential of a habitable world of Europa and the advancement of wearable technology. Mike Dunne of the Lawrence Livermore National Laboratory discussed their recent advances in fusion. The talk gave a thorough introduction into the field as well as an in-depth explanation of the set-up of the national ignition facility (NIF). Due to the experimental set-up the NIF has recently exceeded the design specifications of the lasers and are making strong progress in the field with the reactions delivering more energy than the particles themselves receive. The advancements in recent years have delivered strong consistent improvements in the efficiency of the reactor however there are still major challenges to overcome. Currently, targets of gold are utilised that have a thin coating of plastic. With the lasers concentrated on the target ignition conditions of over 100 million degrees are achieved however due to the coating the ignition quenches itself soon after the reaction start, preventing further reactions occurring. This exciting area is advancing at good pace with significant improvements in recent experiments and the potential for further gains. These advances signify the potential for future clean energy production.

Alongside the future of clean energy we were also given a glimpse into the potential future world of the human race. Images of Europa from the Galileo space mission have suggested the potential for life on Jupiter’s moon. Topographical images of the surface have revealed deep crevices and ridges suggesting the potential of a thick ice crust. Variations in the magnetic field suggest an ice ocean with hot ice permeating through the surface with convection currents due to the liquid ocean underneath the ice. Unfortunately, there is only a partial image of what Europa is like due to limited scans of the surface, therefore there is a proposal for a future Europa centred mission. In order to minimise mission costs, Europa is set as a secondary target with 45 flybys of the planet at varying altitudes to obtain the highest resolution images of the surfaces to date. On top of this, detailed images are to be obtained to provide an insight into potential landing spots for any further missions in the future. There is the potential to gain a deep insight into the possibility of a habitable world within our solar system however this mission is currently only one of a few potential options for NASA to participate in.

From the stars to moons to modern day Earth, the final plenary sessions discussed the future of wearable technology with a focus on Google Glass from the creator himself Babak Parvis, formerly of Google and now Vice President at Amazon. Technology has advanced significantly from the early computers and wearable technology is the next step. Babak provided an insight into Google Glass and how it is changing the future of technology. The interaction of people and technology is changing, Google Glass is allowing people to document moments as they are happening giving people rapid access to information. Despite the advances made, Babak discussed the potential for even faster access to information and how these changes will alter the world we currently live in whether for the good or bad.

Overview of Solar Hydrogen & Nanotechnology IX

Being run for the past eight years at SPIE Optics and Photonics, the symposium brings together researchers across the field of solar hydrogen and nanotechnology. Researchers in oxide semiconductors, nitride materials as well as the chemical interactions of charge transfer reactions were brought together to discuss the research steps required to achieve realistic production of solar hydrogen. Out of the 26 talks the majority were either Keynote or Invited with less than 6 were including my own was given by research students.

Nitrides in Water Splitting

Zetian Mi from McGill University discussed his group's recent advances in utilising GaN and InGaN nanostructures for water splitting. His group has achieved homogeneous production of water splitting with GaN nanowires. Due to the growth of the structures by MBE there are very little defects present on the surface and the band positions of the GaN are suitable for both the reduction of hydrogen and the oxidation of water. Homogeneous production was achieved by loading the GaN wires with a Rh/Cr_2O_3 core/shell structure. The Rh promotes the reduction of hydrogen while the shell prevents the back reaction resulting in the reformation of water. Furthermore, control over the dopant level in the nanowires allows for the band structure and therefore the interactions with the electrolyte to be correctly positioned. In addition to pure GaN structures, their group have also incorporated Indium into the nanowires in an attempt to increase the absorption of visible light. Changes to the structure have resulted in improvements in the IPCE from ~15 % for the GaN structure to ~30 % for the InGaN nanowires. The work they have conducted is some of the best reported for GaN based structures

In addition to the Keynote talk, alongside my own presentation there was another contributed talk from a nitride group at Lehigh University. Based on their talk, their work is in the early stages of research focusing mainly on thin films of GaN and InGaN. The talk provided a broad introduction to water splitting as well as discussing some of the recent work of nitride based structures before discussing their results on planar devices.

Out of the 26 talks in the Solar Hydrogen session, three were on nitride based materials. This was interesting to see the wider community coming to accept the potential for nitride based materials in water splitting. Published work on nitride structures have only originated from a small number of groups in relation to their potential for water splitting with the majority of the water splitting community focusing on oxide based semiconductors. In comparison to IWN2012 there were more contributed talks on the topic which was unexpected but highlights the potential of the material for further development.

Oxide Materials in Water Splitting

As mentioned, the majority of current work on water splitting has been focused on oxide materials due to their relative abundance, correct band positions and reasonable stability. Having never previously attended a conference focused on solar hydrogen it was an excellent opportunity to see some of the additional work that is being conducted on the leading class of materials. The current focus of research is around hematite based photoelectrodes. Recently, world renowned scientist Michael Grätzel published a paper on hematite and its potential to realise the efficiencies required for commercialisation of solar hydrogen. Within the symposium there were a number of talks on hematite, both presenting results as well as studies into the interactions of water with the oxide structure.

Over the two days of the solar hydrogen session there were multiple keynote talks on hematites. The initial discussion by Bruce Koel of Princeton University focused on the surface interactions of Fe_2O_3 based photoanodes and water. The hematite based films were grown by chemical vapour deposition with the incorporation of nickel as well as mixed oxide based materials. Doping the iron oxide film with nickel results in a different termination of the surface which alters the interaction of the OH peaks and changes the desorption properties of the material. Due to the importance of the adsorption and desorption of water for the purpose of water splitting, understanding the mechanism is vitally important. Koel discovered that through the addition of Ni, a more stable surface bound OH peak arises which can alter the overall efficiency of the device.

Vayssieres from Xi'an Jiaotong University presented his work on low-cost fabrication of oxide materials. Oxide materials can be fabricated from various techniques including chemical vapour deposition, sol-gel synthesis and spin coating methods. As a result, it is easily scalable to mass production. Alongside this, control over the deposition technique can alter the structure of the material from thin films to various rod based structures. Vayssieres presented results indicating the significance on control over the size of the device. Due to the short diffusion lengths of oxide materials, with effective control over the size recombination can be minimised leading to enhancements in photocurrent. Further developments on oxide material systems were presented by Sanjay Mathur. His research group has investigated various oxide materials and oxide structures for water splitting, from Fe_2O_3 to WO_3. He highlighted the difficulties that oxide materials still currently face and potential post growth treatments including wet chemical and gas phase techniques to modify the devices. This leads to the formation of nano crystalline material reducing the recombination dynamics of the material often observed in amorphous films.

It was interesting to observe the results from a different material system presented by so many different researchers. From a nitride perspective, oxide materials currently outperform even the best nitride devices quite significantly. Current photocurrents of several mA cm^{-2} have been achieved with oxides due to their decreased band gap in comparison GaN. In addition to this, the number of research groups focusing on oxide materials in water splitting drastically outweighs those investigating nitride materials. Despite this, the research presented on oxides identified similarities between the two systems. The requirements for control over the size of the device are critical to obtain the maximum photocurrent. Current research in nitrides has demonstrated that this is effective in improving the photocurrent however there are still steps to go in order to reduce the band gap of nitride materials.

NREL Keynote Talk

Heli Wang from the National Renewable Energy Lab presented the recent work completed by the US Department of Energy PEC working group. The group cover various researchers across a number of universities and have investigated multiple material systems. Interestingly was the discussion on the achievable and required efficiencies in order to commercialise solar hydrogen. A current density of 15 mA cm^{-2} was stated as required to produce enough hydrogen to realistically meet targets. The optimum device is currently iron oxide, however based on the band gap the device would have to have 100 % incident photon conversion efficiency to achieve this value. Therefore, advancements in materials have to be obtained. Further to this, multiple routes for solar hydrogen were investigated including single junction systems, PV-PEC devices, tandem systems and concentrator systems. Only the monolithic PV-PEC tandem devices operating in concentrated sunlight had the potential based on realistic principles to achieve hydrogen production on a cost comparative scale to gasoline. This allows the use of higher cost III-V materials due to the decrease in size required.

The NREL identified III-V materials, namely $GaInP_2$ as the current ideal. Previously, device efficiencies have been high due to the crystalline nature of the material however it suffers from photocorrosion. Work on surface treatments through N-ion implantation and the use of a PtRu sputtered electrode has extended the life of the device significantly with no degradation observed after 315 hours of operation. The surface treatments and device modifications are helping to achieve the DoE targets with an overall aim of a $2/kg.

Discussion

Within the session there was also a wider group discussion on how materials for solar hydrogen are reported. There is the potential for all transition metal oxides to be active for water splitting due to their band positions and over 30 different materials have been investigated. However, due to the difference in reporting by various research groups, comparison over the different materials is difficult. The attendees discussed the potential for a standardised test similar to that given to solar cell devices. The NREL currently provide standardised testing of solar cell efficiencies yet no such test exists for solar hydrogen production. As a result it is difficult for researchers to truly assess the potential of the fabricated devices. Each group has a different light source, uses various electrolytes and reports different values based on two or three electrode systems. Alongside this, there are various efficiencies reported for devices, from total efficiencies, solar-to-hydrogen efficiency and IPCE to name a few. Recently, the working group at the NREL published a paper on the optimum reporting method, however this requires researchers to both read and follow the papers instructions. The consensus of the group was the need for a standardised test centre, however currently the NREL do not have the capabilities with the resources dominated by solar research.

Solar Plenary Talks

The solar plenary talks ranged from concentrated solar through to organic and inorganic materials and gave an interesting oversight into the current status of each technology. The opening plenary given by Arzon Solar's technical director focused on the rise of concentrated solar technology with approximately 200 MW currently installed worldwide. The main point that was stressed during this talk was the price comparison of concentrated solar in comparison to standard PV modules. Due to the use of optics, sunlight can be focused to a smaller area increasing the power density, thereby decreasing the total required area to achieve the same output. Alongside this, more expensive and higher efficiency PV modules can be utilised. Currently CPV is still more expensive than standard solar on a price per watt rating however it can deliver significantly more power which makes it the only viable solar option if available area and power requirements are unsuitable for standard PV. On top of the price discussion, some interesting works on increasing the potential of CPV were also introduced. Within this there is the possibility of commercially available 5 junction solar cells to further push the efficiency of the device through to the use of spectrum splitting optics to provide improved current density. Lessons had also been learnt from previous installations due to inhomogeneous illumination of the cells causing discontinuities and reduced efficiencies. Overall the plenary gave an interesting overview of current challenges and potential opportunities for CPV but at times came across as a marketing tool for Arzon.

The second solar plenary from GE global research presented their recent work and achievements in CdTe based photovoltaics. GE decided to investigate CdTe PV and formed a new research group from various in house teams, none of whom had any CdTe experience. William Huber, the lead scientist on the team cited the benefits of this as no one was routed in any technique or methodology for the production of CdTe films. Until relatively recently, the efficiency of CdTe PV cells was limited at ~16 % with no major breakthroughs in efficiency since 1993 resulting in the focus on other technologies, such as CIGS. However, GE managed to break this barrier and with continued competition from First Solar have pushed the efficiency of the device to over 21 % identical to the maximum achieved by CIGS cells. Unfortunately, due to the commercial nature of the material, limited specifics on how these improvements were made however, optimisation of the fabrication process has resulted in production modules generating electricity at a $0.55/W. GE now in partnership with First Solar is committed to further improving the device performance.

Other interesting plenaries within the solar topics was focused on the development of organic photovoltaics and the use of hot carrier solar cells. Having now crossed the 10 % efficiency barrier, Karl Leo of KAUST presented recent work on optimising the bulk heterojunction layer for improved device operation with the potential of tandem cells operating at 20 % efficiency. Gavin Conibeer presented an interesting introduction on hot carrier photovoltaics with the use of quantum well structures to slow down carrier cooling to ultimately increase the efficiency of the device.

Overview

The wide ranging topics of the plenaries give an insight into the broad nature of the attendees at SPIE Optics and Photonics. I personally found the discussion into each of the areas very interesting as the nature of the talks provided both overviews of past work as well as research currently being undertaken. It provided me with an opportunity to meet a variety of people outside of the nitride community as well as promoting the potential of nitrides with my contribution entitled Porous GaN for Enhanced Solar Water Splitting. The talk was received quite well and being the final nitride based talk within the symposium gave me an opportunity to answer any of the unanswered questions that had arisen from the previous talks. It also allowed me to focus on the research that is underway at Sheffield University and network with other students and academics in the solar hydrogen field.

Unfortunately, due to the structure of the sessions, I was unable to attend any other nitride based talks with them running parallel to the solar however there were various presentations across the conference on nitride materials from use in scintillator applications through to interesting techniques in LEDs. The two poster events that were run covered the broad range of the conference with the quality of the output being at a reasonably high level across the sessions.

As someone working within a relatively niche area of nitride semiconductors I was pleased to witness a keynote presentation about nitrides in water splitting. Furthermore, it provided me with the opportunity to understand current state-of-the art work in other areas of solar hydrogen production including the differences in regards to the reporting of results. In regards to the whole conference, it was an excellent opportunity to hear about the various work being conducted across the vast field of optics and photonics with some talks of both personal and general scientific interest. SPIE hold a variety pf conferences throughout the year in various locations with Optics and Photonics an annual conference held in San Diego every August.

I would finally like to thank UKNC for providing me the bursary which has allowed me to attend and enjoy SPIE Optics and Photonics 2014.