

Tuesday Morning, December 9, 2014

Energy Harvesting & Storage

Room: Lehua - Session EH-TuM

Solar Cells

Moderator: Eray Aydil, University of Minnesota

8:40am **EH-TuM3 Understanding and Improving Solar Energy Conversion through Interface Engineering**, *Stacey Bent*, Stanford University, USA **INVITED**

Meeting the world's growing energy needs in a sustainable fashion is one of the most pressing problems of our time. The most abundant source of renewable energy is the sun, which can be converted directly to useful forms of energy such as electricity and fuels by photovoltaics and photoelectrocatalysts, respectively. In this talk, we will discuss the use of nanoscale materials in solar energy conversion, and in particular the role of interface engineering in improving conversion efficiencies. Quantum dots (QDs), which are nanoscale materials typically based on low-band-gap metal chalcogenides, have been widely explored for next generation solar absorbers due to their tunable band gap and high absorption coefficient. Colloidal quantum dot (CQD) solar cells made from lead sulfide (PbS) QDs have achieved a power efficiency of ~ 8%. In these devices, it is important to control the band gap as well the band position of the QDs to efficiently inject electrons and holes into their respective electrodes. We will describe experimental and theoretical studies of the effects of interface engineering through surface ligand modification on the band gap and relative band positions in lead chalcogenide (PbSe_xSi_{1-x}) QDs. Multilayer CQD solar cells were fabricated to investigate the effect on carrier collection of QD layers with different relative band positions. We will show that interface engineering can be applied to lead chalcogenide QDs in order to create a favorable band diagram and achieve enhanced photogenerated carrier collection in multilayer CQD devices.

9:20am **EH-TuM5 Understanding Carrier Dynamics in Cu₂ZnSn(S,Se)₄ Using Time-Resolved Terahertz Spectroscopy**, *G.W. Guglietta*, Drexel University, USA, *K. Roy Choudhury*, *J.V. Caspar*, DuPont Central Research and Development, USA, *Jason Baxter*, Drexel University, USA

We have used time-resolved terahertz spectroscopy (TRTS) to measure lifetimes and determine recombination mechanisms in Cu₂ZnSn(S,Se)₄ (CZTSSe) thin films fabricated from nanocrystal inks. TRTS probes photoconductivity on femtosecond to nanosecond time scales that are relevant for recombination in thin film photovoltaics. Terahertz frequencies (0.2-2.5 THz) correspond to typical scattering rates in semiconductors, enabling determination of carrier density and mobility. Ultrafast time resolution permits tracking the evolution of carrier density to determine recombination mechanisms. By manipulating the photoexcitation wavelength and fluence, we can tailor the generation profile of photoexcited carriers to distinguish between surface, Shockley-Read-Hall (SRH), and Auger recombination mechanisms and determine rate constants.

TRTS experiments and modeling were used to understand the role of recombination mechanisms and their contribution to CZTSSe photovoltaic performance. TRTS photoconductivity shows an instrument-limited onset within 1 ps of an ultrafast pump pulse, followed by a slow decay over nanoseconds. Photoconductivity decay kinetics were fit with a bi-exponential model with two time constants and a weight fraction. The short time constant is typically ~200 ps and roughly corresponds to diffusion to and recombination at the surface. The long time constant is typically ~2 ns and is attributed to SRH recombination. Assignment of these mechanisms is supported by the dependence of kinetics upon excitation fluence and wavelength. Normalized kinetics are independent of fluence over a range of 40x, indicating that no Auger recombination is occurring. Without Auger recombination, we can distinguish between surface and SRH rates by tuning the pump wavelength. As the excitation wavelength is shifted towards the blue, carriers are generated nearer to the front surface and the photoconductivity kinetics are sensitive to the surface recombination velocity. With blue excitation, we see that a larger fraction, ~0.5, of carriers recombine with a short time constant. With redder excitation wavelengths, the carriers are generated more evenly throughout the film and the kinetics are dominated by SRH recombination with the long time constant having a majority of the weight fraction, ~0.8. TRTS provides a pathway to determine performance-limiting recombination mechanisms and measure key parameters like SRH lifetime and surface recombination velocity, helping to direct the design of efficient thin film photovoltaics.

9:40am **EH-TuM6 The CdS/CdTe Solar Cell with the Back Contact Protected by ITO/Mo**, *Juan Peña*, *V. Rejón*, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Mexico, *M. Riech*, Universidad Autónoma de Yucatán, Mexico, *N. Hernández-Rodríguez*, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Mexico

Today CdS/CdTe heterojunction is an important photovoltaic system for conversion of solar energy. Due to the simple techniques used for thin films deposition, it has been brought from laboratory to industrial scale. Although the thin films are deposited by using techniques such as sputtering and CSS, the back contact layers are a challenge in both: the formation of an ohmic contact and that endures a long time. There are several prospects for back contacts using Mo as can be seen in [1]. The solar cell with Cu/Mo as a back contact deposited by using rf-sputtering is reported in [2]. There are few researches that studied how Mo film can be protected against oxidation without adding series resistance. The bilayer Mo/ITO has been used in microelectronics devices [3].

In this work, the CdS/CdTe solar cells that uses Cu/Mo as back contact is investigated. It is shown that the formation of MoO_x at surface of Mo thin film influences the series resistance. The oxide is formed when the solar cell is used at outdoor conditions without any encapsulation. Here some indoor experiments were made. First, we show how the Mo/Glass film is oxidized when it is annealed at 400 °C in air. Second, how the Mo is degraded at same conditions when it is used on CdTe/CdS cell and annealed at same conditions. Third, how ITO works when it is deposited over of Mo on the solar cell. Preliminary results indicates that the ITO avoids the formation of MoO_x and mechanical scratching, preserves its electrical properties and the solar cell shows good stability after an annealing at 400 °C.

The films Cu, Mo and ITO were deposited by rf-sputtering. We show evidences that the p-n junction remains working properly and the oxidation of Mo is the main cause of the cell efficiency degradation. By using the thin film of ITO on Mo layer all solar cell characteristics are preserved. The CdTe film was grown by conventional CSS technique. The cells were activated by using CHCIF₂-argon-oxygen gases. DRX spectra and HR-SEM were made for Mo/Glass and ITO/Mo/CdTe structure before and after annealing at 400 °C in air.

Acknowledgement

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References

- [1] D. L. Batzner, et al. *Thin Solid Films*, vol. 451-452, pp. 536-543, 2004.
- [2] V. Rejón, et al. *Solar Energy*, vol. 95, pp. 319-324, 2013.
- [3] H. Piao, et al. *Surface and Interface Analysis*, vol. 39, pp. 493-500, 2007.

10:20am **EH-TuM8 Study of Energy Level Alignment at Electrode Interfaces in Organic Solar Cells**, *Takeaki Sakurai*, *S. Wang*, *T. Miyazawa*, *H. Xia*, *W. Fu*, *K. Akimoto*, University of Tsukuba, Japan **INVITED**

Control of electrical properties at organic semiconductor/metal electrode interfaces is one of the significant issues for improving performances of the organic solar cells since it has an influence on carrier extraction and exciton quenching. In small molecule based organic solar cells, bathocuproine (BCP) is used well as a buffer layer between C₆₀ and metal cathode to improve the device efficiency. Lifetime and the stability of the device with BCP buffer layer, however, are not good for the practical application. To obtain the strategies for the development of the effective buffer layer, we have investigated the electronic structures at the interfaces between C₆₀ and a large variety of organic semiconductors by means of synchrotron based in-situ ultraviolet photoelectron spectroscopy. The C₆₀/buffer/Ag heterostructures were formed by depositing buffer materials on Ag and subsequently depositing C₆₀ onto buffer/Ag stack layer in a step-by-step way in a vacuum deposition chamber. A series of perylene derivatives (PTCDA, PTCDI and PTCBI), TCNQ derivatives (TCNQ and F4TCNQ) and pyridine based acceptor molecules (BCP, TPBi and TAZ) were applied as buffer layers. For all buffer/Ag stack structures, the LUMO level of buffer layers almost accords with Fermi level of Ag, that is, electron is easily transferred from the Ag electrode to the buffer layers due to the disappearance of the electron injection barrier. In contrast, the electron injection barrier height between LUMO of C₆₀ and LUMO of buffer materials correlates with the work function of the buffer/Ag stack structures

(Φ_{buff}). We conclude that to select a buffer/Ag heterostructure with low work function is important in order to maintain good electric contact near Ag cathode. The detailed physical mechanism about the energy level alignment will be discussed using charge transfer model.

11:00am **EH-TuM10 n-type Thin Film WSe₂ for use in Homojunction WSe₂ Solar Cells**, A. Sarkar, *Natale Ianno, R.J. Soukup*, University of Nebraska-Lincoln

Previously we have shown that as-grown p-type thin film WSe₂ is an excellent candidate for an earth abundant photovoltaic absorber.¹ The vast majority of thin solar cells are heterojunction devices with a wide band gap n-type window layer. Many of the device issues are centered on the heterojunction interface, making a homojunction more desirable. The problem here is growing n-type material in thin film systems. In this work we present the structural, optical, and electrical properties of n-type thin film WSe₂ grown via the selenization of sputter deposited copper doped tungsten films. We will show that highly textured films with an optical band gap in range of 1.45 eV, and absorption coefficients greater than 10⁵/cm across the visible spectrum can be easily achieved. In addition we will present Hall Effect and carrier density measurements as a measure of film quality. We employ these results to numerically simulate homojunction solar cells based on this material, where we will show efficiencies greater than 20% are possible.

1. Q. Ma, H. Kyureghian, J. D. Banninga and N. J. Ianno, MRS Proceedings , Volume 1670 , 2014. DOI: <http://dx.doi.org/10.1557/opl.2014.477>

11:20am **EH-TuM11 Samarium Sulfide-Cerium Sulfide, A Potential Band Gap Variable Alloy System for Use in Spectrum Splitting Photovoltaic Systems**, *Rodney Soukup, N.J. Ianno, F. Urias-Cordero, C. Berger, A. Sarkar, M. Hilfiker*, University of Nebraska-Lincoln

A new research thrust to obtaining high efficiency photovoltaic systems is spectrum splitting, where the input solar radiation is physically separated via input optics and channeled to a planar array of individual cells, each with a band gap tuned to absorb a specific band width of radiation. This approach allows for simpler device fabrication and a wider breadth of band gaps than the common multi-junction design, in exchange for a complex optics structure to separate the incoming light. Both these approaches require high efficiency cells over a broad range of band gaps. Currently this is met by III-V alloy single crystal cells and while significant advances have been made in reducing the fabrication cost, recent best estimates place their cost at 1-5x single crystal silicon cells. In addition many of these materials contain indium, whose supply may be limited.

In order for the multi-junction and split spectrum designs to fully realize their potential, it is necessary to explore other classes of semiconducting materials with tunable band gap, better crustal abundance and lower production costs. The Sm_{2-x}Ce_xS₃ alloy system with its potentially broad band gap range (0.8-1.9 eV), as grown p-type majority carrier, potentially excellent optoelectronic properties in polycrystalline form and abundance is an excellent candidate. We will present preliminary data on the growth, optical and electrical properties of thin film Sm₂S₃, and Ce₂S₃ as an initial study of the alloy formation.

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