IPID4all Internship Exchange with Carl von Ossietzky Universität Oldenburg
Feedback report

Brendan Brady, MSc.

University of Victoria, 3800 Finnerty Rd., Victoria, BC, Canada, V8P 5C2

Dr. Alex Brolo

University of Oldenburg

NEXT ENERGY · EWE Research Centre for Energy Technology, Carl von Ossietzky-Str. 15, 26129 Oldenburg, Germany

Dr. Martin Vehse

09.2016 – 12.2016

Nanostructured a-Ge:H Optical Cavity Solar Cells

Introduction

Plasmonic nanostructures have the potential to increase the efficiency of thin-film solar cells while keeping material use, and therefore cost and environmental impact, to a minimum. The Brolo group at the University of Victoria, who specialize in the fabrication of nanostructures, and the PV division at NEXT ENERGY EWE have partnered in multiple student exchanges involving the incorporation of plasmonic nanostructures in thin-film solar cells. The recent development of hydrogenated amorphous Ge (a-Ge:H) optical cavity solar cells by Dr. Steenhoff at NEXT ENERGY EWE has created a unique opportunity to investigate and further understand some of the optical effects of placing metallic and dielectric nanoparticles (NPs) in novel thin-film solar cells.

Research Undertaken

All solar cells were fabricated with a stack sequence as depicted in Fig. 1 (a). All Si and Ge layers were deposited via plasma enhanced chemical vapour deposition, TCO layers were fabricated by DC magnetron sputtering, and the Ag back contact was grown by e-beam evaporation. Fig. 1 (b) shows the quantum efficiency (QE) spectra of the cells depicted in Fig. 1 (a) with various resonant cavity thicknesses.

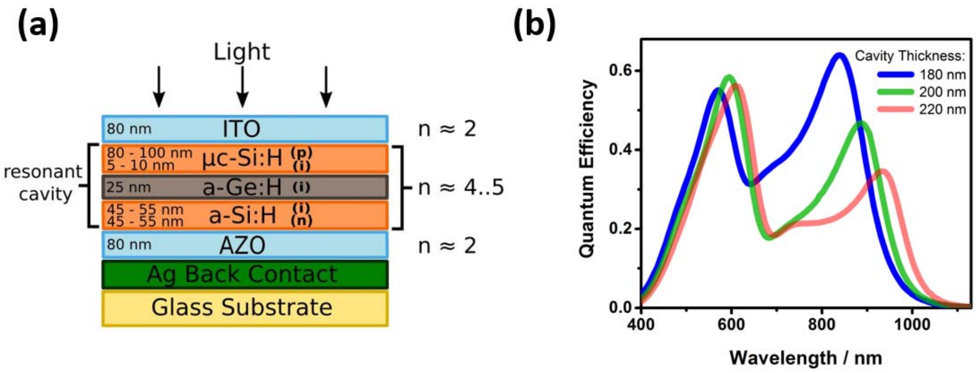

Fig. 1. (a) a-Ge:H flat resonant cavity solar cell layer stack showing layer thicknesses and approximate refractive indices. (b) Quantum efficiency (QE) spectra of the flat solar cells shown in (a) with various cavity thicknesses.

Plasmonic and dielectric NPs were fabricated by nanosphere lithography (NSL) as depicted in Fig. 2. NPs were either deposited prior to the a-Ge:H absorber within the a-Si:H (i) buffer layer or post a-Ge:H absorber deposition within the μc-Si:H (p) doped layer. In both configurations, the NPs were located approximately 10 nm from the Si/Ge interface. SEM images of a completed a-Si:H n-i-p solar cell structured with the same technique are shown in Fig. 3.

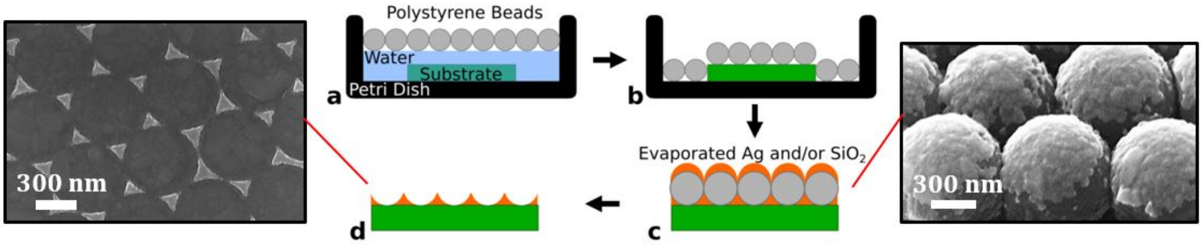

Fig. 2 NP synthesis by NSL. (a) Substrate is submerged in water and polystyrene (PS) beads dropped from colloidal suspension form a close-packed hexagonal monolayer on the surface. Water is left to evaporate (b) and the spheres act as a deposition mask for evaporated Ag and/or SiO_2 (c). SEM image shows PS with evaporated material on the surface. Removal of the PS reveals a periodic arrangement of pyramidal NPs (d).

Fig. 4 (a) displays QE spectra of the resonant cavity cell with SiO_2 particles (height = 100 nm) placed below the a-Ge:H layer along with a flat reference. The corresponding cell stack, shown on the right hand side, and the SEM images in Fig. 3, reveal how the layers grown above the particle carry on the particle profile through the cell stack. The sharp peaks at 715 and 1010 nm indicate optical resonances of the periodic particle array, which may be attributed to a photonic crystal effect. In this case, the increased absorption at these wavelengths would result from light propagation in the plane of the a-Ge:H. To test this, NPs are placed above the a-Ge:H in Fig. 4 (b) to move the plane of propagation away from the a-Ge:H layer. As expected, peaks at the same wavelengths as Fig. 4 (a) are present in Fig. 4 (b) with reduced intensity. When changing the effective refractive index of the NPs, a wavelength shift in the photonic crystal modes is expected. This is observed in Fig. 4 (c) where the NPs now contain Ag while the cell stack remains the same as Fig. 4 (a). A red-shift of the 715 nm peak is seen in the 600 nm PS curve and a further red-shift occurs when the periodicity of the photonic crystal is increased using 700 nm PS, as expected.

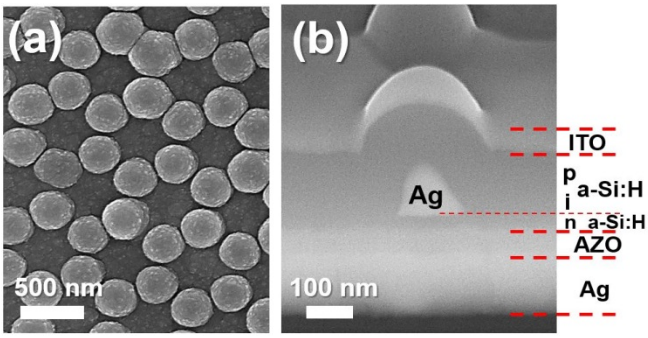

Fig. 3 (a) Top view SEM image of completed cell showing protruding effects of NPs and (b) cross sectional SEM image showing cell stack of an a-Si:H n-i-p cell with NPs.

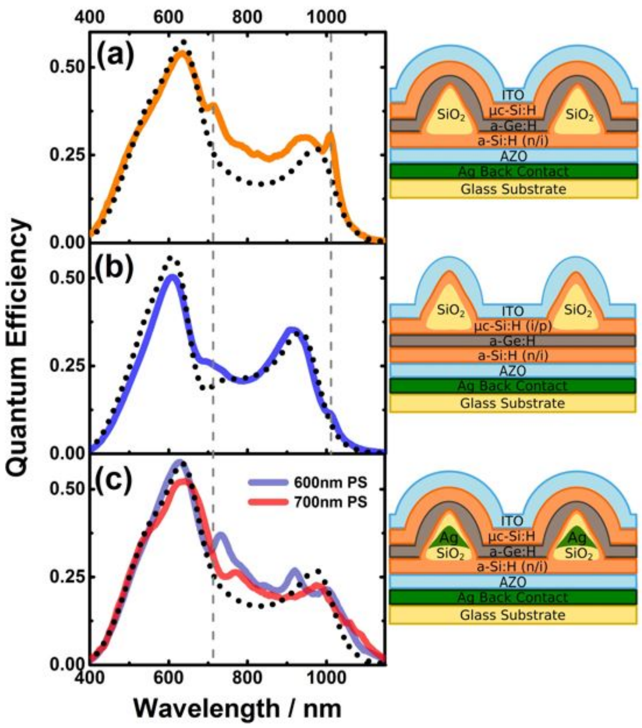

Fig. 4 (a) QE spectra of 100 nm SiO_2 NPs below a-Ge:H (orange) along with a flat reference (black dotted), (b) QE spectra of 100 nm SiO_2 NPs above the a-Ge:H (blue), (c) QE spectra of SiO_2 (20 nm)/Ag (75 nm)/SiO_2 (5 nm) NPs (bottom → top) fabricated with 600 nm diameter PS (purple) and 700 nm diameter PS (red). Corresponding cell stacks are shown on the right (not drawn to scale).

In order to single out the plasmonic effects from photonic crystal effects, NPs containing Ag were placed above the a-Ge:H layer and results are shown in Fig. 5. It is apparent that as the metal portion of the NPs increase, the QE spectra deviates further from the shape of the flat reference and the Fabry-Pérot interference

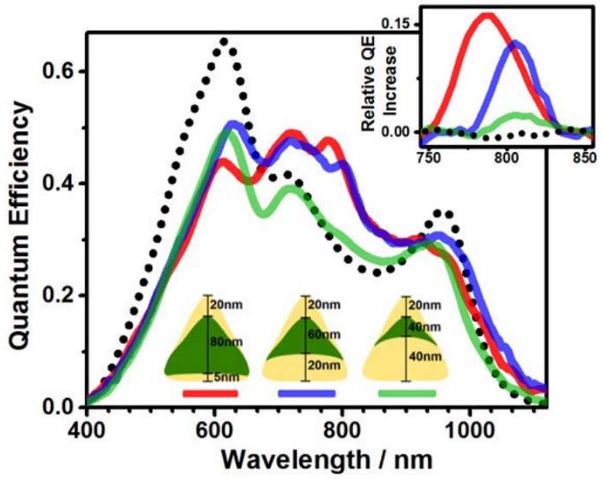

Fig. 5. QE spectra of nanocavity cells with SiO_2/Ag/SiO_2 particles placed above the a-Ge:H absorber. Inset shows QE increase (relative to QE value at the respective peak baseline) due to the LSPR peaks at 800 nm.

pattern diminishes. This observation is consistent with a higher scattering cross-section of particles with higher metal content as light scattered into the cell at angles away from the normal does not contribute to the same optical cavity resonances. A sharp peak begins to develop at approximately 800 nm as the bottom Ag/SiO_2 interface is moved closer to the a-Ge:H absorbing layer. This is explicitly seen in the inset where the relative QE increase due to this peak is plotted for each spectrum. It is evident that as the Ag/SiO_2 interface is moved closer to the a-Ge:H absorbing layer, the peak around 800 nm has a larger influence on the QE. This is evidence that the high intensity evanescent electric field of the localized surface plasmon resonance (LSPR) at this Ag/SiO_2 interface is contributing to charge carrier generation in the a-Ge:H layer.

Personal Experience

Spending three months at NEXT ENERGY EWE provided me with the opportunity to develop academically and professionally. The state of the art facilities at the institute allowed me to focus my attention and learning on the topic of my degree and concentrate on completing novel experiments in the PV field. The support of other individuals at the institute, specifically Dr. Steenhoff, during experiment planning and execution made for a friendly atmosphere to make mistakes, ask questions, and tackle problems as part of a team. Furthermore, I made many professional connections through group discussions and I had the opportunity to present my findings during formal meetings.

Outside of the academics, living in Oldenburg was a fantastic experience for me. The professional connections I made are additionally friends who I plan to stay in contact with in the future. I was able to participate in many German traditions, particularly those associated with the holidays, and was able to learn, discuss and adapt modern German values. Moreover, living in north western Germany made it easy for me to travel to Denmark and Belgium as well as Hamburg and Bremen.

Conclusions

The original objective of this research exchange, which was to investigate the influence of dielectric and metallic particles on the performance of a-Ge:H optical cavity solar cells, was achieved. This work has the potential to provide fundamental understanding that can be applied to increase the performance of nanostructured thin-film solar cells in the future. I am thankful to the IPID4all research exchange program for providing me with this opportunity.

Outlook

- Planning to present results at the 2017 IEEE PVSC-44 conference (oral presentation)
  Title: "Investigation of photonic and plasmonic resonances in nanostructured optical cavity a-Ge:H solar cells"