Abstract

The study on photovoltaic is an important topic in the sustainable and clean energy research field, driven by the deteriorating energy crisis and environmental pollutions due to fossil fuel shortage and combustion. Currently, the crystalline silicon (c-Si) based solar cell dominates the photovoltaic market. However, its high material cost has weakened its competitiveness with fossil fuels. To reduce the material cost, silicon thin film based device incorporated with nanostructures for light trapping can be used.

In this work, we study the nanostructured back reflector (BR) for improved light absorption in silicon thin film solar cells. The nanostructured BRs are patterned and fabricated based on polystyrene sphere (PS) assisted lithography. We adopted "substrate" (n-i-p) structure and highly reflective Ag layer and optical spacer ZnO layer are deposited on glass substrate as the BR materials. The silicon thin films are grown on top of the BRs by Plasma Enhanced Chemical Vapor Deposition (PECVD) technique.

To improve the patterning capability aimed at developing a well-controlled fabrication process of the BRs, we study the etching behavior of PS spheres in Electron Cyclotron Resonance (ECR) oxygen plasma. By tuning the oxygen plasma condition including plasma input power, etching mode, shielding of the ion flux with Faraday cage, we successfully isolated the effect of oxygen radical and of energetic ions on the etching behaviors of PS spheres. The reason behind PS spheres melting and shape deformations are concluded and negative impacts during BR fabrication are avoided. As the results, we developed a well-controlled oxygen plasma etching process for PS spheres using ECR source. After etching, small PS sphere size are achieved which enables various applications.

After that, we study light trapping in hydrogenated amorphous silicon thin film solar cells fabricated by PECVD on various nanostructured BRs. The BRs are patterned using different PS sphere sizes without oxygen plasma etching step. We have investigated the correlation

between the optical properties of the BRs and the performance of their corresponding solar cells. We have introduced double size PS sphere patterned BRs and have shown solid experimental evidence for improved light trapping performance compared with single size polystyrene sphere patterned BRs. We have achieved high performing nanostructured amorphous silicon solar cells with an initial power conversion efficiency of 8.79 % and over 20 % enhancement of the short-circuit current compared with the reference flat BR solar cell.

Due to the usage of Ag and ZnO material and Ag nanostructures in the BRs, parasitic losses are also introduced in the device. Followed from above part, we study parasitic losses and light trapping in hydrogenated amorphous silicon thin film solar cells fabricated by PECVD on nanostructured BRs. The BRs are patterned using single PS sphere size with oxygen plasma etching step. By using O_2 plasma etching of the PS spheres, we managed to fabricate hexagonal nanostructured BRs. With the help of rigorous modeling, we study the parasitic losses in different BRs, non-active layers, and last but not least the light enhancement effect in silicon absorber layer. Moreover, simulation results have been compared and verified with experimental data. We have demonstrated hexagonal nanostructured amorphous silicon thin film solar cells with a power conversion efficiency of 7.7 % and around 34.7 % enhancement of the short-circuit current density, compared with flat amorphous silicon thin film solar cell.

Publication List

Journal:

1. **Zeyu Li**, Rusli, Martin Foldyna, Junkang Wang, Wanghua Chen, Ari Bimo Prakoso, Chenjin Lu, and Pere Roca i Cabarrocas, "Nanostructured back reflectors produced using polystyrene assisted lithography for enhanced light trapping in silicon thin films solar cells," has submitted to Solar Energy.
2. **Zeyu Li**, Chenjin Lu, Ari Bimo Prakoso, Rusli, Martin Foldyna, Rasha Khoury, Pavel Bulkin, Junkang Wang, Wanghua Chen, Erik Johnson, and Pere Roca i Cabarrocas, "Optical study and experimental realization of nanostructured back reflectors for enhanced light trapping with reduced parasitic losses in silicon thin film solar cells," has submitted to Optical Express.
3. Rasha Khoury, **Zeyu Li**, Pavel Bulkin, Rusli, Pere Roca i Cabarrocas, and Erik Johnson, "Detailed study of electron cyclotron resonance oxygen plasma etching of polystyrene nanosphere arrays," has submitted to Journal of Physics D: Applied Physics.
4. Ari Bimo Prakoso, **Zeyu Li**, Chenjin Lu, Changyun Jiang, and Rusli "Design guideline for interdigitated back contact Si/organic hybrid heterojunction solar cell," has been submitted to Semiconductor Science and Technology.
5. Ari Bimo Prakoso, Chenjin Lu, **Zeyu Li**, Changyun Jiang, and Rusli, "High efficiency planar front junction n-Si/PEDOT:PSS hybrid solar cell with ARC compensated layer," has been submitted to Energy Technology.
6. Ari Bimo Prakoso, Lin Ke, Jianxiong Wang, **Zeyu Li**, Changyun Jiang, and Rusli, "Reverse recovery transient characteristic of PEDOT:PSS/n-Si hybrid organic-inorganic heterojunction," accepted 11 December 2016, Organic Electronics, vol. 42, pp. 269-274 (2017).
7. Nastiti Puspitosari, Christophe Longeaud, Raphael Lachaume, **Zeyu Li**, Rusli, and Pere Roca i Cabarrocas, "Comparison of FTPS Performed on Thin Films and Solar Cells," accepted 27 July 2017, Physica Status Solidi C: Current Topics in Solid State Physics, vol. 14, 1700165.

Conference:

1. **Li Zeyu**, Rusli, Ari Bimo Prakoso, Hong Lei and Pere Roca i Cabarrocas, “12.5% Silicon Nanohole/PEDOT:PSS hybrid solar cell with simple solution based surface treatment”, 32nd European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2016), Germany, June 2016.
2. **Li Zeyu**, Rusli, Ari Bimo Prakoso and Pere Roca i Cabarrocas, “Si/PEDOT:PSS hybrid solar cell based on random Si nanowires in periodic Si nanoholes structure,” Hybrid and Organic Photovoltaic 2016, Swansea, UK, June 2016.
3. **Li Zeyu**, Rusli, Lu Chenjin, Ari Bimo Prakoso, Martin Foldyna and Pere Roca i Cabarrocas, "Nanostructured Back Reflectors for a-Si:H Thin Film Solar Cells by Polystyrene Sphere Assisted Lithography", Nano Science & Technology 2017, Fukuoka, Japan, Oct 2017. (invited)
4. Ari Bimo Prakoso, Lin Ke, Jianxiong Wang, **Zeyu Li**, Changyun Jiang, Rusli, "Study of PEDOT:PSS/n-Si hybrid organic-inorganic heterojunction", Materials Science-2017, Valencia, Spain, Sep 2017. (invited)