Manufacturable Nanostructured Solar Cells with Efficient Light Trapping and Charge Carrier Collection

Investigators

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Abstract

Photovoltaics, which utilizes the largest possible energy source to generate electricity, represents one of the most attractive approaches towards renewable energy future. However, the cost of current solar electricity is still too high. Future photovoltaic technologies need to have high power conversion efficiency and can be fabricated with low cost. In this project, we propose novel nanocone and nanodome-like solar cells, which can reduce the cost while enhancing the power efficiency. We design by photonics simulation and fabricate subwavelength inorganic nanostructured substrate, on which solar cell layers can be deposited. We will study our light trapping device concept on solar absorber materials. Our device concept for light trapping is general and is expected to reduce the amount of materials needed, to increase manufacturing throughput and to reduce the capital cost which will be able to reduce the solar cell production cost significantly while still maintaining high efficiency. Our proposed research can lead to important fundamental understanding of photon management in photovoltaics and to the fundamental design of high efficiency solar cells.

Background

Converting sunlight energy into an easily usable format is one of the most attractive solutions toward renewable energy future since everyday sun delivers energy to the earth 10,000 times of the current world energy consumption. Photovoltaic devices, which convert sunlight energy into electricity, are therefore widely studied as a means to harvest solar energy. Although the solar cell industry has indeed seen a large growth rate in the last couple of decades, the energy produced by solar cells only contributes to less than 0.1% of the world total energy consumption. One of the main reasons is that solar electricity is still significantly more expensive than traditional electricity generated by fossil fuels.

Solar cell operation includes a number of physical processes to be optimized. When sunlight reaches the solar cell, some of the light is reflected back and lost, so that a special antireflection layer is needed to minimize the loss. This requires either a material with low refractive index or a textured morphology. Furthermore, to maximize the light absorption the active semiconductor layer needs to be thick enough to harvest as many photons as possible. For crystalline silicon, an indirect bandgap semiconductor, the typical film thicknesses is three hundred micrometers. Last but not least, the electrons and holes created by the absorbed photons need to be separated and collected to generate electricity with minimum loss. Maximizing the light absorption requires a thick layer of absorber although increasing charge carrier collection efficiency and decreasing the cost favors the opposite: thin absorber layer.

It is necessary to develop a solar cell structure with efficient antireflection and light trapping simultaneously so that only a thin layer of absorber layer is needed for photon absorption. It is also important to develop facile processing to produce such solar cell structures. In this project, we study nanocone and nanodome solar cells for efficient photon management. We will study our light trapping device concept on materials including CdTe and $CuIn_{1-x}Ga_x Se_2$ (CIGS).

Results

With GCEP's one-year project support, we have fabricated all types of nanotextured substrate on quartz and glass substrate, which can be used for solar cell fabrication. Several methods have been developed.

LB deposition of nanoparticles and etching

Monodisperse SiO_2 particles with diameters from 50 to 800 nm can be produced by a modified Stöber synthesis, and be assembled into a close packed monolayer on top of substrate surface using the Langmuir-Blodgett (LB) method. The particles are modified with aminopoly methyldiethoxysilane to terminate them with positively charged amine groups to prevent aggregation. The diameter and spacing of the nanoparticles can be further tuned by selective and isotropic RIE of SiO_2. The RIE etching is based on fluorine chemistry using a mixture of O_2 and CHF_3.

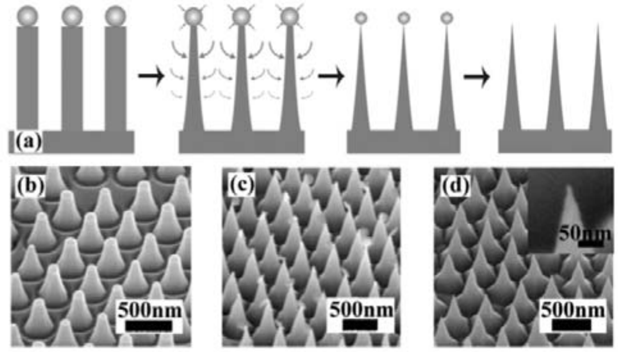

Fig. 1 Process of nanocone fabrication.

By using these SiO_2 particles as etching masks, Cl_2 based selective and anisotropic RIE can be performed to obtain nanocone arrays (Fig. 1). The diameter and spacing of these nanocones are determined by the initial nanoparticle sizes and both SiO_2 and Si etching times. Through control of etching conditions, the RIE undercutting can be utilized to form unique sharp nanocones with wide tunable range of aspect ratio and tip radius. The combination of anisotropic and isotropic etching can lead to a sharpening of the tips to a radius of curvature of 5 nm, which can be helpful for effective antireflection.

The LB method can produce monolayer of naoparticles over wafer-scale substrate but the process in general is slow. This process is suitable for small device demonstration. For large scale and low-cost process, the following methods are needed.

Nanoparticle solution coating

This process involves in fast coating of nanoparticles from solution phase onto substrate surface. We plan to develop a method by spreading the nanoparticles solution with a wire-wound rod, which is a stainless steel rod that is wound tightly with stainless steel wire (Fig. 2). As the rod is pulled over the solution, the precise amount of solution, which is equal to the size of groves between each wire winding, is left on the substrate, forming a flat wet film. Thus, the diameter of the wire on the rod determines the thickness of the wet film. Nanoparticle solution is pushed away by the rod except the amount which passes through the groves, as shown below.

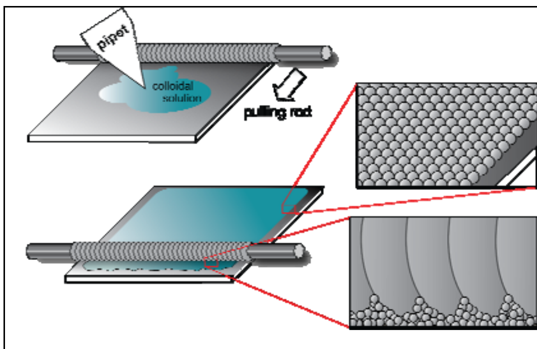

Fig. 2 Scheme of rod-coating process.

In order to make a monolayer of particles as the solvent evaporates, we need to control the contact angle and the evaporation rate. The rod helps to spread the colloidal solution evenly and make the solvent evaporate gradually, but it is not enough to make a monolayer of particles. We will need to tune the viscosity of solution by mixing a polymer with the colloidal solution and spread at a constant rate. The solution has to be viscous enough to form liquid film without breaking up but not too viscous to have high contact angle. For instance, poly-4-vinylphenol

(PVPh) can be added to the silica particle solution (in ethanol). The ink can be spread by a wire-wound rod. Our preliminary result show that monolayer of nanoparticles can be coated onto flexible PET substrate by this rod-coating method. This solution coating method can be done very fast (within minute) and the processing works reproducibly. The process produces nanoparticle films with more packing defects. However, that should not affect antireflection and light trapping property much in this study. The produced nanoparticle films can be used directly as substrate for solar cell fabrication or used as an etch mask to produce nanocones.

Solar cell fabrication

We have started to deposit CIGS and other solar absorber layer onto the nanotextured substrate and tested enhancement of photon absorption.

Publications

None.

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