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Efficient Light Trapping Structure in Thin Film Silicon Solar Cells

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ABSTRACT

Thin film silicon solar cells are believed to be promising candidates for continuing cost reduction in photovoltaic panels because silicon usage could be greatly reduced. Since silicon is an indirect bandgap semiconductor, its absorption coefficient is low for photons in the wavelength ranges between 600nm and 1100nm. For high efficiency thin film modules, effective light trapping is essential. Traditional schemes such as textured transparent conductive oxide (TCO) and metal reflector have several disadvantages such as enhanced surface recombination, parasitic losses at the TCO/metal interface, and the lack of ability to control and optimize the textured surface. We have previously proposed to employ a light trapping structure, which combines a self-assembled submicron grating and a distributed Bragg reflector (DBR) on the backside of thin film silicon solar cells. The DBR works as a one-dimensional photonic crystal to obtain almost 100% reflectivity. The grating scatters the incident light into oblique angles to significantly enhance the optical path length. Numerical calculations predict that by optimizing the feature sizes of the grating and DBR, up to 31% relative efficiency increase can be obtained, compared to the bare thin film Si. By using self-assembly, the organized grating structure can be formed spontaneously at a much lower cost. Current-voltage relations and quantum efficiency measurements were taken to verify the performance of our designed back structure. In the wavelength range of 600-900nm, photon absorption is greatly enhanced. As a result, more than 20% relative efficiency enhancement is achieved for 1.5um thin film silicon cells. These numerical and experimental results show that a light trapping design can be low-cost and increase efficiencies for high performance thin film Si solar cells.

INTRODUCTION

Nowadays, energy shortage has become a worldwide issue along with the consumption of fossil fuel. Among techniques that utilize alternative energy sources, solar energy is considered to be very promising and has already achieved wide applications for space and terrestrial power generation. However, most solar cells are based on silicon wafers. The cost of silicon solar cells, which is dominated by the starting material, is difficult to be reduced [1]. To continue price reduction trends, thin film silicon solar cells based on inexpensive substrates have been developed [2]. As Si films become thinner, the absorption of longer wavelength photons will be weaker due to its indirect bandgap, severely limiting the performance of thin film Si

solar cells. Traditional schemes to improve absorption in thin film Si such as textured transparent conductive oxide (TCO) or metal reflectors [3] have several disadvantages, i.e. enhanced surface recombination [4], parasitic loss at the TCO/metal interface [5], and the lack of ability to control and optimize the textured surfaces. To overcome these limits, we proposed a novel light trapping scheme, which combines two-dimensional self-organized gratings and a distributed Bragg reflector (DBR) [7].

SIMULATION

The design of our backside light trapping structure is showed in Figure 1. The configuration comprises of two components: a distributed Bragg reflector (DBR) and a grating layer [6-8]. The DBR consists of alternating Si and SiO_2 layers, which work as a one-dimensional photonic crystal and is capable of achieving almost 100% reflectivity in the wavelength range from 600nm to 1000nm if a suitable thickness for each layer is selected [10]. In addition, a grating layer is embedded between the active device and the DBR. This grating layer produces diffracted light propagating at oblique angles. Through the combination of the grating and DBR, the light path length in the thin film silicon can be significantly increased, resulting in stronger absorption or red and infrared photons.
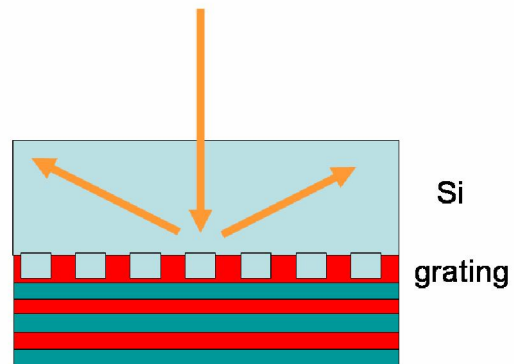
Figure 1 A schematic of light trapping structure combining grating and DBR on the backside of thin film Si.

Numerical calculations [11] were used to predict and optimize the performance of our proposed photonic structure. By choosing appropriate feature sizes for the

grating and DBR, our model predicts that more than 30% relative efficiency increase could be reached for 1.5um thick uc-Si devices. The calculated absorption spectra for devices with different configurations are compared. By integrating the absorption spectra and the AM1.5G solar spectrum, up to 31% relative efficiency increase is predicted, compared to the bare thin film Si.

EXPERIMENTAL RESULTS

We fabricated the grating structure using anodic aluminum, which has a porous structure with a hexagonal pattern, as a template material. Moreover, the feature sizes of this AAO structure (interpore distance, pore size, and etc.) can be experimentally determined by the anodization process. We choose AAO because of the potential to be low-cost due to the fact that the grating is self-assembled. For prototyping we used thin AAO membranes as a deposition mask. Silicon was directly evaporated through the porous AAO structure onto the back surface of uc-Si solar cells, forming hexagonal cylinder arrays with feature sizes that result in light trapping in the near infrared. Subsequently, 5 pairs of alternating SiO_2 (130nm) and Si (40nm) were deposited as DBR. The reflectivity of DBR is measured and compared with the transfer matrix calculation, which is shown in Figure 2.

Our designed light trapping structure is fabricated on a prototyped 1.5um uc-Si solar cell [9]. The performances of cells with difference backside structures are measured and compared. The quantum efficiency spectra clearly reveal the light absorption enhancement of the light trapping structure in the wavelength range between 600nm and 900nm. IV measurements support the wavelength dependent quantum efficiency results. The solar cell with both grating and DBR shows the highest performance and up to 20% relative efficiency increase was achieved, compared to the reference cell without any backside structure.
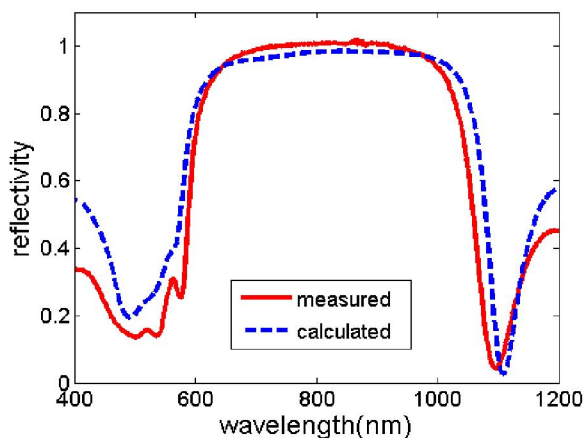

Figure 2 Comparison of the measured and calculated reflectivity spectra for DBR.

CONCLUSION

In summary, a light trapping structure combining grating and DBR was created in the backend process, without affecting solar cell fabrication process. The optimal design of this photonic structure was obtained by modeling to determine the fabrication parameters for grating and DBR. A self-assembly fabrication method based on anodizing aluminum was used to fabricate the back side structure. The fabricated devices show significant improvement over a reference cell without light trapping. This deterministic structure can potentially be a low-cost, easily controllable, highly effective addition for high-efficiency thin film silicon solar cells.

ACKNOWLEDGEMENT

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