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A new approach to increase efficiency of thin Si solar cells with scatterer

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1. Introduction

The energy cost of solar cell is two or three times higher than other main energy sources. The most important problem for solar cell is to decrease energy cost. Lower energy cost can be realized by decreasing the manufacturing cost. Particularly, for Si solar cells, since almost 50% of manufacturing cost is derived from Si wafer, thin film solar cells play a significant role.

The problem of thin solar cell is low electrical conversion efficiency. In case of general solar cell, the optical path length of incident light is several times longer than the wafer thickness with internal reflection. In case of thin solar cell, however, the optical path length should not be long enough by multiple reflection, leading poorer conversion efficiency.

Photonic crystal layer is one of the good methods to increase the optical path length of thin solar cell [1]. Photonic crystal layer on backside of wafer allows incident light to the lateral direction (superprism effect). The optical path can be comparable with the wafer diameter. The wafer thickness is thus not a decisive parameter any more when the superprism is implemented in Si solar cells. However, the photonic crystal approach requires very fine structures and may not be cost-effective.

In the present paper, we have proposed the other approach using Rayleigh scattering by small air spheres embedded in Si, and have shown the proof of concept.

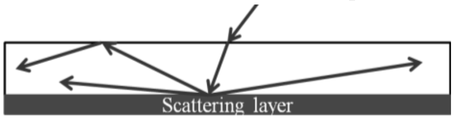

Fig. 1. The schematic structure with scatterers to elongate the optical path along to the wafer plane. This fits with the current trend of thin Si solarcells.

2. The proof of the scattering layer effect

We simulated the absorbance of Si to figure out the effect of our concept [2]. In this simulation, the scatterers are a lot of small air spheres. For simplicity, the air spheres distribute in Si substrate homogeneously. Here, we ignored the surface-reflection and multiple scattering, but took into account that the scattered light with $\theta > \theta c$ is totally reflected and absorbed in 10 cm, typical cell size (Fig.2). The ratio of scattered light against the incident light is calculated using $1\text{-}\exp(-\mu_{sca}t)$. The light without the scattering is only absorbed along the wafer thickness direction [2]. The absorbed light consists of three components, "scattered light confined in the wafer due to total internal reflection ($\theta > \theta c$, optical path=10cm)", "scattered light without the total internal reflection ($\theta < \theta c$, optical path ~ thickness)", and "non-scattered light (optical path = thickness)".

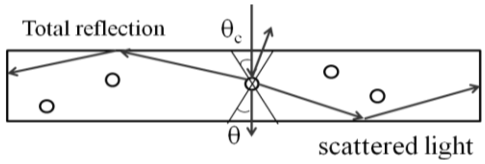

Fig. 2. The structure for simulation ($\theta c = \sin^{-1}(n_{Si}/n_{air})$).

Figure 3 shows typical simulation results. The thin sample, 30 μm thick shows higher absorbance with the scatterers than that without the ones. The solar cell becomes able to absorb the light with the wavelength over 1100 nm, which the thick sample cannot absorb.

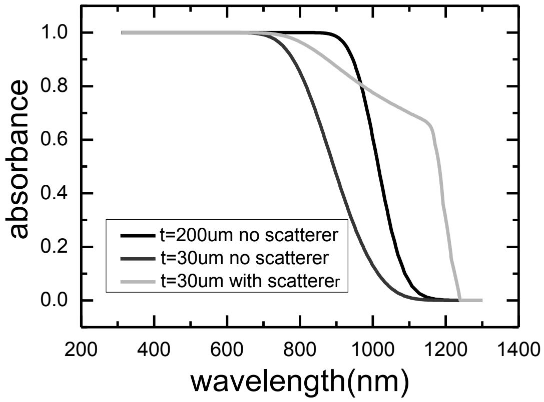

Fig. 3. The simulated absorbance for Si without air spheres (t = 200 μm and t = 30 μm) and for Si with air spheres (t = 30μm, and the volume of air sphere V_{air} of 10%).

3. Experiment

We have used porous Si as the scattering layer instead of air spheres. Porous Si consists of many air pores in Si that can work as scattering layer. So, it should have the similar effect to air spheres. Porous Si does have significant advantage over air spheres because the fabrication is easy and simple, and over photonic crystal reflectors because no regularity is required. If porous Si works as scattering layer, it is very useful to increase the conversion efficiency and decrease the cost.

We conducted the experiments to examine if porous Si layer scatters the incident light. In the experiments, instead of direct measurement of scattered light intensity, we measured the transmittance T and reflectance R for the samples. Incident light should be scattered, reflected, absorbed or transmit. Thus, 1 - (T+R) indicates the percentage of the sum of scattered and absorbed light.

The porous Si layer was formed using an anodic oxidation in a HF-based electrolyte. The electrolyte was a 1:1 mixture (by volume) of HF (50 wt%) and ethanol (99.5 wt%) [3]. Current density was 30 mA/cm^2 and the processing time was 60 s. A both-side mirror-polished p-Si wafer (t = 525 μm) was used. On the backside, a p$^+$-Si layer (t = 0.6 μm) was formed by an ion implantation. Such a heavily-doped Si is useful for the anodic oxidation, which consumes a lot of holes [4]. However, if the heavily-doped layer is too thick, there is no transmission of light due to the free-carrier absorption. Thus, in order to eliminate the free-carrier absorption, we limited the thickness to be 0.6 μm, and this layer was oxidized to form porous Si.

We measured 1 - (T+R) for wafers with and without the porous Si on the backside.

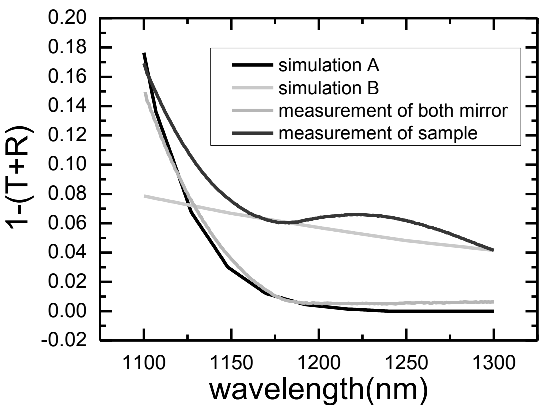

Fig. 5. The measurement and simulated results (A: t = 525 μm without scatterers, B: t = 0.9 μm with air spheres. diameter is 50 nm and V_{air} is 15%).

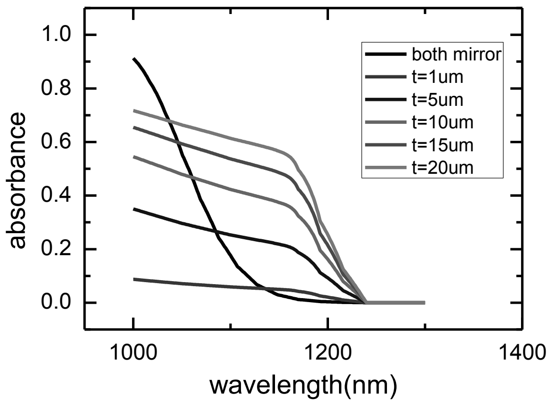

Fig. 6. Simulated absorbance as a ... (D=50nm, V_{air} is 10%, thickness is 1, 5, 10, 15, 20μm)

4. Result & Discussion

Figure 5 compares the measured result of 1 - (T + R) with the simulated ones. The sample with porous Si layer shows 6% higher 1-(T+R) than that without porous Si in the wavelength range over 1100 nm. The measurement results agree well with the simulation. This strongly suggests that the improvement of 1 - (T+R) should be due to the scattering effect due to porous Si layer on the backside.

In the present experiment, the enhancement of 1-(T+R) is only about 6%. The main reason is that the layer is too thin. Figure 6 shows the simulation of absorbance as a function of the wafer thickness with scatterers of air spheres. When the thickness is more than 10 μm, the absorbance is more than 40%.

These results indicate that our proposed approach to use porous Si layer will be promising to increase the efficiency of thin Si solar cell.

5. Conclusion

A method to enhance the solar cell efficiency is proposed, where the scatterers are embedded on the backside. As the scatterers, porous Si layer was examined. We have verified the enhancement by the light scatterers.

Reference

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