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Characterization of Poly-Si Nanowire Array Embedded in ALD-Al_2O_3 by Photoacoustic Spectroscopy

ALD-Al_2O_3に埋め込まれた多結晶シリコンナノワイヤーの光音響分光による研究

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1. Introduction

Silicon nanowires (SiNW) are widely investigated for various device applications such as optical sensors, field effect transistors and thermoelectric deviceses and solar cells. In the case of solar cell applications, a conversion efficiency over 30% is expected by using SiNW/c-Si tandem solar cells with a SiNW ligth absorbing layer with a bandgap of about 1.7 eV. To realize the SiNW ligth absorbing layer, it is important to prepare the SiNW with a very small diameter and furture technological improvements are required. There are two approches to fabricate a SiNW layer. The first approach is growth of SiNW by a deposition technique, such as laser ablasion, physical vapor deposition (PVD), chemical vapor deposition (CVD) and vapor-liquid-solid (VLS) growth process. The other approche is etching of a silicon layer by an etching method such as reactive ion etching (RIE) and metal-assisted chemical etching (MAE). Among these techniques, MAE process has attracted much attention because the SiNW array can be produced in a very easy process.

Our group succeeded in fabricating the amorphous SiNW (a-SiNW) array using MAE process and applied to solar cell absorber layer [1]. In addition, our group also successfully prepared polycrystalline SiNW (poly-SiNW) array by thermal annealing of a-SiNW. We also deposite an Al_2O_3 passivation layer which is well knwn passivation material for c-Si on the poly-SiNW because large surface recombination velocity should be reduced for device applications [2]. However, optical properties of SiNW embeded in Al_2O_3 layer has not been reported.

Optical absorption is one of the important properties of the materials characteristics. Optical properties of nanostructured materials such as nanoparticles, nano pillars and nanowires are also determined by using UV-vis-IR transimittance and reflectance. However, the measurement of the optical absorption properties is very difficult because the SiNW array has a strong light scattering on the surface. That is, the measeurement of the optical absorption characteristics of the SiNW array is necessary to avoid the influence of scattering. Photoacoustic spectroscopy (PAS) is one of the easy way to solve the scattering problem.

In this study, we report the differences in optical properties with the different experimental conditions of the passivation layer of SiNW array.

2. Experimental details

Poly-SiNW arrays were fabricated from poly-Si film on quartz substrates with an aluminum induced crystallized (AIC) poly-Si seed layer using MAE process. Al/a-Si stack structure was prepared on glass substrates by radio frequency (RF) sputtering process. The seed layer was fabricated by annealing of this stacked structure for 4 hours at 773 K under nitrogen ambient. After the fabrication of the AIC poly-Si seed layer, the a-Si was deposited by RF sputtering on the AIC-poly-Si seed layer. The a-Si was crystallized at 1173 K for 30 min. in forming gas ambient to fabricate poly-Si thin film.

Poly-SiNW arrays were fabricated from the poly-Si thin films by using the MAE process. The thickness of the samples was about 1.5 μm. The diameter of the nanowire was about 50-200 nm determined by scanning electron microscope (SEM). Furthermore, Al_2O_3 was deposited on the poly-SiNW by atomic layer deposition at 473 K using trimethylaluminum ($Al(CH_3)_3$) and water (H_2O). The final sample structure was poly-SiNW (1.5 μm) embedded in Al_2O_3/AIC-poly-Si seed layer (200 nm)/quartz. After the deposition of the Al_2O_3 passivation layer, the thermal annealing at 573 K for 90 min was carried out under forming gas ambient.

Figure 1 shows the schematic diagram of PA spectroscopy system. Photoacoustic (PA) spectra were measured between 400 nm to 1600 nm region with 5 nm resolutions. A monochromatized light was irradiated onto the samples. The light source was a halogen lamp. To get modulated light, a mechanical chopper was used and the modulation frequency was about 12 Hz. A lock-in amplifier

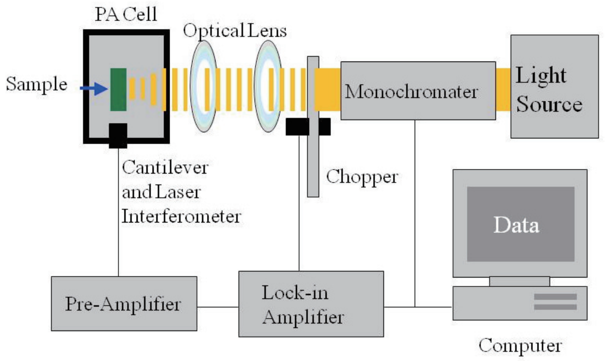

Fig. 1. Schematic diagram of PAS system.

was used to amplify the cantilever and laser interferometer output signal. The PA signal intensity was normalized by the PA signal intensity from carbon black. All samples were measured at room temperature.

3. Results and Discussion

Figure 2 shows the XRD pattern of the SiNW array with Al_2O_3 passivation layer sample after forming gas annealing. The asterisk in figure is a peak of the aluminum holder used at the XRD measurement. Other peaks at around 28.5, 47.3 and 56.2 degree in Fig. 2 are associated to the (1 1 1), (2 2 0) and (3 1 1)-plane of Si, respectively. The peak positions, orientation factors, and full width at half maximum (FWHM) of the annealed sample are almost identical to the sample without annealing process.

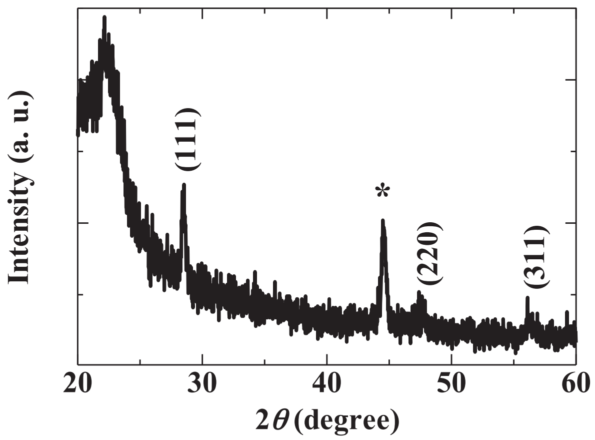

Fig. 2. XRD pattern of the sample with annealing process after passivation layer deposition.

Figure 3 shows the PA spectra of the sample with and without forming gas annealing process. For both samples, the onset of the increase in PA signal is located at around 1.1-1.2 eV. This value is in good agreement with the bandgap of c-Si. These results clearly indicate that PAS measurement can be used for the optical characterization of poly-SiNW embedded in an Al_2O_3 passivation layer. The onset of the increase in the PA signal slightly

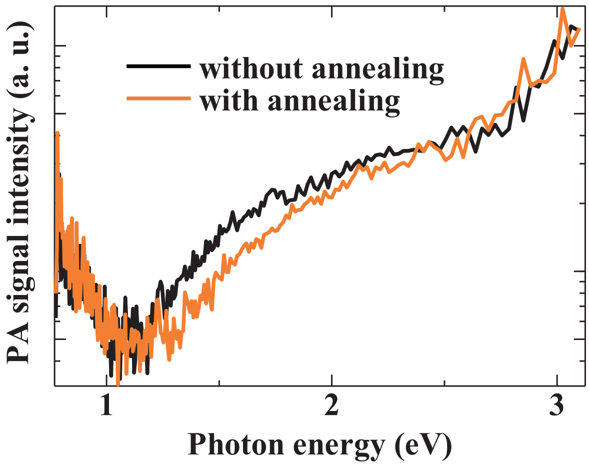

Fig. 3. PA spectra of the sample with and without annealing process after passivation layer deposition.

shifted to larger photon energies after thermal annealing. The reason is not clear at present. A possible explanation is that surface reflectance was changed after thermal annealing because of the change of the optical properties of the Al_2O_3 passivation layer.

Furthermore, as compared to the PA signal of the poly-SiNW array and the a-SiNW array reported at the previous USE conference, the signal intensity is almost half [3]. The shapes of the PA spectra are almost same. A possible explanation of the decrease of the signal intensity is that deposition of Al_2O_3 suppresses the vibration of SiNW.

4. Conclusion

This study clearly shows the PAS measurements are useful to investigate optical properties of poly-SiNW embedded in Al_2O_3 passivation layer. The small change in the optical properties before and after annealing can be detected. We also found that signal intensity is strongly influenced by deposition of Al_2O_3 passivation layer.

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