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Title	湿式化学成長した超極薄AlドープSiOxにより形成されたAl誘起酸化物反転層を有する新規Si系太陽電池
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ABSTRACT

Carrier-selective passivating contacts would realize excellent surface passivation for crystalline Si (c-Si) solar cells with a high conductivity without direct metal electrode contacts, causing a deterioration of the interface properties. Hence, it would be a breakthrough technology to access a practical limit of solar cell performance.

This thesis addresses using a simple process to realize low-cost and high-efficiency c-Si solar cells with a simple device structure of carrier-selective passivating contacts whose emitter is induced by external electrostatic charges.

The main major contribution of this work is developing a novel surface passivation method using a simple wet chemical process, which does not require vacuum, high temperature, or hydrogen treatment processes, which are essential processes in industrial c-Si solar cells. The process is just immersing Si wafers into a hot aluminum nitrate ($Al(NO_3)_3$) aqueous solution to form an ultrathin Al-doped SiO_x layer possessing hole selectivity. On a planar n-type c-Si surface, the maximum effective surface recombination velocity ($S_{eff, max}$) reached as low as 16 cm s^{-1}. The analyzed saturation current density (J_0) of 65 fA cm^{-2} and contact resistivity (ρ_c) of 20 mΩ cm^2, the hole selectivity (S_{10}) value could be estimated to be 13.3 which is competitive to other selective contacts created using vacuum and high-temperature process. Since the process eliminates the complexity of solar cell fabrication processes with an excellent carrier-selective passivating contact property, this study suggests that a wet chemical process using an aqueous solution of $Al(NO_3)_3$ can be an industrial solar cell fabrication process. In addition, the mechanism of the hole-selective passivating contact property was revealed. The field-effect passivation is mainly attributed to the surface passivation.

The second contribution of this work is a demonstration of the device operation of a novel device structure with an inversion layer induced by the negative fixed charges existing in ultrathin Al-doped SiO_x. This result implies that the charge-induced inversion layer acts as a p^+ emitter formed by a simple wet chemical process. Hence, using a surface charge-induced emitter, this type of solar cell realizes high-throughput, low-cost p^+ emitter formation by a simple wet chemical process. This novel solar cell was named an Al-induced charged oxide inversion layer (Al-COIL) solar cell. The conversion efficiency (η) of >10% was achieved for the device fabricated on a pyramidal textured Si substrate. In particular, an excellent FF of 0.794 was realized using a fine Ag grid electrode on the emitter side. The reduction due to a high emitter sheet resistance could be mitigated by improving carrier collection through a fine Ag grid electrode covering a relatively larger emitter surface area. However, still low J_{sc} and V_{oc} were confirmed. PC1D simulation implies that the reductions might originate from carrier recombination at the emitter surface due to the large number of interface states and the increased minority carrier (electron) density by the diminished fixed charge density (Q_f) less than -1×10^{11} cm^{-2}.

The third contribution of this work is a discovery that surface passivation, and the sheet resistance of ultrathin Al-doped SiO_x/Si improve by the light illumination, which is the variable for addressing the origin of the hole-selective passivating contact property. The significant increment of these properties implies that the excited electron trapping in the Al-induced acceptor states existing in the Al-doped SiO_x layer forms negatively charged AlO_4^- structures and enhances field effect passivation induced by the fixed charges.

Lastly, achieving an excellent surface passivation quality on a pyramidal textured c-Si surface was crucial. The lower $S_{eff, max}$ was confirmed as low as 13.3 cm s^{-1}, corresponding to iV_{oc} of 682 mV and J_0 of 59 fA cm^{-2}, respectively. The light-trapping enhancement and slight space charge region compression compensate for the relatively enormous amount of interface state density due to the surface area increment on the textured Si surface, reducing surface recombination velocity and increasing solar cell performance. Hence, this study provides insight into the novel surface passivation mechanism on a practical surface structure for the c-Si solar cell. It requires a suitable surface structure design with a nano-scale size for increasing a hole-selective passivating contact by effectively exploiting electron trapping and space charge region compression.

Keywords: c-Si solar cells, carrier-selective passivating contacts, electrostatic charges, ultrathin Al-doped SiO_x, wet chemical oxidation