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著者(和文)	白取優大
Author(English)	Yuta Shiratori
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論文要約

THESIS OUTLINE

Title

Study of sputtering technology as a SiH_4-free process for silicon heterojunction solar cells
(シリコンヘテロ接合太陽電池応用に向けた SiH_4-free プロセスとしてのスパッタ法に関する研究)

Presented by Yuta Shiratori
Directed by Associated Professor Shinsuke Miyajima
School of Engineering, Department of Electrical and Electronic Engineering
Tokyo Institute of Technology

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Outline of the doctoral thesis

Chapter 1. Overview and objective of this study

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Chapter 2. Basics of silicon heterojunction solar cells, sputtering technique, and characterization techniques

Photovoltaic power generation is expected to be one of the solutions to recent environmental and energy issues. Most of the market share is occupied by crystalline silicon (c-Si) solar cells. A silicon heterojunction (SHJ) solar cells, one of the structures of c-Si solar cells, have achieved very high conversion efficiency. In SHJ solar cells, high quality a-Si:H layers contribute excellent surface passivation and carrier transport. However, the current fabrication process of a-Si:H layer deposition require additional costs for safety system due to the use of CVD with hazardous gases such as SiH_4. To avoid use of hazardous gases, the alternative materials of a-Si:H layers deposited by SiH_4-free process have been actively investigated, but there are several disadvantages. In this thesis, the development of SiH_4-free fabrication process of SHJ solar cells is presented.

Chapter 3. Deposition of i-a-Si:H passivation layers by low damage sputtering technique

Intrinsic a-Si:H passivation layer was deposited by the FTS method, which is a low-damage sputtering technique. It was found that the sputtering power is a key factor in achieving high quality passivation. High quality i-a-Si:H film was obtained when the sputtering power is high, while the damage to the substrate was extremely small when the sputtering power is low. Based on these results, a 2-step deposition technique was proposed. The i-a-Si:H deposited by using the 2-step deposition technique showed a passivation quality comparable to that of the passivation layer deposited by the conventional PECVD method. Additionally, a deposition rate of about 15 nm/min was achieved by using the 2-step deposition technique. This is first report of sputtered i-a-Si:H (about 5 nm) with such high deposition rate and high passivation quality.

Chapter 4. Deposition and characterization of sputtered doped Si thin films

The sputtered p-type and n-type layers were also investigated. For the deposition of p-a-Si:H and p-μc-Si:H, a highly B doped Si sputtering target was used. It was found that the high boron concentration over oxygen concentration in the p-a-Si:H is required to achieve high conductivity. It was also found that RF power and substrate temperature strongly affect the p-a-Si:H film quality. The sputtered p-a-Si:H with a thickness of about 10 nm showed a conductivity larger than 10^{-3} S/cm, and this conductivity is the highest in the sputtered p-a-Si:H with this thickness reported so far. For the n-a-Si:H deposition, we used a low-resistivity n-type monocrystalline silicon sputtering target. The n-a-Si:H deposited with this target showed a relatively high conductivity of about 10^{-3} S/cm. We fabricated sputtered n-a-Si:H/n-c-Si hetero-structure to investigate a potential of sputtered n-a-Si:H as BSF structure in SHJ solar cells. The detail analysis of the sputtered n-a-Si:H/n-c-Si contacts suggests that n-a-Si:H/low work function electrode has a potential of BSF structure in SHJ solar cells.

Chapter 5. Fabrication of silicon heterojunction solar cells with sputtered silicon-based thin films

SHJ solar cells with the i-a-Si:H passivation layer and the p-type layers deposited by sputtering were fabricated. It was found that the thickness control of the i-a-Si:H passivation layer is very important for the SHJ solar cells with the passivation layer deposited by FTS. Finally, a conversion efficiency of 17.4% was achieved for a SHJ solar cell with FTS-deposited i-a-Si:H by optimizing the thickness of the i-a-Si:H passivation layer. This indicates that passivation quality of i-a-Si:H passivation layer deposited by FTS is comparable to that of passivation layer deposited by conventional PECVD. In the case of SHJ solar cells with sputtered p-layers, it was found that the sputtering power and device annealing processes are important factors to obtain good solar cell performance. By depositing a p-a-Si:H layer with higher conductivity at lower sputtering power and improving the device fabrication process, a conversion efficiency of 14.6% was achieved for a SHJ solar cell with sputtered i-a-Si:H passivation layer and p-a-Si:H layer. This is the first demonstration of SHJ solar cells with sputtered emitter structure.

Chapter 6. Proposal of new n-type layer for all SiH4-free process of SHJ solar cells

III-V materials were investigated as n-type layer materials by device simulation. Initially, properties of sputtered nanocrystalline gallium nitride (nc-GaN) were investigated in detail. Based on the I-V characteristics of fabricated nc-GaN/c-Si devices, a GaN layer model was developed, and device simulations were used to discuss the key factor for the n-type layer in SHJ solar cells. According to our simulation study, the SHJ solar cells with GaN layer shows good solar cell performance if carrier concentration of GaN layer is larger than 5×10^{18} cm^{-3}. Additionally, the device simulation also indicated that the carrier concentration is more flexible when InGaN is used instead of GaN.

Chapter 7. General conclusions

In this thesis, application of sputtering method to the fabrication process of SHJ solar cells was investigated. The sputtered passivation layer and p-type layer showed good performance at the device level. Additionally, it was found that sputtered n-type layer has potential as the n-type layer of SHJ solar cells. These results indicate that the sputtering method is promising for the SiH_4-free fabrication process of SHJ solar cells. Finally, this thesis describes remaining issues of SHJ solar cells with sputtered layers. The most important remaining issue is sputtering damage. Adoption of low-damage sputtering technique for all layers in SHJ solar cells is one of the solutions to achieve fully SiH_4-free SHJ solar cells. It is believed that high efficiency SHJ solar cells fabricated by SiH_4-free process is achievable by proposed solution.