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Current–voltage and low-frequency noise analysis of heterojunction diodes with various passivation layers

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ABSTRACT

Low-frequency noise (1/*f* noise) has been analyzed to characterize the amorphous/crystalline silicon heterojunction diodes with passivation layer of a-Si:H (p–i–n), Al_2O_3 (p–Al_2O_3–n), and ZnO (p–ZnO–n) and without passivation (p–n). Four types of diodes show high ideality factors and the dependence of the reverse leakage current on the electric field shows that the diodes commonly follow the Poole–Frenkel model, which is field-assisted thermionic emission from the traps in the materials. However, the conduction mechanism in the reverse bias can be more easily clarified from the bias dependence of the 1/*f* noise. That is, the p–i–n and p–n diodes are affected by the diffusion current mechanism, and the p–Al_2O_3–n and p–ZnO–n diodes with an inferior interface are affected by the generation–recombination current mechanism. This indicates that the p–i–n and p–n diodes have a better interface quality than the p–Al_2O_3–n and the p–ZnO–n. These results show that the 1/*f* noise measurement can be a useful and more sensitive method to estimate the interface quality of heterojunction diodes.

1. Introduction

Amorphous/crystalline silicon (a-Si:H/c-Si) heterojunction solar cells are the most promising single crystal silicon based solar cells that can be fabricated by depositing a-Si:H thin film on c-Si substrate in order to form a p/n junction. The a-Si:H/c-Si solar cells have many advantages, including fabrication with a low temperature process at a low cost and a high rate of light absorption [1]. Moreover, the a-Si:H/c-Si heterojunction solar cells are insensitive to increasing temperature because the devices have much better temperature coefficient than the conventional c-Si solar cells [2]. However, the heterojunction solar cells have more interface defects than c-Si solar cells. In the heterojunction, the interface state density caused by the doped a-Si:H can weaken its junction properties. Therefore, the optimization of the interface characteristics of p/n layer is one of the key-factors in development of the solar cells, especially in the reliable efficiency. On this reason, a-Si:H/c-Si heterojunction structure with a thin intrinsic a-Si:H layer inserted between a-Si:H and c-Si as a passivation layer has been developed, which is called an HIT (Heterojunction with Intrinsic Thin-layer). The intrinsic layer separates c-Si from doped a-Si:H layer and offers a better interface quality with a low recombination velocity resulting in high quantum efficiency [2,3]. Recently, Panasonic HIT cells have achieved a conversion efficiency of 25.6% [4].

In this study, we measured the low-frequency, 1/*f*, noise to evaluate the interface quality of the heterojunction diodes. The devices were fabricated with various passivation layers, such as a-Si:H, Al_2O_3 and ZnO, in order to differentiate the interface properties. A high dielectric material, Al_2O_3 or ZnO, is known to have many defect states while a-Si:H is conventionally used as a passivation layer [5–8]. So the diodes with ZnO or Al_2O_3 passivation layers are expected to have inferior electrical properties. The 1/*f* noise has a 1/*f* slope in the low frequency region and so, it is also called low frequency noise. The study on 1/*f* noise spectra allows describing the noise as a superposition of an individual generation–recombination (G–R) noise source as shown in Fig. 1. G–R noise is observed at low frequency and its spectral density is described by the Lorentzian. When the device has many trap sites with different time constants (τ), 1/*f* slop in frequency region appears by superposition of each G–R noise spectra [9]. τ is an appropriate mean of the emission and capture time constant which is affected by the trap energy level in bandgap. Based on these considerations, further development of 1/*f* noise led to the models explaining the origin of noise: one is by fluctuations in the number of carriers and the other by fluctuations in the carrier mobility via trap sites. Therefore, 1/*f* noise is a sensitive figure-of-merit of defect amount and used to evaluate the interface defects of the semiconductor devices such as MOSFET and a reliable indicator for optical devices [10–14]. Until now, however, there have been few reports on the research that analyzes the interface properties of the heterojunction diode by observing the 1/*f* noise. By applying the 1/*f*

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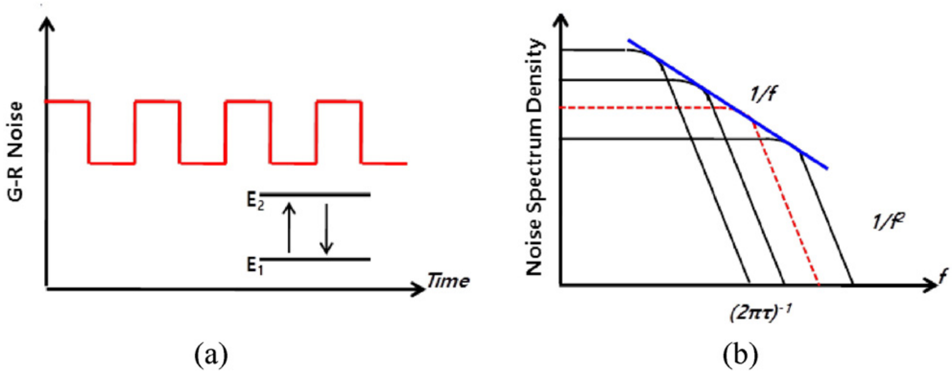


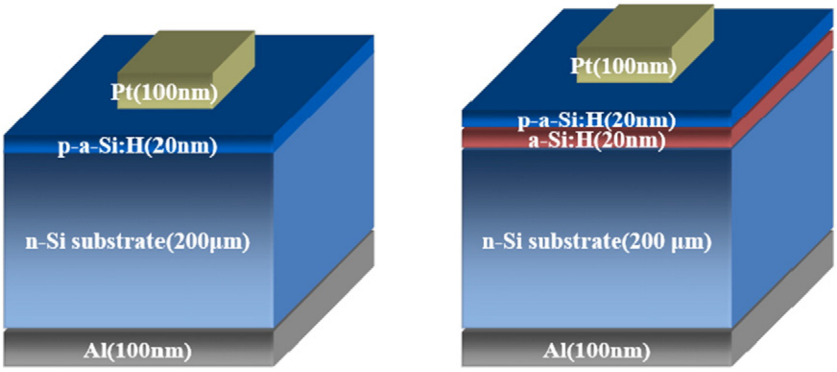
Fig. 1. (a) Noise signal induced by generation–recombination process and (b) the envelope of the G–R noises with different time constants. 1/*f* slop in frequency region appears by superposition of each G–R noise spectrum. Here, the time constant, τ, is an appropriate mean of the emission and capture time constant which is affected by the trap energy level in bandgap.

noise analysis as a non-destructive and a useful method to estimate the junction properties, it is expected to develop the heterojunction solar cells more efficiently.

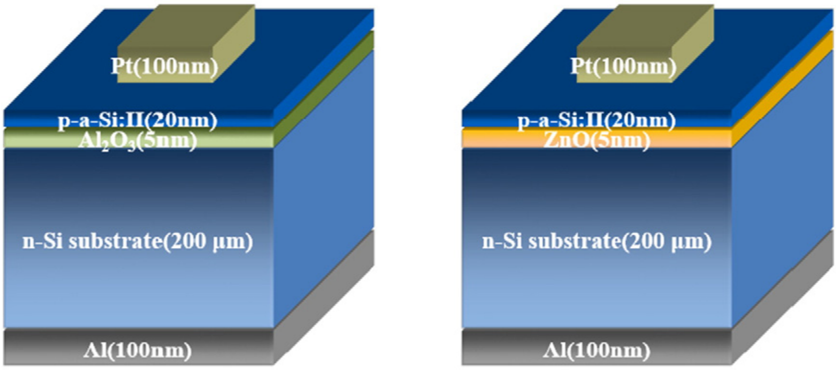
2. Experiments

For this study, the diodes were fabricated on n-type c-Si substrates. Different passivation layers of a-Si:H, Al_2O_3 and ZnO were deposited on the substrate in order to compare the electrical characteristics resulting from the quality of the interface. The process conditions for each passivation layer were as follows.

Prior to the deposition of passivation layers, the n-type c-Si was treated using SPM, RCA-1, and RCA-2 cleaning processes. Before and after each cleaning processes, we rinsed each sample using de-ionized water. Then, the native oxide on the surface of the n-type c-Si substrate was removed in a diluted hydrofluoric (HF) 1% solution. The passivation layers were deposited immediately after HF cleaning. The a-Si:H film with a thickness of 20 nm was deposited by conventional 13.56 MHz plasma enhanced chemical vapor deposition (PECVD) at 160 °C for 20 min. There are previous reports that the conversion efficiency decreases as intrinsic a-Si:H layer thickness increases [15]. However, thicker a-Si:H layer is more effective to reduce the recombination and leakage current in a-Si:H/c-Si heterojunction [16]. So, rather thicker one (20 nm) is chosen to maximize the passivation effect. In the case of Al_2O_3, it was deposited by atomic layer deposition (ALD) with a thickness of 5 nm at 200 °C in a viscous flow reactor using alternating trimethylaluminum (TMA) and water (H_2O). The deposition cycle of Al_2O_3 was composed of 4 times. First time is the TMA reactant exposure, second time is N_2 purge time for 10 s, third time is H_2O exposure, and last time is N_2 purge time for 10 s. All cycle consist of 33 cycles and



(a) p-n diode **(b) p-i-n diode**



(a) p-Al_2O_3-n diode **(a) p-ZnO-n diode**

Fig. 2. Cross-sectional view of the fabricated diode models; (a) p–n diode, (b) p–i–n diode, (c) p–Al_2O_3–n diode and (d) p–ZnO–n diode.