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# Detection of Thermal Energy Loss of the photoexcited Carriers in Polycrystalline Silicon *p-n* Junction Interface Region by a Piezoelectric Photothermal Study

# 圧電素子光熱分光法による多結晶シリコン *p-n* 接合界面における熱エネルギー損失評価

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## 1. Introduction

Recently, solar cells have attracted much attention as one of clean energy sources and their market increases year by year. This is because an exhaustion of fossil energy and an environmental pollution become more serious. Thin-film polycrystalline silicon (poly-Si) is one of the candidates for high-efficiency and low-cost solar cell material because of the low amount of Si usage, long minority carrier lifetime, and high stability against sunlight.

When the solar cell is exposed to the sunlight, two dominant energy losses occur. One is the thermodynamic energy loss that the excess energy than the band gap ($E_g$) converts to heat through phonon emissions. Carriers generated in the higher energy level in the conduction band relax to the bottom of the conduction band. Another is the carrier recombination loss when the photo-excited carriers recombine through the interface or defect levels. Since the poly-Si is composed of many smaller Si crystal grains, the grain boundaries act as the carrier trap center. In these cases, the non-radiative processes are dominant. Therefore, it is important to clarify in more detail the behavior of photo-excited carriers in the poly-Si *p-n* Junction interface, that is a vital component of the solar cells.

We have already adopted the piezoelectric photo-thermal (PPT) and the surface photo-voltage (SPV) techniques to single crystal Si *p-n* junction samples.[1)] The PPT detects the phonon emitting non-radiative transition, and the SPV detects the surface potential changes of the photo-excited carriers. The usefulness of the combination of PPT and SPV to investigate the carrier accumulation and non-radiative transition at the *p-n* junction interface has been clearly demonstrated.

In addition, we have investigated the PPT and SPV signal generation mechanisms in more quantitatively by controlling the photo-excited carrier concentration for single crystal Si *p-n* junction.[2)] The non-radiative signals originated from a thermodynamic energy loss by the phonon emittion have been successfully dissociated. In this study, we investigate the thermal energy loss in poly-Si *p-n* junction interface region by adopting the PPT and SPV techniques. And we will discuss the relationship between the volume content ratio of the grain boundaries and carrier accumulation and non-radiative transitions.

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## 2. Experimental Procedures

For the sample of poly-Si *p-n* junction, a phosphor-doped *n*-type layer (about 5 μm thickness) was prepared by a conventional diffusion method on a *p*-type cast poly-Si substrate (about 200 μm thickness). After the sample was cut into about 1.5 cm-square size, a rear surface *n*-type layer was removed by the chemical etching. We defined the volume content ratio of the grain boundaries ($R_{GB}$) as the area to be included in the sample surface. $R_{GB}$ of the present sample was 25%.

Two experimental configurations of the sample and detector were employed for both PPT and SPV measurements, as in refs. 1 and 2. The incident light illuminated the sample from the *n*-type layer side (the layer illumination scheme) and from the *p*-type substrate side (the substrate illumination scheme), respectively. In these measurements, the light intensity of the incident light was adjusted by using ND filter to keep constant. The chopping frequency of the incident light was set at 500 Hz. Details of the PPT and SPV methods have been reported.[3, 4)]

## 3. Results and Discussion

**Figure 1** shows the observed SPV spectra at room temperature. The spectrum of the substrate illumination scheme drawn by a solid line showed a broad peak at 1.20eV. This spectral shape coincides

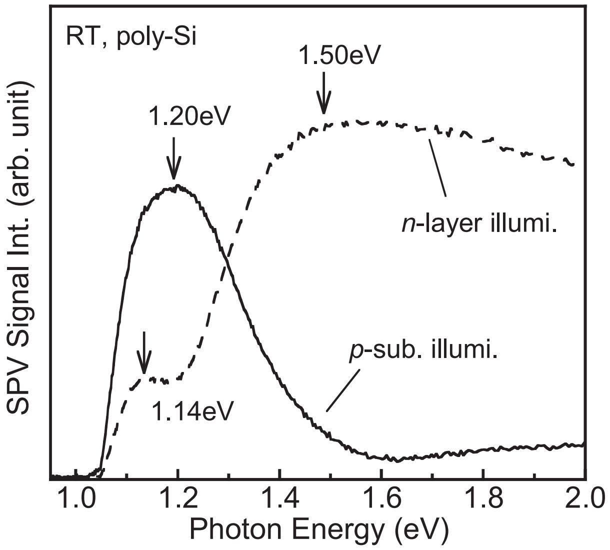

Fig.1 SPV spectra of both schemes

well with the open circuit voltage spectrum. The SPV signal mainly arises from the difference of the Fermi level in the *p-n* junction. As discussed in our previous paper,[1)] the peak position of the substrate illumination scheme spectrum corresponded to the specific photon energy at which optical penetration length of the incident light $\alpha^{-1}$ (= 190 μm, $\alpha$ is an absorption coefficient of Si[5)]) was equal to the distance from the irradiated surface to the *p-n* junction interface. For the layer illumination scheme, two peaks at 1.14 and 1.50 eV were observed. At 1.50 eV, $\alpha^{-1}$ of 5μm coincided with the layer thickness of this sample. Since $E_g$ of Si is 1.12 eV at room temperature, the origin of 1.14-eV peak is the band-to-band optical absorption. In the case for *p-n* junction, the photovoltaic signal caused by a built-in potential is superposed on the SPV signal of the substrate.[1)]

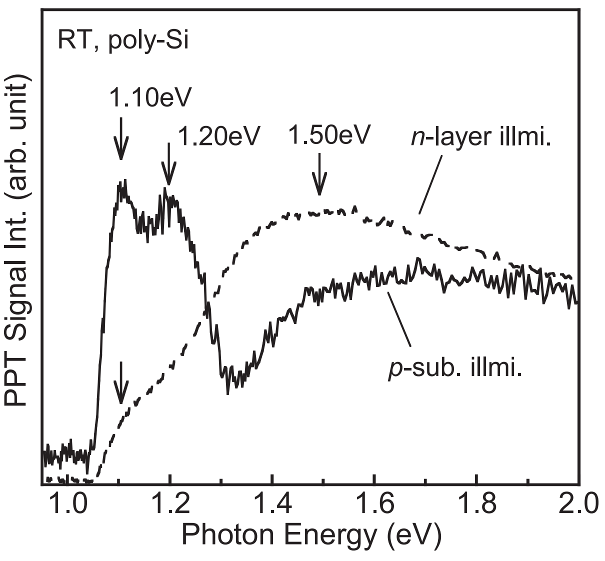

Fig.2 PPT spectra of both schemes

**Figure 2** shows the observed PPT spectra. The spectrum of the substrate illumination scheme showed two peaks at 1.10 and 1.20 eV in the lower photon energy region. This tendency corresponded to the previous results for the single crystal Si *p-n* junction.[1)] The higher energy peak at 1.20 eV was caused by the *p-n* junction interface as well as in the case of the SPV, whereas the lower energy peak at 1.10 eV might be due to some kinds of defect levels. For the spectrum of the layer illumination scheme, photon energy positions of observed two peaks at 1.10 and 1.50 eV gave close agreement with those of SPV spectrum.

It is noted that broad band around 1.7 eV was observed in the PPT spectrum for the substrate illumination scheme. This broad band could not be observed in the single crystal Si *p-n* junction sample.[1)] Since there is no SPV signal in the corresponding scheme, we could tentatively concluded that this broad band was caused by the non-radiative recombination at the grain boundaries.

To conclude, we have investigated the carrier accumulation and non-radiative recombination of photo-excited carriers in the poly-Si *p-n* junction by adopting the combination of PPT and SPV methods. To confirm the origin of the broad band around 1.7 eV observed in the PPT spectrum, we will measure the several samples with different $R_{GB}$.

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