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Imaging of Photoexcited Carrier Responses in a Solar Cell with a Dynamic Terahertz Emission Microscope

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Abstract

We applied a pump-probe laser terahertz emission microscope to investigate dynamic response of photoexited carriers in a solar cell. We could clearly observe the change of terahertz radiation at the grain boundary in the polycrystalline silicon solar cell using the pump-probe methods, which could not be obtained by simple terahertz emission imaging.

1. Introduction

There is an urgent need to improve performance while reducing cost for development of solar cells. It is also desirable to develop evaluation techniques in order to realize more efficient solar cells and optimize the manufacturing processes [1]. The laser terahertz emission microscope (LTEM) is a THz imaging technique that visualizes the intensity of THz emission generated in electronic materials and devices excited by femtosecond laser pulses [2]. We employed LTEM as a tool for evaluating solar cells. We detected the THz emission generated in a polycrystalline silicon solar cell by femtosecond laser pulse illumination and demonstrated THz emission imaging of a solar cell. The THz image corresponded to the crystal grain structure, which indicated that this technique could be a valuable inspection tool for evaluating the local photoelectric properties in a solar cell [5]. Moreover, we observed the decrease of intensity of THz radiation by CW laser illumination [6]. In this study, we applied a pump-probe technique to LTEM to investigate the dynamic response of photoexcited carriers in a solar cell. We succeeded in the observation of the change of terahertz intensity at the grain boundary in the polycrystalline silicon solar cell.

2. Experimental results

Pump-probe terahertz (THz) emission technique is one of the useful tools to investigate ultrafast carrier dynamics in semiconductors [3, 4]. In this technique, pump-pulses are illuminated to inject electron-hole pairs into a material prior to probe pulse illumination. THz emission induced by probe pulses are detected as a function of the delay-time after the pump-pulse illumination to evaluate temporal carrier dynamics, e.g. carrier lifetime and temporal screening effect by photoexited carriers. We combined the pump-probe technique with LTEM (DTEM : Dynamic Terahertz Emission Microscope) to visualize the change of terahertz emission intensity which must reflect local photoelectric characteristics of solar cells. A solar cell is usually composed of large-area p-n junction of silicon.

Figure 1 shows a schematic of the experimental set-up. A modelocked Ti:sapphire laser produces the pulses (width: 100fs, center wavelength: 800nm, repetition rate: 80MHz). The laser pulses were split into pump pulses, probe pulses and the trigger pulses. The probe pulses and pump pulses were focused onto the solar cell at the incidence angle of 45 and 90 degrees, respectively. The THz waves from the solar cell are radiated into free space, and a pair of off-axis parabolic mirrors focuses them onto a spiral-type photoconductive antenna made of low-temperature-grown GaAs. The trigger pulses were focused on the gap of the photoconductive antenna through an optical delay. By fixing the time delay at the maximum amplitude of the THz emission, images are acquired by moving the solar cell mounted on a computer-controlled x-y stage. The probe pulses are chopped to observe the THz radiation and the pump pulses are used to generate photoexcited carriers. The time delay between probe and trigger pulses was fixed at the position at which the maximum amplitude of the THz beam was observed, and the

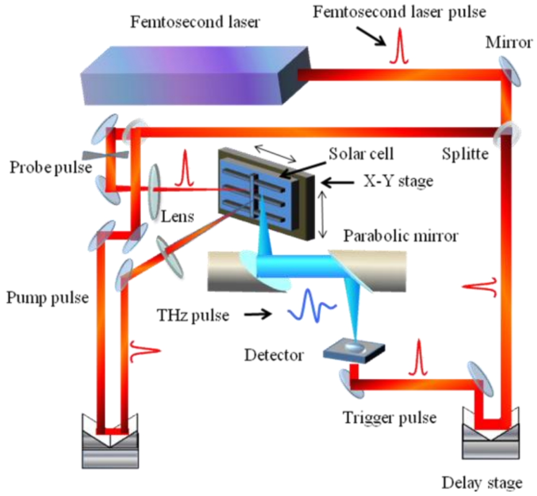

Fig.1 The experimental setup of the pump and probe THz emission microscope.

transient response of the probe THz amplitude is monitored as a function of the relative time delay between pump and probe pulses.

Figure 2 show the pump-probe delay time dependence of THz peak amplitude at five different points of the polycrystalline silicon solar cell. The insert shows the optical image of the solar cell, and the circles from no.1 to no.5 are observed points excited by probe pulses. Reverse bias voltage is 5.0 V, pump and probe pulse intensities are 30 mW and 10 mW, respectively. It can be seen that there is a clear difference of the intensity in between the grains and the grain boundary. The probe THz intensity in the grain boundary, which is potted as blue line, decreased and became smaller than that in the inside of grains at the minimum point of 13.3 ps in delay time. And the THz intensity at grain boundary recovers to almost same value as the intensity at inside garains up to 20 ps.

Figure 3 show the optical image, LTEM and the DTEM images of the polycrystalline silicon solar cell. The DTEM images of the polycrystalline silicon solar cell in Fig. 3 (c) was obtained at delay time of 13.3 ps that is minimum point in the pomp-probe measurement as shown in Fig. 2. The clear grain boundary of the polycrystalline silicon solar cell can be seen in DTEM, however, we cannot detect the grain boundary by LTEM as shown in Fig. 3 (b). Moreover, the THz intensity around the grain boundary obtained by DTEM largely changed which appeared as yellow and blue lines in Fig. 3(c).

3. Summary

We succeeded in the observation of the dynamic carrier responses of the grain boundary in the polycrystalline silicon solar cell using DTEM by optical resolution. This technique enables to visualize the carrier dynamics in the solar cell, and will develop to be effective analysis methods to improve the energy conversion efficiency.

Acknowledgements

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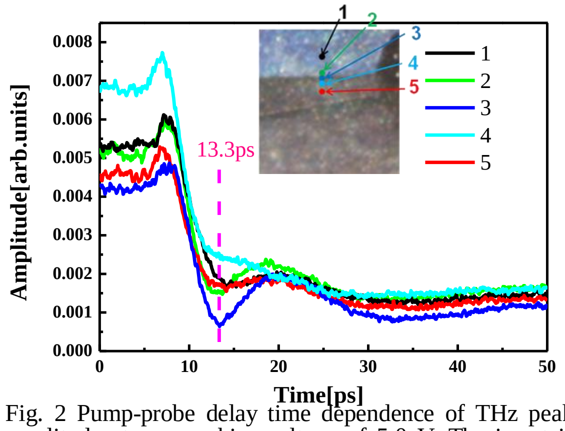
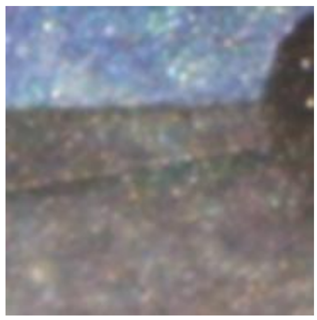
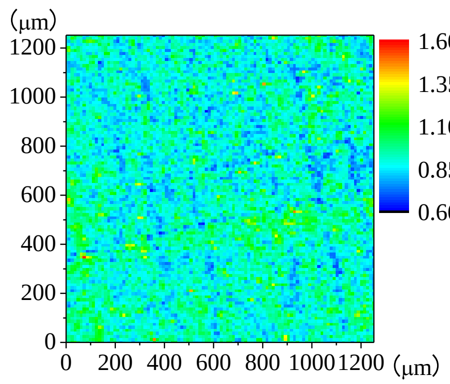


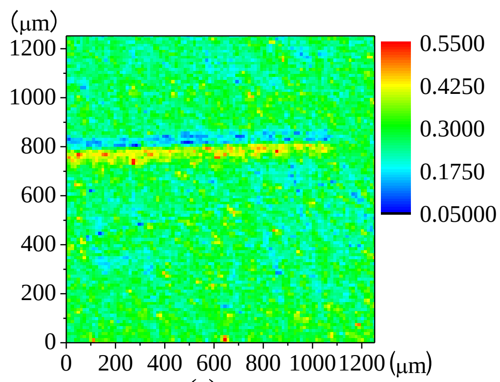
Fig. 2 Pump-probe delay time dependence of THz peak amplitude at reverse bias voltage of 5.0 V. The insert is optical image of the polycrystalline silicon solar cell.



(a)



(b)



(c)

Fig.3 (a)Optical image of the polycrystalline silicon solar cell. (b) LTEM image (Probe THz image without irradiating pump pulses).(c) DTEM images at the delay time 13.3ps.