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Evaluation of SiO_x/Si and SiN_x/Si Interfaces using Laser Terahertz Emission Microscope

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Abstract

We measured THz peak amplitude using laser terahertz emission microscope (LTEM) and capacitance-voltage(C-V) characteristics to evaluate the passivation surfaces of Si wafers with SiO_2 and SiN_x layers. The shapes of THz peak amplitude and C-V curve showed correlation. The results indicated that LTEM can diagnose and map surface passivation quality of Si solar cells.

1. Introduction

Laser terahertz emission microscope (LTEM) is a THz imaging technique that visualizes the amplitude of THz emission generated in electronic materials and devices excited by femtosecond laser pulses[1]. We employed LTEM as a tool for evaluating solar cells[2].

In Si solar cells, passivation layers of various materials including SiO_x, SiN_x and AlO_x are formed and their field-effect passivation characteristics are often evaluated by the capacitance-voltage (C-V) measurement. The surface band-bending at these silicon surfaces causes transient currents by charge separation of photoexcited carriers when excited by femtosecond laser pulse.

In this study, we measure THz peak amplitude using laser terahertz emission microscope (LTEM) and the electrically capacitance-voltage(C-V) characteristics to evaluate the passivation surfaces of Si wafers with SiO_2 and SiN_x layers. We investigate the suitability of LTEM for evaluating band-bending.

2. Results and Discussion

First, we explain about experimental results of Si metal-oxide-semiconductor (MOS) sample with SiO_2 layer. Figure 1(a) shows the schematic of the silicon MOS sample used. A phosphorus-doped n-type Si substrate was used with an area of 5.0 cm× 5.0 cm. We formed a wet-oxidized layer on the top surface then annealed the sample in 3% forming gas at 400 °C for 20 minutes. A transparent indium tin oxide (ITO) electrode disk with a diameter of 16 mm was deposited on the top surface. The native oxide on bottom surface was removed by abrasion, and Al electrode was deposited on it. The sample was contacted to a bias voltage source and a C-V measurement instrument.

A schematic illustration of the experimental setup is shown in Fig.1(b). Laser pulses (width: 100 fs, center wavelength: 800 nm, repetition rate: 80 MHz, laser power: 100 mW, excitation diameter: 10 mm) were focused onto the solar cell at the incident angle of 45 degrees. The surface band-bending at Si surfaces causes transient current by charge separation of photoexcited carriers when excited by femtosecond laser pulse, and the generated transient current emits the THz wave. The THz wave radiated into free space and is focused onto a spiral antenna by a pair of off-axis paraboloidal mirrors. The trigger pulses were focused on the gap of the photoconductive spiral antenna through an optical delay.

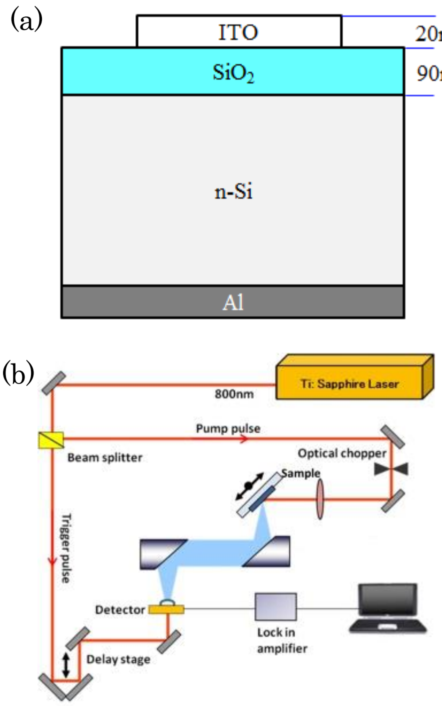

Fig. 1 (a) Schematic of the sample with SiO_2 layer. (b) Schematic of the experimental set-up.

Figure 2(a) shows the THz waveforms measured using LTEM at various bias voltage. The waveforms significantly change with bias and inverted from -0.5 V to -1.0 V. Figure 2(b) shows the bias voltage dependence of THz signal amplitude at 10.5 ps, where waveforms showed the largest peaks with ±10 V biases. The electrically measured C-V curve at a frequency of 1 kHz is also shown. The THz amplitude and C-V curve showed strong correlation. The amplitude changed from negative to positive near the flatband voltage. These results strongly indicate that the LTEM detected a THz emission from Si which originates in the separation of photoexcited carrier caused by surface band-bending.

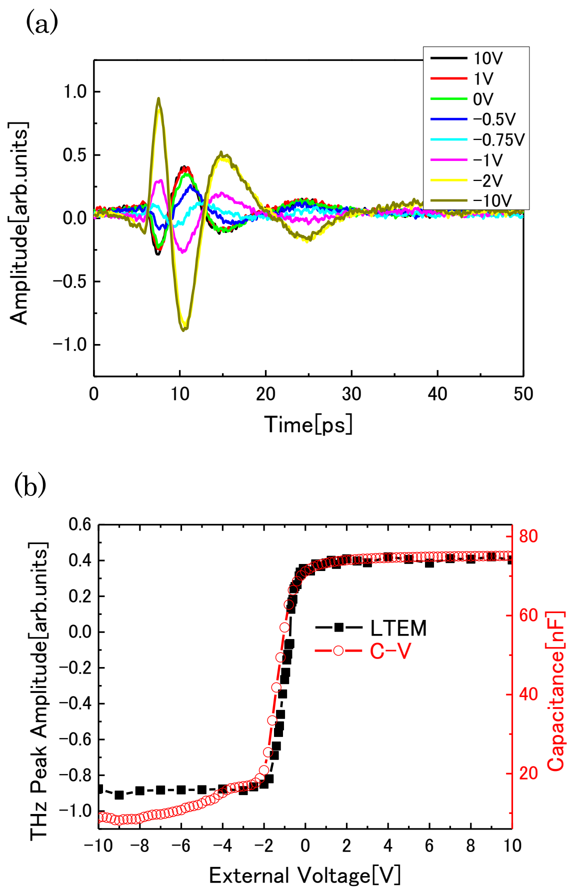

Fig.2 (a) THz waveform at various bias voltage. (b) THz peak amplitude at 10.5 ps and C-V curve of Si-MOS sample with SiO_2 layer.

Next, we explain about experimental results with SiN_x layer. The C-V characteristics with THz peak amplitude measured using LTEM to evaluate the passivated surfaces of Si wafers with SiN_x layer, especially used in Si solar cells. Figure 3 shows the schematic of the Si metal-insulator-semiconductor (MIS) sample with SiN_x layer.

Figure 4 shows the bias voltage dependence of THz signal amplitude measured in the similar way to the SiO_2 sample. The waveforms showed the largest peaks with 0 V and -20 V biases. The electrically measured C-V curve at 1 kHz is also shown. We observed hysteresis in both THz peak amplitude and C-V curve in Fig.4. The hysteresis arises from charge or discharge of trap states in the SiN_x layer upon applying a large positive or negative bias voltage[3]. In Fig.2(b) and Fig.4, it is indicated that the flatband voltage of SiN_x layer is lower than that of SiO_2 layer, because fixed charge of SiN_x layer are larger than that of SiO_2 layer[4]. The voltage shift of around -2 V from C-V curve to THz peak amplitude is also observed, but the shapes of THz peak amplitude and C-V curve showed good correlation. As LTEM technique is measured with irradiating laser beam, we think this difference between LTEM and C-V is caused by laser radiation increasing the trapped charges in the nitride layer.

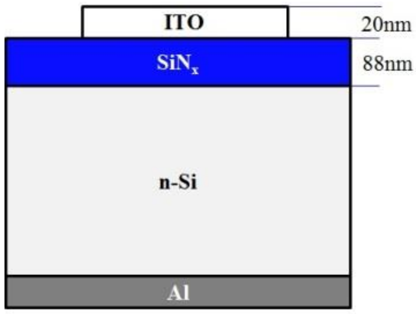

Fig. 3 Schematic of the sample with SiN_x layer.

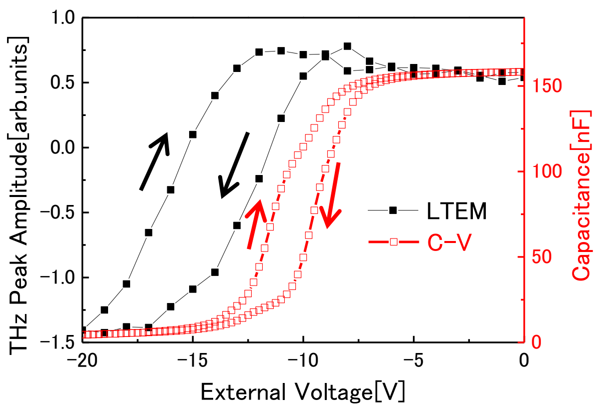

Fig.4 THz peak amplitude and C-V curve of Si-MIS sample with SiN_x layer.

3. Conclusions

We evaluated the suitability of LTEM for detecting a THz emission from Si which originates in the separation of photoexcited carrier caused by surface band-bending. We showed good correlation between LTEM and C-V. LTEM has been shown to be a powerful diagnostic and mapping tool for surface passivation quality of various layers used in solar cells and Si-MIS devices.

References

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