Terahertz Radiations from Triple Junction Solar Cells Excited by Wavelength-Tunable Laser Pulses

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***Abstract*—We observed waveforms and images of THz radiations from a triple-junction-solar-cell (TJSC) with InGaP-GaAs-Ge layered structure excited by wavelength-tunable laser pulses, and wavelength-dependent THz signals and images could be observed. The results indicate that characteristics of an each layer in TJSC can be extracted with this system.**

I. INTRODUCTION

WHEN p-n junctions in semiconductor devices are excited with femtosecond laser pulses, the electrons and holes are accelerated by the electric field of depletion layers in p-n junctions, and the generated ultrafast transient current emits the terahertz waves.

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. We employed the 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 [1].

In this study, we observe THz pulses radiated from the triple junction solar cell (TJSC) excited by femtosecond laser pulses with various wavelengths, and demonstrated that the properties of each layer in the TJSC could be extracted with this method.

II. RESULTS

The TJSC is consist of InGaP, GaAs, and Ge layers, each layer is excited by the light with the wavelength of λ_1=360~670, λ_2=670~890, and λ_3=890~1750nm, respectively, which correspond to the quantum efficiency spectra of the TJSC [2] as shown in Figure 1.

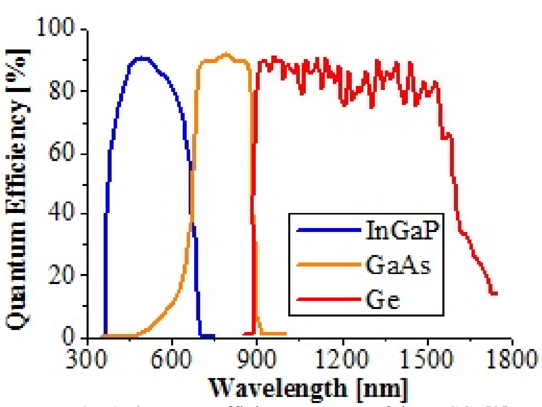

Fig. 1. Quantum efficiency spectra of the TJSC [2].

Figure 2 shows concept of THz emissions from the TJSC with the InGaP-GaAs-Ge structure, where THz pulses with the wavelengths λ_1, λ_2, and λ_3 are emitted from the InGaP, GaAs, and Ge layer, respectively.

We observed waveforms by using the THz time-domain technique. Figure 3 shows the waveforms excited by laser pulses with 509~747nm. The amplitudes and pulsewidths are clearly different in each waveform. The frequency-dependence of these THz waveforms can be explained by considering quantum efficiency of each layer and interferences of excitation laser pulses due to the InGaP-GaAs-Ge layered structure.

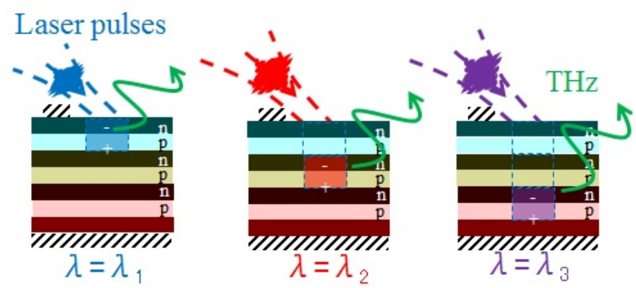

Fig. 2. Concept of THz emissions from the TJSC with the InGaP-GaAs-Ge structure.

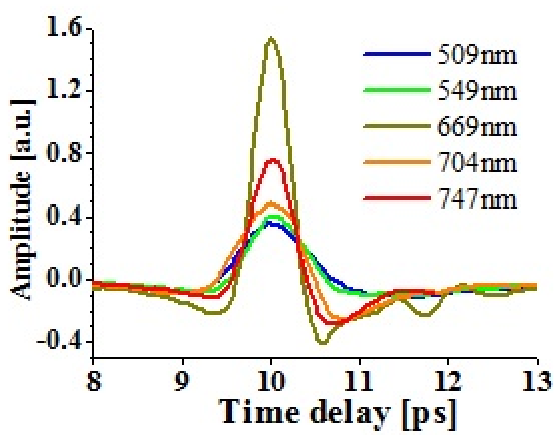

Fig. 3. THz signal waveforms radiated from a TJSC excited by laser pulses with various wavelengths

Next, we show the LTEM images and cross sections of the images of the TJSC excited by laser pulses with 570 and 747 nm wavelengths in Figure 4. The positions of red arrows and black ones in the cross sections are cracks and electrodes, respectively, and changes of the THz amplitudes at the cracks are larger as the wavelengths become longer. Fig. 4 indicates that we can observe individually each layer by means of THz emissions by changing wavelength of excitation laser pulses.

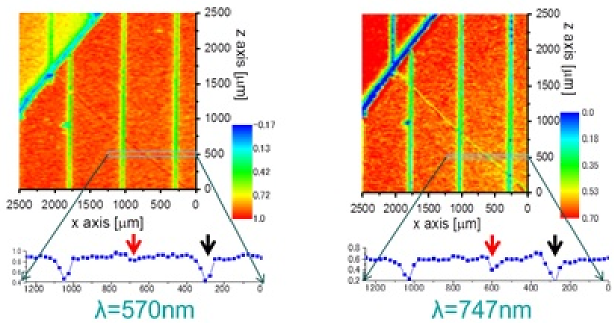

Fig. 4. THz images of a TJSC excited by laser pulses with the wavelength of 570 and 747nm, respectively.

III. SUMMARY

We demonstrated experiments of excitation and detection THz waves emitted from the triple-junction solar cell (TJSC) excited by laser pulses generated by the tunable-wavelength optical parametric oscillator (OPO) driven by an optical pulse laser apparatus. We measured THz signal waveforms by using the THz-TDS, where the TJSC is excited with various wavelength. Next, we took LTEM images of the TJSC excited by pulses with various wavelengths, and tried to extract information of each layers in the TJSC. These results indicate that we can distinguish properties of each layer from THz emissions by changing wavelength of excitation laser pulses, which strongly suggest that the wavelength-tunable LTEM become a powerful tool to discriminate physical properties of the each layer selectively in the TJSC along the depth direction.

REFERENCES

[1]. H. Nakanishi, S. Fujiwara, K. Takayama, I. Kawayama, H. Murakami and M. Tonouchi, "Imaging of a Polycrystalline Silicon Solar Cell Using a Laser Terahertz Emission Microscope, " *Applied Physics Express,* vol. 5, pp. 112301, 2012.

[2]. Personal communications from *Advanced Technology Institute* (*ATI*), limited partnership in Yokohama.