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Characterization of SiO_2/SiC interface using a Laser Terahertz Emission Microscope

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Abstract

We applied laser terahers emission microscope (LTEM) for characterization of SiO_2/SiC interface. The sample with high interface state density estimated from capacitance-voltage (C-V) method showed the relatively gentle slope on the relation between the THz peak amplitude and the gate voltage. Since LTEM is sensitive for measuring the surface electric field in principle, LTEM has the capability of characterizing the difference of the interface state densities as is the case for C-V measurement. We think that LTEM can be a useful evaluation technique for SiO_2/SiC interface state density.

1. Introduction

SiC is known as a wide-bandgap semiconductor and expected to be one of the materials for future power devices because of its higher breakdown voltage and thermal conductivity compared to Si and other conventional semiconductors. SiC, the same as Si, can yield stable SiO_2 insulator with thermal oxidation. It is known that a large amount of interface defects and traps exist at SiO_2/SiC interface formed by thermal oxidation. As a consequence, MOS channel mobility and oxide reliability are limited [1]. In order to utilize attractive material properties of SiC, it is necessary to characterize and improve SiO_2/SiC interface. C-V measurement has been used generally as a conventional electrical technique which evaluates interface property from C-V curves.

2. Laser Terahertz Emission Microscope

Laser terahertz emission microscope (LTEM) is a THz imaging technique which visualizes the intensity of THz emission generated by the sample excited by femtosecond laser pulses [2]. LTEM enables to analyze the electric field and/or carrier dynamics of interfaces of various materials including p-n junctions, insulator/semiconductor interface and semiconductor surface. LTEM has been applied to evaluate silicon solar cells, silicon surface passivation [3] and GaN wafers, and proved to be effective.

Figure 1 shows the principle of LTEM. In a p-type semiconductor, holes in the valence band are captured by the surface states (in an n-type semiconductor, electrons in the conduction band are), and the Fermi energy is pinned at the surface. As a result, energy bands at the surface in p-type and n-type semiconductors are bended, and the surface electric field is formed in opposite directions. Photocarriers are produced near the surface of a semiconductor when illuminated by femtosecond laser pulses. Photocarriers are accelerated by the surface electric field, and a transient current is generated. Thus, THz wave is emitted as shown for eq. (1): where E is the amplitude of electric field of the THz wave, J is the current density, e is the electron charge, $n(t)$ is the carrier density and $v(t)$ is the carrier velocity.

$$E \propto \frac{\partial J}{\partial t} \propto e\left(\frac{\partial n(t)}{\partial t}\right)v(t) + en(t)\left(\frac{\partial v(t)}{\partial t}\right) \qquad (1)$$

If we can characterize the difference of electric fields at the various qualities of SiO_2/SiC interfaces by LTEM, it is expected that LTEM is effective for characterization of SiO_2/SiC interface property.

Figure 2 shows the schematic of the LTEM system. The third harmonics (wavelength: 280 nm) of Ti: sapphire laser pulses (pulse width: 100 fs, center wavelength: 840 nm, repetition rate: 80 MHz) were focused on the sample surface at the incident angle of 45 degrees. THz wave emitted from the sample was focused on the spiral antenna with a pair of off-axis parabolic mirrors. Ti: sapphire laser pulses (wavelength: 840 nm) illuminated the LT-GaAs photoconductive detector through an optical delay stage.

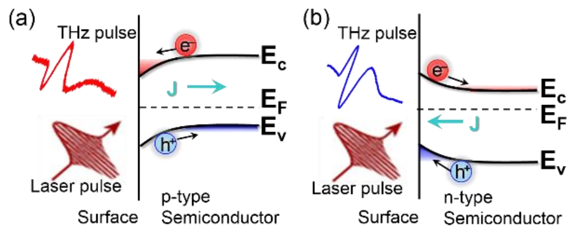

Fig.1 Schematic diagram of LTEM. (a) in a p-type semiconductor. (b) in an n-type semiconductor.

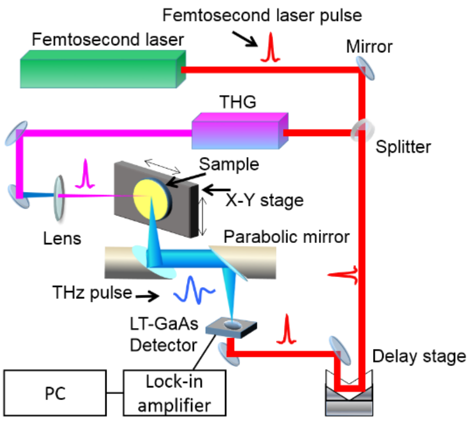

Fig.2 Schematic of the experimental set up.

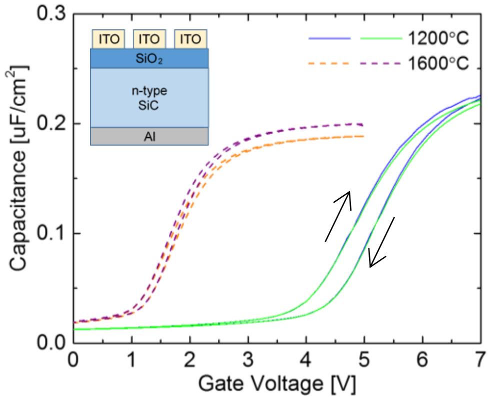

Fig.3 C-V characteristics of the samples.

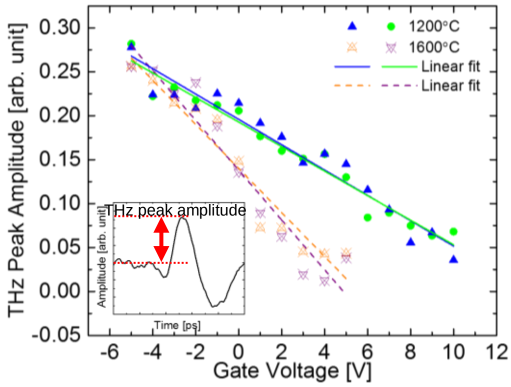

Fig.4 Relation between the peak amplitude of the THz pulse and the gate voltage.

3. Results and Discussion

SiC MOS capacitors are fabricated according to the following procedure. Thermal oxide was formed on n-type 4H-SiC(0001) substrate with n-epilayer (epi thickness: 5 um, doping density: 5 x 10^{15} cm^{-3}). The oxidation conditions are shown in Table I. Indium tin oxide (ITO) transparent electrode was used for the gate electrode. The gate electrode consists of an area for C-V measurement (0.5 mm x 0.95 mm) and one for LTEM measurement (1.0 mm x 1.0 mm). ITO electrode (thickness: 40 nm) are deposited on the oxide by sputtering. Al electrodes was prepared on the back surface of the sample.

Table I Oxidation conditions of the samples

Oxidation temperature [°C]	Oxygen partial pressure [%]	Oxidation time [min]	SiO_2 thickness [nm]
1200	100	60	19.5
1600	0.3	4	22.0

Figure 3 shows C-V curves of SiC MOS capacitors. We measured C-V characteristics of two ITO electrode pads of each sample at 1 kHz AC frequency. C-V curves of MOS capacitors oxidized at 1600°C show smaller hysteresis and are steeper than that of ones oxidized at 1200°C. Thus it is found that the sample oxidized at 1600°C has better interface property than the sample oxidized at 1200°C [4]. Next, we measured THz waves from the samples excited by femtosecond laser pulses (wavelength: 280 nm, average power: 1 mW, spot size: ϕ0.7 mm). Figure 4 shows the relation between the peak amplitude of the THz pulse and various DC gate bias voltage. The slopes of the THz-V_g curve of the SiC MOS capacitors oxidized at 1200°C (the average of the slope: -0.0267) and that of SiC MOS capacitors oxidized at 1600°C (the average of the slope: -0.0142) are clearly different. SiC MOS capacitors oxidized at 1600°C have about 1.9 times steeper slope of the THz-V_g curve than ones oxidized at 1200°C.

It is assumed that a large amount of interface traps capture a lot of carriers. Therefore in the sample with high interface trap density, more carriers are required to obtain the same band bending compared to the one with low interface trap density. As a result, the THz-V_g curves are stretched out in the voltage direction, and the slope becomes gentler. Results of LTEM measurement mean that the sample oxidized at 1600°C has better interface property than the sample oxidized at 1200°C. It is suggested that LTEM is selective and sensitive for characterization of the change of electric field at SiO_2/SiC interface. We believe that LTEM has the capability of measuring the difference of the interface state densities clearly compared to C-V measurement.

4. Conclusions

We applied LTEM for characterization of SiO_2/SiC interface. We measured THz waves from SiC MOS capacitors through ITO gate electrode with different interface trap densities estimated by C-V measurement. We found that the interface trap density can be determined by the slope of THz-V_g curve. Because LTEM is an optical technique, laser pulses are absorbed only near the surface of a semiconductor, furthermore THz wave are emitted only in the interface of the materials where electric field exists. Our results suggest that LTEM can detect information about SiO_2/SiC interface selectively and be a useful evaluation technique for characterizing SiO_2/SiC interface.

References

[1] T. Kimoto, Jpn. J. Appl. Phys. **54** (2015) 040103.
[2] M. Tonouchi, Nat. Photonics **1** (2007) 97.
[3] T. Mochizuki *et al.*, Appl. Phys. Lett. **110** (2017) 163502.
[4] T. Hosoi *et al.*, ICSCRM (2017) MO.C2.5.