Anisotropic Temperature Dependence of Carrier Transport in Beta-Gallium Oxide Epilayer Evaluated by Terahertz Time-Domain Spectroscopy

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1. Introduction

Gallium oxide (Ga_2O_3), an emerging ultra-wide bandgap semiconductor (~4.9 eV), holds great promise for power electronics and deep-ultraviolet optoelectronic devices due to its high breakdown field and Baliga's figure of merit. Among its polymorphs, β-Ga_2O_3 is the most stable and exhibits strong anisotropy owing to its monoclinic structure. Terahertz time-domain spectroscopy (THz-TDS) offers a non-contact approach to probe anisotropic charge transport and phonon modes. While prior studies focused on room-temperature behavior [1-3], this work investigates anisotropic carrier transport in β-Ga_2O_3 over a wide temperature range, providing insights critical for device optimization.

In this study, we investigate the anisotropic terahertz response of β-Ga_2O_3 epitaxial layers along the a-axis [100] and b-axis [010] directions using THz-TDS. The measurements were conducted over a frequency range of 0.2-3 THz and a temperature range of 90-400 K. By fitting the experimental spectra with the Drude–Lorentz model, we quantitatively extracted key anisotropic transport parameters. These results offer fundamental insights into the direction-dependent carrier dynamics of β-Ga_2O_3 and provide valuable theoretical guidance for its integration into high-frequency electronic and optoelectronic devices.

2. Results

A 4.5 μm-thick Si-doped n-type β-Ga_2O_3 homoepitaxial layer was grown on a 647 μm-thick Fe-doped semi-insulating (001)-oriented β-Ga_2O_3 substrate. The highly doped epilayer have a carrier density of ~5×10^{17}cm^{-3} at room temperature measured by Hall method. THz-TDS measurements were conducted using a commercial system (Tera Prospector, Nippo Precision Co., Ltd.) equipped with photoconductive antennas for both THz pulse generation and detection. The sample was mounted in a liquid-nitrogen-cooled cryostat with precise temperature control from 90 to 400 K, housed in a dry-air-purged enclosure to minimize atmospheric water vapor absorption. The transmitted THz time-domain waveforms were recorded and subsequently Fourier-transformed to obtain the complex refractive index spectra.

The frequency-dependent complex refractive index of β-Ga_2O_3 was derived via Fourier transform and Fresnel transmission analysis. By fitting the spectra to Drude-Lorentz model considering only the effect of the first phonon mode of β-Ga_2O_3 on its terahertz response, we obtained the temperature-dependent parameters of carriers.

Figure 1 presents the temperature dependence of the DC conductivity, derived from the extracted plasma frequency and scattering time via the Drude-Lorentz model. At lower temperatures, the conductivity increases with the thermal activation of dopants, while at higher temperatures it decreases due to enhanced carrier scattering by lattice vibrations. The temperature dependence reveals clear anisotropy in carrier transport between the a- and b-axis directions. The observed anisotropic conductivity may come from slight differences in the electron effective mass, which become less pronounced at elevated temperatures. As temperature rises, DC conductivity anisotropy diminishes, consistent with electron mobility being increasingly limited by optical phonon scattering.

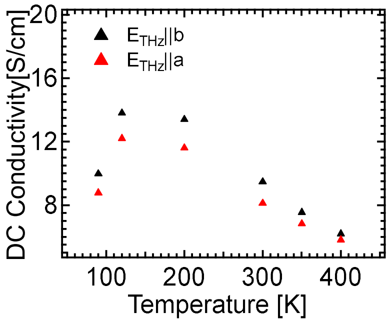

Fig. 1. The temperature dependence of DC conductivity along a- and b-axis.

3. Conclusions

We examined the anisotropic carrier transport in a Si-doped β-Ga_2O_3 epilayer along the [100] and [010] directions using THz-TDS over 90–400 K. The temperature-dependent anisotropy and its underlying mechanisms were discussed.

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