Abstract of Dissertation

Title of the Dissertation Femtosecond Carrier Dynamics in Bulk GaAs under High Electric Fields Investigated by Time Domain Terahertz Spectroscopy

(時間分解テラヘルツ分光法を用いた高電界下
バルク GaAs 中のフエムト秒キャリアダイナミクスに関する研究)

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Ultrafast nonequilibrium transport of carriers in semiconductors under high electric fields is of fundamental interest in semiconductor physics. Furthermore, clarifying carrier dynamics under extreme nonequilibrium conditions is also strongly motivated by the need to obtain information relevant for the design of ultrahigh speed devices. It is, therefore, essential to understand nonequilibrium transport of carriers subjected to high electric fields in such devices. The time domain terahertz (THz) spectroscopy gives us a unique opportunity of observing motions of electron wave packets in the sub-ps time range and measuring the response of electron systems to applied bias electric fields. By understanding the nonequilibrium transport of carriers in bulk GaAs, the intrinsic property of the negative differential conductivity (NDC) in the THz region, which means the gain, can be clarified.

Chapter 1 introduces the background and the purpose for this work. We first explain the existence of the “THz gap” in the semiconductor technology. The technology gap exists because electron devices can be operated up to several hundred GHz, while photonic devices can be operated only down to 200 THz. Then, we describe the most commonly used sub-THz oscillators, i.e., Gunn diodes. GaAs exhibits well-known NDCs, which is the criterion for the microwave oscillation. Therefore, it is extremely important to understand the intrinsic property of NDCs in GaAs. Finally, we state the purpose for this work.

In chapter 2, we describe the experimental technique for the time domain THz spectroscopy used in this work. Ultrafast carrier motion in the femtosecond time regime accompanies electromagnetic (EM) wave radiation that is proportional to dv/dt. Consequently, the investigation of such EM wave (or THz radiation) allows us a very unique opportunity of looking directly into the acceleration/deceleration dynamics of carriers in semiconductors. Time domain THz spectroscopy uses femtosecond laser pulses to excite carrier motion in semiconductors. Free space electro-optic (EO) sampling is a powerful tool for THz detection. In this chapter, time domain THz EO sampling via the Pockels effect is discussed in detail.

In chapter 3, the femtosecond acceleration of carriers in bulk GaAs under very high electric fields, F, was investigated by time domain THz spectroscopy. It is found that the initial acceleration signal in THz emission waveforms, which is usually interpreted as the acceleration of electrons in the Γ valley, gradually saturates and starts decreasing for $F > 50$ kV/cm. This result suggests that the effective acceleration mass of electrons significantly

increases with increasing *F*. The mass enhancement is most likely due to strong band mixing under very high fields.

In chapter 4, we have investigated the transient velocity of carriers in bulk GaAs by analyzing the time domain THz traces emitted from intrinsic bulk GaAs photoexcited by femtosecond laser pulses under strong bias electric fields. It is found that the initial velocity of carriers does not start from zero at the time of photoexcitation, which is far from the expectation from a semiclassical picture. Possible origins of this surprising behavior are discussed.

In chapter 5, we have investigated the gain due to intervalley transfer under high electric fields, which is of practical importance for its exploitation in microwave oscillators. In this work, we measured the THz radiation from the intrinsic bulk GaAs under strong bias electric fields. The energy density spectra under step-function-like electric fields in THz range have been obtained by using the Fourier transformation of the time domain THz traces. From the energy density spectra, the cutoff frequencies for negative energy density (i.e., gain) in bulk GaAs have been determined. The cutoff frequency for the gain gradually increases with increasing electric field up to 50 kV/cm and saturates at around 1 THz at 300 K. Furthermore, we also investigated the temperature dependence of cutoff frequency. The experiment result strongly suggests that the observed cutoff frequency is governed by the energy relaxation process of electrons from the L valley to the Γ valley via successive optical phonon emission.

Chapter 6 describes the conclusion of this thesis. We have investigated the carrier acceleration dynamics in bulk compound semiconductors under very high electric fields by time domain THz spectroscopy. Taking advantage of the novel experimental method, invaluable information on nonequilibrium carrier transport in the femtosecond time range, which has previously been discussed only by numerical simulations, has been obtained. The present insights on the nonstationary carrier transport contribute to better understanding of device physics in existing high speed electron devices and, furthermore, to new design of novel THz oscillators.