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Two-dimensional imaging of surface acoustic waves and photoluminescence on GaAs

GaAs における弾性表面波とフォトルミネッセンスの２次元イメージング

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1. Introduction

It has been reported that SAWs can control relaxation dynamics of photo-generated electrons and holes in piezoelectric semiconductors[1]. Surface acoustic waves (SAWs) spatiotemporally modulate the electronic band structure through the piezoelectric field induced by the propagating strain field. In such studies the spatially resolved measurement of photoluminescence (PL) is commonly used to investigate the dynamics of the photo-generated electrons and holes. However, for a detailed understanding of the behavior of the photo-generated electrons and holes controlled by SAWs, it is desirable to measure both the PL and SAW fields simultaneously.

We previously developed a time-resolved SAW imaging system for solid surfaces in the GHz frequency range with micron lateral spatial resolution[2,3]. Here we extend this method to obtain PL images as well as SAW images, the latter using an optical interferometric technique. PL images can be obtained together with a SAW images for the same area of the sample.

2. Experimental setup

The sample is a Cr-doped semi-insulating GaAs (100) wafer, which has a direct band gap and exhibits a piezoelectric field along the propagation direction of the SAWs when they propagate along the [110] and equivalent directions. The sample is held in a vacuum chamber to avoid photo-induced degradation in air.

Figure 1 shows a schematic diagram of the imaging system. The upper and the lower arrangements are for detecting SAW and PL images, respectively. The SAW imaging system is the same as one previously developed[2,3], and is based on the pump and probe technique, involving a Sagnac interferometer[4]. Optical pulses (used as probe pulses) at central wavelength 820 nm originate from a mode-locked Ti:Sapphire laser at an 80.2 MHz repetition frequency. Second harmonic pulses (used as pump pulses) at wavelength 410 nm are used for generating the SAWs. The pump and probe pulses are focused

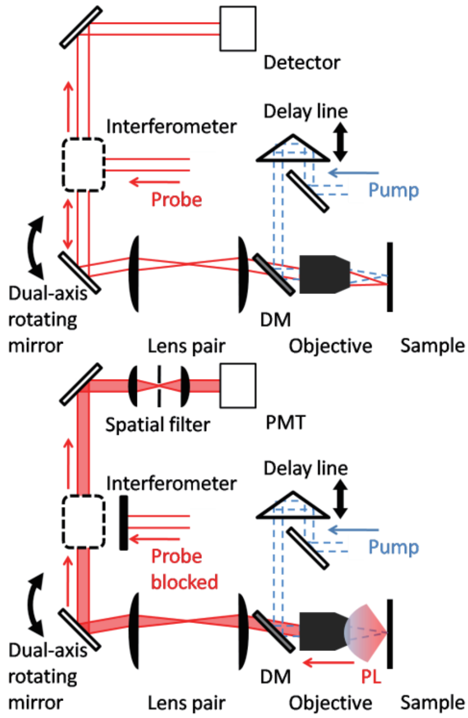

Fig. 1. Schematic diagram of the imaging system. The upper and the lower arrangements are for detecting SAW and PL respectively. DM: Dichroic mirror, PMT: Photomultiplier tube

through a ×20 microscope objective lens with a 13 mm working distance to a ~5 μm spot diameter on the sample surface[5]. The pump pulses excite GHz SAW pulses in all directions on the sample. The probe pulses interferometrically detect the out-of-plane surface velocity. The probe spot is scanned in two dimensions over the sample surface by means of a dual-axis rotating mirror and a 4f lens pair. By changing the delay time with a ~4 m delay line (delay time 0-13 ns), we can obtain images at any time after each pump pulse arrival with ~5 μm spatial resolution.

The pump pulses also excite conduction electrons and holes. To detect the resulting PL we block off the probe beam. The PL passes through the same optical path as the probe beam for the SAW imaging, and PL images are obtained with the same scanning system as is used for the SAW

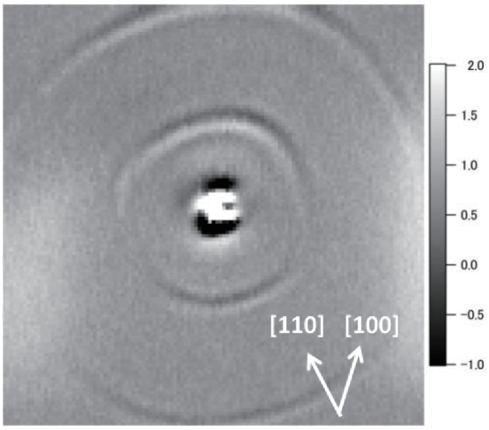

Fig. 2. Snapshot of propagating SAWs for an area of 120 × 120 μm^2. The pump-probe delay time is 9.5 ns. Units are arbitrary.

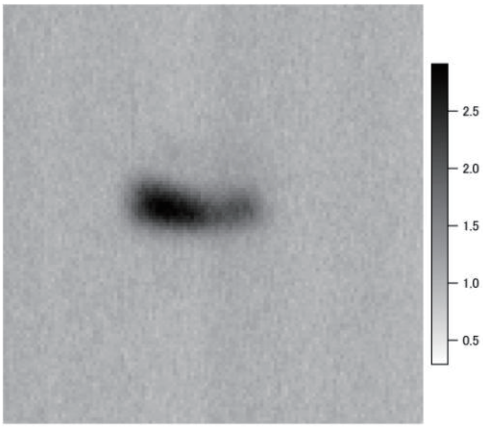

Fig. 3. PL intensity image corresponding to Fig. 2. Units are arbitrary.

imaging. We use a photomultiplier tube (PMT) as a detector for the PL, because the PL intensity is too small to be detected with the photodetector for the SAW imaging system (a Si photodiode). In addition we make use of a spatial filter to achieve a spatial resolution ~10 μm. All measurements were made at room temperature.

3. Results

Figure 2 shows a typical SAW propagation image of area 120 × 120 μm^2. The pump beam is focused at the center of the image. The rounded-square shaped wave front of the SAW pulses is a result of the anisotropy of the GaAs sample. We can estimate the acoustic velocity of SAWs on the GaAs sample from the distance between the two rings which are generated by two adjacent pulses temporally separated by the laser repetition period 12.5 ns. The acoustic velocity for [100] and [110] propagating waves are ~2.9 km/s and ~2.7 km/s, respectively, in agreement with literature values.

Figure 3 shows the PL intensity image over the same area with the same pump conditions. The central spot corresponds to the excitation point in Fig. 2. The reason for the elongated spot is not clear at present, but it may be associated with aberrations in the optical system or anisotropy in the pump spot intensity distribution (which is evident in the wave fronts in Fig. 2).

4. Conclusions

We have demonstrated that it is possible to obtain SAW and PL images with the same optical system. This system should be useful for investigating PL in situations where SAWs control photo-generated electrons and holes.

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