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Optical Properties of Dynamically-Modulated Dots and Wires Formed by Surface Acoustic Waves

Tetsuomi Sogawa[1], Hideki Gotoh[1], Yoshiro Hirayama[1], Tadashi Saku[1], Sen Miyashita[2], Paulo V. Santos[3], and Klaus H. Ploog[3]

[1]NTT Basic Research Laboratories, NTT Corporation,
3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0198, Japan
Phone: +81-46-240-3453, e-mail: sogawa@will.brl.ntt.co.jp
[2] NTT Advanced Technology Corp.,
3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0198, Japan
[3] Paul Drude Institute, Hausvogteiplatz 5-7, 10117 Berlin, Germany

1. Introduction

Recently, dynamic dots (D-dots) [1] and dynamic wires (D-wires) [2], which are formed by the spatial modulation of the piezoelectric potential and strain of surface acoustic waves (SAWs), have attracted much attention from the view point of low-dimensional physics and their device application. In fact, novel optical properties such as dynamic polarization anisotropy due to strain-induced band mixing [2, 3] as well as spin manipulation capability [4] have been reported for these structures. In this study, we investigate the temporal behavior of the photoluminescence (PL) of D-dots and D-wires by using a synchronized excitation method. The spatial distribution of PL intensity clearly demonstrates the formation of an uniform array of D-dots and D-wires by SAWs.

2. Experimental

In this experiment, we used high-quality GaAs/AlAs quantum wells (QWs) with various well thicknesses (L_z = 8.3, 9.9, 12.2, 15.2, 19.8, 83 nm). Two inter-digital transducers (IDTs) are formed on the surface to generate SAWs along the [1-10] and [110] directions, as illustrated in Fig. 1. As the SAW frequency is 820 MHz, the spatial modulation period corresponds to about 3.8 μm. Mode-locked Ti-sapphire laser pulses (1.5 ps, 82 MHz, 720 nm), which are synchronized with SAWs, were used to generate carriers. Low-temperature (4 K) spatial-resolved photoluminescence (PL) spectra were measured using a micro-PL setup with a spatial resolution of about 1 μm. The PL was spectrally analyzed by a spectrometer connected to a CCD detector or a streak camera.

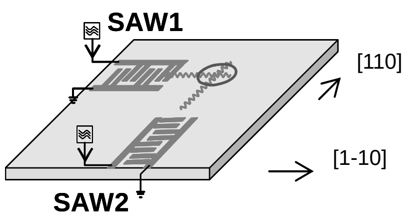

Fig. 1 Illustration of the experimental configuration. Two IDTs are formed on the sample along the [1-10] and [110] directions.

3. Results and discussion

Figures 2 (a) and (b) show time-resolved PL spectra measured by the streak camera without a SAW and by exciting just one SAW beam, respectively. Since the piezoelectric field is partially screened due to the higher carrier density just after the laser pulse, PL remains high for a while. Then, with the reduction of the carrier density, the piezoelectric field effectively separates electrons and holes and sweeps them from the carrier-generation position, resulting in the rapid PL quenching. The PL spectra under a SAW show the energy splitting reflecting the band gap modulation due to the SAW strain field [2].

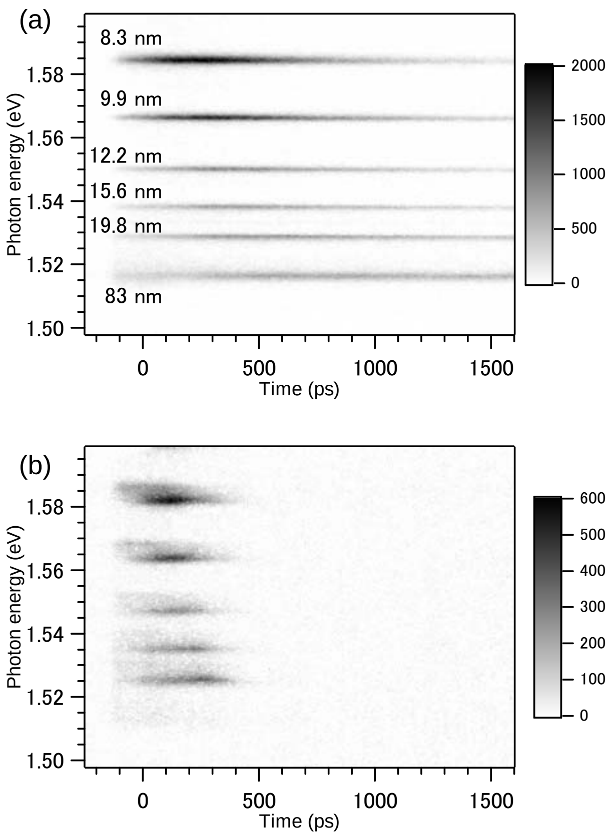

Fig. 2 Time-resolved spectra from various QWs: (a) without a SAW, and (b) by exciting one SAW beam.

We found that the time-resolved PL spectra vary with the relative phase shift between SAW and laser pulse because the band structure and piezoelectric field depend on the phase of SAW. It is also found that the time-integrated PL spectra measured by the CCD detector primarily reflect the band structure and piezoelectric field at the moment of the pulse excitation because the subsequent carrier separation reduces the PL intensity. Figures 3 (a), (b), and (c) show the spatial distribution of the PL intensity measured by the CCD on the QW with L_z=8.3 nm, when only SAW1 is ON, only SAW2 is ON, and both SAW1 and SAW2 are ON, respectively. These results clearly demonstrate the formation of the D-dots and D-wires by SAWs.

A previous study on D-dots reports the formation of two interpenetrating square lattices of D-dots: one of potential dots (type-II band structure) formed by the piezoelectric potential, and the other of strain dots (type-I band structure) resulting from the strain-induced band-gap modulation [1]. Under this experimental condition using pulse excitation, the PL is mainly detected when the piezoelectric field is reduced due to the screening effect. Actually, the PL peak energy of the strain dots is lower by about 4 meV compared to that of QW without SAW. Thus, the observed D-dots in Fig. 3 (c) are attributed to the strain dots.

4. Summary

We have shown that it is possible to control dimensionality in structures dynamically modulated by SAWs. The synchronized excitation method clearly reveals the spatial modulation of the band structure by SAWs.

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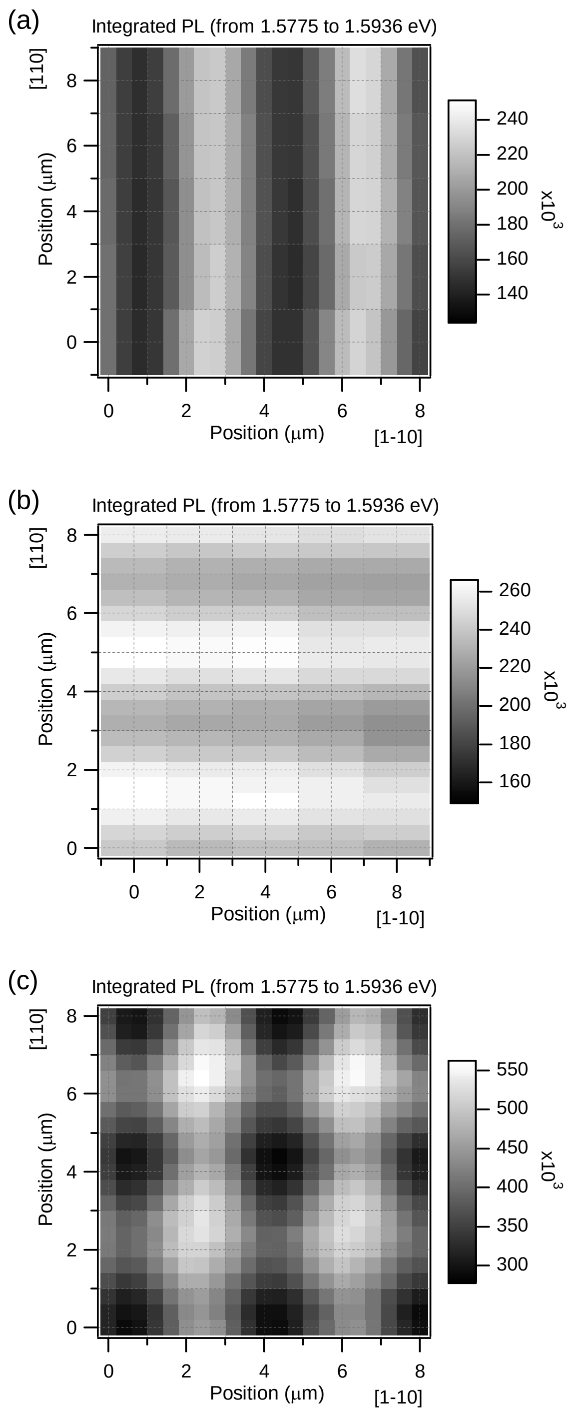

Fig. 3 Spatial distribution of PL intensities for QW (L_z = 8.3 nm): (a) SAW1 is ON, (b) SAW2 is ON, and (c) both SAW1 and SAW2 are ON.