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Polarization Anisotropy of Photoluminescence Spectra in Gallium Arsenide under Different Surface Waves

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ABSTRACT We have studied the dynamic polarization anisotropy of photoluminescence spectra in gallium arsenide under different surface waves configurations by applying microscopic photoluminescence setup. We have found a periodic emission energy oscillation due to the strain induced band gap modulation. Time related polarization anisotropy spectra obtained under the one dimensional standing surface acoustic waves revealed that the photoluminescence polarization anisotropy became the stronger when the band gap energy reached its minimum value and that the polarized direction was perpendicular to the surface acoustic wave propagating direction. We have also found that the time resolved photoluminescence spectra from the dynamic quantum dots exhibited emission energy oscillations similar to the results for the one dimensional standing surface acoustic waves, while no polarization anisotropy appeared. It was also found that dynamic quantum dots formed by the two dimensional surface acoustic waves due to interference between two orthogonally propagating surface acoustic wave beams. The obtained results were compared with previously obtained results.

KEYWORDS Polarization, dynamic, anisotropy, photoluminescence, surface wave, microscopic, emission, oscillation, quantum dot.

INTRODUCTION

Sogawa et al.[1] studied strong polarization anisotropy of the interband transitions in quantum wires induced by one dimensional quantum confinement has attracted a lot of attention for device applications in photonic network systems. It was reported that the polarization anisotropy can be controlled by changing the cross sectional shapes of the quantum wires, where the relative strength

between lateral and vertical confinements significantly modified the mixing states between the heavy hole band and the light hole band. Santos et al.[2] and Rocks et al.[3] showed that surface acoustic waves technology combined with the quantum wires is known to provide one dimensional and zero dimensional dynamically confined structures called dynamic quantum wires and dynamic quantum dots. Shilton et al.[4] and Santos[5] studied that surface acoustic waves are generated by applying radio frequency electrical signals to interdigital transducers formed on a piezoelectric samples such as GaAs/AlAs quantum wires. Sogawa, Zhang et al.[6] presented that dynamic polarization anisotropies defined as temporally and spatially varying polarization properties controlled by external electrical signals. Stotz et al.[7] and Couto et al.[8] showed that the dynamically confined structures enable the long distance electron spin transport and coherent spin modulation. Alsina et al.[9] studied that the two dimensional surface acoustic wave forms two kinds of interpenetrating square arrays of dynamic quantum dots that is one is called as potential dynamic dots, which are created by the modulation and other as strain dynamic dots, which are formed by the strain induced band gap modulation. Weisbuch and Vinter[10] presented a variety of attempts to improve or modify the electric and optical properties of materials; the introduction of the quantum confinement in artificial semiconductor structures such as quantum well structures has been one of the most successful ways which contribute to fundamental scientific studies and actual device applications. Sanada et al.[11] theoretically analysed the modulation of the band structures and photoluminescence anisotropy for the quadrupole like surface acoustic waves to explain experimental results. Alsina et al.[12] presented symmetry of the Gallium arsenide lattice caused the sign surface acoustic wave to the opposite for surface acoustic waves along [110] and [1-10] directions. Sogawa et al.[13] showed that the lateral piezoelectric fields are strongly screened by the photo excited carriers under the relative intense excitation condition, the photoluminescence quenching due to the exciton ionization becomes less effective. The obtained results were compared with previously obtained results.

METHOD

The research work were done on a sample containing eight gallium arsenide quantum wires with different well thickness 6.3, 7.1, 8.3, 9.9, 12.2, 15.2, 19.8 and 83 nm separated by seven period aluminum arsenide 2.0nm/ gallium arsenide 2.0nm short period super lattice barriers grown on [001] gallium arsenide by molecular beam. The quantum wires are located between 100 and 400 nm from the surface. Four inter digital transducers were deposited in a cruciform arrangement to generate surface acoustic waves propagating along the [110] and [1-10] directions. The sample was rotated by 45 deg to compensate the residual polarization properties of the optical setup. Low temperature 4 K spatially and time resolved photoluminescence spectra were obtained in a helium gas flow cryostat using a confocal micro photoluminescence setup with 45X objective lens. As the surface acoustic wave frequency was 820 MHz that is the surface acoustic wave period was 1.2 nanosecond, the surface acoustic wave wavelength corresponded to approximately 3.6 μm as obtained from the surface acoustic wave phase velocity of 2450m/s. Mode locked pulses 1.5ps, 82 MHz, 720 nm from a Ti-sapphire laser synchronized with the surface acoustic wave frequency were used to generate carriers that is one optical excitation pulse for every 10 surface acoustic wave. The photoluminescence was spectrally analysed by using a spectrometer. The surface acoustic wave linear power density per beam was roughly estimated to range from 70 to 100 w/m by comparing the observed band gap energy shifts in the photoluminescence spectra and theoretically obtained values.

RESULTS AND DISCUSSION

Figure (1) to 1 (c) show the photoluminescence intensity photoluminescence difference and spectra under the inter digital transducer corresponds to the phases that form an array of moving dynamic quantum dots as observed. We have adopted excitation laser power for each surface acoustic wave beam. Graph (1)(a) shows the emission energies oscillated at $2 f_{SAW}$ between $E_{\min}$ and the flat band energies. This suggests that excitons do not come close to the arriving $E_{\max}$ sites but move diagonally that is in the [-1-10] or [-110] direction as shown in graph (1)(c) from initially trapped $E_{\min}$ sites to

the nearest $E_{\min}$ sites during a half T_{SAW}. The absence of anisotropic emission from the $E_{\min}$ sites which correspond to the tensile strain dynamic dot, excitons emitting around the flat band energies also exhibits no anisotropy as shown in Figure (1) (b) and (1)(c), the potential dynamic dots must have a strong anisotropy. The emissions from two side by side potential dynamic dots with opposite anisotropy are detected simultaneously; the photoluminescence signals totally cancel the anisotropy.

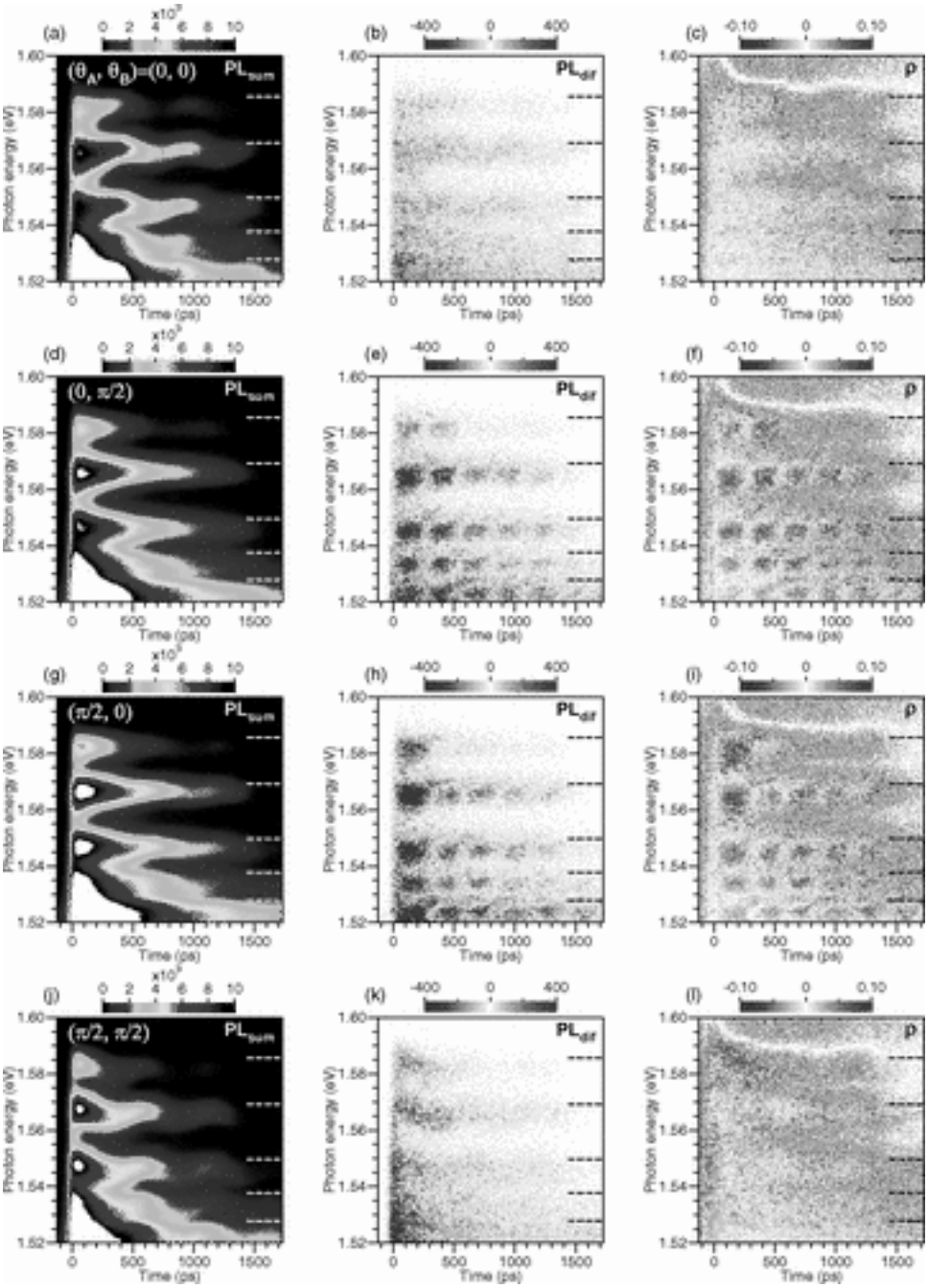

Figure 1: Time-resolved Photoluminescence intensity, Photoluminescence difference and ρ spectra, under the Two dimensional surface acoustic wave for phase of $(\theta_A,\theta_B)=(0,0),(d)-(f)$ for $(0,\pi/2),(g)-(i)$ for $(\pi/2,0)$, and $(j)-(1)$ for $(\pi/2,\pi/2)$.

We have found that the energetic oscillatiory behavior disappears by electrically adding a $\frac{\pi}{2}$ phase difference only to interdigital transducers of square array as shown in Figure (1)(d). Figure (1) (e) and (1) (f) demonstrate that the polarization direction changes every quarter T_{SAW} of 300 ps. We have found that the initial polarization direction is altered by adding the $\frac{\pi}{2}$ phase difference only to inter digital transducer another square array as shown in Figure (1) (h) and (1) (i). If phase difference of $\frac{\pi}{2}$ for both inter digital transducers the emission energy oscillation is reproduced and the anisotropy oscillation disappears as shown in Figure (1) (j) to (1) (l). Figure (1) (a) and (1) (j) show that the photoluminescence emissions from the $E_{\min}$ energies and flat band energies, the phase of $\frac{\pi}{2}$, $\frac{\pi}{2}$ cause a time shift by a quarter T_{SAW}. In the case of time resolved and anisotropic photoluminescence spectra under one dimensional standing surface acoustic waves, the photoluminescence intensity spectra exhibit the typical monotonous decay of excitonic recombination in quantum wires. The emission energies oscillate between $E_{\min}$ and $E_{\max}$ when the excitons have extremely low mobility. The emissions appear between $E_{\min}$ and the flat band energies and disappear while the band gap is larger than the flat band values due to the escape of excitons from the detection spot with relatively high mobility. In both cases the emissions around $E_{\min}$ appear which are inconsistent with the experimental finding that the emission energies oscillate at $2f_{SAW}$ between the $E_{\min}$ and flat band energies. The combination of the time resolved measurement and the one dimensional surface acoustic wave technique under the high carrier density condition provides stable observation of the photoluminescence modulation. The emission energy oscillation observed under the two dimensional travelling surface acoustic wave is explained by the characteristics of the dynamic quantum dots.

CONCLUSION

We have studied dynamic polarization anisotropy of the photoluminescence spectra in gallium arsenide. We have found that emission energy oscillate due to strain induced band gap modulation. When band gap energy reached its minimum value the photoluminescence spectra exhibit the strongest polarization anisotropy. If a perfect quadrupole modulation is obtained by using orthogonal two pairs of well balanced stranding surface acoustic waves with a $\frac{\pi}{2}$ relative phase difference between the pairs the dimensionality of the modulation oscillates between zero dimensional and one dimensional case and the direction of the one dimensional modulation turns by 90 deg every quarter T_{SAW}. We have found that unbalanced standing waves are to be formed due to the partial reflection of the surface acoustic wave beams at the opposite inter digital transducers or cleaved edges of the sample. Two orthogonal unbalanced standing surface acoustic waves form an imperfect quadrupole modulation if the relative phase is $\frac{\pi}{2}$, while an array of moving dynamic quantum dots with oscillating modulation amplitude is formed for the case of no phase difference. One dimensional standing surface acoustic wave is formed by the interference of two counter-propagating surface acoustic wave beam. Two dimensional surface acoustic waves are formed by the interference between two orthogonally propagating surface acoustic wave beams also cause the emission energy to oscillate; while no polarization anisotropy appears. The time resolved measurements have shown that the strongest photoluminescence polarization anisotropy appeared and the polarized direction was perpendicular to the surface acoustic wave propagating direction when two band gap energy reached its minimum value. The obtained results were compared with previously obtained results of theoretical and experimental works and were found in good agreement.

REFERENCES

1. Sagwa. T, Ando. H and Kanbe. H, (1997), Phys., Rev. B, 56, 1958.
2. Santos. P. V, Alsina. F, Stotz. J. A.H, Hey. R, Eshlaghi. S and Weik. A. D, (2004), Phys. Rev. B. 69, 155318.
3. Rocke. C, Zimmermann. S, Wixforth. A, Kotthaus. J. P, Bohm. G and Weimann. G, (1997), Phys. Rev. Lett. 78, 4099.
4. Shilton. J. M., Talyanski. V. I, Pepper. M, Ritchie. D. A., Frost. J. E. F., Ford. C. J. B, Smith. C. G. and Jones. G. A.C, (1996), J. Phys. Condens Matter, 8, L531.
5. Santos. P. V, (1999), Appl. Phys. Lett. 74, 4002.
6. Sogawa. T, Santos. P. V, Zhang. S. K, Eshlaghi. S, Wieck. A. D and Ploog. K. H, (2001), Phys. Rev. B. 63, 121307 (R).
7. Stotz. J. A. H, Hey. R, Santos. P. V and Ploog. K. H, (2005), Nat. Mater. 4, 585.
8. Couto. O. D. D, Iikawa. F, Rudolph. J, Hey R and Santos. P. V, (2007), Phys. Rev. Lett. 98, 036603.
9. Alsina. F, Stotz. J. A. H, Hey. R and Santos. P. V, (2004), Solid State Commun. 129, 453.
10. Weisbuch. C and Vinter. B, (1991), Quantum Semiconductor Structures, Fundamentals and applications (Academic. San Diego. C. A. 1991).
11. Sanada. H, Sogawa. T, Gotoh. H, Onomitsu. K, Kohda. M, Nita. J and Santos. P. V, (2011), Phys. Rev. Lett. 106, 216602.
12. Alsina. F, Santos. P. V and Hey. R, (2002), Phys. Rev. B, 65, 193301.
13. Sogawa. T, Sanada. H, Gotoh. H, Yamaguchi. H, Niyashita. S and Santos. P. V, (2007), J. Appl. Phys. Part 2. 46, L758.