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Low-temperature Photoluminescence Characteristics of GaAs Quantum-well Waveguides

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1. Introduction

In recent years, the rapid development of the information society has led to an increase in the speed of data transfer. In the future, we can expect that there will be a requirement for faster data transfer with further development of the information society. To satisfy this requirement, the realization of a new optical device that breaks down the limit of the operation speed and the size of the element of a current optical device is necessary.

We have paid attention to a new opto-electronic device that uses propagation of an exctonic polariton. An excitonic polariton is a composite quasi-particle formed by the coupling of an exciton and photon. One of the most significant inherent features of an excitonic polariton is high sensitivity to an electric field. In order to achieve low voltage operation and downsizing, this highly sensitive response is very useful [1], [3].

In the previous research, a result has been given that the large electric field-induced phase shift of the light transmitted in a GaAs quantum-well waveguide is obtained up to the relatively high temperature, i.e., 70 K [1]. Since the mechanism for giving so high critical phase shift temperature have been unclear yet, we measured the temperature and polarization dependence of the photoluminescence emitted from the GaAs quantum-well waveguide and discussed this mechanism.

2. Sample structure

Figure 1 shows a cross sectional structure of the waveguide device, which consists of a 2 μm-wide GaAs/AlGaAs single-mode waveguide. The waveguide is made of p-i-n GaAs/AlGaAs layers. A 1.8 μm-thick $Al_{0.13}Ga_{0.87}As$ core layer is sandwiched between $Al_{0.17}Ga_{0.83}As$ cladding layers. At the center of the core layer, ten layers of 7.5 nm GaAs/$Al_{0.3}Ga_{0.7}As$ quantum wells (QWs) are formed.

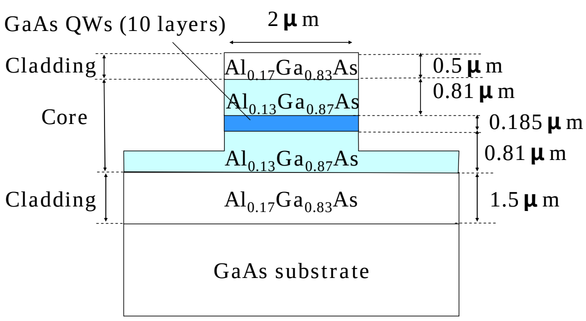

Fig. 1 Cross sectional structure of the waveguide device

3. Experimental procedure

Figure 2 shows a diagram of the optical measurement system. A Ti-sapphire laser excited by an Ar laser is used for the optical characterization. The laser beam is focused into the GaAs QW waveguide, and then the spectrum of the light emitted from the opposite side of the waveguide is measured from 4.5 K to 170 K. By observing an image with a CCD camera, the beam emitted from the waveguide can be observed.

In order to measure the polarization dependence of the photoluminescence, a half wavelength plate is placed in the incident beam, and a polarizer is placed in the output beam. Thus, we can observe the TE (transverse electric) and TM (transverse magnetic) dependence for both of the incident and output beams.

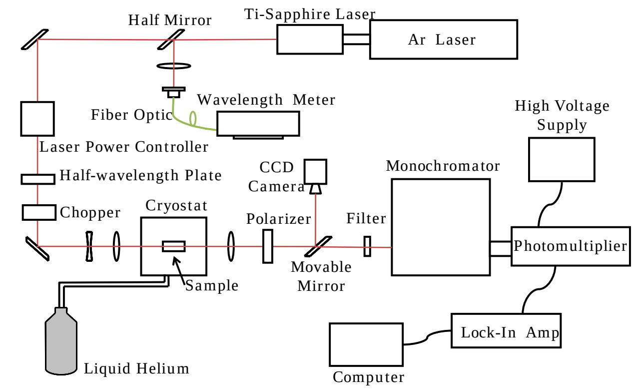

Fig. 2 Optical measurement system

4. Results and discussion

4.1 Temperature dependence of the peak photon energy

At first, we measured the temperature dependence of the peak photon energy of the luminescence emitted from the GaAs QW waveguide, as shown in Fig. 3. The measured result shows that the peak photon energy remains constant up to 50 K and then begins to decrease as the temperature increases. In addition, the peak photon energy is well fitted to the relation,

$$E_g(T) = a - b\left(1 + \frac{2}{\exp\left(\Theta_B/T\right)}\right).$$

which is derived by considering the phonon effect [2].

Where, (a - b) is the band gap energy at 0 K, b represents the strength of the exciton-average phonon interaction, Θ_B indicates the average frequency of acoustic and optical phonons. The relation is indicated as a solid line in the figure. Thus, the dependence can be explained by a phonon effect.

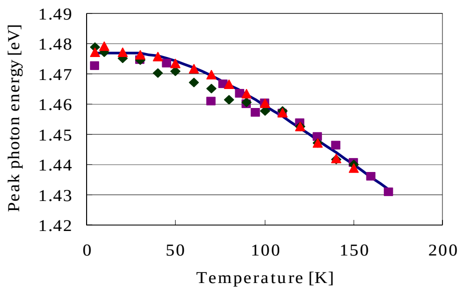

Fig. 3 Temperature dependence of the peak photon energy

4.2 Temperature dependence of the linewidth

Figure 4 shows the temperature dependence of the photoluminescence linewidth, which corresponds to the FWHM (Full Width at the Half Maximum) of the photoluminescence spectrum. The result shows that linewidth remains constant up to 70 K, and then begins to decrease as the temperature increases. This result is different from the behavior of the luminescence so far reported [2]. This critical temperature (70 K) coincides with that of the electric field-induced phase shift of the light transmitted in a GaAs QW waveguide [1]. Since the mechanism for giving so high critical phase shift temperature is unclear, this coincidence gives some information about the mechanism for such high temperature, which may relate to the exciton polariton effect [3].

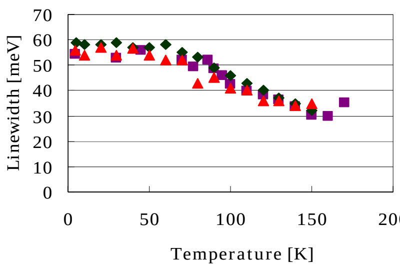

Fig. 4 Temperature dependence of the linewidth

4.3 Polarization dependence of the luminescence

In order to discuss the detail of the luminescence mechanism, we investigated the polarization dependence of the luminescence. Figure 5 shows the result on the light emission intensity, which corresponds to the peak height of the luminescence. The measured result shows that in case of output emission, the intensity of TE mode is higher than that of TM mode. This behavior can be well explained by the anisotropic effect of the hole wave function in the quantum well [4].

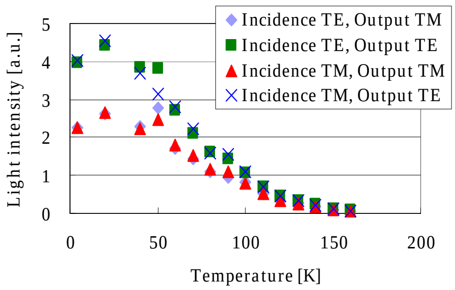

Fig. 5 Polarization dependence of the light intensity

Figure 6 shows the polarization dependence of the peak photon energy of the luminescence. The measured result shows that the temperature dependence of the peak photon energy is almost the same for different polarization. Furthermore, it reproduces the same behavior as the result shown in Fig. 3.

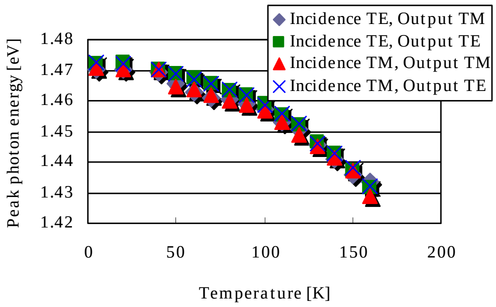

Fig. 6 Polarization dependence of the peak photon energy

Figure 7 shows the polarization dependence of the luminescence linewidth. The measured result shows that the linewidth begins to decrease from 70 K, which is just same as the result shown in Fig. 4. Thus, we can conclude that the emission intensity shows a strong anisotropic behavior, and the emission peak photon energy and linewidth are less influenced by the anisotropy of the quantum well.

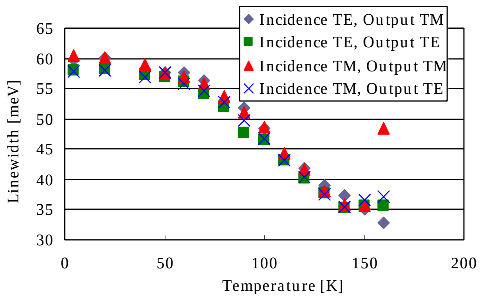

Fig. 7 Polarization dependence of the linewidth

5. Summary

We investigated the temperature dependence of the photoluminescence in the GaAs/AlGaAs quantum well (QW) waveguide. The luminescence was measured at temperatures from 4.5K to 170K. In the polarization dependence, we can conclude that the emission intensity shows a strong anisotropic behavior, and the emission peak photon energy and linewidth are less influenced by the anisotropy of the quantum well. In addition, the linewidth of the luminescence remains constant up to 70 K, and begins to decrease as the temperature increases. This critical temperature (70 K) coincides with that of the electric field-induced phase shift of the light transmitted in a GaAs QW waveguide. Thus, this coincidence of the critical temperature may give some information about the mechanism why so large phase shift of the transmitted light can be obtained in a relatively high temperature such as 70 K.

References

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