Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 318-320 **D-3-3**

Optical Properties of an InGaAlAs/InP Type II Superlattice

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Optical properties of an InGaAlAs/InP type II superlattice are studied for the first time. Electroabsorption, photocurrent, electroluminescence, and transmissivity in a superlattice are measured at room temperature. The results are compared to those in bulk InP. The superlattice shows a change in absorption coefficient occuring in the wavelength region where linear absorption is small. An excitonic structure in the type II superlattice is observed in the photocurrent spectra.

1. Introduction

An InAlAs/InP type II superlattice (SL) has a staggered Γ–Γ energy band structure. [1] Optically–pumped laser emission [2] and electroabsorption [3] in the SL have been reported for the application to optical devices. The wavelength region of this lattice–matched SL is around 1 μm where some strained–layer type I SLs have also been studied recently. [4] This wavelength region can be expanded by introducing quaternary layers.

This paper shows the first experiment conducted for an InGaAlAs/InP type II SL. Electroabsorption (EA), photocurrent (PC), electroluminescence (EL), and transmissivity (T_0) in the SL were measured at room temperature. Optical absorption in the quaternary SL shows a change as observed in a ternary Type II SL. An excitonic absorption structure can be seen as well.

2. Experiments

Undoped $In_{0.52}Ga_{0.48-y}Al_yAs/InP$ SL, sandwiched by n– and p–InP layers, was grown on an n–InP substrate by means of gas source molecular beam epitaxy at a growth temperature of 500 °C. Measurements of photoluminescence, absorption, and electron mobility with varying Al composition (y) revealed that transition from the type I to type II structure occurs around y = 0.18. The details of the sample growth and the experiments for the y–dependence are reported elsewhere. [5]

The SL used in this experiment has 40 periods of 8 nm–thick InP and 7 nm–thick InGaAlAs layers with $y = 0.28$. Doughnut–shaped electrodes are attached to allow a probe light to be transmitted through the sample. This experimental arrangement is similar to one described in an earlier paper. [3] An optical power meter was used to correct the photocurrent spectra.

3. Results

Fig. 1 (a) and (b) show the PC and EA spectra obtained for the InGaAlAs/ InP SL under different reverse bias voltage. The EL peak position is shown by arrows in the figures, and the spectra for T_0 is indicated by the dashed line in figure (a). The EL peak position is at about 1080 nm for the type II SL. This value corresponds to the energy difference between the first (n = 1) electron quantum level (1e) in the

InP conduction band and the first heavy hole level (1h) in the InGaAlAs valence band. Transmissivity is more than 90 % for the wavelength around the EL peak without accounting for Fresnel loss, which indicates a small absorption coefficient. However, absorption changes with the reverse bias voltage in this wavelength region.

cal transition is indirect in real space. The change around 1050 nm is thought to be related to the transition between the 1e electron level and higher heavy hole levels. An optical transition is possible between states having different quantum numbers in type II SLs. [6] The structure in spectra around 960 nm is discussed in the next section.

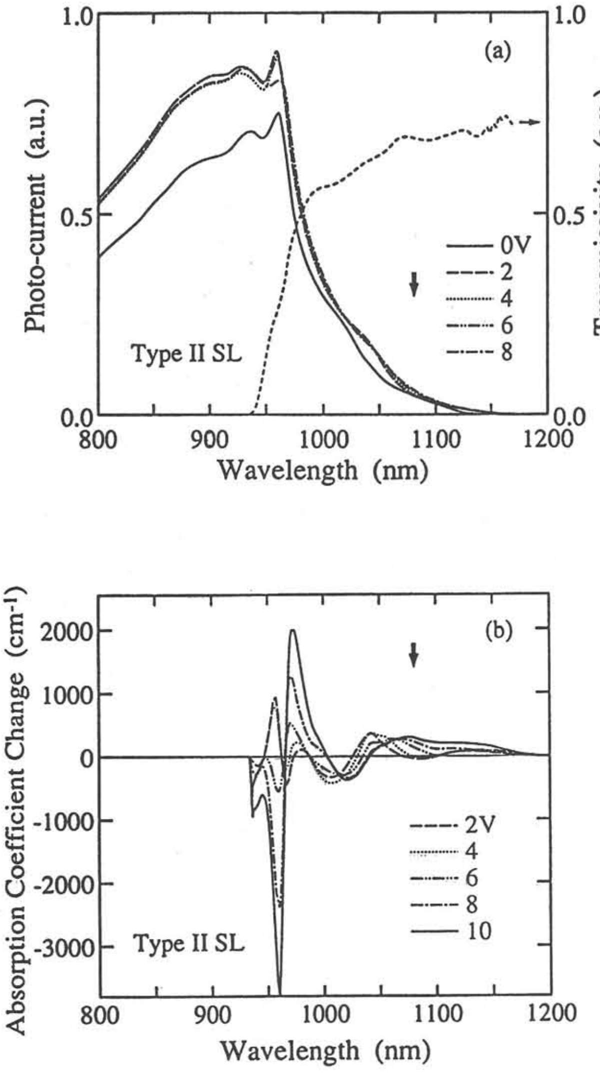

Fig. 1. (a) Spectra of PC and T_0 for InGaAlAs/InP type II SL , and (b) spectra of EA for the type II SL. EL peaks are shown by arrows.

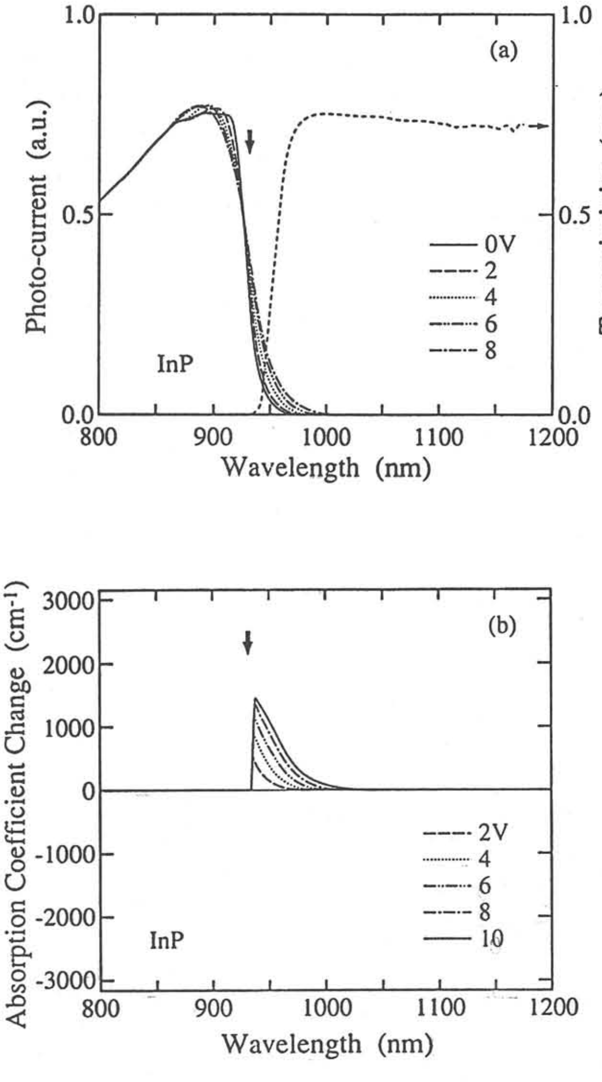

Fig. 2. (a) Spectra of PC and T_0 for InP, and (b) spectra of EA for the bulk.

The EA spectra in Fig. 1 (b) shows a change in the absorption coefficient. This is attributed to an increase in the overlapping of electron wavefunctions, and is characteristic for type II SLs in which optical transition is indirect in real space.

Results obtained for an InP having an undoped layer thickness of 0.6 μm are shown in Fig. 2 for comparison. The EL peak position for the InP is found at about 930 nm, which is close to the absorption edge. The spectra for the InP are quite different from those of the SL, which clearly show the Franz–Keldysh effect. Strong optical absortion by the InP substrate makes it difficult to observe changes in the absorption coefficient in a wavelength shorter than 930 nm, as shown in Fig. 2 (b).

4. Discussion

The peak structure in PC spectra for the type II SL is found at around 960 nm. This structure does not resemble that observed in the InP spectra at around 900 nm and does not reflect the step–like density of state. The peak increases with a reverse bias voltage between 0 V and 2 V with slight shifts toward a higher energy, and decreases between 4 V and 8 V with shifts toward a lower energy. This is caused by the exciton associated with the higher ($n = 2$) energy level. Confinement of the 2e level in the InP conduction band is weak and, as a result, the wavefunction of the 2e level overlaps with that of the 2h level in the InGaAlAs valence band. This overlapping results in a large binding energy for the exciton in a type II SL. [7] An increase in bias voltage enhances the excitonic state and dissolves it when the voltage exceeds a critical value. The increase in the PC spectra between 0 V and 2 V is related to the change in quantum efficiency in the *pin* structure.

Linear absorption is small in the type II SL at the EL peak wavelength where the electroabsorption occurs. InP, however, shows strong absorption at the EL peak. When light–emitting and light–modulating operations are required by the same material, the type II SL is better.

An InAlAs/InP SL shows a luminescence peak at around 1 μm. [3] By introducing InGaAlAs layers, the luminescence peak can be varied between 1 μm and 1.15 μm. [5] If the InP layer is exchanged with other quaternary layers, the peak wavelength will become longer.

5. Conclusion

We studied optical properties for an InGaAlAs/InP type II SL. The spectra of photocurrent and electroabsorption were quite different from those for the bulk InP. The spectra revealed features in the type II SL, to be similar to those observed in an InAlAs/InP SL. The InGaAlAs/InP type II SL was also found to have excitonic property. The introduction of quaternary layers expanded the operational wavelength region. The SL can therefore be used in light–emitting and light–modulating devices.

Acknowledgements

The authors are indebted to Mr. Shin-ichi Iida for processing the electrodes. They also thank Dr. Yoshihiro Imamura and Dr. Tatsuo Izawa for their encouragement.

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