Observation of Stark Shift of ErP/InP Single Quantum Well by Erbium Delta-Doping on InP

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Abstract

A Stark shift due to external applied electric field of ErP/InP single quantum well caused by Erbium delta-doping technique on InP was firstly observed using photocurrent spectroscopy (PC). PC spectra clearly exhibited the interband transition energies of the well on a doped sample. When applying external biased voltage, Its spectra showed significant Stark shift with increasing voltage.

Keywords: quantum well devices

1. INTRODUCTION

In recent years, rare-earth(RE) doped III-V semiconductors have attracted considerable interest because of their sharp luminescense spectra due to the RE intra-4f shell transition. Physical properties of this semiconductor may lead to the application of new optical and electronic devices such as resonant tunneling device[1]. Y. Tekeda *et al.* [1] reported that when erbium was delta-doped (δ–doped) on InP, erbium atoms formed rocksalt ErP with a lattice constant of 0.5595 nm. Fujita *et al.* [2] used a X-ray crystal truncation rod (CTR) scattering to monitor the distribution of erbium atom around the delta-doped layers. It was found that the distribution had approximate thickness of 2.1-2.4 nm (7-8 ML) with erbium exposure time ranging from 10 minutes to 80 minutes. A.G. Petukov *et al.* [3]theoretically calculated the electronic properties of RE-V semiconductor. They reported the energy gap of ErP of 1.24 eV. The optical properties of delta-doped III-V semiconductor have been widely characterized. J. Nukeaw *et al.* [4] observed the trap states in erbium doped InP using photoreflectance spectroscopy. It was revealed that the transition of bandgap of InP from 1.35 eV to 1.31 eV is involved by an erbium trap. V.L. Alperovich *et al.* [5] studied built-in interface electric field in delta-doped GaAs by a modification of photoreflectance spectroscopy. The proposed technique of phase separation , along with the Fourier analysis of Franz-Keldysh oscillations leaded to quantitatively defined energy band diagram of a delta-doped semiconductor. Fujiwara *et al.* [6] investigated effects of growth temperature on erbium-related photoluminescense (PL) in erbium-doped InP. The PL spectra exhibited strong dependence on the growth temperature, and the intensity increased drastically in specimens prepared at temperature lower than 550°C.

Photocurrent spectroscopy is one of the most efficient technique to investigate the excitonic transition in heterostructure semiconductor especially quantum well structure. Moreover PC spectroscopy is easy to set up and can be operated at room temperature. T.W. Kim *et al.* [7] employed this technique to investigate the excitonic transitions in $In_xGa_{1-x}As/In_yAl_{1-y}As$ multiple quantum wells with and without applied electric field. The results for the PC data at 300 K for several applied electric fields displayed that many excitonic transitions shifted to longer wavelengths as the applied electric increased. H. Kobayashi *et al.* [8] carried out the PC spectra at room temperature of InGaAlAs/InP type-II superlattice. PC spectra exhibited the stark shift of interband transition energies under various voltages.

In this work, we report the observation of the interband transition and Stark shifts of ErP/InP type- II single quantum well caused by erbium delta doping on InP with and without biased voltages using photocurrent spectroscopy.

2. EXPERIMENTAL SETUP

All samples used in this work were grown by organometallic Vapor Phase Epitaxy (OMVPE) with vertical quartz reactor at 0.1 atm. TMIn (trimethyl-indium), TBP (tertiarybutyl-phosphine) and $Er(MeCp)_3$ (tri(methyl-cyclopentadienyl)erbium) were used as sources materials. Firstly, an 100 nm undoped InP buffer layer was grown on Fe-doped InP (001) substrate at 530 °C. TMIn was then stopped to suspend the growth of InP. $Er(MeCp)_3$ was subsequently supplied so that the atomic plane of erbium was formed. Its coverage and formation quality was controlled by varying Er – exposure duration time. After the Er source was suspended, a 10 nm undoped InP cap layer was epitaxed. More details of growth is present in Ref [1] and [2]. The structure layer of ErP/InP SQW is schematically shown in Figure 1.

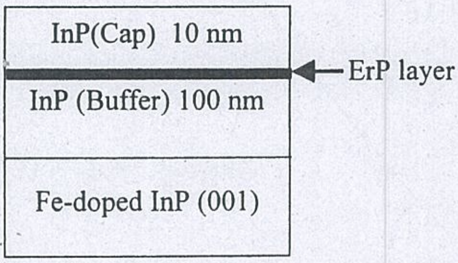

Figure 1. Sample structure of erbium delta-doped InP.

The photocurrent spectroscopy was performed by using a SDMCI1-06 monochromator and the excitation source is tungsten lamp. Schematic diagram of PC measurement is illustrated in Figure 2. Light beam from tungsten lamp passes through a monochromator and the is chopped by a chopper. Chopped light illuminates on the samples with and without biased voltages. Its photocurrent signal is gathered using a SR510 lock-in amplifier and then sent to computer via RS-232 port. Real time signal is executed and displayed. A stepping motor of a monochromator is automatically controlled in order to select a designed wavelength. All PC signals were measured at room temperature.

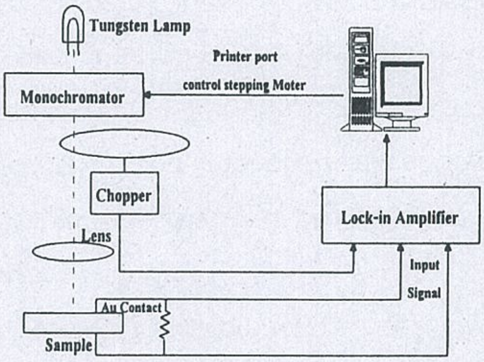

Figure 2. Schematic diagram of Photocurrent spectroscopy.

3. RESULTS AND DISCUSSION

Figure 3 shows PC spectra of erbium delta doped InP with 80 minutes exposure duration without biased voltage. Its signal is compared to the signal of undoped InP. Photon energies range from 0.8 to 1.1 eV. Three peaks with corresponding photons energies of 0.86, 0.92 and 1.04 eV labeled as (1), (2) and (3) respectively are only observed in the doped sample. These features should be affected by delta doping since it is not been observed so far in undoped specimen. When ErP with energy gap of 1.24 eV was formed on InP whose energy gap of 1.35 eV, a single quantum well (SQW) of

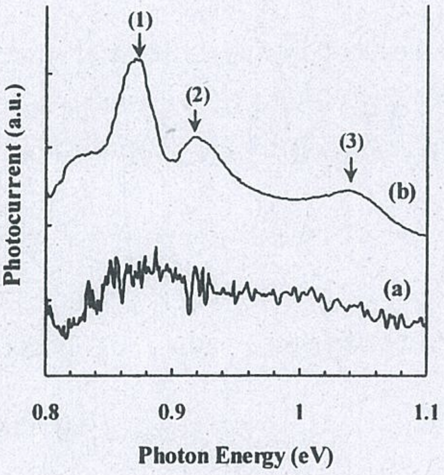

Figure 3. room temperature photocurrent of (a) undoped InP and (b) erbium delta-doped InP at 80 minutes erbium exposure duration

ErP/InP is therefore aligned because of the difference of their energy gaps. All PC peaks have lower photon energies than either of individual energy gap of InP or ErP. According to this fact, the alignment of the well should be a type-II model [9],[10]. This assumption also well agrees with the energy band diagram of delta-doped semiconductor whose alignment at doped layer is type-II like quantum well [5]. Consequently, It can be concluded that these three spectra in doped specimen show the corresponding interband transition energies of ErP/InP type-II SQW. Theoretical calculation of subband energy levels in the conduction band of ErP/InP SQW was accomplished by W.Pecharapa and J. Nukeaw [11]. In their model, the single finite square well is assumed with the related energy gap of 1.35 eV for InP and 1.24 eV for ErP. The band offset is designated as 56:44 and the well width determined by the full width at half maximum of distribution of ErP layer is 2.4 nm (8ML). There are three valid energy levels of -0.47 eV, -0.404 eV and -0.27 eV under the well edge. For valence band, because of type-II structure, holes are in a finite barrier. The calculated energy levels are therefore continuum. The transition energies which is the difference between valence bandedge of InP and each subband levels are achieved. Their values are 0.86, 0.95 and 1.08 eV. This simple model shows good agreement to the PC spectra in Figure 3.

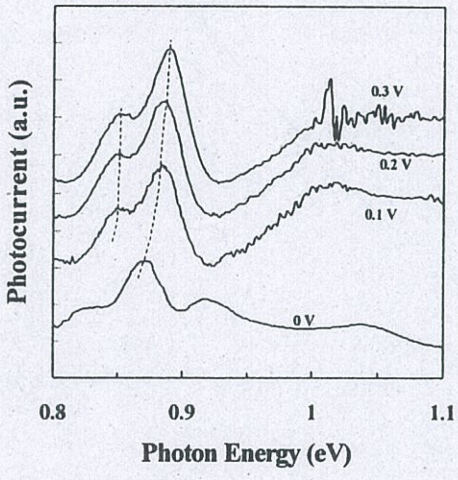

Figure 4. room temperature photocurrent of ErP/InP SQW at 80 minutes exposure duration with 0V, 0.1V, 0.2V and 0.3V biased voltages.

Figure 4. exhibits the PC spectra of the ErP/InP SQW with 80 minutes exposure duration time under several applied voltages. Comparing to the signal of the sample without any biased voltage, the dominant peaks clearly show a significant shift because of applied electric field which is called Quantum Confined Stark Effect. The shift is consequently called Stark shift. The tendency of the shift is shown by a dashline. The dominant peak whose photon energy of 0.86 eV corresponded with the transition form valence bandedge to the ground state of the well in conduction band shifts to the higher photon energy with increasing voltage. The Stark shift is estimately 20 meV when the biased voltage is increased from 0V to 0.1 V. After this voltage, the increment of the shift is approximately 40 meV/V when the voltage varies from 0.1 to 0.3 V. However, when the biased voltage is higher than 0.4 V, the shift is not observed because this

voltage can cause too high electric field for very narrow quanfum well. In addition, a new peak with lower photon energy is observed when the sample is biased. This appearence can be explained theoretically. When the external electric field is applied to a quantum well structure, the well will be tilted and a new ground state will align at lower level than the exist one. This new peak therefore corresponds to the transition energy of the new ground state. Moreover, because the well is inclined when biasing, the higher energy levels will increase and exceed the welledge. At this point, the subband level will be absent. The absence of the higher subband level is also observed when the biased voltage is increased. All features revealed by photocurrent spectroscopy strongly confirm the formation of ErP/InP SQW with type II structure.

4. CONCLUSION

In conclusion, we employed the technique of photocurrent spectroscopy to observe the PC spectra of the interband transition and the Stark shift of a ErP/InP SQW caused by delta-doping. The peak position is shifted to higher energy when the biased voltage is increased from 0.1 – 0.3 V. The new peak of lower energy caused by the inclination of the well is also observed.

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