Growth and Characterizations of Liquid-Phase-Epitaxial Fe doped GaAs

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Abstract

The iron doped GaAs single crystals were grown by liquid phase epitaxial method and its some physical properties were evaluated with a view to investigate the crystal quality and emission property. The isomer shift of 0.303mm/sec is calculated from low-temperature Mössbauer spectroscopy and we know that charge state of iron ion is 3+ in GaAs crystal. In low temperature photoluminescence, the deep emission bands with wide-line width have been observed at 0.99eV and 1.15eV in addition to sharp excitonic peaks. We attributed that these deep emissions are originated from substitutional Fe-acceptor which has charge state of 3+ and 2+, respectively.

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I. Introduction

The research on the transition metal impurities including iron(Fe) in III-V compound semiconductors started in the mid-1960s by several researchers.(1) The Fe impurity is receiving more and more attention in III-V compounds because: (a) Fe is widely used as a dopant when growing semi-insulating(SI) InP substrates; (b) Fe can be present unintentionally in SI GaAs substrates and therefore change the properties of active layers during heat treatment.(2),(3) Transition metal impurities occupy substitutional, cation sites in the hosts and has neutral charge state. In GaAs, for example, Fe replaces Ga^{3+} and roles as a deep acceptor of which binding energy is about 520meV. Electronic energy levels of Fe-related trap in GaAs are evaluated by various experimental techniques.(2), (4) To research the behavior of Fe and doping effects in GaAs, most of researchers used to thermal diffusion or ion implantation methods into GaAs, or used to ultra-trace of residual concentration level in GaAs.(5), (6) In this work, however, we have intentionally incorporated Fe impurity as a dopant in liquid phase epitaxial(LPE) GaAs. We report crystal quallity, charge state of Fe ion, and emission property of Fe doped GaAs grown by LPE.

II. Experiment

We have grown the Fe doped GaAs by conventional LPE method. 4N-Fe source used in this study is supplied from Oak Ridge National Laboratory, and in which content of isotype ^{57}Fe is 92.4%. In growth Fe doping concentration in GaAs was controlled by weight of 0% to 0.46% before load the growth materials in boat. 6-N purity Ga ingot and single crystal GaAs(undoped) wafer were used as LPE growing sources. Especially we used undoped GaAs as a substrate because ultra-trace Fe could be diffused into epitaxial layer if we use Cr doped GaAs. Growth temperature was 750℃. After growth, thickness of the Fe doped layer was monitored by secondary ion mass spectroscopy(SIMS). SIMS depth profiles of Fe impurities in GaAs layers have good uniformities and of which value are 5000Å to 6000Å from surface.

To analyze the charge state of Fe ion in GaAs, we have investigated the Mössbauer effect of Fe doped GaAs. Driving system of the Mössbauer spectrometer was computerized and ^{57}Co supplied from Dupont used as gamma ray source. The Mössbauer spectra were taken in the temperature range of 18K to room temperature. Double crystal x-ray rocking curve(DCRC) is analyzed with a view to investigate the crystal quality of Fe doped GaAs.

The optical emission properties of the epitaxial layers studied by low temperature photoluminescence(PL) experiment with single monochromator system. PL excitation souce is 5145Å of argon ion laser. As a detector we used the photomultiplier tube in the spectral range below 900nm and liquid nitrogen cooled Ge detector above it. The effective spectral range of our PL system is 500nm to 1500nm.

III. Results and Discussion

The DCRC results for Fe-doped GaAs epitaxial layer grown in this work are shown in Figure 1. As shown in this DCRC spectrum, only single peak is observed with sharp FWHM

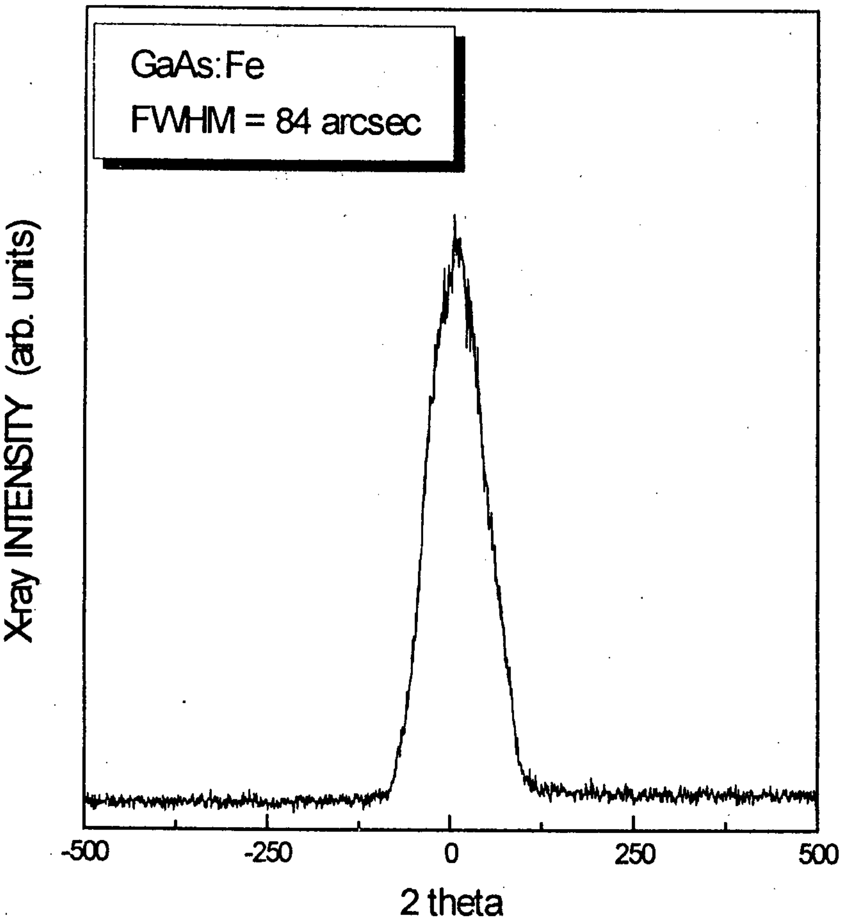

Figure 1 DCRC results from Fe doped GaAs epitaxial layer.

of 84arcsec. These results mean that crystallinity of our LPE species is good and there are no lattice mismatches between epitaxial layer and substrate.

The Mössbauer spectra at 18K and 300K from the Fe doped GaAs layer is shown in Figure 2. In this figure, the Mossbaur spectrun is consisted of only singlet resonance absorption peak rather than quadrupole splitting(QS). Similar results have been obtained by Isayev et al. The isomer shift(IS) value calculated by least square method from this result are 0.303mm/sec at 18K and 0.26mm/sec at 300K, respectively. This mean that Fe ion in GaAs has charge state of mainly 3+ as like expected we had and that thus Fe^{3+} replaces Ga-site as a substitutional impurity.

Low temperature PL properties of Fe doped GaAs epitaxial layer shown in Figure 3. In the region of band edge emission(Fig. 3-a), all species revealed exciton emission peaks and

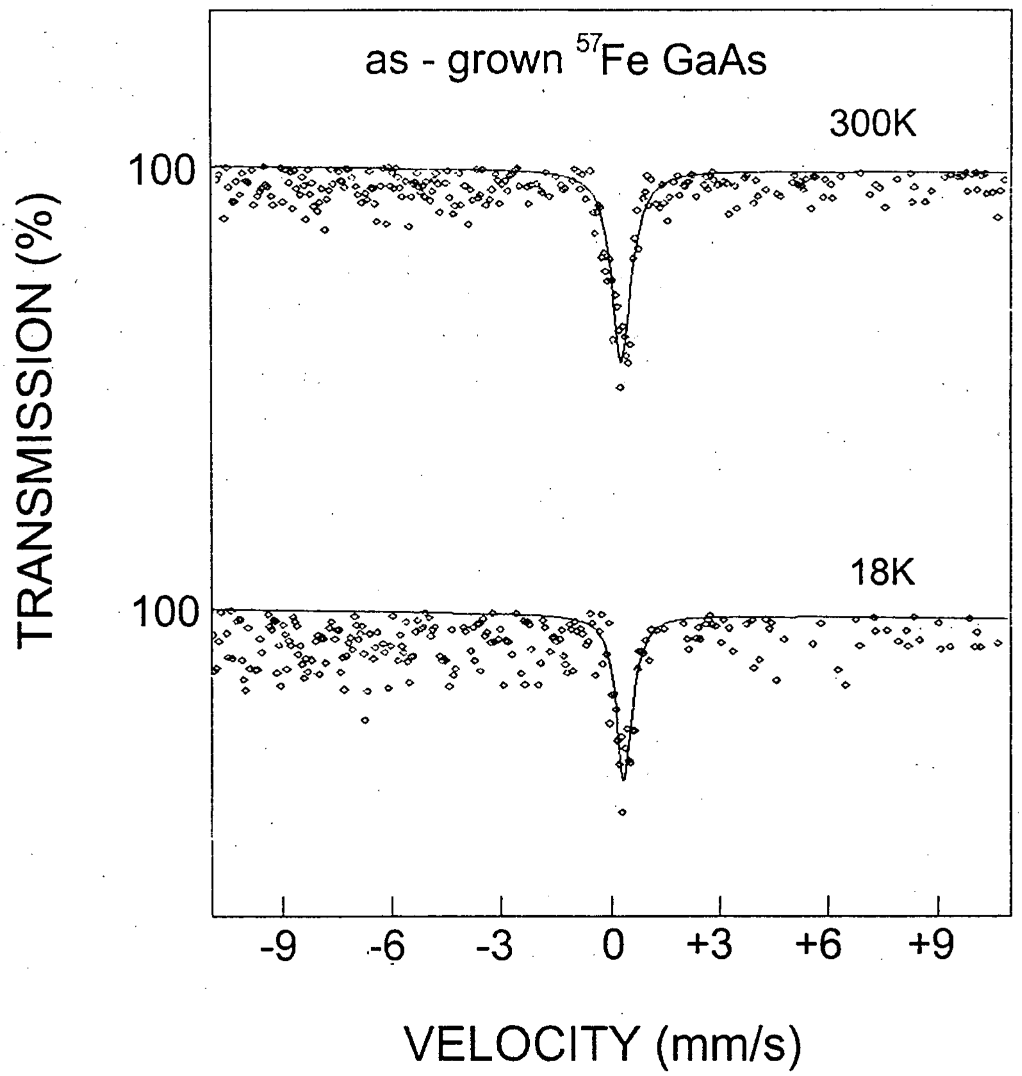

Figure 2. Mössbauer spectra of Fe doped GaAs epitaxial layers. (a) 18K and (b) 300K

carbon related emission peak. The peaks at 1.515eV and 1.512eV are emission by free exciton and bound exciton, and 1.493eV peak by neutral carbon acceptor which is most dominant residual impurity in GaAs. These emission peaks are observed in high-quality GaAs in typical. Unusual emission property is appeared in the emission energy range of deep region from band edge as we could seen Fig. 3-(b). In Fe doped GaAs very broad emission peaks are observed near 1.15eV and 0.99eV. These emission couldn't be observed in undoped GaAs. The peak at 0.99eV(F1) is below 520meV from low temperature band edge and this energy difference is same as the ionization energy of neutral Fe acceptor in GaAs. So we could attributed that the F1 emission is originated from the recombination mechanism of conduction band to neutral acceptor state, $Fe^{3+}{}_{Ga}$.

After this recombination, the charge state of Fe^{3+} transfer to Fe^{2+}. This charge transfer process can be occures also when state of Fe^{3+} is photoionized with a excitation energy below E_g. The atomic energy levels of Fe^{2+} free ion state in splitted into ^5E and $^5T_2$ as a ground state and a lowest excited state, respectively, by crystal field in host. In the case of the host crystal is GaAs, the $^5T_2$ level locates 1.15eV and ^5E level 0.8eV above valence band, respectively.(7) Then radiative transition between $^5T_2$ and valence band is possible with a emission energy of 1.15eV. Thus we attribute that the peak F2 in Fig. 3 is resulted from the excited state of Fe^{2+}. After all, the emission peaks F1 and F2 reflects the two charge states of Fe^{3+} and Fe^{2+}, respectively.

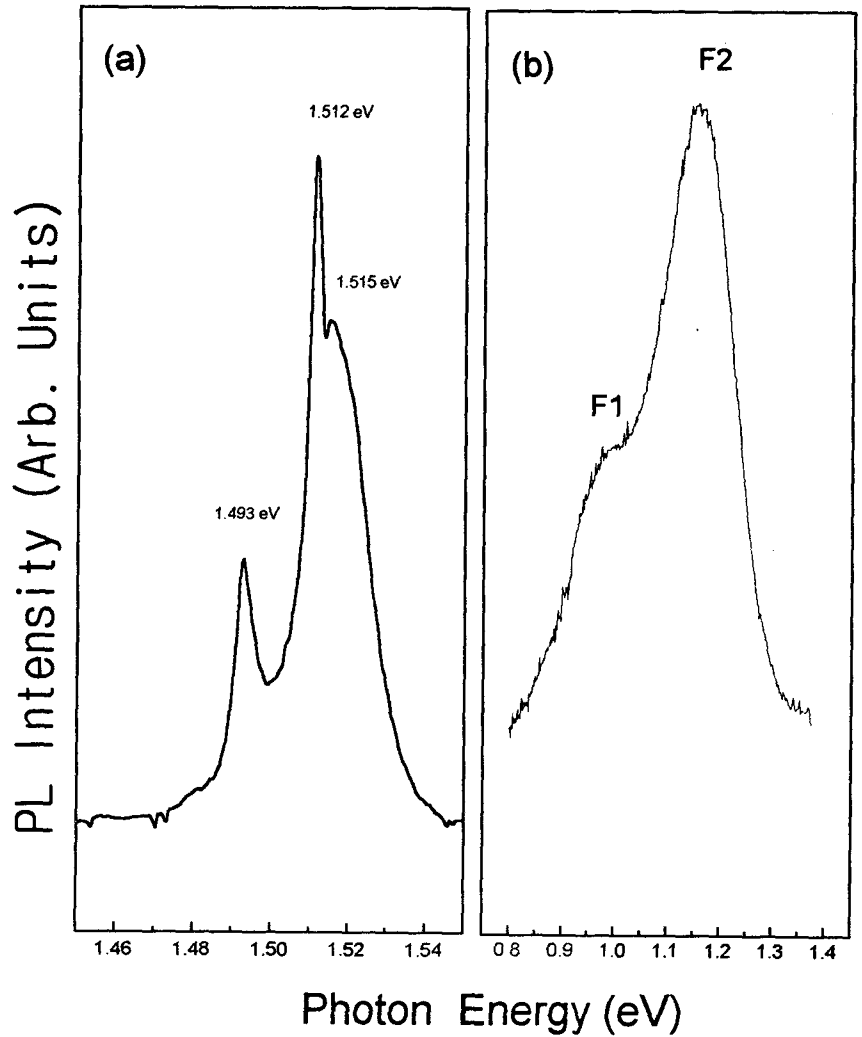

Figure 3. Low temperature PL spectrum from Fe doped GaAs epitaxial layer (a) band edge region and (b) deep region

IV. Conclusion

In this work we have grown the Fe doped GaAs epitaxial layers by LPE method and these species are evaluated with a view to investigate a cystal quallity and charge state of Fe impurity in GaAs. From the Mössbauer spectroscoty, we observed the singlet resonance Fe absorption peak and we know that charge state of Fe ion is 3+. In the low temperature PL measurement Fe^{3+} and Fe^{2+} related emission peaks are appeared at photon energy of 0.99eV and 1.15eV in addition to exciton peaks.

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