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Carrier concentration profiling in magnetic GaMnSb/GaSb investigated by electrochemistry capacitance-voltage profiler

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Abstract **Depth profiles of carrier concentrations in GaMnSb/GaSb are investigated by electrochemistry capacitance-voltage profiler and electrolyte of Tiron. The carrier concentration in GaMnSb/GaSb measured by this method is coincident with the results of Hall and X-ray diffraction measurements. It is indicated that most of the Mn atoms in GaMnSb take the site of Ga, play a role of acceptors, and provide shallow acceptor level(s).**

Keywords: electrochemistry C-V, magnetic semiconductor, GaMnSb.

Diluted magnetic semiconductor (DMS) is a semiconductor based solid solution in which a part of host atoms are substituted by magnetic transition metals or rare earth elements. DMSs have attracted a considerable attention of the scientific and industrial community because they combine the semiconductors with magnetism. Traditionally, the study of DMS is concentrated mostly on Ⅱ-Ⅵ semiconductor based materials, such as CdMnTe. Ⅲ-Ⅴ based DMSs are attracting more and more attention because of their low temperature ferromagnetism[1—5] and the importance of Ⅲ-Ⅴ semiconductors in electronic and optoelectronic devices. Among these, InMnAs[6—8], GaMnSb[9,10] and GaMnAs[11—14] are the most studied Ⅲ-Ⅴ DMSs. An extremely attractive feature of GaMnAs is the fact that they order ferromagnetically at temperature up to 110 K depending on the Mn concentration[4]. The highest Curie temperature realized so far appears at a Mn concentration of 7%. At higher or lower Mn concentrations the Curie temperature drops down again[14]. Evidently, it is important to measure the concentration of the magnetic elements (such as Mn) for understanding the properties of DMS.

In zinc-blende GaMnSb single crystals the Mn atoms substitute Ga atoms and play a role of acceptors. So, the density of holes in GaMnSb single crystals is proportional to the content of Mn. According to our knowledge, the report on profiling of carriers in diluted magnetic semiconductors has not been seen up to now. In this note we report the depth profiling of carrier concentrations in GaMnSb/GaSb measured by electrochemical capacitance-voltage (ECC-V) technique.

1 Experiments

The zinc-blende magnetic GaMnSb single crystals were prepared by a low-energy ion-beam epitaxy (LEIBE) system. There are magnetic analyzers in the LEIBE system, with which the manganese can be purified as pure as isotope. First, the manganese ions with energy of 1 keV were implanted into unintentionally doped p-type [001] oriented GaSb wafer at 200℃. Then, the manganese ions with energy of 100 eV were deposited on the surface of the wafer, which formed a thin layer about 5 nm thick. After the Mn-ions implantation and deposition, the wafers were annealed at 400℃ in an argon ambience for 30 min. The thin layer of manganese on the surface of the GaSb wafer can prevent the implanted manganese ions from diffusing out of the surface of the wafer, and keep the content of Mn at a high level near the surface of MnGaSb while annealing. The Mn film on the surface of the samples were stripped off with diluted phosphorous acid, $H_3PO_4 : H_2O = 1 : 10$ (in volume), after the annealing.

The depth profiling of carrier concentrations in GaMnSb/GaSb was measured by Bio-Rad PN4300PC carrier concentration profiler. Tiron electrolyte[15] is used as the etchant and an electrode. The back of the sample wafer is another electrode. The differential capacitance of the Schottky barrier formed at the semiconductor /electrolyte interface is measured to give the massage of carrier concentrations. Meanwhile, the anodic dissolution is taking place at the interface yielding a continuous depth profile of carrier concentrations.

2 Results and discussion

The typical depth profile of carrier concentrations in GaMnSb/GaSb is shown in fig. 1. The carrier concentration near the surface of the sample is about 1×10^{21} cm^{-3}, and it drops abruptly to 1×10^{19} cm^{-3} within a depth of 70 nm. The drop in carrier concentrations is resulted from the Mn-ion implantation and from the diffusion of Mn atoms during the annealing. Then the carrier concentration drops flatly till it reaches about 9×10^{17} cm^{-3} in the depth of 4 μm. The carriers in GaMnSb are p-type, which indicates that the Mn atoms play a role of acceptors in GaMnSb.

The carrier concentration profile in unintentionally doped p-type GaSb wafer was also measured with ECC-V, as shown in fig. 2. The concentration of carriers is about 2.9×10^{17} cm^{-3}, and distributes uniformly. For comparison, the unintentionally doped GaSb wafer was measured with Hall method, which gives the carrier concentration of 1.7×10^{17} cm^{-3}. It can be seen by comparing the results that the carrier concentration measured by ECC-V and Hall methods are similar. Because the carrier concentration profile in GaMnSb/GaSb cannot be measured by Hall method, the ECC-V profiler is the only facility which can be used for measuring carrier concentration profile in GaMnSb/GaSb.

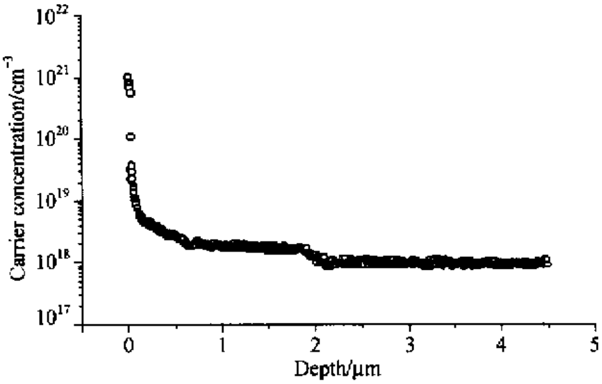

Fig. 1. Depth profile of carrier concentrations in GaMnSb/GaSb.

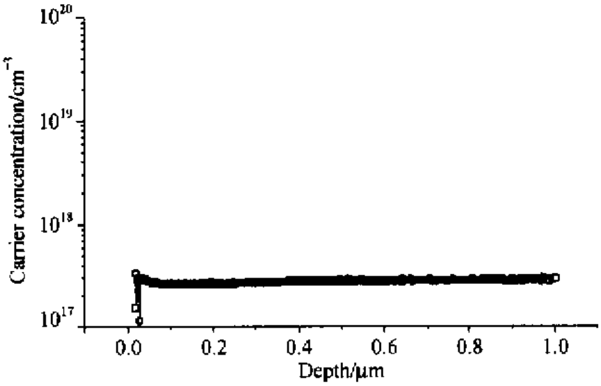

Fig. 2. Depth profile of carrier concentrations in GaSb.

It can be seen, by comparing fig. 1 with fig. 2, that the carrier concentration in the Mn ions implanted and post annealed sample GaMnSb at the depth of 4 μm is higher than that in the GaSb wafer. This result indicates that the diffusion depth of Mn in GaSb is more than 4 μm.

From X-ray diffraction measurements it is known that substituting Mn for Ga, as shown in fig. 3, expands the lattice parameter of GaSb. Point A in fig. 3 is corresponding to the maximum lattice expanse in $Mn_xGa_{1-x}Sb$. According to a physical model[16,17], the maximum content of Mn in $Mn_xGa_{1-x}Sb$ resulting in the maximum lattice expanse can be calculated as $x = 0.09$. Therefore, the content of Mn gradually decreases from $x = 0.09$ near the surface to $x = 0$ in the $Mn_xGa_{1-x}Sb$ wafer inner.

Comparing these results it can be concluded that most of the Mn atoms in GaMnSb take the site of Ga, and play a role of acceptors which provide shallow acceptor level(s).

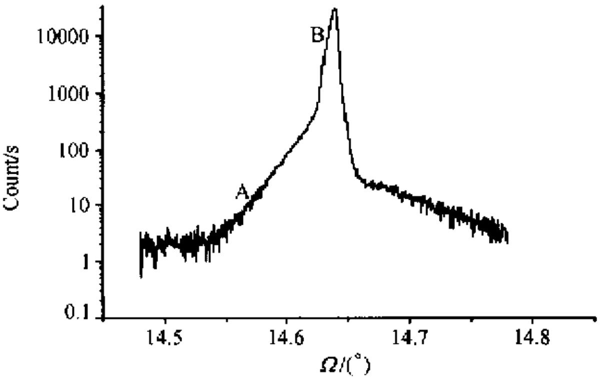

Fig. 3. X-ray diffraction curve measured from GaMnSb/GaSb.

3 Conclusions

The depth profiles of carrier concentrations in GaMnSb/GaSb were investigated using commercial ECC-V depth profiler. The carrier concentration near the surface of the sample is about 1×10^{21} cm^{-3}, and it drops abruptly to 1×10^{19} cm^{-3} within a depth of 70 nm. Then the carrier concentration drops flatly till it reaches about 9×10^{17} cm^{-3} in the depth of 4 μm. By comparing the results from Hall and X-ray diffraction measurements it is sure that the carrier concentration in GaMnSb measured by ECC-V profiler and electrolyte of Tiron is reliable. Most of the Mn atoms in GaMnSb take the site of Ga, and play a role of acceptors, which provide shallow acceptor level(s).

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