Molecular beam epitaxial growth of MnAs/InAs/GaAs(111)B heterostructure

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In spintronics, hybrid ferromagnetic-semiconductor structures have been being expected to play an important role in new applications, such as spin field effect transistor (spin-FET) [1], in which spin-FET requires two-dimensional electron gas (2DEG) channel with spin-orbit coupling effect (SOC), ferromagnetic source, and ferromagnetic stacking for spin transport, injection, and detection. InAs with electron accumulation layer at surface/interface due to Fermi level pinning below conduction band edge [2] can work as 2DEG channel with SOC. For ferromagnetic source and drain, MnAs is one of the suitable candidates because MnAs can be synthesized with InAs in the same MBE chamber, and good interface can be expected. Many researchers have focused on a structure MnAs/GaAs(111)B, in which hexagonal MnAs grows mainly along $c$-axis perpendicular to the substrate GaAs(111)B, or [0001] orientation [3–6]. Because of well-known Zinc-blende InAs epitaxially grown on GaAs, the same growth orientation [0001] of MnAs on InAs is expected. There is only one report on molecular beam epitaxial growth (MBE) of the structure MnAs/InAs/GaAs(001) [7], in which ultra thin InAs was not a channel. Therefore we first aim to establish growth technique, and investigate crystal structure of MnAs/InAs/GaAs(111)B with thick InAs.

We have carried out MBE growth of MnAs/InAs/GaAs(111)B heterostructure. Growth conditions are shown in diagrams in Fig. 1. After cleaning, semi-insulating GaAs(111)B substrate was loaded into a conventional solid source MBE. It should be noted that the sample always exposed to an excess As ambient with beam equivalent pressure (BEP) $\sim 1.5 \times 10^{-5}$ Torr shown by a solid-red line in Fig. 1. After native oxide removal at $\sim 600^\circ$C, substrate temperature was decreased to and stabilized $\sim 480^\circ$C for growth of 1.2 $\mu$m InAs (In BEP $\sim 8.0 \times 10^{-7}$ Torr) in 1 hour. When InAs growth was finished, the substrate temperature immediately decreased to and stabilized $\sim 250^\circ$C for growth of MnAs (Mn BEP $\sim 6.4 \times 10^{-8}$ Torr) in 1 hour. We observed mirror like surface of the grown sample.

In summary, we have successfully carried out MBE growth of hexagonal-MnAs(0001)/InAs(111)B/GaAs(111)B heterostructure. XRD spectra show epitaxially single crystal growth of MnAs hexagonal and InAs Zinc-blende. The concrete stacking structure relation of the epilayeral layers were given.

References

Figure 1: Diagram of conditions for MBE growth of MnAs/InAs/GaAs(111)B shown by an inset figure.

In order to clarify the crystal structures and their relations of layers we carried out X-ray diffraction (XRD) as shown in Figs. 2 and 3. Figure 2 shows XRD spectra of MnAs/InAs/GaAs(111)B obtained by $\theta$-scanning. Peaks are shown with their $2\theta$ values.

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Figure 2: XRD spectra of MnAs/InAs/GaAs(111)B obtained by $\theta$-scanning. Peaks are shown with their $2\theta$ values.

Figure 3: XRD spectra of MnAs/InAs/GaAs(111)B obtained by in-plane $\varphi$-scanning for (a) GaAs(004), (b) InAs(004), and (c) MnAs(102) planes, showing 3-fold, 3-fold, and 6-fold rotational symmetry, respectively.

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References

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