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

Cong Thanh Nguyen, Md. Earul Islam, Masashi Akabori
Center for Nano Materials and Technology (CNMT), Japan Advanced Institute of Science and Technology (JAIST)
1-1 Asahidai, Nomi, Ishikawa 923-1292, JAPAN
E-mail: akabori@jaist.ac.jp

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 drain 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 by 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°C, substrate temperature was deceased to and stabilized $\sim$ 480°C for growth of 1.2 μm InAs (In BEP $\sim 8.0 \times 10^{-7}$ Torr) in 1 hour. When InAs growth was finished, the substrate temperature immediately deceased to and stabilized $\sim$ 250°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.

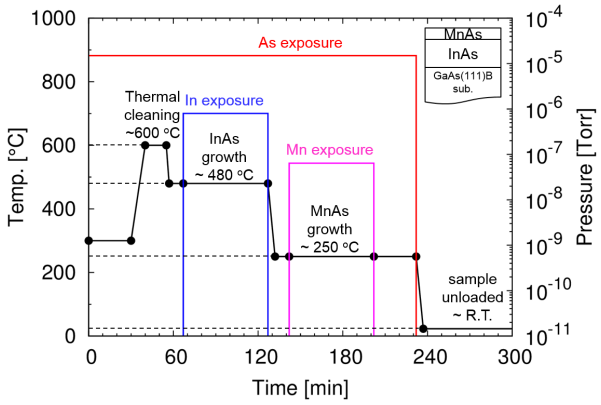

Figure 1: Diagram of conditions for MBE growth of MnAs/InAs/GaAs(111)B shown by an inset figure.

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 2θ-scanning. In the XRD spectra, we found sharp main and no small extra peaks, suggesting epitaxially single crystal growth of MnAs hexagonal and InAs Zinc-blende on GaAs(111)B. The peak InAs(111) at 25.4394°, and MnAs(004) at 65.2682°gives estimated $a \sim 6.06$Å almost similar to that of InAs bulk despite of large lattice mismatch ($\sim$ 7%), and $c \sim 6.1$Å slightly smaller than 6.3Å of hexagonal MnAs on GaAs(111)B [6], respectively. Figure 3 shows XRD spectra obtained by in-plane φ-scanning for GaAs(004), InAs(004), and MnAs(102) planes, showing respectively 3-fold, 3-fold, and 6-fold rotational symmetry, which can be easily recognized through relative angle relations. Through XRD spectra, we could confirm concrete stacking structure relation of the epitaxial layers, in which GaAs[$\bar{1}$10], InAs[$\bar{1}$10], and MnAs[$\bar{2}$110] are parallel. Further investigation such as surface topology, magnetic domain structure, and electrical properties will be done soon in the near future.

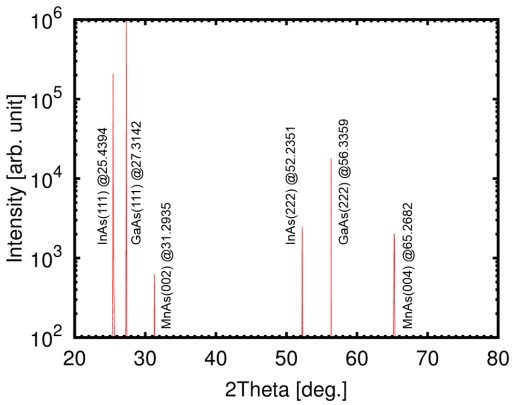

Figure 2: XRD spectra of MnAs/InAs/GaAs(111)B obtained by 2θ-scanning. Peaks are shown with their 2θ values.

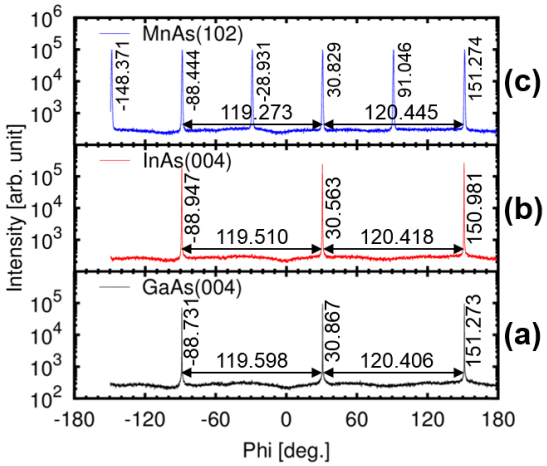

Figure 3: XRD spectra of MnAs/InAs/ GaAs(111)B obtained by in-plane φ-scanning for (a) GaAs(004), (b) InAs(004), and (c) MnAs(102) planes, showing 3-fold, 3-fold, and 6-fold rotational symmetry, respectively.

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

References

[1] S. Datta and B. Das, Appl. Phys. Lett. **56**, 665 (1990).
[2] M. Noguchi, K. Hirakawa, and T. Ikoma, Phys. Rev. Lett. **66**, 2243 (1991).
[3] Y. Morishita, K. Iida, J. Abe, and K. Sato, Jpn. J. Appl. Phys. **36**, L1100 (1997).
[4] M. Tanaka, K. Saito, and T. Nishinaga, Appl. Phys. Lett. **74**, 64 (1999).
[5] S. Sugahara and M. Tanaka, J. Appl. Phys. **89**, 6677 (2001).
[6] M. Kastner, L. Daweritz, and K. Ploog, Surf. Sci. **511**, 323 (2002).
[7] H. S. Lee, S. Yi, T. W. Kim, D. U. Lee, H. C. Jeon, T. W. Kang, K. H. Lee, and J. Y. Lee, J. Appl. Phys. **87**, 071907 (2005).

© 2015年 応用物理学会