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Epitaxial Growth of III-V Semiconductors on Ferrite Substrates

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1. Introduction

InSb and InAs have been regarded as promising candidates for various sensors such as infrared detectors and Hall sensors because of their large electron mobilities and narrow energy band gaps.[1][2] These devices are often fabricated with use of epitaxial growth techniques such as MBE and MOCVD. So far, most researchers have utilized bulk III-V crystals as substrates for these epitaxial growths to avoid the lattice mismatch problem. It is true that the use of hetero-substrates instead of bulk III-V wafers often causes defects in the epitaxial films but the hetero-substrates offer possibilities for new types of devices which use both the epitaxial semiconductor films and the substrates as active regions. The use of single crystalline Mn-Zn ferrite as substrates of epitaxial semiconductor films is extremely attractive especially for magnetic sensors because its outstanding soft magnetic properties such as the large permeability help to improve the sensitivity.

Recently, we have reported the first epitaxial growth of MnSb films on the single crystalline Mn-Zn ferrite substrates with MBE and demonstrated a potential to intergate the hard magnetic metal and the soft magnetic materials with atomically abrupt interfaces.[3] Many of the techniques developed for the MnSb growth such as the surface treatment of the ferrite substrates should be applicable even to growth of semiconductors. In this presentation, we report on the first successful epitaxial growth of InSb and InAs on single crystalline Mn-Zn ferrite with MBE and characterization of the epitaxial films with reflection high energy electron diffraction (RHEED), X-ray diffraction (XRD), and X-ray photoelectron spectroscopy (XPS).

2. Experimental

MBE growths of the InSb and InAs on (110) Mn-Zn ferrite substrates were performed with a conventional solid source MBE system. After the Mn-Zn ferrite substrates were dipped in acetone and ethanol at room temperature for five minutes repeatedly, the ferrite substrates were introduced into the MBE growth chamber. Just before the growths, the substrates were subjected to thermal cleaning at 600-900 ℃ for 10 minutes. Then, the substrate temperature was reduced to 300-350℃, at which the growths of InSb and InAs were carried out.

The InSb growth was initiated by opening the shutter of In and Sb K-cells simultaneously. On the other hand, the growth of InAs was initiated by opening the sutter of an In cell under an As beam ambience. The beam equivalent pressures for the In, Sb, and As were set at 1-2x10^{-7}Torr, 3x10^{-7}Torr and, 2x10^{-6} Torr, respectively. During the growth, the evolution of the epitaxial growth was in-situ monitored by observing RHEED patterns. After the growth of thin films, XRD analysis was used to obtain information on the crystal structure. We have also investigated the quality of the hetero-interface at the early stage of the epitaxial growth using XPS apparatus which is connected to the MBE with an ultra high vacuum chamber.

3. Results and Discussions

Figure 1 (a) shows the RHEED pattern of the ferrite substrate during the thermal cleaning prior to the film growth. The fact that the pattern has changed into the streaky one indicates that the atomically flat surface of the Mn-Zn ferrite substrate can be obtained with this treatment. The period of the plane in the real space calculated with the distance between the streaks in this figure is 0.30nm. This value coincides with the lattice spacing along the [1-10] axis of the ferrite substrate, which has a spinel-type structure with the lattice constant of about 0.85nm. This is reasonable since Fig. 1(a) was taken with the electron beam along the [001] azimuth of the (110) Mn-Zn ferrite substrates. The opening of the In shutter and Sb shutter has weakened the electron beam intensity of the RHEED pattern from the ferrite substrate and the growth of a few monolayers of InSb film has made a new spotty pattern seen in Fig. 1(b) show up. The period of the planes in the real space calculated with the lateral distances between these spots is estimated to be 0.46nm. This value coincides with the lattice constant along the [1-10] axis of the InSb. The fact that the RHEED patterns for InSb films are spotty from the initial stage of the growth indicates that InAs grows epitaxially and three-dimensionally.

Figure 2 shows a symmetric XRD rocking curve for the InSb film grown on the (110) Mn-Zn ferrite substrate. The diffraction peaks from (111) and (333) InSb planes can be seen with peaks from (220) and (440) Mn-Zn ferrite planes, indicating that InSb (111) grows on the ferrite (110). These observations are consistent with the change in the RHEED patterns during the film growth. With these results, it can be concluded that the InAs films are single

crystal and that (111) InSb grows on (110) Mn-Zn ferrite with in-plane alignment of [11-2] InSb // [001] Mn-Zn ferrite. Further studies are necessary to clarify the reason why this alignment is favorable. Note that the InSb (111) has three fold symmetry while Mn-Zn ferrite (110) does not. This lack of common symmetry should cause large interface energy and the residual stress in the film. In fact, the root mean square of the AFM surface image for the InSb (111) / ferrite (110) is much larger than that for homo-epitaxial InSb films, which is probably due to the residual stress.

We have performed similar investigations even on InAs/ferrite structures. We have found that single crystal (111) InAs grows on (110) ferrite and the epitaxial relationship is the same as that for the InSb/ferrite structure although InAs has a much smaller lattice constant.

To investigate the quality of the InSb/ferrite interface, we have stopped the growth, time to time, and transferred the sample to the XPS apparatus which is connected to the MBE in UHV. The decay of the normalized intensity for O1*s*, Zn2*p*, and Fe2*p* and Mn2*p* by the InSb film growth is shown in Fig. 3. Since the escape depth estimated from the exponential attenuation of the O1*s*, Zn2*p*, and Fe2*p* and Mn2*p* coincides with the reported values (8~14Å),[4] we have concluded that there exists almost no interdiffusion of those atoms at the interface. This abruptness of the interface is important for fabrication of advanced magnetic devices.

4. Conclusion

In conclusion, we have succeeded in growing epitaxial single crystalline InSb and InAs films on Mn-Zn ferrite substrates for the first time. From the RHEED and XRD measurements, it has been found that (111) InSb grows on (110) Mn-Zn ferrite with in-plane alignment of [11-2] InSb // [001] Mn-Zn ferrite. It has turned out that InAs films on (110) Mn-Zn ferrite substrates also have the same epitaxial relationship. XPS measurements have shown that the InSb/ferrite hetero-interface is abrupt and the thickness of the transition layer is at least less than 1nm. Since Mn-Zn ferrite substrates have excellent soft magnetic properties, the successful epitaxial growth of single crystalline InSb and InAs opens up the possibility for fabrication of new types of magnetic sensors with high sensitivity.

Acknowledgment

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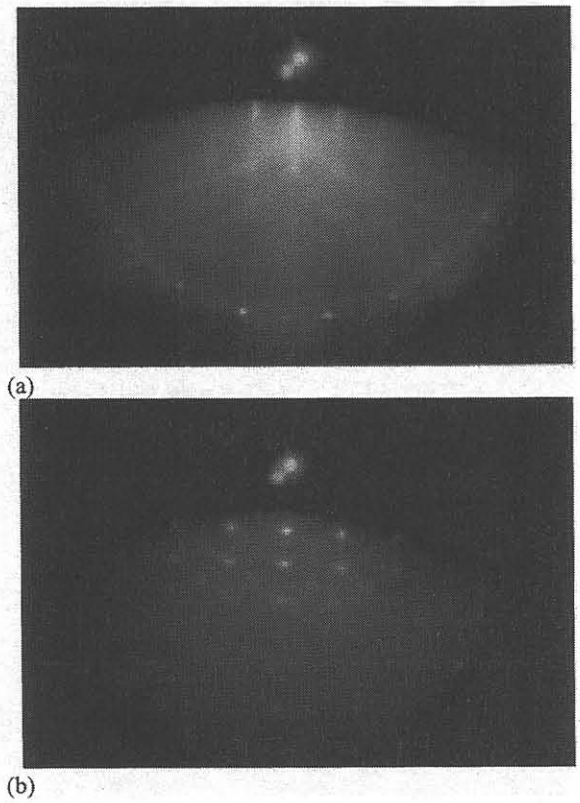

Fig.1 RHEED patterns (a) before and (b) after the InSb growth on (110) Mn-Zn ferrite.

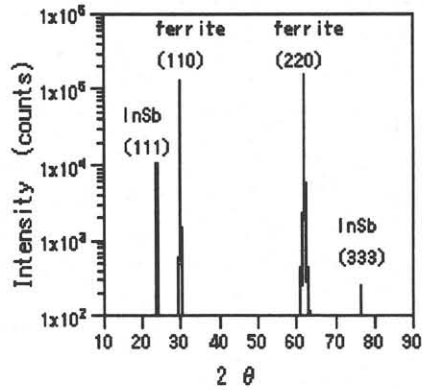

Fig.2 The symmetric XRD rocking curve for the InSb film deposited on the (110) MnZn ferrite substrate.

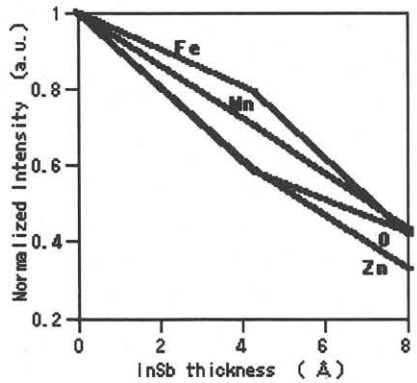

Fig.3 The decay of the normalized XPS signals by the InSb film growth.