Integration of Nitride Semiconductors with GaAs, InAs, and MnAs Using Hetero-Epitaxial Growth Techniques

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Group III nitride semiconductors have attracted much attention because of their exellent optical properties which are suitable for the light emitting devices. In the field of electron devices, however, use of group III nitride devices are limited in high temperature applications because of their low carrier mobilities. To fabricate OEICs using group III nitride optical devices, it is desirable to incorporate GaAs or InAs which can accommodate high-speed circuits on it. Integration of ferro-magnetic materials with the nitride OEICs is also attractive because it allows us to make high-density on-chip memery devices such as MRAM. Manganese pnictides which include MnAs and MnSb are promising candidates for this puopose because of their process compatibility with GaAs and InAs. The simplest way to achieve the OEIC structures described above is to integrate the single crystals of these materials on one substrate using hetero-epitaxial growth techniques. We chose $SrTiO_3$ (STO) as a substrate for the hetero-epitaxial growths because of its cubic lattice system with relatively small mismatches and its atomically flat surfaces. An additional advantage with the use of the STO substrate lies in the possibility of integration with high-Tc superconductors, which can be possibly used as sensors, high-speed circuits, and zero-resistance wiring materials. In this presentation, we report on the successful epitaxial growths of the group III nitrides, GaAs, InAs, and MnAs on the STO substrates.

For the growths of GaAs, InAs, and MnAs, a solid source MBE was used. After wet treatments, the STO substrates were introduced into an MBE growth chamber and were subjected to thermal cleaning at around 700℃ to improve the surface morphology. Then, the substrates were cooled down to the growth temperatures which are 580℃, 350℃, and 300℃ for GaAs, InAs, and MnAs, respectively. We also grew AlN and GaN using laser MBE at a substrate temperature of 750℃. The KrF laser light irradiated the target with an energy density of 3 J/cn^2 and a pulse repetition rate of 10 Hz. The background pressure of the growth chamber was $3x10^{-9}$ torr. During these growths, N_2 gas was introduced up to $1x10^{-5}$ torr through a variable leak valve. The evolution of the epitaxial growths was monitored in-situ by observing the RHEED patterns. To investigate the chemical bonding of the epitaxial films, we used an XPS apparatus, which is connected to the laser MBE chamber and the solid source MBE chamber. After the growths, the surface morphology of the films were investigated with AFM. The magnetic properties of the MnAs films were investigated with a superconducting quantum interference device (SQUID).

Firstly, we tried to grow GaAs on STO (001) substrates. A RHEED pattern from the STO (001) substrate just before the growth of semiconductors has been streaky, which indicates that the surface of the STO substrate is atomically flat. This flatness of the surface is essentially important for the success of the epitaxial growths. Figure 1 (a) shows a RHEED pattern from 30nm-thick GaAs grown on STO. Although the crystallinity of the film is poor, it can be still concluded that GaAs (111) is a dominant growth plane. It is known that the GaAs (111) plane has three-fold symmetry while STO (001) does not. This lack of common symmetry should cause formation of a high density of defects. At the present stage, we attribute this alignment to the low dangling bond density of the GaAs (111) plane. To solve this problem, we have tried the use of STO (111) as a substrate. Figure 1 (b) shows a RHEED pattern of the GaAs grown on the STO (111) substrate at the film thickness of 30nm. One can see that GaAs (111) grows on the STO (111) substrate as expected. The RHEED pattern shows improved crystallinity compared with that on STO (001), although it still shows the existence of two domains which are rotated by 60° along the c-axis each other. The existence of this type of defects indicates that the interface energy is high and the alignment of the 2nd layer from the interface is not important. We have also tried the epitaxilal growths of InAs and obtained similar results with the case of GaAs growths.

Figure 1 (c) shows a RHEED pattern from 50nm-thick MnAs grown on STO. Analysis of this pattern has revealed that the growth plane of the MnAs film is (1-101) with in-plane alignment of MnAs [11-20]// STO [010]. As seen in this figure, the RHEED image has streaky pattern which corresponds to atomically flat surface. This provides a striking contrast to the case for MBE growth of GaAs on STO in which the surface becomes rough as the growth proceeds. This difference can be attributed to the softness of the metal bonding in MnAs. SQUID measurements have shown that the MnAs films grown on STO possess ferromagnetic properties even at room temperature.

We have also tried the epitaxial growth of III-V nitrides on STO by the laser MBE. Figure 1 (d) shows a RHEED pattern of 100nm-thick AlN grown on STO. It can be seen that AlN (0001), which has the similar symmetry to GaAs (111), grows epitaxially. We have also succeeded in the epitaxial growth of GaN (0001) using the AlN film as a buffer layer.

In summary, we have grown group III nitrides, GaAs, InAs, and MnAs on STO substrates epitaxially. We believe that the successful epitaxial growths of these materials lead to the advent of new types of integrated devices which utilize ferromagnetic, semiconducting, and superconducting properties.

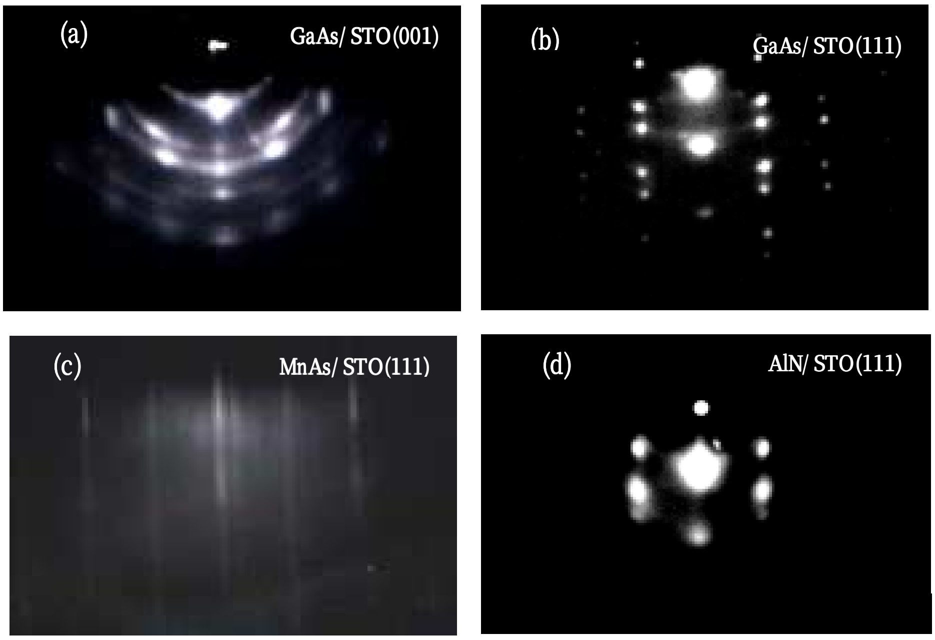

Fig.1 RHEED patterns from (a) GaAs/STO (100), (b) GaAs/STO (111), (c) MnAs/STO(111), and (d) AlN/STO (111).