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Migration Enhanced Epitaxy of InP Using Polycrystalline-InP as Phosphorus Source

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InP was successfully grown in a conventional GaAs-type MBE chamber by the MEE mode using polycrystalline InP as phosphorus source. Long and persistent RHEED oscillation was observed. The (2x4) RHEED pattern was observed in both In-supply and P_2-supply periods, being different from the GaAs MEE growth. Compared with the conventional MBE, the MEE growth gives epitaxial layers of better surface morphology and much improved photoluminescence properties. A new model is suggested for the reconstruction on the In-stabilized (001) surface.

1. INTRODUCTION

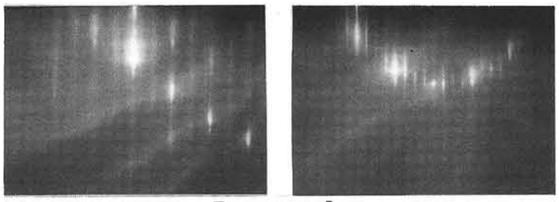
Migration enhanced epitaxy (MEE)[1] is an attractive epitaxial growth method which allows a longer migration length of III-group atoms even at very low temperature. So far many studies has been reported on GaAs, but not on InP, except for a very recent attempt using a PH_3-based gas source system[2].

In this paper, we report for the first time a successful MEE growth of InP using polycrystalline InP as the phosphorus source. The phosphorus beam from this source is mainly P_2[3] whose beam intensity can be controlled easily and precisely. Thus a standard GaAs-type MBE system can be used for the growth without any difficulty.

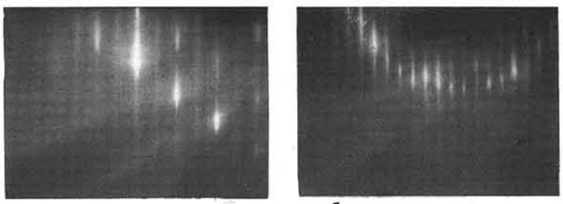
2. EXPERIMENTAL

A conventional GaAs-type MBE system with a 320 l/s ion pump and a Ti-sublimation pump was used. Polycrystalline InP with n=1-$2\times10^{15}cm^{-3}$ was used as the P-source, and metallic In(6N) as the In-source. The growth was done on (001)-oriented Fe-doped semi-insulating InP substrates. The shutters were driven mechanically with a switching time of about 0.2 sec. The growth was monitored by the reflection high-energy electron diffraction (RHEED) pattern at the electron energy of 14.5keV. The layers were characterized by Hall and photoluminescence (PL) measurements.

3. RESULTS AND DISCUSSION



P_2-supply



In-supply

Fig.1 RHEED patterns from (001) InP surface during MEE growth. Left side from the [110] azimuth and right from the [$1\bar{1}0$].

3.1 RHEED Pattern and Oscillation

Figure 1 shows the RHEED patterns during the MEE growth at 380°C. The (2x4) patterns were observed in both P_2 and In supply periods. This is different from the case of the GaAs MEE growth where the alteration of As-stabilized (2x4) and Ga-stabilized (4x2) patterns was observed.

Well defined and very persistent RHEED intensity oscillation of the specular beam spot was observed during the whole MEE growth as shown in Fig.2. More than 3,000 periods of such oscillation were confirmed at 300°C growth. As seen from inset of

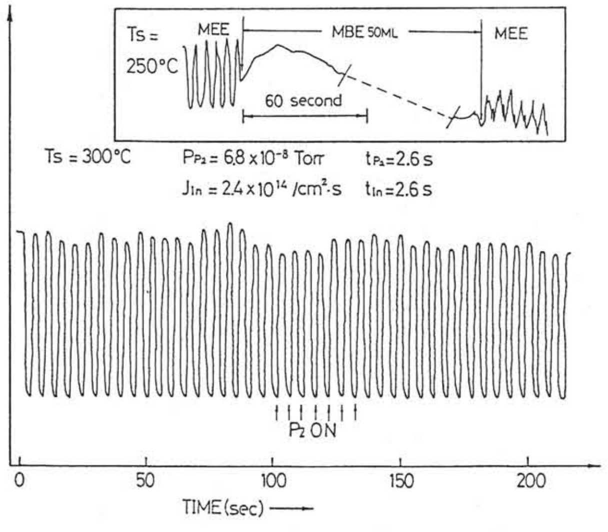


Fig.2 RHEED specular beam intensity oscillation during the MEE growth at 300°C. The inset shows the insertion of MBE mode in the MEE growth at 250°C.

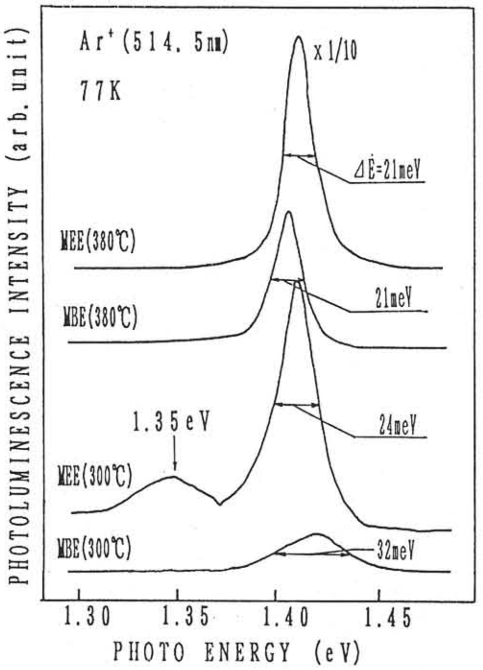


Fig.3 PL spectra of MEE and MBE samples grown at 300°C and 380°C. A peak appears at 1.35eV in the 300°C MEE sample.

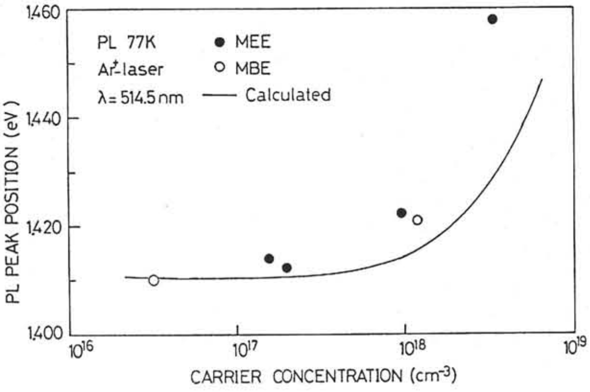


Fig.4 Dependence of PL peak-position on carrier concentration at 77K. Solid line is the calculated result based on the theory(6).

Fig.2, the oscillation was adversely affected by insertion of the MBE growth mode, suggesting deterioration of surface flatness by the MBE mode and its partial recovery by MEE.

3.2 Morphology and Electrical Properties

Epitaxial layers with good surface morphology were obtained by MEE at as low as 250°C. At relatively high temperature such as 380°C, it was found that the dissociation of the phosphorus during the In supply periods occurred, making achievements of mirror-like surfaces somewhat difficult.

Growth rate was about 0.4μm/h corresponding to 2.6s for one monolayer growth. Carrier concentration determined by Hall measurement increased with the decrease of the growth temperature. The behavior is similar to that of InP grown on (111)B using red-phosphorus[4)]. The typical residual donor concentration was in the rang of 10^{16}–10^{17}cm^{-3}. No noticeable difference has been found in electrical properties between MEE and MBE samples.

3.3 Photoluminescence Properties

Photoluminescence spectra of some MEE and MBE samples are shown in Fig.3. PL intensity decreased with the decrease of the growth temperature both in MEE and in MBE samples. However, PL intensities from the MEE samples were always much stronger than the MBE samples at same temperature, being nearly 20 times stronger at 380°C. In the 300°C grown MEE sample, two PL peaks, the main peak and one subpeak at 1.35eV were observed. The main peak intensity is even larger than that of MBE sample grown at 380°C. The subpeak, not observed in other samples, may be attributed to a defect-induced acceptor level reported in the literature[4,5)].

Dependence of PL peak-position on carrier concentration is shown in Fig.4. The MBE and MEE samples behave in nearly the same way, and their behavior is in reasonably good agreement with the calculated curve using the theory by Bugajski and Lewandowski[6)].

The values of the full-width at half maximum (FWHM) are also shown in Fig.3. The FWHM values of the MEE samples were equal to or smaller than those of the MBE samples. The smallest FWHM of 21meV at 77K was observed in the MEE sample, being comparable to that of MBE sample using red phosphorus source grown at a higher temperature[7].

3.4 Discussion

The experimental results described above demonstrate that the MEE growth mode improve the quality of epitaxial layers a great deal. The reason is attributable to the enhancement of the migration of In-atoms. The RHEED intensity oscillation mechanism in MEE may be different from that in MBE. However, the observed non-decaying and high amplitude of RHEED intensity oscillation in the MEE mode seems to indicate the maintenance of highly perfect surface flatness during the whole growth period. This is most probably the reason for the better morphology in MEE samples.

The largest advantage of the MEE mode lies in the large improvement of the PL properties. The strong PL intensity as shown in Fig.3 indicates that the non-radiative deep recombination centers are much reduced. The subpeak in the MEE sample grown at 300°C is possibly caused by the substitution of In-atom for the P-atom which then behaves as an acceptor.

Dependence of the PL peak-position on the carrier concentration in Fig.4 suggests that impurity species and their incorporation mechanism in MEE and MBE samples are the same. This is consistent with nearly the same electrical properties observed in MEE and MBE samples.

The difference in the RHEED pattern between the In-stabilized (001)-InP surface and the Ga-stabilized (001)-GaAs surface is an interesting issue. The same result was also observed in the gas-source MEE of InP[2]. This implies the difference in (001)-surface reconstruction between InP and GaAs. In fact, a similar difference has been reported on the (111)B surfaces of these two materials[4].

To explain this phenomenon, a model for the In-stabilized (2x4) surface during the MEE growth is suggested as shown in Fig.5. Starting from the P-stabilized (2x4) structure of InP (001)-surface having the same missing-dimer structure with GaAs[8], our model assumes that a part of the In-atoms under the In-stabilized condition attach to the positions of the phosphorus missing dimers, rather than forming the In-stabilized (4x2) pattern. This results in an In-rich surface groove extending along [1$\bar{1}$0] direction. The observed PL subpeak at 1.35eV may be related to incorporation of excess In-atoms from this In-rich groove at low temperatures.

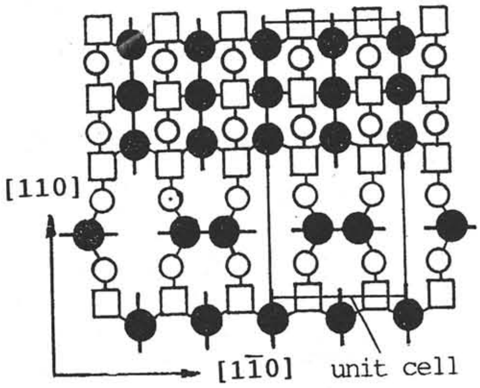


Fig.5 A new model for the In-stabilized InP (001)-surface of (2x4) structure.

4. CONCLUSION

(1) InP can be successfully grown in a conventional GaAs-type MBE chamber by the MEE mode using polycrystalline InP as phosphorus source.
(2) Long and persistent RHEED oscillation was observed in MEE growth.
(3) The (2x4) RHEED patterns were observed in both In-supply and P_2-supply periods, being different from those in the MEE growth of GaAs.
(4) Compared with conventional MBE, MEE growth gives epitaxial layers of better surface morphology and much more improved PL properties.
(5) A new model is suggested for the reconstruction of the In-stabilized (001) surface.

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