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Phase transition from zinc blende to wurtzite and green emission of AlInP grown on (10-10) GaN by crystal structure transfer epitaxy

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Abstract

Phase transition from zinc blende to wurtzite was observed for AlInP layer grown on GaN (10-10). Strong green emissions from the WZ AlInP layer were obtained by cathode luminescence, suggesting the energy bandgap change from indirect to direct.

1. Introduction

Phosphorus related compounds, such as InP, GaP, and AlP, have attracted considerable interest in recent years because they can have wurtzite (WZ) crystal structures, especially in nanowires, due to their small energy difference between the WZ and zinc blende (ZB) structures [1], even though they are stable in the ZB phase of the bulk crystal. Band-structure calculations suggest that GaP and AlP in the WZ phase have *direct* band gaps [2], although those in stable ZB phase have indirect band gaps. Furthermore, the emission wavelengths of quaternary WZ AlGaInP cover the entire visible spectral region, and they can solve the '*green gap issue*'.

Recently, WZ GaP nanowires have been experimentally shown to have direct band gap emission, which wavelengths can be tuned across the visible spectral region by incorporating Al or As in GaP nanowires [3]. However, planar WZ AlGaInP, which would be easy for optical device application, has not been reported so far.

In this study, we attempt to grow planar phosphorous related ternary alloys with WZ structures by using GaN substrates, which have a perfect WZ structure and are used as a template for transferring the WZ structure. We used two types of GaN substrates: polar (0001), nonpolar (10-10) GaN. A layer grown on a polar GaN substrate has probably stable ZB structure because both the WZ and ZB phases are geometrically possible in the <0001> direction. While nonpolar GaN substrate case, the ZB phase is not possible without introducing many defects. Therefore, a grown layer on nonpolar GaN substrates is expected to change to a WZ structure due to the crystal structure transferring from GaN substrates.

2. Crystal growth and Characterization

Planar AlGaP and AlInP were grown on GaN substrates by metal organic vapor phase epitaxy (MOVPE). The MOVPE was carried out in a horizontal low-pressure MOVPE system by using trimethylaluminum (TMAl), trimethylgallium (TMGa), trimethylindium (TMIn), and tertiarybutylphosphine (TBP) as source materials. AlGaP layer was grown at 700°C with a V/III ratio of 68. An AlInP layer was grown at 580°C with a V/III ratio of 60. The grown structures were characterized by using a transmission electron microscope (TEM) and X-ray diffraction (XRD). The AlGaP on the polar (0001) GaN substrates had the ZB structure. The AlGaP on the nonpolar (10-10) GaN substrate was a poly-crystal, and no crystal structure transfer effect was observed.

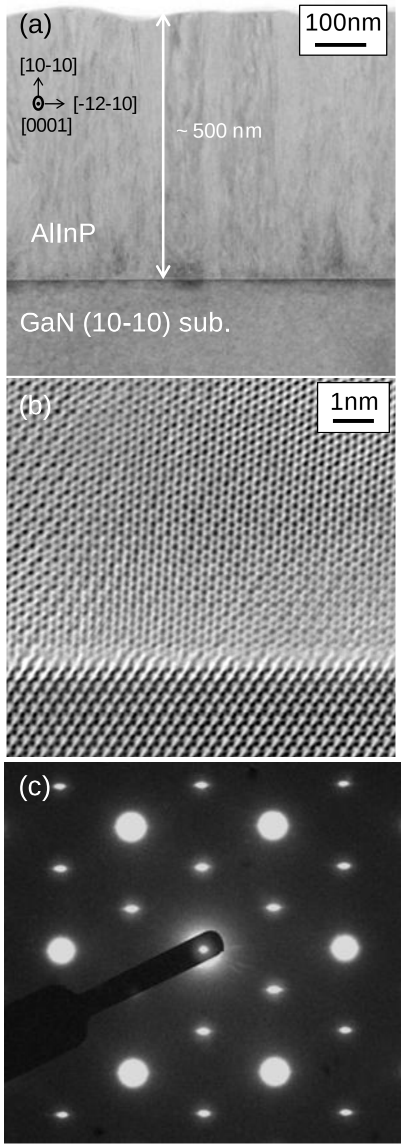

Fig. 1 (a), (b) TEM images of AlInP/GaN (10-10).
(c) SAED pattern of AlInP layer.

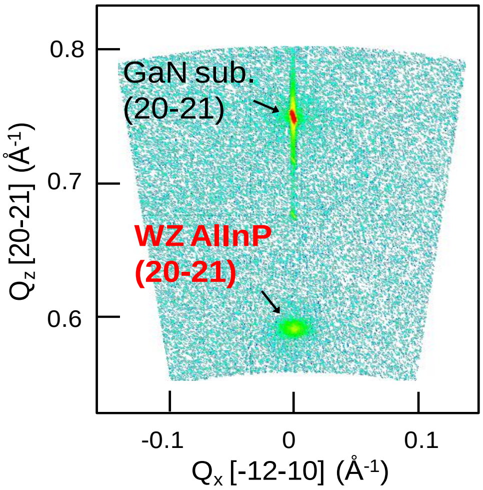

Fig. 2 RSM image of AlInP/GaN (10-10).

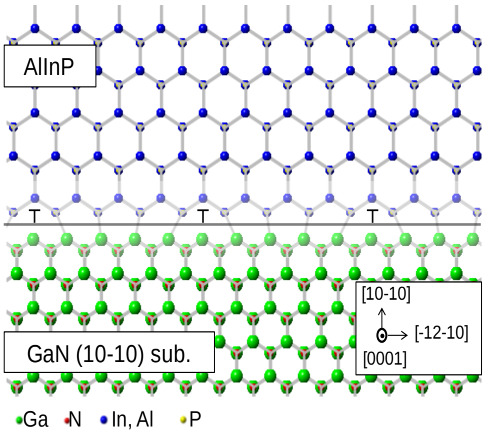

Fig. 3 Growth model of AlInP/GaN (10-10).

AlInP/GaN (0001) had the same result as AlGaP/GaN (0001). However, the result of AlInP/GaN (10-10) was different from AlGaP/GaN (10-10). Figures 1(a) and (b) show TEM images of AlInP/GaN (10-10), and Fig. 1(c) shows selected-area electron diffraction (SAED) of AlInP grown layer. The electron-beam projection was parallel to the <0001> direction. These images and SAED reveal that the AlInP layer grown smoothly on GaN with WZ structure. This sample has Al composition of 58% in AlInP, and the estimated lattice mismatching to GaN is 25%. From lattice image in Fig. 1(b), we clarified that the lattice mismatching is mostly accommodated by introducing misfit dislocations at the AlInP and GaN interface. Figure 2 shows reciprocal space map (RSM) using XRD measured with an incident X-ray beam along the [-12-10] axis. Diffraction peak at (20-21) of WZ structure agrees well with the calculation. To combine with the previous results of TEM and XRD measured from perpendicular direction in plane of the sample [4], we confirm that the AlInP grown layer is WZ with stacking faults to [0001] direction. Figure 3 shows growth model of AlInP/GaN (10-10) observed from [0001] direction.

3. Optical Properties

To analyze optical properties of AlInP grown layers, we carried out cathode luminescence (CL) measurements at 35K. Figure 4 shows CL spectra and corresponding SEM images from AlInP/GaN (10-10). The multiple peaks were observed, and the peak intensities are dependent on measurement locations. The shortest wavelength which may correspond to the band edge emission is around 540 nm (2.30 eV) in '*green*' color area. This emission energy agrees with the theoretical band gap energy of WZ AlInP with Al of 58% (2.34 eV) using liner approximation from InP and AlP bandgaps. The location dependency of intensity and multiple peaks which are longer wavelength than band edge emission can be attributed to stacking faults. WZ AlInP is stronger intensity than ZB AlInP on GaN (0001) with indirect band gap, although ZB AlInP is better crystalline quality. This result suggests that WZ AlInP grown layer on GaN (10-10) substrates have a direct band gap.

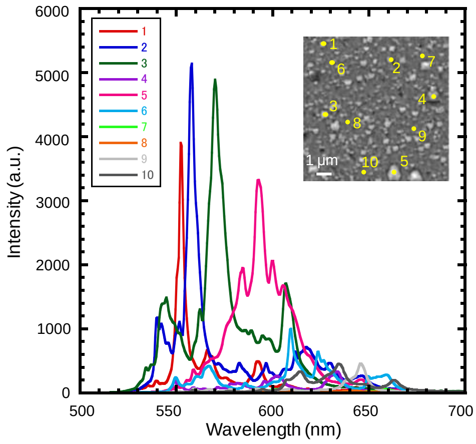

Fig. 4 CL spectra from AlInP/GaN(10-10).

4. Conclusions

Phase transition from zinc blende to wurtzite was obtained for AlInP layer grown on (10-10) GaN by crystal structure transfer epitaxy. CL measurements indicate strong green emission, suggesting the energy bandgap change from indirect to direct.

References

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