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Fabrication and Characteristics of High Quality AlGaAs Film Grown on Al_2O_3 Substrate

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***Abstract:* -** In this work, the characteristics of AlGaAs film grown on transparent Al_2O_3 substrate are investigated. AlGaAs films having various Al compositions were fabricated on the GaAs buffer layer of an Al_2O_3 substrate using metal organic chemical vapor deposition. It was found that the crystal quality and surface roughness of the AlGaAs film was gradually improved by increasing the Al composition. The relatively improved surface and crystallizations were observed at AlGaAs film having an Al composition of 80%. A marked decrease in the d-spacing between the AlGaAs plane and Al_2O_3 substrate was clearly observed under the same condition. From these results, the high-quality AlGaAs film on the Al_2O_3 substrate was attributed to an increase in the substitutional effect of Al for Ga caused by increasing the Al composition.

***Keywords:* -** *AlGaAs, Al_2O_3, GaAs, MOCVD*

I. INTRODUCTION

AlGaAs materials are known to be suitable for optical devices such as solar cells, laser diodes, and light emitting diodes because of their higher mobility and direct band-gap structure [1-4]. Over the past several decades, the efficiency of optical devices based on AlGaAs materials has been significantly improved using progressive growth systems and then applying more effective structures [5,6]. However, although numerous works have reported optical devices having a high efficiency, certain intrinsic limitations remain that considerably decrease their overall efficiency.

Specifically, it was shown that the efficiency of optical devices markedly decreased when using an absorbing GaAs substrate [7], though this type of substrate has been deemed necessary for fabricating optical devices based on an AlGaAs material because GaAs is typically lattice-matched with AlGaAs.

Some studies have also shown that the efficiency of optical device could be increased by inserting a distribution Bragg reflector (DBR), consisting of n-AlAs and n-$(Al_{0.5}Ga_{0.5})As$, between the device and absorbing substrate [8]. Elsewhere, AlGaAs having a rough 150 μm thickness was used as the transparent substrate in order to fabricate higher efficiency optical devices [9]. At present, improving this efficiency has been the main focus of many researchers, in attempts to replace the absorbing substrate with a transparent substrate through a post-wafer bonding process [10]. However, current methods remain inefficient because lower yields and additional process costs are incurred.

In this work, we grow AlGaAs films on a transparent Al_2O_3 substrate under various Al compositions, subsequently finding that the crystallization and surface roughness of the AlGaAs film is significantly influenced by the Al composition. Here, a high quality AlGaAs film is obtained at an Al composition of 80%.

II. EXPERIMENTAL

The AlGaAs films developed were grown on an n-type Al_2O_3 C-plane (1111) substrate at a 0.2° tilt toward [M-Axis]±0.1°, [A-Axis]±0.15° using a metal organic chemical vapor deposition (MOCVD) system. Here, trimethylgallium (TMGa) and trimethylaluminum (TMAl) were used as the group III sources and arsine (AsH_3) was used as the group V source; hydrogen (H_2) was used as the carrier gas for all sources.

The GaAs used as the buffer layer was grown on an Al_2O_3 substrate for 5 min at 650 °C using an MOCVD system, in which the group V/III ratio used to grow the GaAs buffer layer was 52. Then, AlGaAs films having various Al compositions were grown on the GaAs buffer layer having an Al_2O_3 substrate for 10 min at a growth temperature of 650 °C; the group V/III growth ratio of the AlGaAs films was 30. In this work, both the Ga and Al were precisely introduced into the reactor chamber using a mass flow controller (MFC) in MOCVD. During experiments, Ga and Al bubblers were used to maintain a constant temperature of 0 °C and 17 °C, respectively, under a pressure of 1,000 mbar.

The crystallization and interactive growth direction for the AlGaAs films grown on the Al_2O_3 substrate were measured using the ω-2θ and mapping scans of x-ray diffraction (XRD). The surface morphology and cross-section images were then obtained through atomic force microscopy (AFM) and scanning electron microscopy (SEM), respectively. In addition, x-ray photoelectron spectroscopy (XPS) was used to measure the relative percent of distribution of each atom included into the AlGaAs films grown on the Al_2O_3 substrate.

III. RESULTS AND DISCUSSION

Fig . 1(a) and (b) show cross-sectional scanning electron microscopy (SEM) images of GaAs and AlGaAs films grown on the Al_2O_3 substrate. In the figures, the ~0.2 μm thick GaAs film and the 0.8 μm thick AlGaAs film were grown flatly on the Al_2O_3 substrate. Overall, the practical thickness of AlGaAs film is ~0.6 μm because the AlGaAs film was grown directly on the GaAs film used as buffer layer. Fig. 1(c) shows the ω-2θ scan XRD results obtained from these samples. The Al_2O_3 (0 0 12) peak was observed at the same point (45.17°) in all samples, whereas the GaAs (0 0 6) peaks were observed at 44.79°, near the Al_2O_3 (0 0 12) peak. Note that the AlGaAs (0 0 6) peak at 44.77° shows a higher intensity and slightly left-shifted position compared to the GaAs (0 0 6) peak. From these results, it was confirmed that a flat AlGaAs film could be effectively grown on an Al_2O_3 substrate by using a GaAs buffer layer.

To obtain further improved AlGaAs films, AlGaAs films having various Al compositions were grown on the Al_2O_3 substrate. The component ratio of Al to Ga in the AlGaAs material displayed a trade-off relationship. Fig. 2 presents the XRD results for AlGaAs films having Al compositions ranging from 20% to 80%. At an Al composition of 40%, the AlGaAs peak was left-shifted slightly. The peaks from 20% and 40% were at 44.77° and 44.74°, respectively. Above 60%, significant left-shifted movements were observed from the AlGaAs film peaks of. At 80%, a peak of 44.53° was observed, which is markedly left-shifted compared to the GaAs film.

Fig. 3 presents the results of an XPS analysis for AlGaAs films having various Al compositions. XPS analyses have often been used to measure the relative content of atomics in a material [11]. For this analysis, etching was performed on the top surface of the sample. In the figure, it is seen that basic atoms such as Ga, As, Al, and O were obtained from the AlGaAs films based on the Al_2O_3 substrate ; the curve inversion presents the boundary between the AlGaAs film and the Al_2O_3 substrate. In addition, regions having the highest percent of Ga atom are observed in GaAs films used as the buffer layer. From the figure, the atomic percent of Ga was seen to be strongly influenced by the insertion of Al atoms because they have a trade-off relationship. However, it also seems that both As and O were slightly influenced by the Al atoms. At an Al composition of 60%, the atomic percent of Ga decreased by 3% for Al increases of 20%; there was a significant decrease in Ga atoms of 12% observed at 80%. Overall, a marked increase in Al atoms was observed, one that ultimately exceeded the As atomic percent.

Fig. 4 shows AFM images for AlGaAs films grown on the Al_2O_3 substrate, in which the surface morphology is seen to improve with an increase in Al the composition. At 80%, the surface morphology was very smooth. In the inset, the rms results clearly show that there was a marked improvement in surface morphology at an Al composition of 80%.

The XRD map images obtained from AlGaAs films fabricated under various Al compositions are shown in Fig. 5. As the d-spacing presents the difference between the theta-2 theta line of substrate and matched-line from substrate to grown material, we measured the interactive growth crystallization between the Al_2O_3 substrate and AlGaAs film. Specifically, the d-spacing could be related to the condition of the lattice-match between two materials having different lattice constants. In the figure, the strain and relaxation of the lattice-match increased and decreased, respectively, with a decrease in d-spacing. Previous reports have shown that the poor crystal quality and defects could be attributed to an increase in the relaxation between materials [12]. Therefore, it was assumed here that an AlGaAs film having a higher crystal quality and lower defects could be obtained by using a higher Al composition, especially as the d-spacing could be effectively decreased by increasing the Al composition. In particular, a marked decrease in the d-spacing was clearly observed at 80%. These results thus confirmed that the crystallization of the AlGaAs film grown directly on an Al_2O_3 substrate strongly depends on an effective substitution of Al to Ga.

IV. CONCLUSION

In this work, we directly grew AlGaAs films on a transparent Al_2O_3 substrate. To improve the crystal quality, AlGaAs films having various Al compositions were then grown on the Al_2O_3 substrate using MOCVD. It was found that the surface roughness of AlGaAs films were gradually improved by increasing the Al composition; the d-spacing between the AlGaAs (0 0 6) plane and Al_2O_3 (0 0 12) substrate displayed the same trend as the surface roughness. From the experimental results, it was thus posited that the crystallization and surfaces of AlGaAs films grown on Al_2O_3 substrate depend strongly on the Al composition. At 80%, AlGaAs films having a relatively higher crystal quality and improved surface were obtained compared to previous reports. From these results, the high-quality AlGaAs films grown on Al_2O_3 substrates was subsequently attributed to an increase in the substitutional effect of Al for Ga caused by the increase in Al composition.

V. ACKNOWLEDGEMENTS

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VI. FIGURES

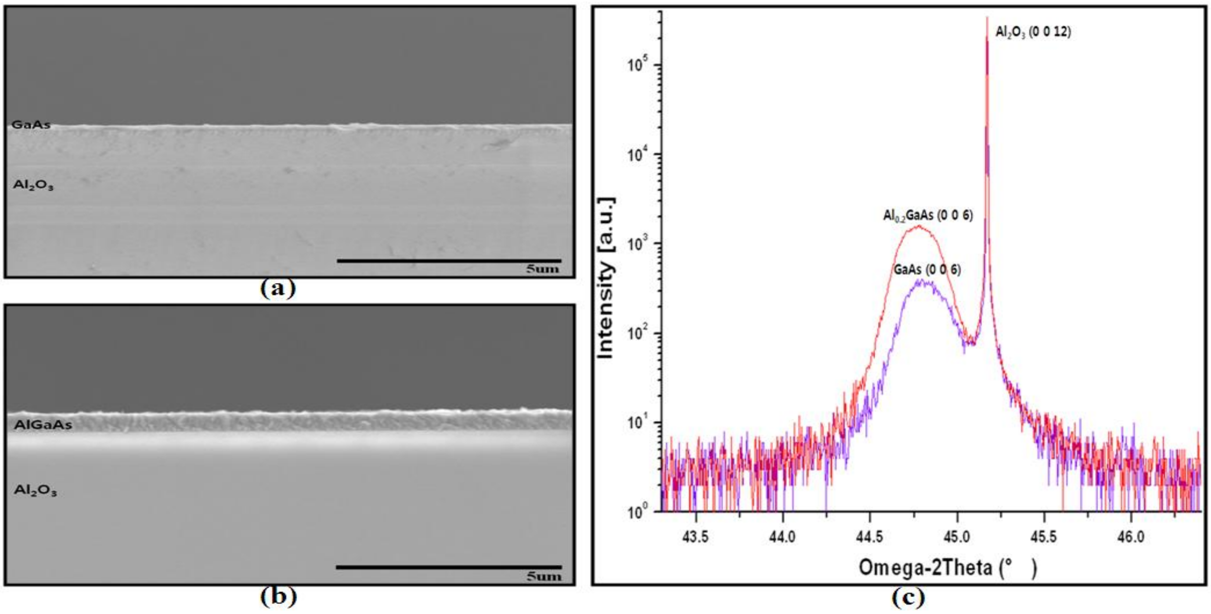

Fig. 1. (a)-(b) SEM and (c) XRD images for AlGaAs and GaAs films grown on Al_2O_3 substrates.

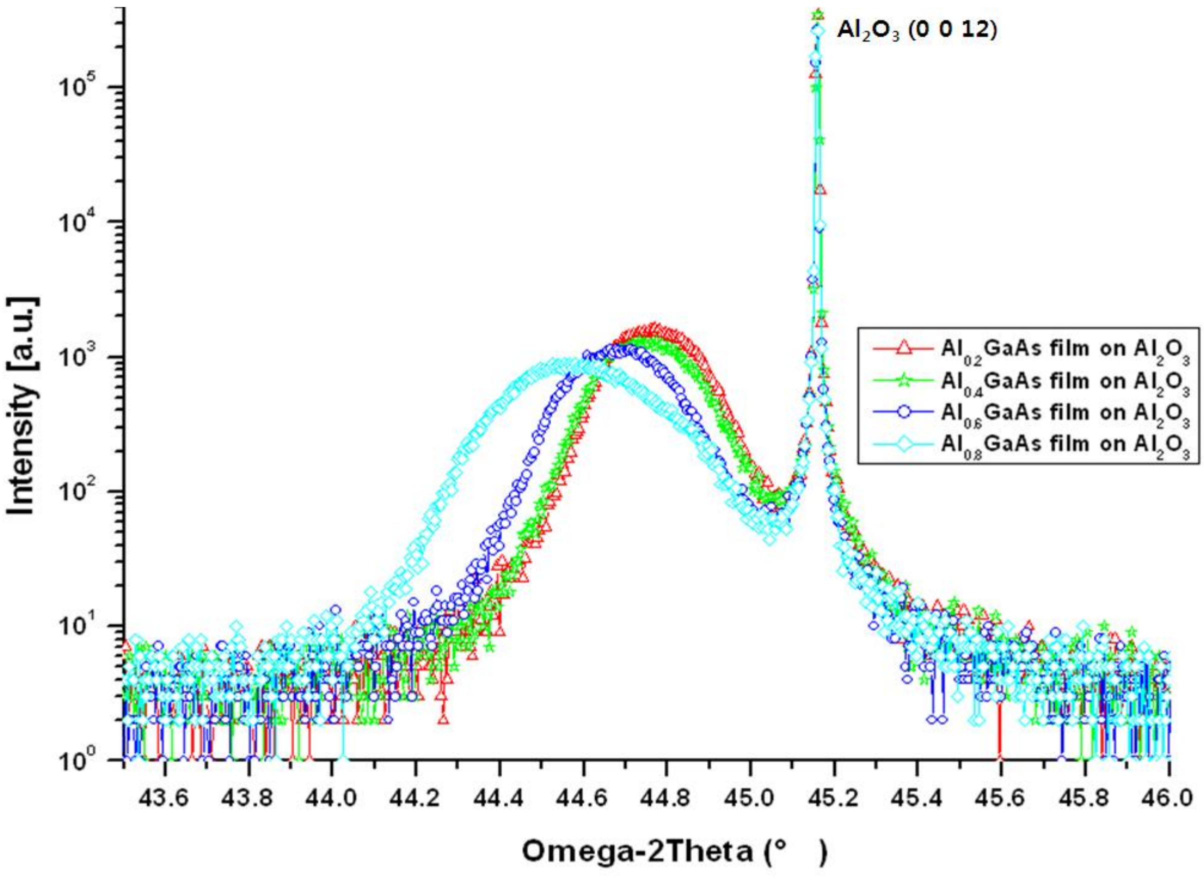

Fig. 2. XRD results for AlGaAs films having various Al compositions on an Al_2O_3 substrate.

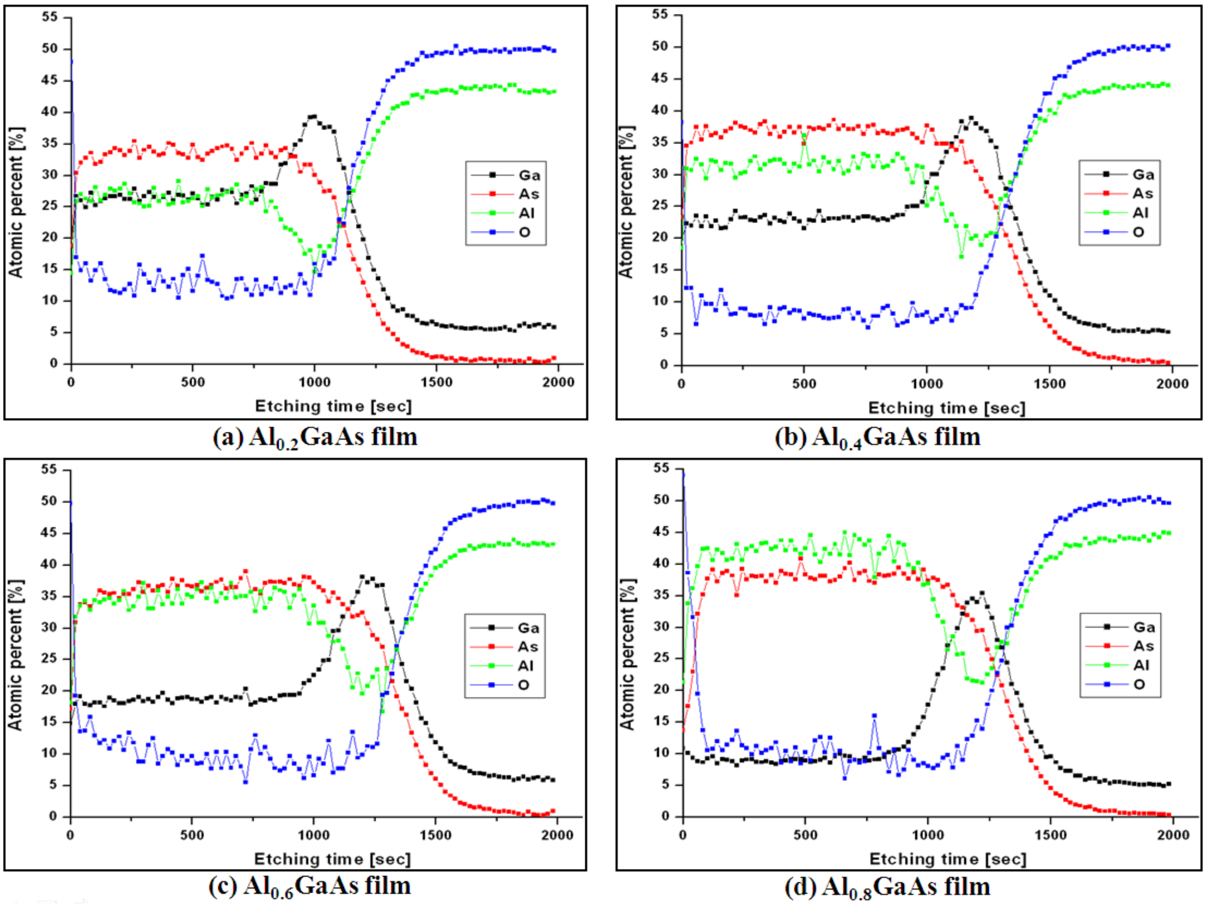

Fig. 3. XPS analyses of AlGaAs films having various Al compositions on an Al_2O_3 substrate.

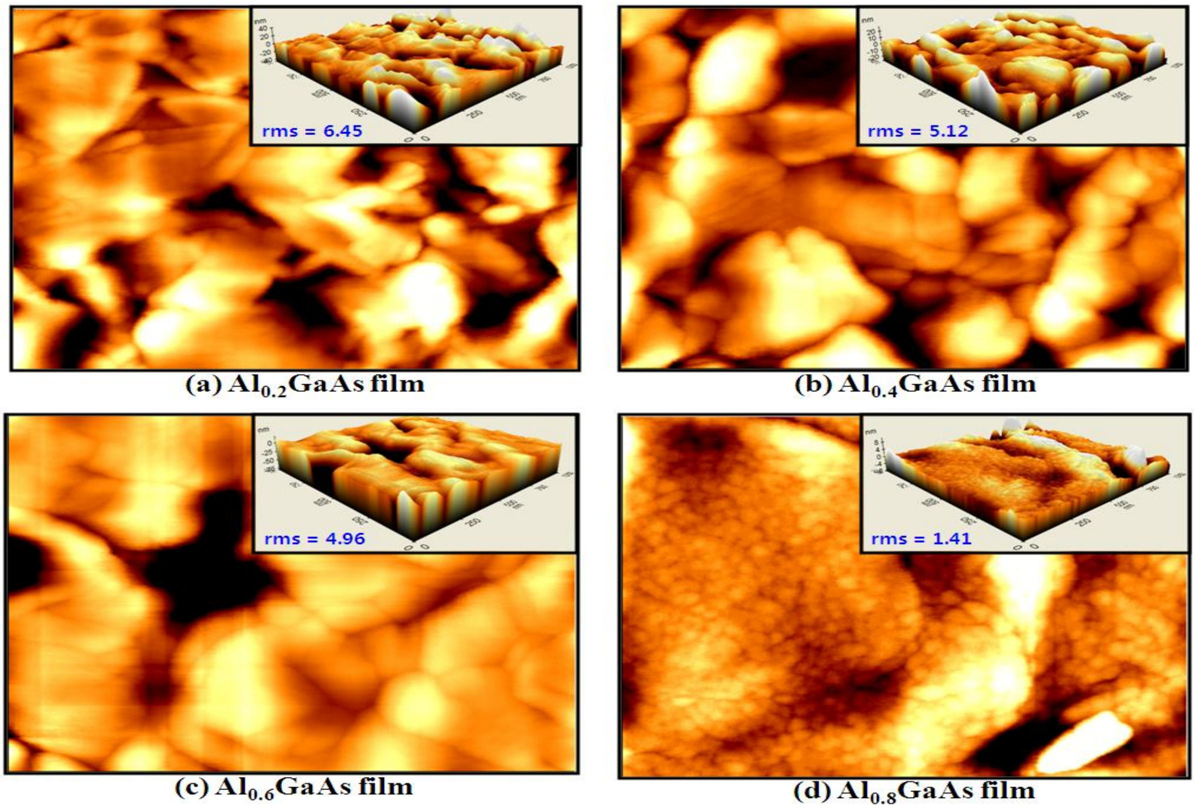

Fig. 4. AFM images for AlGaAs films having various Al compositions on an Al_2O_3 substrate.

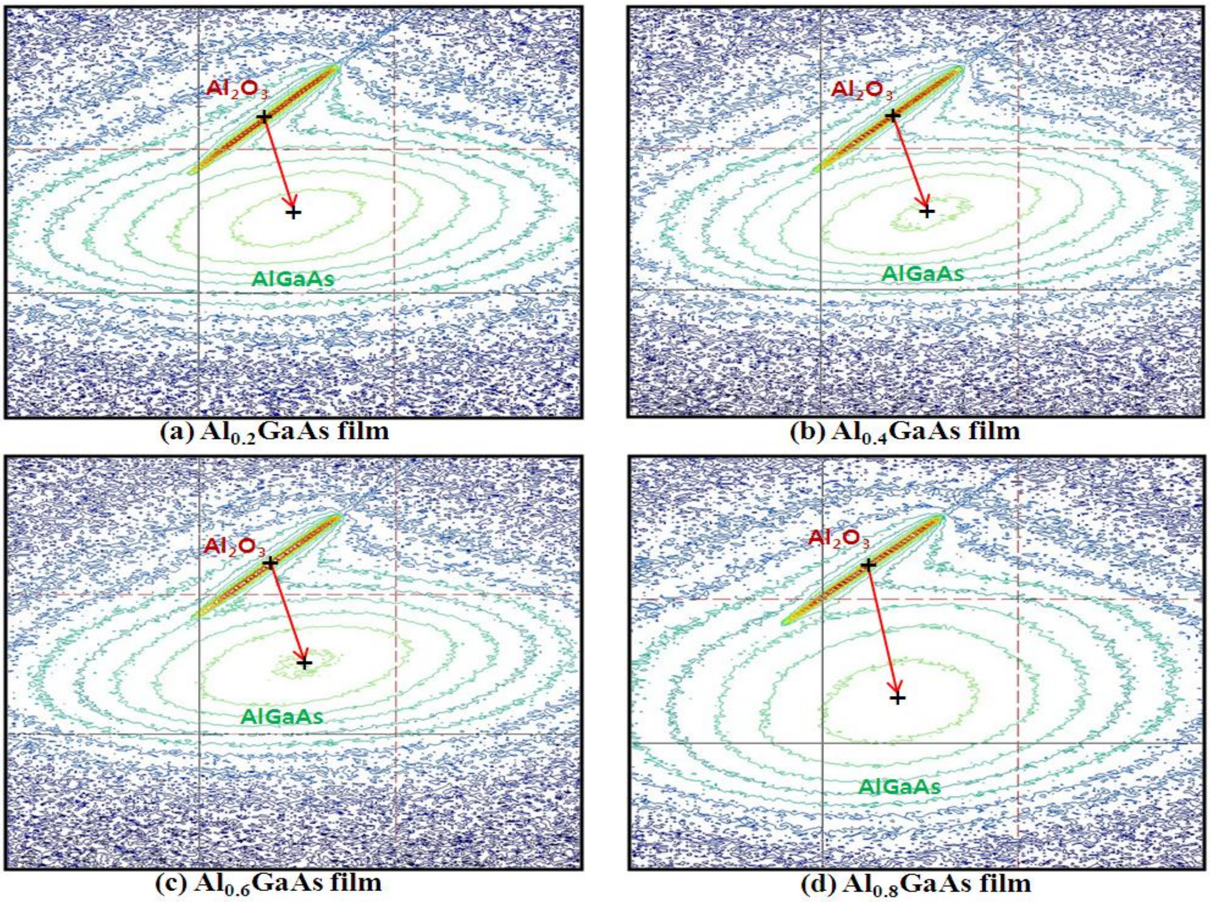

Fig. 5. XRD map images showing d-spacing between Al_2O_3 and AlGaAs films having various Al compositions.

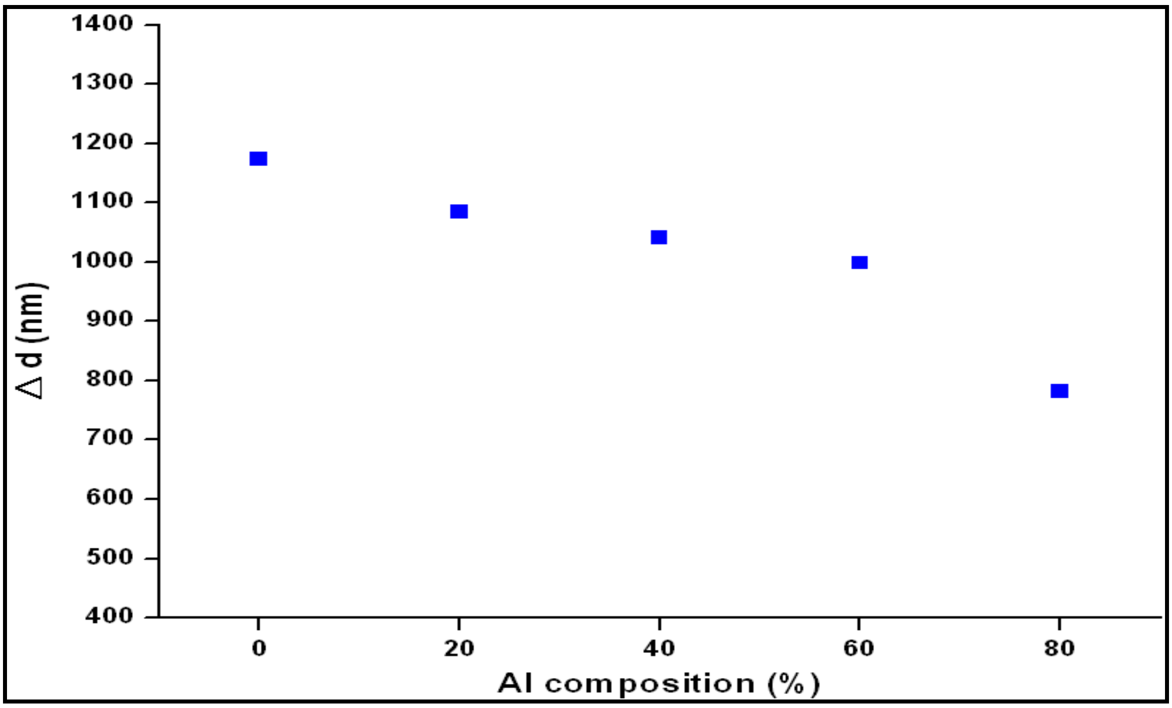

Fig. 6. Results of d-spacing obtained between Al_2O_3 and AlGaAs films having various Al compositions.

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