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Multi-Layered Structure of GaAs/ZnSe by Plasma-Assisted Epitaxy

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GaAs/ZnSe/GaAs double-layered structures on (100) GaAs substrates have been successfully fabricated at substrate temperatures as low as 375°C by plasma-assisted epitaxy (PAE). Thermal stability of ZnSe thin films at growth temperature of GaAs was clarified by photoluminescence (PL) measurement on ZnSe films annealed at 400-700°C. The mirror-face GaAs layers, which were shown to be epitaxial by RHEED and improved crystallinity by PL, were obtained on the ZnSe/GaAs structure at growth temperature of 420°C by PAE.

1. Introduction

Multi-layered structures of GaAs/ZnSe are of great interest for their application to electronic and optoelectronic devices including optoelectronic and high speed three-dimensional GaAs integraded circuits (3-D GaAs IC). These structures should be fabricated by lower-temperature processes than those which would be used for 3-D Si IC.

ZnSe is an attractive material for 3-D GaAs IC because it has good lattice matching to GaAs[1] and similar nature of chemical bonding with GaAs, compared with more ionic fluoride or oxide wide band-gap compounds. Moreover it can be highly resistive, depending upon the growth conditions[2]. The growth of ZnSe compound semiconductors, however, is more difficult than IV and III-V materials because the self-compensation effect by native defects or residual impurities, which are easily incorporated at high growth temperatures, prevents their electronic properties to be well controlled. The temperature of successive growth of GaAs has also to be low enough not to degrade the crystalline quality of ZnSe layers.

One of the important aspects in epitaxial growth of semiconductor crystals is a low temperature growth process for the fabrication of the controlled device structures. Plasma-assisted epitaxy (PAE) has been intended for epitaxial growth at low substrate temperatures by giving high chemical reactivity and enhanced atomic migration on the growing surface of crystal with the help of plasma. This low-temperature epitaxial-growth process has been successfully applied to grow GaAs, GaSb, ZnS and ZnSe epitaxial layers on (100)GaAs substrates[1,3-5].

In this paper, plasma-assisted epitaxy in hydrogen plasma is successfully applied to the successive growth of ZnSe and GaAs to fabricate GaAs/ZnSe/GaAs double-layered structures on (100) GaAs at the growth temperature as low as 375°C.

2. Plasma-Assisted Epitaxy

Experimental PAE apparatus and typical deposition conditions of ZnSe are already described else [1]. ZnSe layers are grown by the simultaneous supply of 6-nine Zn and 6-nine Se, which are evaporated by resistive heating, in hydrogen plasma which is held by rf power at 13.56MHz through capacitive coupling. The (100) p-type and semiinsulating GaAs substrates, after chemical etching to get mirror surface, were treated in hydrogen plasma to remove native oxide layers before the growth of ZnSe. GaAs layers are grown at the same way in the different apparatus from ZnSe's in order to prevent the incorporation of Zn and Se atoms to growing GaAs layers. Typical deposition conditions of GaAs in this experiment are shown in Table 1. Thicknesses of both ZnSe and GaAs are about 1μm in this experiment.

Table.1 Typical deposition conditions of GaAs

H_2 Pressure	$7.0\text{-}9.5\times10^{-2}$ Torr
RF Power for Etching	100-160W (30min)
for Growth	35 - 50W
Substrate Temperature	340 - 540°C
Ga Cell Temperature	870 - 940°C
As Cell Temperature	235 - 275°C

3. PAE of ZnSe thin films on GaAs substrate

Firstly ZnSe thin films have been epitaxially grown on (100) GaAs substrates by PAE in hydrogen plasma in the substrate temperature range of 170-440^{o}C. It was confirmed that the plasma is effective in increasing the growth rate, decreasing the temperature for epitaxial growth by about 100^{o}C with the growth rate around 1.5 μm/h and also in improving the crystallographic and photoluminescent properties.

Photoluminescence, which is very sensitive to the crystal quality and impurities, was employed to characterize the relation between the growth conditions and the quality of grown layers. PL of ZnSe was measured at 4.2K with the sample immersed in liquid helium. A 500W Xe lamp was used as an excitation light source by cutting off the light of wavelength longer than 400nm with a filter UVD-36A. PL measurement showed clear and improved exciton emission spectra, according to the optimization of the supply ratio Zn/Se and the substrate temperature.

The interface properties of GaAs/ZnSe heterostructures was investigated by comparing the emission intensities of photoluminescence from ZnSe-coated GaAs substrate. PL of GaAs was measured at 4.2K and excited by a CW argon laser at a wavelength of 514.5nm. Intensities of the band edge emissions from GaAs substrates are enhanced by the existence of ZnSe thin films on GaAs substrates. However, those from deep levels are almost constant whether GaAs is covered with ZnSe or not. This shows that surface property of GaAs is improved by epitaxially grown ZnSe thin films on GaAs substrate.

In order to investigate the thermal stability of these ZnSe thin films on GaAs substrates, PL spectra of ZnSe annealed for 10 min at temperatures ranging from 400 to 700^{o}C in hydrogen atmosphere, were compared. Fig. 1 shows the emission intensities of exciton bands, which are very sensitive to crystal quality, as a function of annealing temperature. Those emission intensities of ZnSe films grown at various temperatures kept almost constant up to 600^{o}C, while the emissions due to deep levels extin-guished. Therefore it is possible to grow GaAs thin films on the above ZnSe thin films without degradation because the typical growth temperature of GaAs is below 600^{o}C in PAE[4].

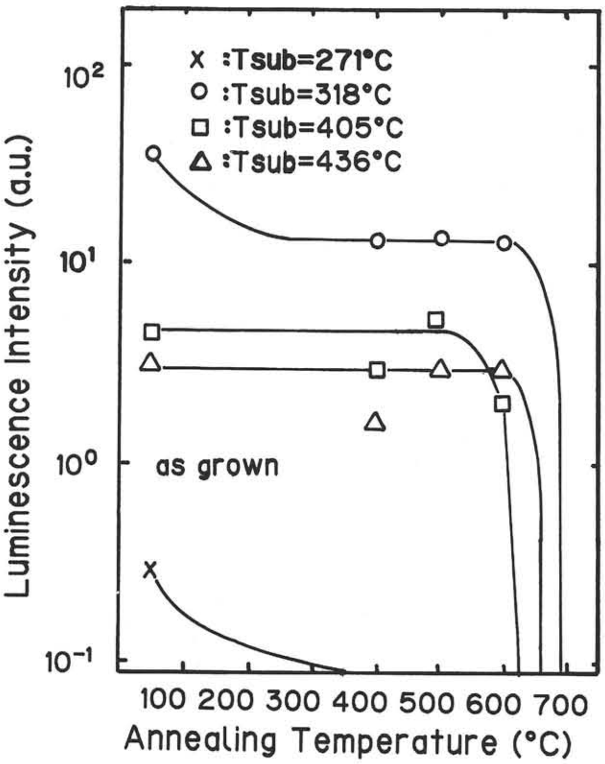

Fig. 1 The variation of photoluminescence intensities of ZnSe layers grown on GaAs substrate with variable substrate temperature as a function of annealing temperature. The intensities of exciton band, which are very sensitive to crystal quality of ZnSe layers, were measured.

Table 2 Half-widths of the X-ray locking curves of GaAs substrate and GaAs layers grown by PAE.

	Epitaxial Temp.	Half-Widths of (400)
GaAs Substrate		8.8"
GaAs/GaAs Sub.	550^{o}C	7.7"
GaAs/ZnSe/GaAs	420^{o}C	14.4"

4. PAE of GaAs thin films on ZnSe/GaAs structure

The successive growth of GaAs thin films on ZnSe/GaAs structure was achieved by the same PAE and mirror-face GaAs layers were obtained at growth temperature as low as 375°C. The crystallographic quality of the grown GaAs layers was characterized by X-ray diffraction, X-ray locking curve and electron diffraction measurements. The X-ray diffraction measurement for the GaAs layers grown at the substrate temperature ranges of 375-540°C shows that the GaAs layers are epitaxially grown on the GaAs substrate and the half-widths are same as the bulk GaAs substrate.

Table 2 shows the half-widths of the X-ray locking curve measurement of a GaAs substrate, a PAE-GaAs layer on GaAs substrate and a PAE-GaAs layer on a ZnSe/GaAs structure. The half-width of the GaAs layer grown on ZnSe/GaAs structure is a little larger than those of the GaAs substrate and/or the PAE-GaAs grown on GaAs. It may be due to the lattice mismatching between GaAs and ZnSe and the thinness of 1 μm thickness of GaAs layers. Therefore we believe that the crystallinity of the GaAs layer grown on ZnSe/GaAs structure will be as good as those of PAE-GaAs layers grown on GaAs substrate, if GaAs layer has proper thickness not to be affected by the lattice mismatching of the interface between GaAs and ZnSe.

Fig.2 shows the RHEED patterns of the GaAs layers grown on ZnSe/GaAs structures at the substrate temperature ranges of 375-540 °C. Those photographs indicate that epitaxial GaAs layers are obtained not only on a GaAs substrate but also on ZnSe/GaAs structure at the substrate temperature above 375°C. The weak ring pattern, for example shown in Fig.2(b), may be due to the surface oxidized layers of GaAs.

Fig.3 compares the PL spectra of GaAs layers grown with variable substrate temperatures. PL intensities of D-A emission from GaAs layers are increased, however, those from deep levels are decreased as the substrate temperature was increased. The GaAs layers grown on ZnSe have good PL properties when substrate temperatures are higher than 420°C.

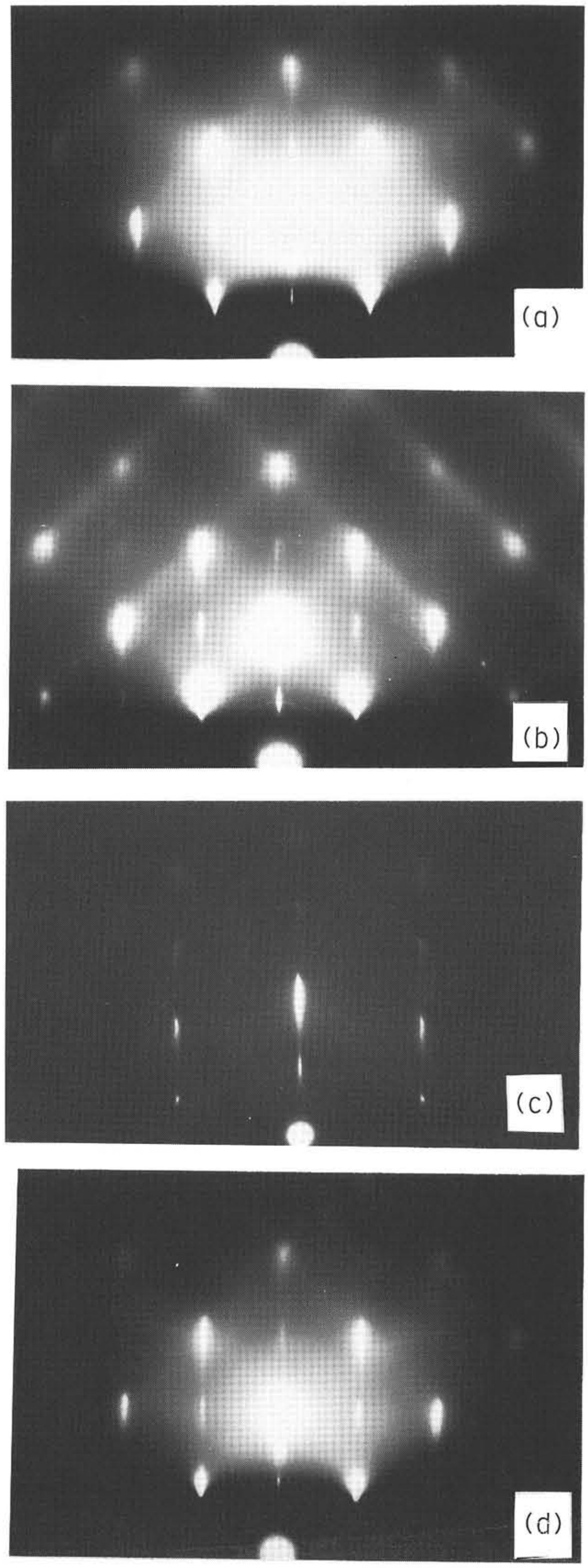

Fig. 2 RHEED patterns of GaAs layers grown by PAE in hydrogen plasma at the substrate temperatures of (a) 375°C on GaAs substrate, and (b) 375 °C, (c) 420°C and (d) 540°C on ZnSe/GaAs structures.

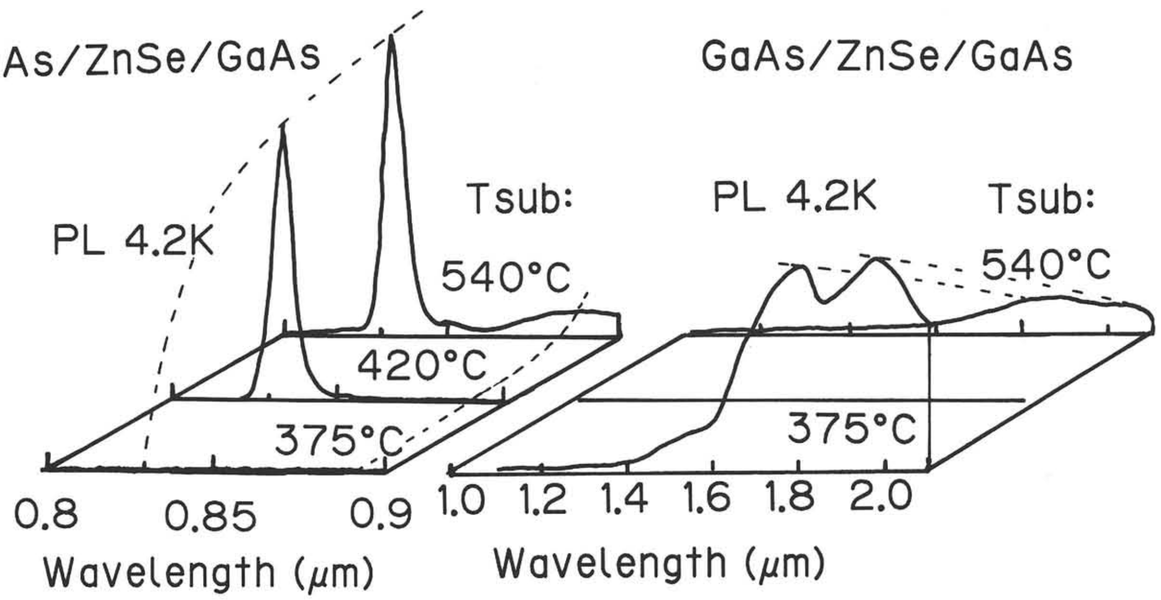

Fig. 3 Photoluminescence spectra of GaAs layers grown on ZnSe/GaAs structures at the substrate temperatures of 375°C, 420°C and 540°C.

5. Conclusion

GaAs/ZnSe/GaAs double-layered structures on (100)GaAs substrates have been successfully fabricated at substrate temperatures as low as 375°C by plasma-assisted epitaxy. Thermal stability of ZnSe thin films at growth temperature of GaAs was clarified by PL measurement on ZnSe films annealed at 400-700°C. The mirror-face GaAs, which were shown to be epitaxial by RHEED and good crystallinity by PL, was achieved on the ZnSe/GaAs structure at growth temperature of 420°C by PAE. Plasma-assisted epitaxy in hydrogen plasma would be then very promising technology to fabricate multi-layered or 3-D GaAs structures because of its capability of low temperature epitaxial growth of compound semiconductors as well as the low temperature surface cleaning by hydrogen plasma.

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