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Abstract Device quality epitaxial layers of undoped GaAs were grown by the MOCVD technique, on both semi-insulating and semiconducting GaAs substrates with (100) orientation, offset by 2 degrees towards the (110) direction. Systematic variation of the As/Ga ratio was performed to gain an understanding of the growth process, the type of formation and other related physical properties. The films were characterized using a variety of techniques, such as SEM, EDAX, HRTEM, XRD, and PL. Optical and electrical properties of undoped GaAs epilayers are presented with reference to the growth conditions and AsH/sub 3//TMGa ratio. Photoluminescence measurements of GaAs epilayers were recorded at 4.2 K and show the emission of free excitons and confirmed their high purity. The dominant residual impurities in GaAs are presented using PL. Finally, electrochemical depth profiling exhibited almost homogeneous background carrier distribution and excellent abruptness between the thin GaAs epilayer and the substrate. Abstract no. A9706-8115H-003B9703-0510D-084.

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Subjects carrier density
excitons
gallium arsenide
III-V semiconductors
interface structure

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scanning electron microscopy
semiconductor epitaxial layers
semiconductor growth
transmission electron microscopy
vapour phase epitaxial growth
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Chemical Indexing	GaAs/int As/int Ga/int GaAs/bin As/bin Ga/bin. GaAs/sur As/sur Ga/sur GaAs/bin As/bin Ga/bin
Numerical Indexing	temperature 4.2E+00 K
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GROWTH AND CHARACTERIZATION OF GaAs EPITAXIAL LAYERS BY MOCVD

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ABSTRACT

Device quality epitaxial layers of undoped GaAs were grown by MOCVD technique, on both semi-insulating and semi-conducting GaAs substrates with (100) orientation, offset by 2° towards (110) direction. Systematic variation of As/Ga was performed to gain an understanding of growth process, type of formation and other related physical properties. The films were characterized by using the variety of techniques, such as SEM, EDAX, HRTEM, XRD, and PL. Optical and electrical properties of undoped GaAs epilayers are presented with reference to the growth conditions and AsH_3/TMGa ratio. Photoluminescence measurements of GaAs epilayers were recorded at 4.2K and shows the emission of free exciton and confirmed their high purity. The dominant residual impurities in GaAs are presented by using PL. Finally, electrochemical depth profiling exhibited almost homogeneous background carrier distribution and excellent abruptness between the thin GaAs epilayer and substrate.

INTRODUCTION

Metal Organic Vapor Phase Epitaxy (MOVPE) is widely used for the epitaxial growth of GaAs and related III-V compounds and their heterostructures. In particular, the use of such high quality epilayers, an optoelectronic, microwave, and high speed digital circuits[1] has given very excellent results. In addition, this family(AlGaAs/GaAs) of compounds also promise number of interesting properties such as high mobility, resonant tunneling, and fractional Hall effect etc. Numerous attempts have been made for developing epitaxial layers of GaAs, AlGaAs and to apply the MOVPE layers to development of advanced devices ,such as, high electron mobility transistors (HEMTs)[2], multiple-quantum well (MQW)[2] and other electronic and optoelectronic devices. With all the success in the area of device development, the optimization process for obtaining high quality GaAs epilayers still remains unsolved. It has not been clearly understood what are the limiting factors that determine the layer quality. In order to achieve good performance of the device, high quality epitaxial layers are essential to satisfy the device requirements. Present paper reports the results from the growth and characterization of undoped GaAs epilayers and discusses a close process-property correlation.

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EXPERIMENTAL

Undoped GaAs epitaxial layers were grown in a low pressure horizontal MOCVD reactor. The source materials were palladium-purified H_2, Trimethylgallium(TMGa) and Arsine(AsH_3, 100%). Both semi-insulating (Cr-doped) (100) GaAs and Si-doped n^+-GaAs (100) substrates misoriented towards [110] direction offset by 2°, were used for epitaxial growth process. Each substrates was thoroughly degreased and cleaned and given a brief 1:1:10 H_2O_2:H_2SO_4:H_2O to remove surface oxide and residual contamination. Prior to initiation of growth and after the temperature of the susceptor reaches 350°C, AsH_3 flow was initiated to avoid arsenic escape from the substrate and was maintained throughout the growth process. Once the desired temperature was reached, TMGa was introduced into the reaction chamber to initiate growth. The growth rate was linearly dependent on the flow rate of TMGa in the growth chamber. For reduced pressure growth, the exit of the reactor was connected to the high capacity vacuum pump. The pressure in the reactor tube was maintained at 100 Torr. After the completion of growth, the flow of TMGa was cut-off and AsH_3 flow was maintained until the temperature cooled below 350°C. The unspent reactants were cracked by using cracking furnace at a temperature of 800°C and the process gasses were allowed to go directly to the activated charcoal scrubber. The total flow rate was about 2.5 SLPM. The V/III ratios of the samples were varied from 21 to 80.

Photoluminescence (PL) measurements were carried out at 4.2K using a MIDAC Fourier Transform PL (FTPL) system. An Argon ion laser operating at a wavelength of 5145A° was used as a source of excitation. The exposed area was about 3mm^2. PL signal was detected by a LN_2 cooled Ge-Photodector whose operating range is about 0.75-1.9eV, whole resolution was kept at 0.5meV.

RESULTS AND DISCUSSION

The undoped GaAs epilayers were characterized in terms of structures, surface morphology, optical and electrical properties.

Surface Quality

The surface of epilayers is greatly influenced by the growth parameters, such as, pressure inside the reactor tube, growth temperature, substrate orientation, AsH_3/TMGa mole ratio[3] etc. In the case of growth on (100) oriented GaAs substrates, mirror-like surfaces as viewed by the naked eye can be obtained over a wide range of V/III ratios. But by using optical microscopic observation some of the samples shows the white spot on the surface, may be considered as hillocks. Since the temperature of the growth process was kept at 700°C, the mirror-like surfaces, as viewed by naked eye on (100)GaAs was obtained.

Some of the samples were grown under constant AsH_3 flow rate, the stoichiometry of the samples was found to be unchanged, as observed by Energy Dispersive Analysis of X-rays (EDAX). The other sets of samples were grown by varying the AsH_3 flow rate while the TMGa flow rate kept constant. In this case the stoichiometry of samples was found to be changed. The thickness of each layer was varied by varying TMGa flow rate, and the typical growth rate was about 20A°/sec. The thickness was measured by cross-sectional Scanning Electron Microscopy (SEM). Cross-sectional SEM (Fig.1) studies on undoped GaAs films exhibit a uniform smooth surface, a dense cross-section and a clear

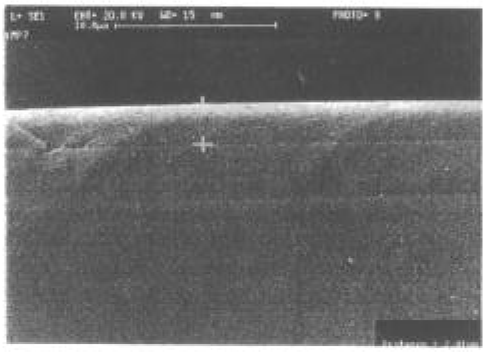

Fig.1: Cross-sectional SEM pattern of epi-GaAs film/substrate

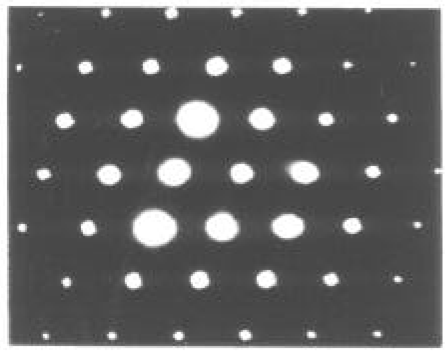

Fig.2: Selective area diffraction pattern of epi-GaAs film.

interface between the film and substrate. The compositional homogeneity of the films was quantified in terms of estimating the Ga/As ratio, using EDAX analysis. Results indicated a near stoichiometric Ga/As ratio, irrespective of the flow ratios of incoming gas precursors.

Besides conventional structural studies by using Double Crystal X-ray Diffraction (DCXRD), the epitaxial growth of the films was established by High Resolution Transmission Electron Microscopy (HRTEM) selective area diffraction studies, and the typical data is presented in Fig.2. It was observed by lattice indexing that our MOCVD growth layers of GaAs, in the present growth conditions, clearly exhibits epitaxial growth in (100) direction normal to the substrate surface. The film was further envisaged in terms of observing the lattice imaging by HRTEM, to visualize the atomic arrangement. The results are shown in Fig.3, for a typical film, which clearly exhibited a lattice for GaAs, consistent to give zinc blend structure.

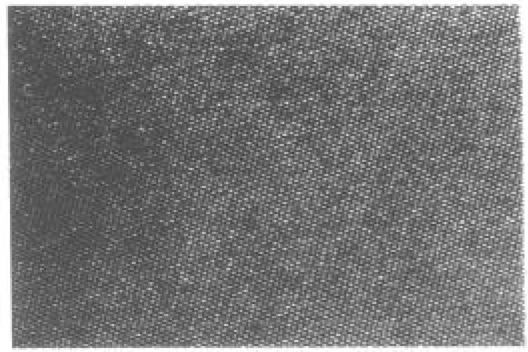

Fig.3: HRTEM lattice imaging of epi-GaAs film.

Optical Properties

The Photoluminescence (PL) spectroscopy is used for concerning the type, distribution of defects and impurity in a crystal. Typical photoluminescence spectra observed in the near band-edge region can be seen in Fig.4. Two characteristic photoluminescence bands were obtained from all the samples: the exciton complexes and the acceptor related transitions. In the exciton related region, these peaks are identified as the radiative recombination of a free exciton (FE) (1.5151eV), exciton bound to neutral donor (D^o,X)(1.5141eV),an ionized donor (D^+,X)(1.5133eV), and exciton bound to neutral acceptor(A^o,X)(1.5125eV). Since the emission due to the free exciton was observed from our samples, it confirmed their high purity[4,5].

The other photoluminescence bands were observed around 1.49eV(GaAs acceptor related region). The FWHM of this band was 3.0meV. Two of the more common impurities incorporated during the MOCVD growth of undoped GaAs epilayer are identified C and Zn[6]. The photoluminescence peaks at 1.490 eV and 1.4933eV(weak shoulder compared to peak intensity at 1.490eV at 4.2K) are due to the donor-to-acceptor transition (DA) and the conduction band-to-acceptor (also called free -to-bound, FB) transition, respectively. At very low temperatures(e.g.4.2K), the donor originated transition (DA) dominate over the conduction band originated transition (FB) and when the temperature is increased from 4.2K, DA pair intensity decreases rapidly because of the donor ionization energy.

To observe the effect of V/III ratios on impurity incorporation in GaAs epilayers, we have shown in Fig.5 the peak intensity of the(D^oA^o) t transition due to carbon and the peak intensities of the (D^o,X) and (A^o,X) as a function of V/III ratios. From the figure it is seen that the intensities of the luminescence lines due to the (D^oX), (A^oX), and (D^oA^o)(C) are strongly dependent on the V/III ratios. The intensity of the D^oA^o(C) transition

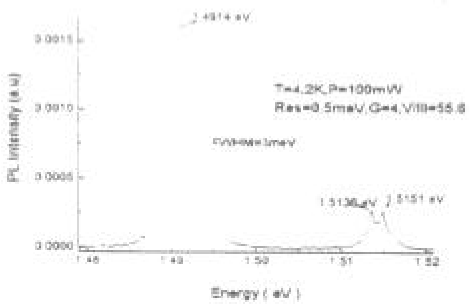

Fig.4: PL spectrum of MOCVD grown epi-GaAs film.

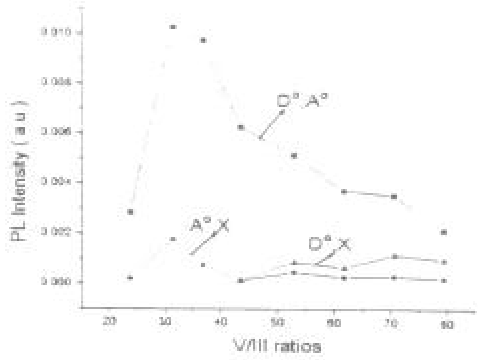

Fig.5: PL intensities of (D°A°), (A°X), (D°X) vs. V/III ratios

decreases with increasing V/III ratio, which is expected since C substitutes on As site as an acceptor. Nevertheless, the donor/acceptor exciton ratios increases with increasing V/III ratios indicating more donor incorporation and hence more n-type behavior. Therefore, the density of C atoms incorporated in epilayers is low under our growth conditions. Similar behavior was observed in GaAs films at 50Torr growth pressure.

Electrical Properties

Electrical characterization can give considerable information about the purity of the epitaxial layers. Such information is important for the growth process as well as the high quality epitaxial layers for device applications. Hall effect by Van der Pauw method was utilized to measure carrier concentration and mobility of the epitaxial films at room temperature. The measured carrier concentrations and room temperature mobilities of n-type and p-type samples are 10^{15} cm^{-3}, $4500 cm^2/V$-sec at V/III=55.6 and $7*10^{15}$ cm^{-3} $400 cm^2/V$-sec (V/III=21), respectively. The electrical properties of GaAs epilayers vary with V/III ratios, as illustrated in Fig.6. At low V/III ratio, the sample is p-type and converts to n-type at higher ratios which is consistent with the literature[6] and also can correlate with PL spectra at 4.2K.

Electrochemical Capacitance-Voltage (ECV) profiler was used to determine the carrier concentration of undoped GaAs layers, type of formation and abruptness between the 3.5μm thin GaAs epilayer and substrate. The results are presented in Fig.7, which clearly establish an abrupt and unreacted interface, which is an essential requirement for

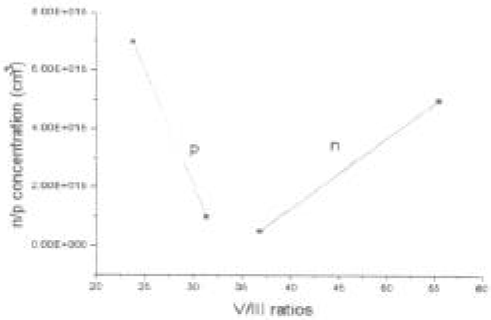

Fig.6: n or p (cm^{-3}) vs. V/III ratios.

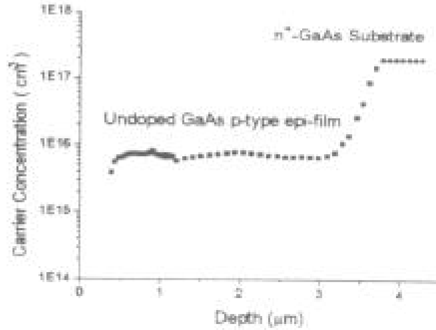

Fig.7: ECV depth profiling of back ground impurity for MOCVD grown epi-GaAs film.

multilayer structure development, such as in heterostructure lasers, MQWs and optoelectronic devices.

CONCLUSION

Device quality epilayers of undoped GaAs were grown by MOCVD, with excellent smooth surface of n and p type films were successfully grown, by varying As/Ga mole ratios. Studies of photoluminescence at 4.2K indicates the emission of free exciton and confirmed the high quality of the films. Epitaxy was confirmed by HRTEM selective area diffraction and lattice imaging. Electrochemical depth profiling exhibited homogeneous background carrier distribution and excellent film/substrate interfaces.

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