OMVPE Growth and Characterization of Undoped and Si Doped GaAS Epitaxial Layers on Ge

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Abstract

Low Pressure Organometallic Vapor Phase Epitaxy (LP-OMVPE) growth of undoped and silicon doped epitaxial GaAs on Ge was carried out with a variation in growth temperature and growth rate. In case of both the undoped and doped GaAs, A-B etch confirmed the absence of anti phase domainx(APDs). Double Crystal X-ray Diffraction (DCXRD) indicated that the epilayers are compressive in nature and the full width at half maxima (FWHM) for Si doped samples increased with increasing growth rate and decreased with increasing growth temperature. For the undoped GaAs, the photoluminescence(PL) showed an acceptor bound excitonic peak (A^0X transition) at 1.5125 eV along with the LO phonon replicate of the acceptor bound exciton band at 1.4749 eV. The PL spectra from the Si-doped GaAs showed two hole transition of Si acceptor levels corresponding to an energy level of 1.4866 eV along with the excitonic peak at 1.507 eV. This result confirms the absence of outdiffusion of Ge into GaAs in our present growth process. The ECV data reveals a npn structure where the p region is in GaAs and may be due to As vacancies created by the indiffusion of As into Ge substrate. The Ge substrate was found to be heavily doped with As in the range of 10^{19} cm^{-3}.

A. Introduction

GaAs solar cells offer the highest efficiency demonstrated to date for space applications[1]. In terms of power-to-weight ratio, GaAs on Ge can outperform GaAs on GaAs solar cells in space applications. Furthermore, the reverse breakdown voltage of GaAs cells grown on Ge substrates is lower than that of GaAs cells grown on GaAs substrates, which can reduce the cell degradation caused by large reverse currents[2].

The use of Ge instead of GaAs substrates involves materials growth issues like the growth of polar semiconductors on nonpolar substrates, GaAs doping by Ge, Ge doping by Ga and As. The slight charge imbalance between the Ge and GaAs has been reported to form Anti Phase Domains(APDs) which are small areas resembling polycrystalline grains which reduce the electronic quality of GaAs layers grown on Ge. The p-n junction in the Ge is created by diffusion of Ga and As into the Ge during the GaAs cell growth. This results in a shallow p-n junction (called active-Ge), just below the GaAs epilayer which contributes extra photovoltage in cascade with the GaAs p/n junction. However, this active-Ge structure does not provide any extra power output and, in fact, reduces the total efficiency[2].

In this work, we have studied the effects of LP-OMVPE growth conditions on the interface properties of both the undoped and Si doped epilayers of GaAs on both the Ge and GaAs substrates. Attempts have been made to grow GaAs on Ge which is free from APD's and possesses passive GaAs on Ge junction.

B. Experimental Details

Growth of undoped and Si doped epitaxial GaAs layers was carried out in a horizontal low pressure organometallic vapor phase epitaxy (LP-OMVPE) reactor at 100 Torr using high purity hydrogen as the carrier gas and Trimethylgallium(TMG) and 100% Arsine(AsH_3) as the group III and group V sources respectively with Silane (SiH_4) as the Si dopant gas. Sb doped Ge substrates of (100) orientation 6° off towards <110> were used for the growth process. Details of the growth procedure can be found elsewhere[3]. Doping studies were carried out with a variation in temperature from 600 to 725 °C and TMG mole fraction was varied between 8.92×10^{-5} and 2.67×10^{-4}.

In order to investigate the epilayer quality and the GaAs/Ge interface, the epilayers were subjected to various characterization techniques viz., A-B etch, Double Crystal X-ray Diffraction (DCXRD), low temperature photoluminescence (LTPL) using Argon ion laser and the Electrochemical CV(ECV) profiler.

C. Results and discussions

(I) A-B etch studies

A-B etch revealed the etch pits in our samples and this can be seen from Fig.1. TimÓ et. al.[4] observed similar results under higher growth rate conditions. Mizuguchi et. al. [5] reports of APD's on GaAs grown on Ge of exactly (100) orientation. There, the hexagonal etched slots are clearly seen and the patterns are typical APD's in which small regions have two different orientations. The directions of hexagonal etch pit of neighboring domains are at right angles. Our figure shows typical etch pattern of an epitaxial GaAs/Ge layer and all the pits are oriented in the same direction. This result confirms that the GaAs layers grown on 6° off oriented(100) toward (110)Ge substrate consists of single domain.

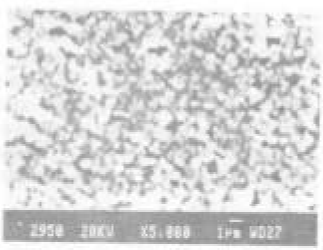

Fig.1. AB etch plot of a GaAs/Ge sample

(II) DCXRD

Before growing Si doped GaAs on Ge we confirmed the epitaxial nature of undoped GaAs on Ge. The GaAs epilayer peak appeared on the right side of the Ge peak which is in accord with the fact that the GaAs epilayer lattice constant is higher than that of the Ge. The FWHM corresponding to the GaAs layer was around 45 arc sec which proved that the epilayer quality was of a high order.

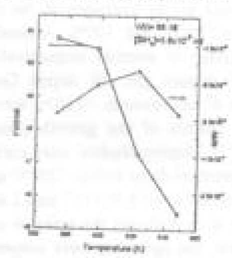

Fig.2. DCXRD plot showing the variation of FWHM and compression with growth temperature of Si doped GaAs/Ge.

For the Si doped GaAs, the FWHM reduced with higher growth temperature as also with lower TMG mole fraction. The compression initially increases and then decreases with growth temperature (Fig.2). Eres et. al. [6] report that the FWHM of Ge(400) diffraction lines of both slowly and rapidly grown films were broadened. If instrumental broadening is neglected, the major contributions to broadening would be due to diffraction from a finite number of lattice planes (particle size broadening) and dislocations.The reduction in FWHM with growth temperature may be due to slips occuring as a result of plastic deformation when the stress due to differential thermal expansion exceeds the critical yield stress of Ge. This shows that at least for some purposes, it is wrong to assume that the small differences between the lattice constants and thermal expansion coefficients of Ge and GaAs can be neglected.

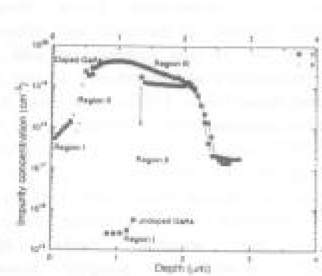

Fig.3. ECV profile of undoped and doped GaAs/Ge.

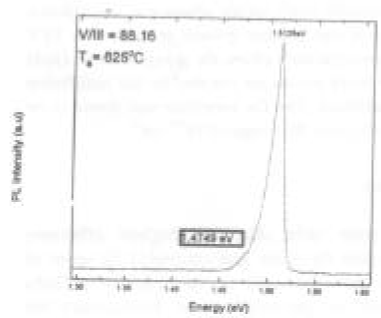

Fig.4. PL spectra of undoped GaAs/Ge.

(III) Photoluminescence:

The photoluminescence studies have been carried out both on the sample surface and after etching some thickness of the epilayer as per the regions defined in Fig(3). The region I corresponds to the n-type epilayer GaAs, the region II is p type GaAs (confirmed by photovoltage spectroscopy measurements) and the region III is Ge substrate. For the undoped GaAs, the PL spectrum (Fig.4) from the region I showed an acceptor bound excitonic peak (A^0X transition) at 1.5125 eV along with the LO phonon replicate of the acceptor bound exciton band at 1.4749 eV[7]. The FWHM of photoluminescence peaks were around 10.3 meV which indicated the GaAs epiaxial layers were high quality. There were no Ge related peaks i.e., (e,Ge^0_{As}) transition were not observed in this spectrum. This confirmed that there was no Ge outdiffusion into GaAs in our present growth conditions. The photolumiscence spectrum correspondimng to the region II for undoped GaAs was taken after etching about 0.3 µm. The PL peak was at 1.516 eV with a FWHM of 13.2 meV which corresponded to the free excitonic emission. This p type region may be believed to be due to the As vacancies in the epilayer caused by indiffusion of As into the Ge substrate. The PL spectra (Fig.5) for the surface of the Si doped GaAs showed two hole transition of Si acceptor levels corresponding to an energy level of 1.4866 eV [8] along with the excitonic peak at 1.507 eV with a FWHM of 7 meV. The PL spectrum for the region II also showed the same peaks as we obtained in region I. This PL spectrum suggested that there was no Ge out diffusion from the substrate. Similar results have been observed by Fischer *et al* [7] in the molecular beam epitaxy (MBE) growth process.

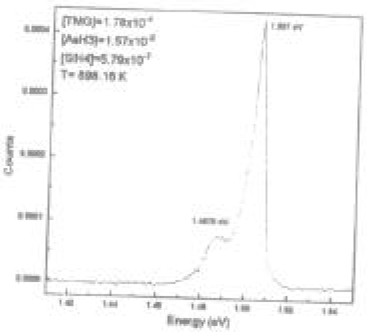

Fig.5. PL spectra of Si doped GaAs/Ge.

(IV) ECV profile

As shown in the Fig.3 , the ECV plot for both the undoped and doped GaAs on Ge, there are three clearly defined regions. Region I correponds to the surface of the GaAs epilayer which was n-type. Region II was p-type; as per Photovoltage spectrum (not shown), this is GaAs. Region III was n-type Ge substrate; it can be seen that this part of the substrate adjacent to the GaAs epilayer is heavily doped n type with As. N. Chand et. al. [9] report thyristor like npnp structure for MBE growth of n-GaAs on p-Ge substrate. They show that Ge from the substrate diffuses into the growing GaAs layer and As from the GaAs into the Ge substrate inverting the Ge surface from p to n type. If Ge in GaAs is occupying As sites (As vacancies being created by As indiffusion into Ge), Ge will behave as a p dopant in GaAs. This phenomenon will result in an npnp thyristorlike structure with no gate as proved by electrical and optical characteristics. However, in our case, although there was As out-diffusion into Ge, no out-diffusion of Ge into GaAs had taken place. This was confirmed by PL measurements.

D. Conclusions

Epitaxial growth of both the undoped and doped GaAs on Ge by LP-OMVPE technique has been carried out. The AB etch studies revealed etch pits and clearly indicated that all the etch pits were oriented in the same direction. This result further confirms that the GaAs layers grown on 6° off (100) toward (110) Ge substrates consist of single domain. The DCXRD results confirmed compressive GaAs on Ge as also indicated better nucleation at lower growth rates. The PL spectra indicated the absence of Ge out-diffusion into GaAs. The ECV profile revealed an npn structure with the p type region being loated in the GaAs at the GaAs/Ge heterointerface. This p type conductivity may be due to the As vacncies created by the indiffusion of As into Ge during the growth process.

E. References

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