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Effect of growth parameters on the MOVPE of GaAs/Ge for solar cell applications

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Abstract

GaAs has been grown on Ge substrate oriented 6° off towards (1 1 0) by atmospheric pressure MOVPE. Various growth rates and growth temperatures were tried to get device quality epitaxial layers suitable for solar cell applications. It was observed that the growth temperatures and the growth rates affect the surface morphology, optical and interface properties and crystalline quality of the epitaxial layers. This was studied using optical microscope, photoluminescence, photovoltage measurements, ECV and double crystal X-ray diffractometry. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

In past few years GaAs/Ge material system have attracted considerable attention due to its close matching in lattice spacing (0.12%) and thermal expansion. But, very little work is done for MOVPE grown materials specially for studying the effect of growth conditions on interface properties and epilayer quality. Ge has higher mechanical strength as compared to GaAs and therefore thinner Ge substrate can be used, resulting in lighter weight cells. In terms of power/weight ratio, GaAs/Ge solar cells can outperform GaAs/GaAs for space applications. GaAs/Ge cells also have lower reverse breakdown voltage, which can reduce the cell degradation caused by large reverse currents.

Recently, high efficiency GaAs solar cells on Ge substrate have been reported [1–4]. The growth of good quality GaAs epitaxial layers on Ge substrate require highly

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controlled growth conditions, as there is slight lattice mismatch in GaAs and Ge and it also involves the growth of polar GaAs on non-polar Ge substrate. Some growth conditions results in active Ge in which extra photovoltage can be generated at the GaAs/Ge interface (called active interface) [4,5], in tandem with the GaAs p–n junction, when the GaAs p–n junction is grown on a n-type Ge substrate. This arises because Ga has higher solid solubility than As in Ge, diffuses to the Ge and behave as a p-type dopant for Ge. However, this active Ge structure does not provide any extra power output and infact either reduces or does not change the total efficiency. Careful studies show that some of the projections of air-mass-zero (AMO) efficiencies were high mainly due to the inaccurate simulated AMO spectrum. When realistic AMO spectra are used, the tandem cells shows the "kink" in the I–V curve which results in a significant decrease in the fill-factor with a decrease in the efficiency. This "kink" in the I–V curve appears due to insufficient carrier generation in the Ge when illuminated with realistic AMO spectra. As a result, the GaAs/Ge interface generates less current than the GaAs p–n junction and in operation, the GaAs/Ge cell is driven into reverse bias, leading to a kinked I–V curve. In case of other growth conditions, extra photovoltage is not generated at the interface (called passive) and Ge acts only as a robust substrate. Such a passive interface is preferred for solar cell fabrications.

Though high efficiency GaAs/Ge solar cell on passive Ge substrate have been reported, however, detailed study of growth conditions which control the interface and epilayer quality are scantily available. In this paper, we present the effect of growth conditions on interface properties and epilayer quality for high efficiency solar cells.

2. Experimental

An atmospheric pressure, horizontal MOVPE reactor was used to grow GaAs epitaxial layers. The graphite susceptor, which can hold upto 1 inch diameter wafer, was heated using RF system. The reactants used were trimethylgallium (TMGa) as group-III material and pure arsine (AsH_3) as group -V material. DEZn and SiH_4 were used as p- and n-type dopant sources, respectively. The ultrapure H_2 was used as a carrier gas as well as for purging the system. The n-type Ge substrate having orientation (1 0 0) 6° off towards (1 1 0) were used to grow GaAs epitaxial layers. Total flow rate was kept at 4 SLM and V/III ratio was maintained to 50. Prior to growth, the Ge substrate were degreased with organic solvent, then etched by an etchant $HF : H_2O_2 : H_2O$ (1 : 1 : 5) for 2 min, and finally etched in dilute HF to remove surface oxide. Prior to loading into the reactor, the substrates were dried by blowing dry N_2.

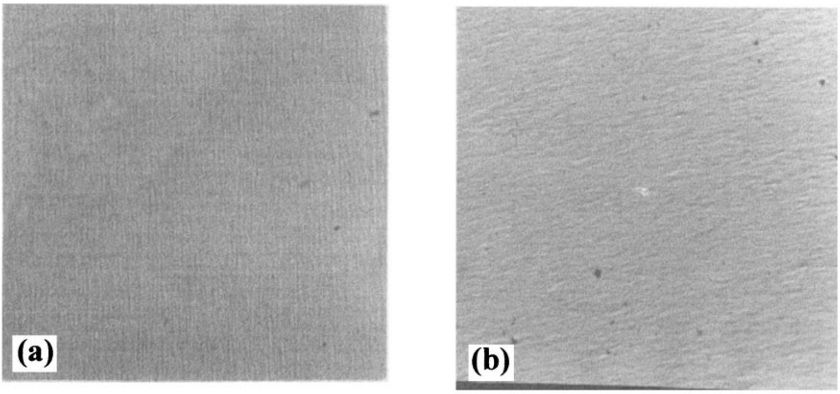
Two sets of experiments were carried out to grow n-GaAs epitaxial layers ($t \approx 3$ μm) on Ge substrate. In one of them the layers were grown in a single step at different temperatures (620°C, 640°C, 660°C, 680°C and 700°C) keeping the growth rate fixed at 4 μm/h. While in another, two step growths were carried out, in which the first layer ($\approx$ 1000 Å) were grown at the rate of 1 μm/h at the growth temperature of

620°C, 640°C, 660°C, 680°C and 700°C. The second step were grown at 660°C using 4 μm/h growth rate.

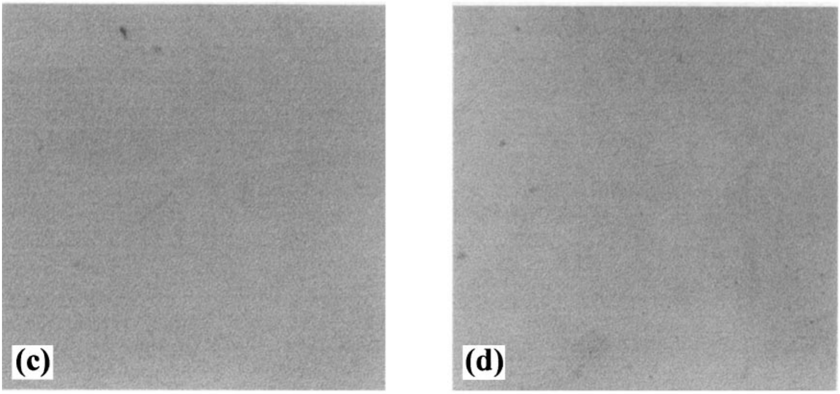
3. Results and discussion

3.1. Surface morphology

The surface morphology was studied using optical microscope. The growth temperature below 640°C and above 680°C yielded rough surfaces for single-step growth. The epilayers grown at 660°C (Fig. 1a) shows a cross-hatch pattern indicating that the



Single step growth



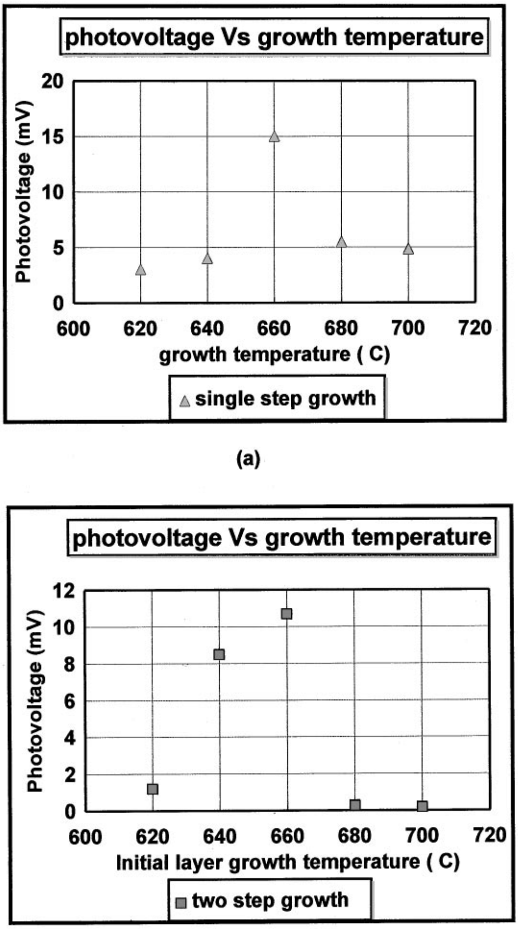
Two step growth

Fig. 1. Surface morphology of the GaAs/Ge layers grown in the single step at 660°C (a), 680°C (b) and in two step at 660°C (c) and 680°C (d).

stress is completely relieved by creations of misfit dislocations. This morphology is preferred for solar cell fabrication in contrast to the rough surfaces. The surface morphology of the sample grown at 680°C shows slightly patterned surface as shown in Fig. 1b. However, in case of two-step growth shiny mirror-like surfaces were obtained for growth temperatures of 660°C and 680°C (Fig. 1c and d).

3.2. Interface properties

Photovoltage measurements were carried out to investigate interface properties of these layers grown under variety of growth conditions such as growth temperature



(a)

(b)

Fig. 2. Photovoltage measurements of GaAs/Ge layers grown in single step and two steps growth at different temperatures.

and growth rate, in a single-step as well as two-step growth. This was done by making ohmic contacts on both sides of the sample and then photovoltage measurement was done across GaAs/Ge junction/interface by shining light of photon energy < 1.42 eV on the samples. Fig. 2a shows the results of photovoltage measurement from the samples grown in a single step at different growth temperatures. As can be seen, samples grown at 660°C shows photovoltage, indicating that the junction is active. Though this value is much smaller than the photovoltage reported in literature for active junction. On the other hand samples grown at 620°C, 640°C, 680°C, and 700°C show passive nature of GaAs/Ge interface. PV measurement on samples grown in a two-step process (Fig. 2b) follow the same trend as in a single step except that sample grown at 640°C initial layer growth temperature also becomes active.

The interface type (passive or active) was also studied using Polaron PN-4300 ECV profiler. Fig. 3a shows that the layers grown at 660°C have a thin p-type region at the interface, indicating that the interface is active, while the layers grown at other temperatures result in passive interfaces as no p-type region were observed at the interface (Fig. 3b).

3.3. X-ray studies

Double crystal X-ray diffraction (Bede Scientific Instrument Ltd, UK QC-1a) with Cu $K_{\alpha}(\lambda = 1.54\ \text{Å})$ radiation and (0 0 4) reflection was used to study the crystal quality of the GaAs epitaxial layers grown on Ge substrate. Fig. 4 shows the rocking curve of epilayers grown at 660°C. The FWHM of the layers grown in two steps (Fig. 4b) is less than the FWHM of the layer grown in a single step (Fig. 4a) indicating a superior crystal quality in case of a two-step growth. Two-step growth results in a better

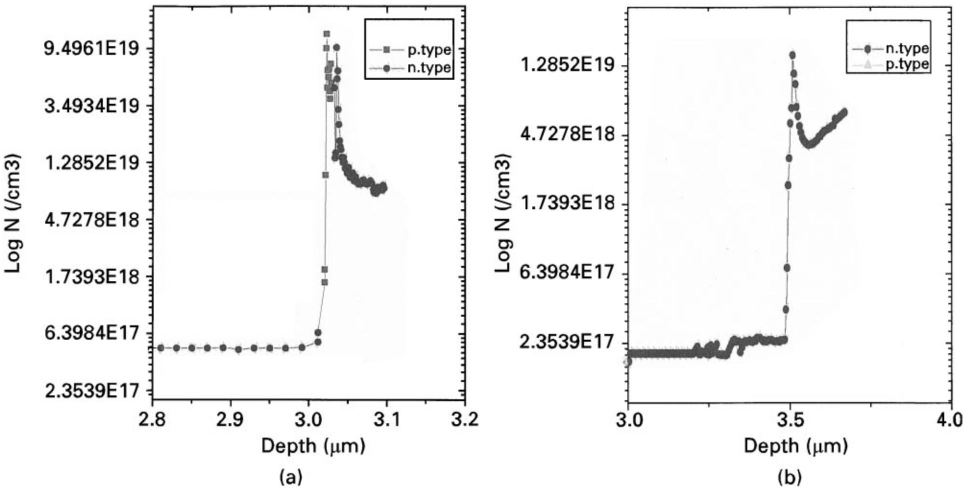


Fig. 3. ECV profiles of GaAs/Ge layers grown at initial layer growth temperature a. 660°C and b. 680°C.

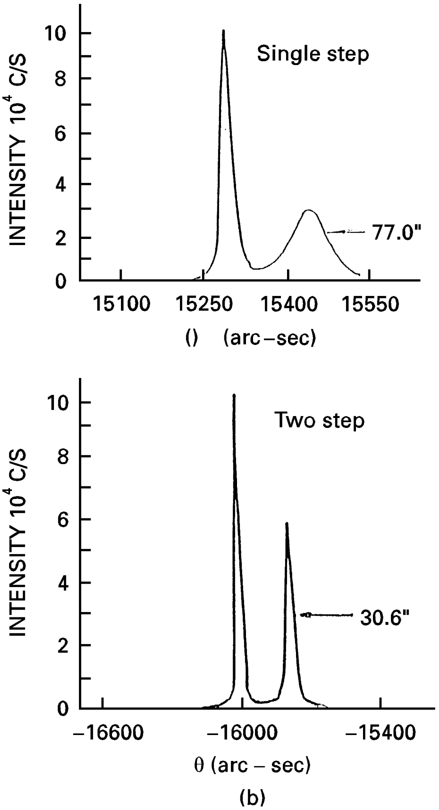


Fig. 4. X-ray rocking curve of GaAs/Ge layers grown at 660°C.

quality epitaxial layers as compared to a single-step growth probably because when the first thin layer was grown at a slower growth rate, the atoms get sufficient time to reach to their respective sites thereby reducing defects and APDs, if any, at the interface.

3.4. Optical properties

The optical quality of these GaAs epitaxial layers grown on Ge was studied by photoluminescence (PL) measurements at 17 K using a 488 nm Argon ion laser. Samples grown at temperature below 620°C and above 680°C show poor PL thereby indicating poor optical quality. Fig. 5 shows the PL spectra of GaAs layers grown by a single-step process at 660°C and 680°C. The PL spectra of the layers grown at 660°C has two peaks at 1.504 and 1.514 eV, with total FWHM = 32 meV, not resolved completely. The peak at 1.504 eV can be assigned to a defect bound exciton and at 1.514 eV due to bound exciton indicating a very good optical quality. While PL spectra of the layers grown at 680°C shows only one peak at 1.506 eV

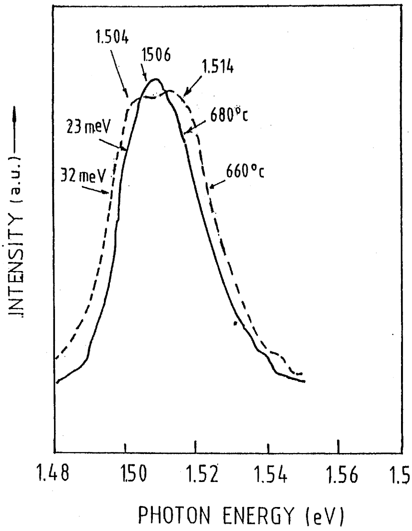


Fig. 5. Photoluminescence spectrum of GaAs/Ge layers at 17 K.

(FWHM = 23 meV) and could also be related to a defect bound exciton. This result indicates the optical quality of layer grown at 660°C is superior to the layer grown at 680°C.

4. Conclusion

It is clear from the above results that only certain growth conditions will produce GaAs epitaxial layers with good surface morphology, optical and crystal quality with passive interface on Ge substrates. The growth temperatures and growth rates are the important parameters which influence the ultimate epilayer quality. However, good quality epilayers with passive interface could be obtained with initial deposition of 1000 Å GaAs at 1 μm/h growth rate at 680°C and subsequent growth at 4 μm/h at 660°C.

High efficiency GaAs/Ge Solar cells have been fabricated using a two-step growth process at 680°C initial layer growth temperature.

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