Ga and As codiffusion in HgCdTe

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Abstract-Diffusion and electrical behaviour of Ga and As atoms in HgCdTe epilayers from GaAs wafers placed in contact has been studied with heat treatment in 200-420°C range under Hg-saturation conditions. The Ga and As concentrations have been determined using Secondary Ion Mass Spectrometry (SIMS) depth profiling. The atomic concentrations were deduced from secondary ion yield using predetermined relative sensitivity factors with respect to $^{130}Te^{+}$ ion yield. Variable field Hall/Resistivity measurementswere carried out in the temperature range 1.7-300 K to obtain longitudinal and transverse resistivity components. Experimental data fitted with Multicarrier fitting (MCF) algorithm to obtain carrier density and mobility values.The results are useful from the point of view of fabrication of Ga/As diffused infrared photodiodes in HgCdTe**.**

Index Terms- HgCdTe, Diffusion, SIMS, magnetotransport, multicarrier fitting, photodiodes

1 Introduction

HgCdTe has for long been a material faoured for fabrication of infrared detectors for a variety of thermal imaging applications [1]. The photodiode arrays used therein are fabricated either from p/n doped epitaxial homo/heteroepitaxial structures or from ion–implantated planar structures. Among a variety of dopants used for fabricating photodiodes, As has proved to be a favorite p-type dopant. Both As doping during epitaxial layer growth as well as As ion-implantation have been extensively utilized for fabricating p on n photodiodes in HgCdTe [2]. Recently Smith and co-workers have diffused As into the epilayer using elemental As along with Hg [3].

In the present work some of the results of a study on the diffusion of Ga and As in HgCdTe from a GaAs wafer source placed in contact has been reported. Earlier studies indicate that Ga is a much faster diffuser in HgCdTe compared with As. Gallium is known to be a donor type impurity in HgCdTe whereas arsenic has an amphoteric behaviour in this semiconductor material i.e. it can occupy both metal as well as tellurium sites acting as donor or acceptor respectively. In order to activate arsenic as an acceptor in HgCdTe, a site transfer activation anneal (from cation site to Te site) at around 420°C under Hg saturated conditions is required in addition to the conventional stoichiometric annealing (at around 260°C) for reducing Hg-vacancy concentration[4]. The kinetic model for transfer of As from Hg sites to Te sites has been well understood [4].

The main aim of this work has been to explore the possibility of a simultaneous diffusion of Ga and As in HgCdTe. Electrical properties of both the dopants as well as activation of arsenic as acceptor have been studied for the purpose of generating diffused p-n junction for photodiode applications.

2 Experimental Details

Liquid phase epitaxy grown HgCdTe (x~0.29) layers, prepared from Te-rich melts using a horizontal slider have been used in this work. The as grown layers were heated in contact with GaAs wafer in evacuated and sealed quartz ampoules under Hg saturated conditions (FIG.1) at various temperatures as well as for different time durations. Results of two specific experiments are included here. Sample A was first heated at 420°C in contact with a GaAs wafer for 24 h and later on heated alone at 260°C for 12 h for reducing Hg vacancies to $<10^{13}$ cm^{-3} level. Sample B was directly heated at 260°C for 12h in contact with a GaAs wafer under Hg-saturation ambient to facilitate activation of As.

Depth profiles for concentration of in-diffused Ga and As in the sample was obtained from SIMS using a 150 KeV $^{230}Cs^{+}$ primary ion beam in a CAMECA 7F SIMS. The quantification of the secondary ion yield versus sputtering time

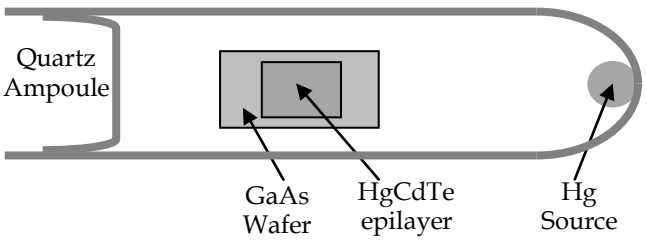

FIG.1. Schematic representation of the arrange ment for heat-treatment of HgCdTe samples in contact with GaAs wafer under Hg saturation ambient in an evacuated and sealed ampoule

data was done by (a) utilizing predetermined relative sensitivity factors (RSF) with respect to ^{130}Te ion yield to evaluate concentration and (b) measurement of crater depths at different sputtering times using a Dektak surface profiler.

Magneto transport measurements were performed on Sample B in van der Pauw configuration using a 5mm×5mm square cut piece. Cryogenics UK made cryogen free variable field (0-8T) magnet with variable temperature (1.6-300K) insert was used to obtain Field dependent transverse (R_{xy}) and longitudinal (R_{xx}) resistivity respectively. Measurements were carried out in the temperature range 1.7-300K. The data was then fitted using multicarrier fitting at each temperature to obtain concentration and mobility values of carries present in the sample.

3 Results and Discussion

FIG. 2 shows the SIMS profile for Ga and As in sample A after being heat treated (a) first at 420°C for 24 h in contact with a GaAs wafer and (b) later at 260°C for 12 h under Hg Saturaion. The SIMS profile for sample B after 260°C heat treatment is depicted in FIG 3. A clear co-diffusion of Ga and As in the near surface region of ~2 μm is evident after 420°C heating with GaAs in sample A. After which the As concentration drops rapidly to a very low value, primarily limited by the SIMS sensitivity though. However, the Ga shows a somewhat diffusion tail with saturation at of ~ 2×10^{16} cm^{-3} into deeper regions, which is also close to the sensitivity limit of SIMS under our experimental conditions. The low temperature Hg saturation annealing has resulted in dispersion of this co-diffused region. The Ga and As base concentration in deeper regions has somewhat increased, indicating again a co-diffusion behavior. At 260°C (Sample B, Fig.3) interestingly an As pile-up close to the surface is observed, although in deeper regions of 2-5 μm again a co-diffusion of the two species is evident. However, in regions beyond 5μm As concentration again drops down to very low values while Ga concentration saturates to a sort of ~10^{17} cm^{-3} level. The profile indicates that a p on n type electrical junction can be formed by this process.

It may further be noted here that the flux of Ga and As atoms leaving the surface of GaAs will be same as temperature range chosen is well below the congruent sublimation temperature for GaAs(~625°C) [5]. But since the diffusion coefficient of Ga in HgCdTe at these temperatures (D_{Ga}~ $7\times10^{-12}cm^2s^{-1}$) is much higher than for As (D_{As}~2.9×10^{-14} cm^2s^{-1}) [6], the Ga penetrates deeper into the bulk of the material whereas As mostly remains confined to the surface. However, there is a clear evidence of Ga and As co-

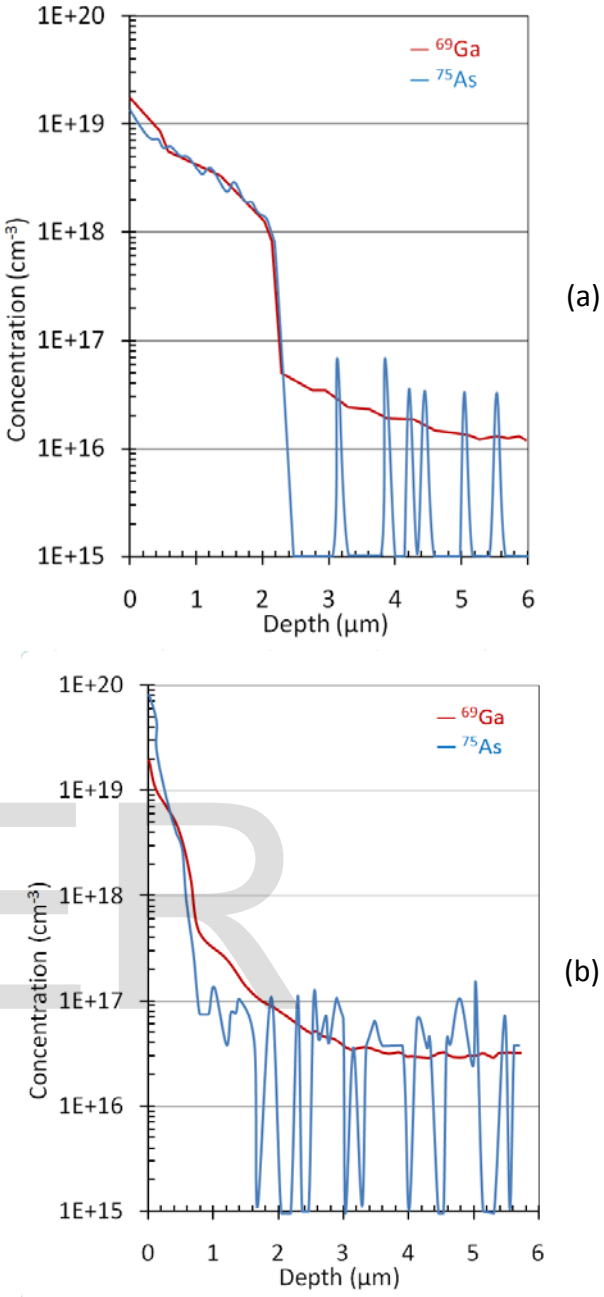

FIG.2. SIMS depth profiles for Ga and As in sample A: (a) heat treated with GaAs at 420°C for 24h and (b) subsequently heat treated at 260°C for 12h.

diffusion in HgCdTe, which is being emphasized for the first time.

Fig. 4 shows temperature dependent concentration and mobility for various carriers in Sample B as obtained from multicarrier fitting analysis. At all the temperatures the data best fitted with four carriers - two holes and two electrons. According to their mobility we classify them as heavy hole, light hole, bulk electron and surface electron.

Presence of heavy hole with mobility of > ~ 600 cm^2/Vs suggested that As atoms got successfully activated.

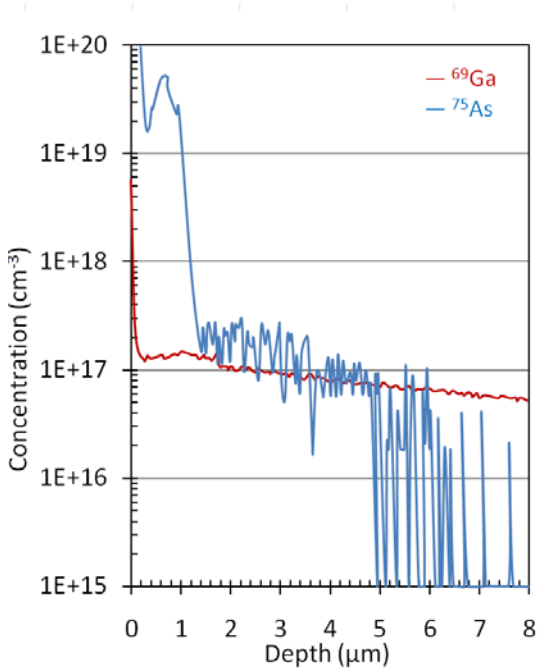

FIG.3. SIMS depth profiles for Ga and As in sample B heat treated with GaAs at 260°C for 12h.

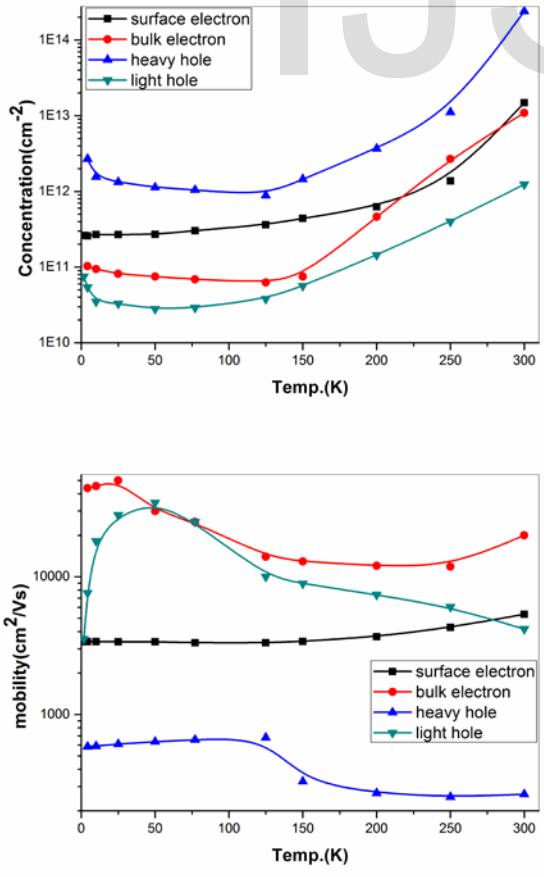

FIG. 4(a),(b). Temperature dependent concentration and mobility of carriers in sample B

However, very low Arsenic activation efficiency was achieved. Maximum heavy hole sheet concentration obtained was of ~2.4×10^{14} cm^{-2} whereas sheet concentration obtained from integral area under the curve for arsenic depth profile is of ~1.8×10^{15} cm^{-2}. Thus an activation effieciency of about 13% was achieved. This could be attributed to the low temperature annealing conditions. Bulk electron with low temperature mobility values of ~ 45000 cm^2/Vs can be attributed to n-type bulk conduction due to Ga donors. Bulk electron concentration was found to be lower than heavy hole concentration by two orders of magnitude in agreement with the SIMS profile of Fig. 3. However, for temperatures <150 K, both heavy hole and bulk electron concentration decreased simultaneously indicating recombination of carriers in the junction region. At higher temperatures the increased intrinsic carrier concentration would weaken the junction the concentration for both carriers increase. The surface electrons with low mobility values of ~ 4000 cm^2/Vs can also be due As occupying cation positions due to the observed surface pileup.

5 CONCLUSION

In conclusion, studies on Ga and As codiffusion in HgCdTe from a GaAs wafer sources have been presented. Simultaneous diffusion of both the dopants in HgCdTe upon heat treatment has been observed. Agglomeration of As atoms near the surface along with diffusion of Ga deeper in the material at conventional stoichiometric annealing temperatures has been observed. Simultaneous activation of arsenic atoms as acceptors alomgwith their low temeparture diffusion has been achieved. The study indicates the possibility of fabrication of diffused p on n photodiodes from this simple technique. The usefulness of this process for fabricating infrared photodiodes however requires further investigation. A detailed study involving (a) electrical depth profile using differential Hall and (b) fabrication of photodiodes could conclusively establish this aspect.

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