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MOVPE GROWTH OF HgCdTe EPILAYER WITH ARSENIC DOPING

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ABSTRACT

We report on p-type arsenic doping of metalorganic vapor phase epitaxially (MOVPE) grown HgCdTe on (100) GaAs. HgCdTe was grown at 370℃ in a horizontal reactor with using dimethy-cadmium, diisoprophyltelluride, and elemental Hg. We used tris-dimethylaminoarsenic (DMAAs) as the metalorganic for p-doping. 4micron thick CdTe and subsequently 10micron thick HgCdTe were grown on (100) GaAs substrate. Interdiffused multilayer process in which thin CdTe and HgTe layers are grown alternately and interdiffused to obtain homogeneous HgCdTe alloys was used. Arsenic was doped during CdTe growth cycle. After growth HgCdTe was annealed at 415℃ for 15 min and then annealed again at 220℃ for 3 hr, both with Hg-saturate condition. We could obtain p-doping from 2.5×10^{16} to $6.6\times10^{17}cm^{-3}$, depending on the DMAAs partial pressure. With the dual Hg-annealing,activation of arsenic was aboutt 90%, which was confirmed by SIMS measurement. With only low temperature annealing at 220℃ for 3hr, activation efficiency was about 50%.

INTRODUCTION

$Hg_{1-x}Cd_xTe$ is the most widely used semiconducting material for infrared detectors. Several properties favoring HgCdTe as infrared detector materials include tunability of bandgap energy and good electrical properties such as high electron mobility [1]. HgCdTe can be grown by both bulk and epitaxy growing methods. Since early 80's liquid phase epitaxy (LPE) has become a standard procedure for producing state of art devices [2].

Metalorganic vapor phase epitaxy(MOVPE) and molecular beam epitaxy (MBE) have been also developed actively due to their ability of growing multilayer structures with different compositions and doping concentrations [2]. For example, a structure with P-type HgCdTe of high x on n-type HgCdTe of low x is expected to give better detection properties [3]. In order to make a P-on-n structure it is very important to dope HgCdTe as P-type at a concentration as high as $10^{17}cm^{-3}$.

In this work, we have studied p-doping behavior of arsenic in HgCdTe. The effectiveness of high temperature activation annealing was also investigated.

EXPERIMENTAL PROCEDURE

MOVPE growth of HgCdTe was performed in a horizontal reactor, using the interdiffused multilayer process (IMP) by which several tens of alternating layers of HgTe and CdTe are grown and interdiffused during growth to obtain homogeneous HgCdTe. Diisoprophytelluride (DipTe), dimethylcadmium (DmCd), and elemental mercury were used for the layer growth, and tris-dimethylaminoarsenic (DMAAs) for arsenic doping.

The graphite susceptor was rotated slowly in order to increase the uniformity of both composition and thickness (100). GaAs with 4° off toward <110> was used as substrate. GaAs substrate was prepared by etching in 5 : 1 : 1 H_2SO_4 : H_2O : H_2O_2 followed by rinsing in water and drying with pure nitrogen gas. A CdTe buffer layer of 4㎛ was grown and then HgCdTe of 10㎛ was grown on top of it at 370℃. During growth partial pressures of DipTe and DmCd in purified hydrogen gas were $6 \sim 7 \times 10^{-4}$ atm. Mole ratio of DmCd to DipTe was 1.2. Arsenic doping was performed during only CdTe growth cycle. Partial pressure of DMAAs was varied between 5×10^{-7} and 5×10^{-6}atm.

Fourier transform infrared spectroscopy was used to measure both the composition of the layers. After the growth HgCdTe was annealed at 415℃ for 15 min and then annealed again at 220℃ for 3 hr, both with Hg -saturated condition (dual annealing). The first high temperature annealing was to activate arsenice atoms and the second one was to remove Hg vacancies. Electrical properties of the materials were obtained from van der Pauw Hall effect measurements at 77K. Secondary ion mass spectrometry (SIMS) analysis was performed at Charles Evans and Associates in order to obtain depth profile of arsenic composition.

RESULTS AND DISCUSSION

HgCdTe layers grown have mirror-like surface with typical facet structure. The density of pyramid-like hillocks of about 10㎛ width was less than $10cm^{-2}$.

Table 1 shows electrical properties of undoped HgCdTe. After Hg-annealing at 220℃ for 3hr, n-type carrier concentration of about $2 \times 10^{-4}cm^{-3}$ was observed for all wafers with different composition x. This value of carrier concentration is almost the same as the ones by Mitra [4-5] who used CdZnTe as substrate. Nishino [6] used (100) GaAs substrate the backside of which was coated with silicon nitride to suppress autodoping of Ga during growth. However, their carrier concentration was as high as $10^{14}cm^{-3}$. Our low carrier concentration value could be due to the high growth rate of 10㎛/h which might have reduced the boundary layer thickness of the incoming reactant gas, resulting in reduced autodoping of Ga.

Table 2 shows the Hall measurement results on arsenic doped HgCdTe which were annealed either by dual annealing or only low temperature annealing. Fig. 1 shows hole

Table 1. Electrical properties of undoped HgCd-Te after Hg-annealing at 220℃ for 3hr

Sample No.	Composition (X)	Carrier concentration(cm^{-3})	Mobility (㎠/V. sec)
q^{0731}	0.23	2.4×10^{14}	34,000
q^{0726}	0.25	2.5×10^{14}	16,000
q^{0808}	0.26	2.6×10^{14}	17,000

Table 2. Electrical properties of arsenic doped HgCdTe after either only low temperature annealing or dual Hg-annealing.

Sample No.	DMAAs pressure (atm)	Low temperature annealing (220℃, 3hr)		Dual Hg-annealing (415℃ ,15min+220℃, 3hr)	
		Carrier conc. (cm^{-3})	mobolity (㎠/V. sec)	Carrier conc. (cm^{-3})	mobility (㎠/V. sec)
q^{0803}	5.2×10^{-7}	—	—	2.3×10^{16}	470
q^{0820}	1.0×10^{-6}	7.9×10^{16}	340	1.3×10^{17}	310
q^{0816}	2.0×10^{-6}	1.8×10^{17}	290	2.5×10^{17}	240
q^{0813}	5.0×10^{-6}	2.5×10^{17}	250	6.6×10^{17}	210

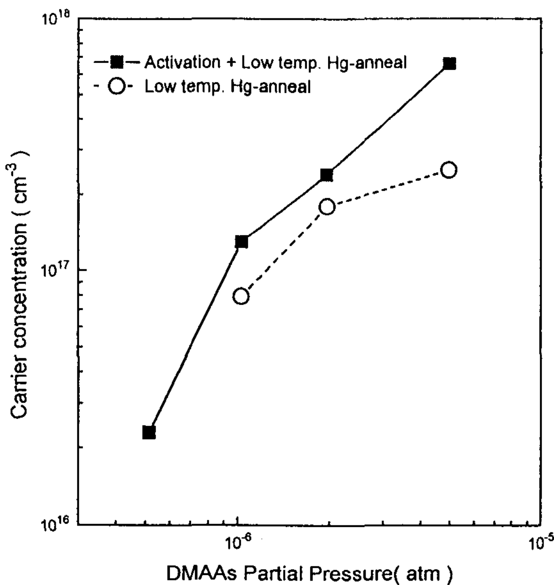

Fig. 1 Dependence of Hole Concentration on DMAAs Partial Pressure

concentration vs. DMAAs vapor pressure in the reactor tube. As the vapor pressure was increased, doping concentration increased. For the specimen q^{0803} doped with lowest level, only vacancy removing annealing without high temperature activation annealing could not convert the wafer to p-type. Actually this specimen must have mixed conducting property. Hole concentration after only low temperature Hg-annealing was about 50% of the value obtained by the dual annraling. After dual annealing all specimens had p-type conductivity with concentrations of $2.3\times10^{16}cm^{-3}$ to $6.6\times10^{17}cm^{-3}$.

Fig. 2 shows temperature dependence of carrier concentration for the specimen q^{0803} with hole concentration of $2.3\times10^{16}cm^{-3}$. this is a typical temperature dependence for p-type HgCdTe without having any anomality. In other words, our arsenic doping combined with dual Hg-annealing results in normal p-type doped HgCdTe. The low pn conversion temperature of 93K observed is due to the low hole concentration of this specimen.

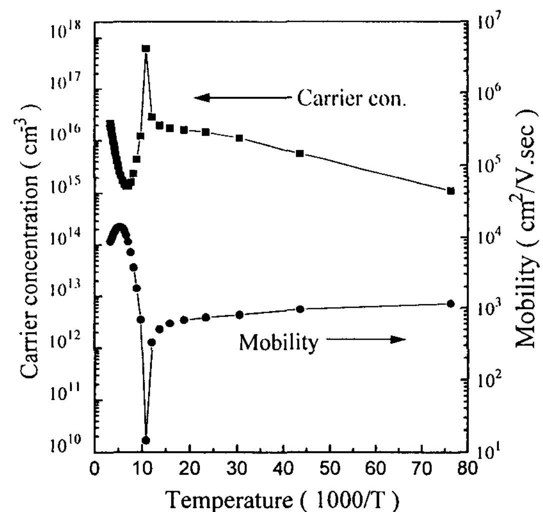

Fig. 2 Temperature Dependence of Carrier Concentration and Mobility for q^{0808} after Dual Hg-annealing

Fig. 3 is the SIMS analysis result for P(x =0.28)-on-n(x=0.23) structure. Arsenic concentration of this specimen is 3.5×10^{17} atoms/cm^3. DMAAs vapor pressure for this specimen was the same as the one for the specimen q^{0813} in Table 2. Considering that arsenic doping was performed during only CdTe growth cycle and that the thickness of CdTe alternating layer in HgCdTe (x=0.23) is 18% thinner than in HgCdTe (x=0.28), we expect arsenic concentration of 2.5×10^{17} cm^3 for this specimen. So we could obtain about 90% activation of arsenic by the dual annealing.

In order to remove Hg vacancies formed in cation sites during growth, we usually perform Hg-annealing at 220-250℃ in Hg-saturated condition. This range of temperature is low enough for equilibrium Hg-vacancy concentraton to become lower than residual donor impurity concentration and high enough for diffusion of Hg atoms. However, this temperature range is not high enough for arsenic atoms placed improperly during growth to diffuse to their proper anion sites. In order to place most of arsenic atoms in the anion sites we need annealing at temperature higher than 400℃. Because we are using GaAs as substrate, we have to worry about diffusion of gallium atoms and subsequent autodoping by them during high temperature arsenic activation annealing. In fact, when we annealed undoped HgCdTe (x=0.295) at 450℃, the specimen showed n-type rather than normal p-type. Due to autodoping of gallium, we have very low gallium composition in the HgCdTe layer, actually lower than the detection limit (Fig. 3). This means that gallium atoms did not diffuse into HgCdTe from the substrate by any sensible amount. In conclusion, Hg-annealing at 415℃, 15 min is the optimum annealing condition for activating arsenic in our HgCdTe/CdTe/GaAs structure.

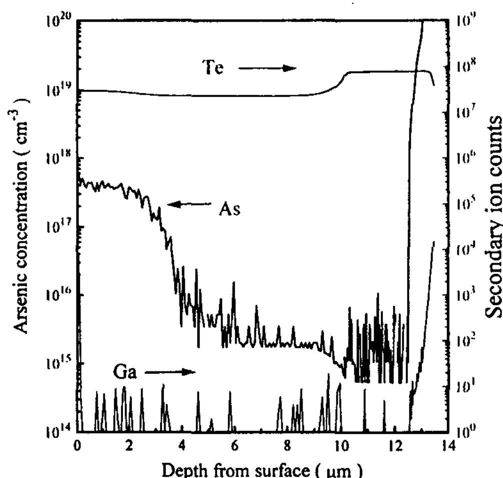

Fig. 3 SIMS result of P(x=0.28)on n(x=0.23) HgCdTe

SUMMARY

In situ P-type doping was performed on MOVPE grown HgCdTe, using DMAAs as a source of arsenice doping together with the dual Hg-annealing. We could obtain p-type carrier concentration in the range of 2.3×10^{16} to 6.6×10^{17}cm^{-3}, with almost 100% activation of dopants.

415℃, 15min was the optimum annealing condition for activating arsenice in HgCdTe/CdTe/GaAs structure without causing autodoping of Ga and deteriorating the abru-pt junction.

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