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P-TYPE ACTIVATION RESEARCH OF As-DOPING IN MBE HgCdTe FILMS

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Abstract: The study on As₄-doped HgCdTe epilayers grown by MBE was presented. The electrical activation of arsenic impurities was achieved by annealing that caused As to occupy Te sites. By using the secondary ion mass spectrometry (SIMS) and Hall measurements on the in situ arsenic doped HgCdTe epilayers, the results show that P-type MBE HgCdTe can be obtained by doping with As₄ source and annealing with high temperature.

Key words: As doping; anneal; MBE; HgCdTe

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分子束外延 HgCdTe 薄膜 As 掺杂 P 型激活研究

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摘要: 报道了利用 As₄ 作为掺杂源获得原位 As 掺杂 MBE HgCdTe 材料的研究结果. 利用高温退火技术激活 As 使其占据 Te 位形成受主. 对原位 As 掺杂 MBE HgCdTe 材料进行 SIMS 及 Hall 测试, 证实利用原位 As 掺杂及高温退火可获得 P 型 MBE HgCdTe 材料.

关键词: 砷掺杂; 退火; 分子束外延; 碲镉汞

Introduction

Photovoltaic HgCdTe IFPAs device has been the focus of research in infrared technology over the last decade. As reported, in situ doping technology was developed to prepare optimal PN heterojunction. Since the successful incorporation of arsenic using Cd₃As₂ was firstly reported by Wu et al^[1], arsenic-doping in MBE HgCdTe has been extensively studied^[2]. Because of the low surface-sticking coefficient and amphoteric doping behavior of arsenic^[3], arsenic is difficult to dope and act as acceptor in HgCdTe. In this paper, the results of arsenic doping MBE HgCdTe using pure As₄ source were presented. The arsenic impurities are activated by high temperature annealing^[4] as acceptors.

1 Experiment

As-doped HgCdTe was grown by MBE on 3-inch GaAs (211)B substrates in RIBER 32P MBE system. HgCdTe was grown at 170°C and high purity arsenic was used as doping elements. To avoid arsenic out-diffusion from GaAs substrates, about 3 μm CdTe buffer layer was grown prior to the 6 ~ 7 μm As-doped HgCdTe. 3 μm undoped HgCdTe was then grown to avoid uncertainty of SIMS measurement on surface. The growth details can be found elsewhere^[5].

The composition and thickness of samples were measured by using infrared transmission curves and step depth profiles (Dektak 3). The x value of Hg_{1-x}Cd_xTe was in a range between 0.25 ~ 0.33. The arsenic con-

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centration was quantitatively analyzed by using a Cameca IMS-6f SIMS. The relative sensitivity factors (RSFs) for As in HgCdTe was used to analyze arsenic concentration. The details can be found in Ref[6].

The wafer was cut into small pieces ($10 \times 10\text{mm}^2$) for annealing. The electrical properties of samples were measured by temperature-dependent Hall measurements in Van Der Pauw configuration in a temperature range of 300 ~ 12K at a magnetic field strength of 0.2T. The 3 μm undoped HgCdTe layers were removed by etching in order to prevent surface electron effect on Hall measurements.

2 Results and discussion

Figure 1 shows the result of SIMS depth profile of sample g257. The left axis is the counts of SIMS signal and the right axis is the arsenic concentration. It is clear that arsenic concentration keeps a stable level, and the interface of doped and un-doped regions is sharp. Figure 2 shows the arsenic concentration in the epilayers as a function of cell temperature, showing linear dependence. The Arsenic cell temperature of 306°C ~ 335°C corresponds to the arsenic concentration of $2 \times 10^{17}\text{cm}^{-3}$ to $2 \times 10^{18}\text{cm}^{-3}$, demonstrating that arsenic is successfully doped into HgCdTe. The arsenic concentration can be controlled by adjusting arsenic cell temperature, and the concentration keeps a stable level in whole HgCdTe layer.

Table 1 shows the Hall properties for the doped samples annealed under 440°C/30min + 240°C/48hr condition. Except the sample g266, all samples show strong P-type properties in 77K.

In the semiconductor material, the hole concentration p can be calculated by Eq. 1. By considering two kinds of carriers in the material, the Hall coefficient can be calculated by Eq. 2, where $b = \mu_n/\mu_p$ is the e-

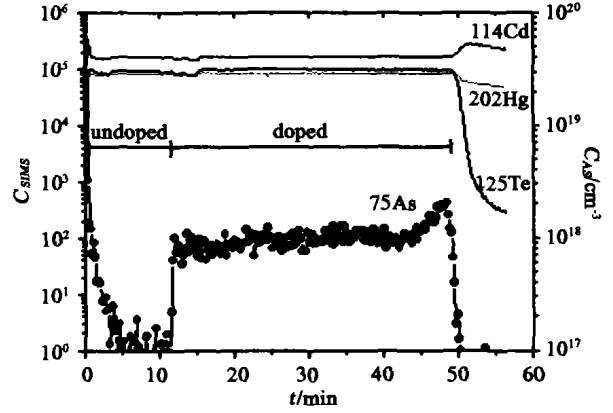


Fig. 1 SIMS depth profile of sample g257

图1 样品 g257 的 SIMS 深度测试谱

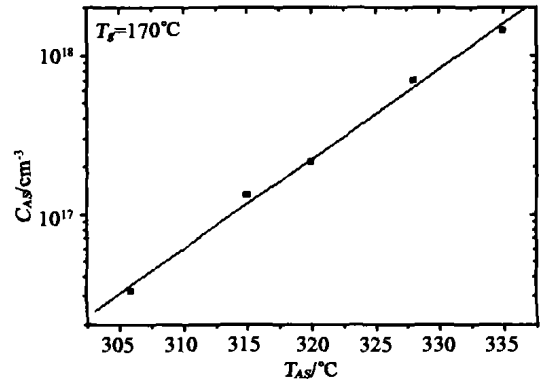


Fig. 2 170°C As doping curve

图2 170°C下 As 掺杂曲线

lectron mobility vs. hole mobility.

$$p + N_D = \frac{n_i^2}{p} + \frac{N_A}{1 + \frac{gp}{N_V} \exp\left(\frac{E_A}{kT}\right)}, \quad (1)$$

$$R_h = \frac{p(p^2 - b^2 n_i^2) + (p^2 - n_i^2)\mu_n B^2}{e(p^2 + b^2 n_i^2) + (p^2 - n_i^2)\mu_n B^2}. \quad (2)$$

Given a group of N_A , E_A and N_D , the hole concentration p can be calculated iteratively by Eq. 1, then the Hall coefficient can be obtained by Eq. 2^[6].

The samples were measured by temperature-dependent Hall measurements. The results are shown in Figure 3. In the low arsenic-doped samples, the active

Table 1 Hall properties of As doped samples annealed under 440°C/30min + 240°C/48hr

表1 As 掺杂样品在高温 440°C/30min + 240°C/48hr 退火后霍尔测试结果

Sample Number	x	Thickness (um)	300K	300K	77K	77K	Arsenic Conc. (cm ⁻³)
			Hall Conc. (cm ⁻³)	Hall Mob. (cm ² /V s)	Hall Conc. (cm ⁻³)	Hall Mob. (cm ² /V s)	
g266	0.317	5.5	-2.82E+15	-8.44E+02	1.51E+16	2.29E+02	3.23E+16
g261	0.304	5.45	-4.82E+16	-1.89E+02	6.50E+16	2.40E+02	1.32E+17
g259	0.31	7	4.52E+17	5.55E+01	2.80E+17	1.95E+02	2.13E+17
g253	0.328	6.35	3.44E+17	9.49E+01	2.81E+17	1.93E+02	1.43E+18
g251	0.287	7.9	9.47E+17	9.17E+01	1.00E+18	1.45E+02	4.65E+18

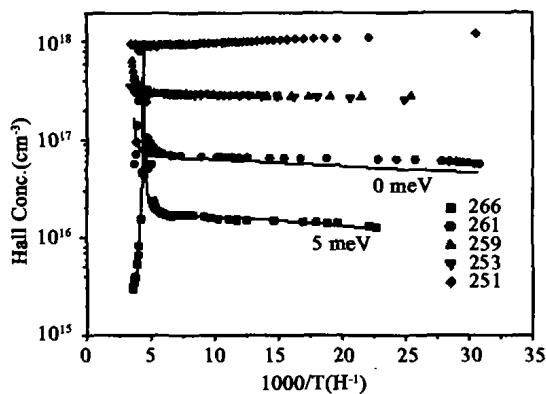


Fig. 3 The temperature-dependent Hall measurements
图3 变温霍尔拟合结果

energy can be analyzed and the active energy is lower than metallic vacancy energy ($\sim 15\text{meV}$)^[7]. However, in the heavily arsenic-doped samples, the curves are aclinic and the active energy can not be obtained.

This phenomenon must be caused by heavy arsenic-doping. In the heavy doping level, the interaction of impurity atoms can not be ignored, and the impurity energy levels become band. The impurity energy band and valence band overlap, leading to complete ionization of impurity atoms^[8].

Table 2 shows Hall properties for undoped samples annealed under $440^\circ\text{C}/30\text{min} + 240^\circ\text{C}/48\text{hr}$. It shows that the metallic vacancies were annihilated and the samples were N-type. It is certain that the P-type properties in Table 1 are due to activated arsenic. This result indicates that arsenic can be activated by $440^\circ\text{C}/30\text{min} + 240^\circ\text{C}/48\text{hr}$ annealing and occupy Te sublattice as acceptor.

3 Conclusions

P-type MBE HgCdTe material can be obtained by

Table 2 Hall properties of un-doped samples annealed under $440^\circ\text{C}/30\text{min} + 240^\circ\text{C}/48\text{hr}$

表2 非掺杂样品在 $440^\circ\text{C}/30\text{min} + 240^\circ\text{C}/48\text{h}$ 退火后霍尔测试结果

Sample Number	Thickness (um)	300K		77K	
		Hall Conc. (cm^{-3})	Hall Mob ($\text{cm}^2/\text{V s}$)	Hall Conc. (cm^{-3})	Hall Mob ($\text{cm}^2/\text{V s}$)
g233-20	9.5	$-3.88\text{E}+15$	$-4.99\text{E}+03$	$-6.78\text{E}+14$	$-1.61\text{E}+04$
g233-5	9.8	$-3.29\text{E}+15$	$-5.43\text{E}+03$	$-6.08\text{E}+14$	$-2.31\text{E}+04$
g233-5	9.8	$-3.35\text{E}+15$	$-5.42\text{E}+03$	$-5.97\text{E}+14$	$-2.45\text{E}+04$
g233-7	11.2	$-4.19\text{E}+15$	$-4.35\text{E}+03$	$-7.88\text{E}+14$	$-7.72\text{E}+03$
g233-9	10.5	$-3.39\text{E}+15$	$-5.54\text{E}+03$	$-4.49\text{E}+14$	$-2.93\text{E}+03$

doping with pure As_4 source. The arsenic concentration keeps at a stable level in HgCdTe layer, and the interface of doped and un-doped regions is sharp. Arsenic impurities can be activated by $440^\circ\text{C}/30\text{min} + 240^\circ\text{C}/48\text{hr}$ annealing and occupying Te-sublattice as acceptors. Analyzing on the temperature-dependent Hall measurements shows that the active energy of arsenic is lower than metallic vacancy energy. Compared with the undoped samples, it is indicated that high temperature annealing could activate arsenic atoms as acceptors.

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