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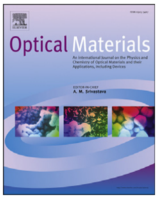

Raman investigation of optical phonons in the ion implanted $Hg_{1-x}Cd_xTe$

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ABSTRACT

Raman scattering is studied here for $Hg_{1-x}Cd_xTe$ ($x = 0.3$) samples implanted with 180-keV of B^{11} ions with various doses up to 1×10^{15} cm^{-2}. Considering disorder in the implanted HgCdTe material, the correlation length of Raman active optical phonons is determined as a short range order in the nanocrystals. Phonon softening and asymmetric broadening are investigated for HgTe like LO and TO phonon modes in the Raman spectrum while CdTe like modes almost disappeared for the dose greater than 5×10^{13} cm^{-2}. Disorder is measured quantitatively for wide ranges of doses on the basis of phonon confinement model. Nanostructures of the near-surface implantation-induced damage layer are known to consist of a mixture of amorphous HgCdTe and its nanocrystals. A significant reduction of the nanocrystallites size is reported here with increasing dose i.e. $L = 34–46$ A^0 at dose of 1×10^{15} cm^{-2}.

1. Introduction

The HgCdTe ternary alloy is an excellent material to develop infrared (IR) detectors, such as p-n, PBπn (π represents p-type absorption layer) and multicolour, for future generation of IR systems with ultra small pitch size [1–5]. Path breaking junction formation technology is essential to push detector pitch below 10 μm in the HgCdTe photodiode arrays because implantation induced defect creation and role of junction formation in HgCdTe are different from semiconductors like Si and GaAs [3–5]. Implanted ions only create the damage and are electrically neutral into HgCdTe. Conversion of p-HgCdTe to n-HgCdTe by energetic ions or plasmas has been extensively used for n-on-p HgCdTe detector arrays. It is beneficial to achieve a good degree of control on the converted region for fabricating a detector array such as avalanche photodiode/hot-operation detector array [4]. The n-type behavior of this converted region is predominantly governed by the generated defect profile. Implantation induced disorder is required in a controlled manner for these arrays. Therefore, the issues such as non-crystallinity and the possible existence of both crystalline and amorphous formation must be probed in the implanted HgCdTe epitaxial layer.

Raman spectroscopy is a nondestructive technique to estimate the amount of disorder and change in morphology of the implanted samples. Raman scattering can discriminate between the separate crystalline and amorphous components. It is based on the lattice vibration, which is sensitive to nearest neighboring atoms. Asymmetrical broadening of Raman line shapes is used to study the structural disorder [6–11]. Raman spectroscopy of crystalline semiconductors is a quantitative and qualitative way to measure stress, micro/nano-crystallinity and homogeneity of the material within spatial resolution of 1 μm. If the size of microcrystals is smaller than 300 A^0, the Raman active mode leads to phonon softening [12,13]. These effects are considered to characterize the material by downshift and asymmetric broadening of Raman active optical mode. A distribution of tensile stress in the material may also modify Raman spectrum that appear identical to those produced by small crystallites. In order to distinguish these mechanisms, nanocrystal of HgCdTe is studied here for different sizes.

Raman studies of HgCdTe have been published largely with qualitative results [14–20]. Wagner et al. have reported Raman spectra of implanted HgCdTe samples and the effect of disorder after thermal annealing [21,22]. In this paper, disorder and its morphology on B^{11} ion implanted HgCdTe wafers are investigated here using Raman spectroscopy. Phonon confinement model is used for the observed phonon softening and broadening in the Raman line shape of implanted material. It is invoked that the structural disorder on the surface of material restricts the phonon

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correlation length. Finite size of nanocrystals causes a relaxation of selection rules for first-order Raman scattering. To the best of our knowledge, this is the first Raman study on the size (i.e. correlation length) of the nanocrystals in the implanted HgCdTe material for a wide range of doses.

2. Experimental

The p-type $Hg_{1-x}Cd_xTe$ ($x = 0.3$) epilayer was grown on (111)B CdZnTe substrates by liquid phase epitaxy (LPE). The epilayer was 10 μm thick and had very good compositional homogeneity. The sample cut into several parts and was subjected to ion implantations of ^{11}B at energy of 180 keV for doses from 1×10^{12} cm^{-2} to 1×10^{15} cm^{-2}. The beam current was kept low enough during the implantation to avoid undesirable heating during implantation. The ion implantation was directed 7^0 off the (111) surface normal to avoid channeling effect along the lattice planes. The ion beam had a Gaussian distribution with a standard deviation of 40 A^0.

In the junction formation process, implanted ions create damage in the sub-surface layer creating a pool of Hg atoms. It triggers out-diffusion of Hg vacancy defects in the vacancy doped HgCdTe material. A pool of Hg generated by the ion implantation process diffuses into the wafer. Ion implanted boron in HgCdTe is not activated by annealing. Boron is widely accepted the most suitable implanted species in the n-on-p junction formation in HgCdTe. Implantation of Be, Zn, As, Au etc. have also been studied. Low atomic mass of boron-ion creates relatively lesser damage in HgCdTe during implantation process. Diffusion of boron in HgCdTe is relatively less thus forming a thermally stable junction.

Micro Raman spectra were collected in the back scattering geometry at 77 K. The samples were excited with the 514.5 nm (2.41 eV) line form an Ar-ion laser which was approximate close to the E_1 gap resonance for the present HgCdTe alloys composition [16]. The probing depth was 13 nm to study near-surface region of implanted layer. It was calculated by $1/2\alpha$, where $\alpha \sim 3.3 \times 10^5$ cm^{-1} is the absorption coefficient for excitation laser line [23]. Thus, the probing depth was much smaller than the depth of the implanted layer. Optical power of laser beam was kept low at 20 mW to avoid heating effect and thermal damage during measurement. The spatial resolution of Raman instruments was at 1 cm^{-1} while all other measurement conditions like optical power density and integration time were kept constant for all the wafers.

3. Results and discussion

Fig. 1 shows Raman spectra of the boron implanted $Hg_{0.7}Cd_{0.3}Te$ with doses ranging from 1×10^{12} cm^{-2} to 1×10^{15} cm^{-2}. Raman spectrum was recorded using Ar-ion laser line ($\lambda = 514.5$ nm) at 77 K. In the virgin sample, the first-order Raman spectrum shown in Fig. 1 is dominated by the HgTe like TO and LO modes at 126 cm^{-1} and 143 cm^{-1}, respectively. CdTe like LO and TO-modes, which are not clearly resolved here, are observed around 156 cm^{-1} [16–19]. Raman line shapes of HgTe like TO and LO phonon modes have asymmetrical broadening and reducing oscillator strength with increasing implantation dose. The CdTe like phonon mode around 156 cm^{-1} is disappeared at the dose of 5×10^{13} cm^{-2}. The crystalline features in the Raman spectrum are observed for doses up to 1×10^{13} cm^{-2} in Fig. 1. First-order Raman spectrum of samples implanted with doses less than 1×10^{14} cm^{-2} shows both crystalline and amorphous features, whereas a completely amorphized surface layer is observed for exceeding implantation doses above 1×10^{14} cm^{-2}. The effect of ion implantation on HgTe like- LO mode is even more sensitive, i.e. both its frequency down shift and the asymmetry are larger than those of the TO line for the same dose. The peak position and asymmetrical broadening of all phonon modes for implanted samples are listed in Table 1. It is observed that the intensity of CdTe like mode is gradually decreased with increasing implantation dose in comparison to that value of HgTe like mode. Furthermore, an asymmetrical broadening and small downshift in energy are also observed in the Raman peaks of CdTe like mode. Intensity of this mode is reduced drastically (very weak) at 5×10^{13} cm^{-2} dose and is almost disappeared for further higher dose. It indicates that the CdTe like TO and LO modes are more sensitive to disorder on the surface.

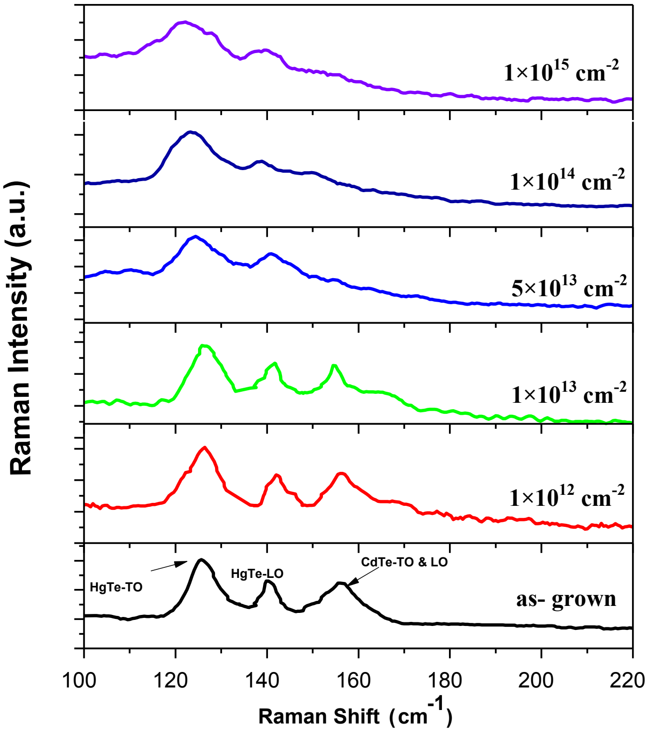

Fig. 1. Raman spectrum using 514 nm wavelength for implanted samples for various doses ranging from 1×10^{12} cm^{-2} to 1×10^{15} cm^{-2} at energy of 180 keV.

Raman shift to lower frequencies and the broadening of Raman modes have been explained by strains, antisites and structural defects [14–16]. Generally, selection rules for the first-order Raman scattering allows zone centers optical phonons, i.e. optical phonons at Γ-point of Brillouin zone. Asymmetry of these modes reflects the extension of the area in k-space and correlatively the reduction of the size in real space i.e. nanocrystals [7]. Moreover, the phonons of crystalline region reflect the density of states at Zone centre of Brillouin zone. Tiong et al. [11] have used a spatial correlation model for explaining the line broadening of LO phonons in the As^+ implanted GaAs material. Desnica et al. [8] have also reported Raman spectra on Si^+ ion implanted GaAs material using a wide range of ion doses where TO phonon lines shows a very small red shift and slight broadening at higher doses. Basically, the frequency softening of optical phonons is sensitive to the interatomic forces and ion masses which determine the vibrational frequencies. Furthermore, intensity of Raman lines is sensitive to the oscillator strength of dipole transition involving Raman polarizability tensor.

Raman study is focused here to analyze the disorder quantitatively by the line width and position of Raman mode. The experimental HgTe like LO mode (143 cm^{-1}) is shifted to lower frequency side and is more broadened asymmetrically with increasing implantation dose. It has been reported that the LO-mode is more sensitive to structural disorder generated by ion implantation in the polar crystals like GaAs etc. [8,11]. Therefore, HgTe like LO mode