CONFOCAL RAMAN MAPPING OF THE TOPMOST LAYER HETEROEPITAXIAL $InAs_{1-x}Sb_x$ STRUCTURES

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The spectra of Raman scattering (RS) in surface epi-layer of $InAs_{1-x}Sb_x$ heteroepitaxial structure in more than 200 points on 50μm·50μm square by the means of the step-by-step scanning of focused laser beam on the surface layer (mapping) are investigated. The two-mode reconstruction of phonon spectrum in $InAs_{1-x}Sb_x$ solid solution is revealed. It is shown that such characteristics of spectral lines as the peak position and FWHM of spectral lines are identical in mainly points, that shows on the crystallinity and high degree of homogeneity of the obtained structures. Mapping is made for two more intensive spectral lines in RS (cadmium, mercury, stibium) spectrum of $InAs_{1-x}Sb_x$ solid solution thin films 187 cm^{-1}(InSb-like LO mode) and 222 cm^{-1} (InAs-like LO mode).

Keywords: Raman spectroscopy, optical phonons, epi-layer, heteroepitaxial structures, scanning, thin-film, Full width at half maximum (FWHM), homogeneity.
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INTRODUCTION

$InAs_{1-x}Sb_x$ solid solutions have the unique property of wide range variation of the forbidden band width on the composition (x value). As it is known the forbidden band width of semiconductor compound InAs is E_{g0}=407,4meV and InSb is E_{g0}=227,3meV at temperature 77K [1]. The forbidden band width in $InAs_{1-x}Sb_x$ solid solutions slowly changes decreasing with Sb atom concentration increasing. The forbidden band width achieves the minimum value and can be the less than even in InSb achieving the value 100meV at Sb atom concentrations close to 60%(x=0,6) [2,3]. This fact is the most interesting. This unusual property is actively used nowadays for the development of optoelectronic devices (sources and radiation detectors) in technologically important spectrum range from 8 μm up to 12 μm in which the atmospheric windows are situated.

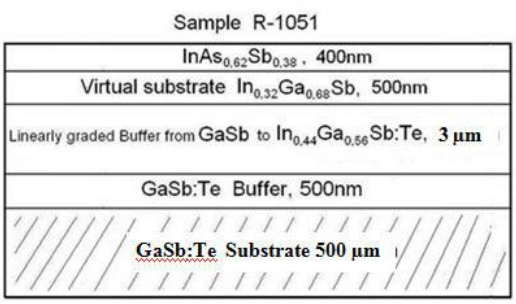

Fig. 1. The composition and thicknesses of heteroepitaxial structures $InAs_{0,57}Sb_{0,43}$ (sample R811) and $InAs_{0,62}Sb_{0,38}$ (sample R1051).

The absence of substrates with close values of the lattice constant is the main constraint for the obtaining and the wide application of thin-film photoelectronic devices (in particular, on the base of $InAs_{1-x}Sb_x$ solid solutions). The difference of lattice constants of work layer and substrate is the reason of appearance of the film stress and deformations leading to the formation of big density of defects and dislocations influencing on the main physical parameters and consistency of photoelectronic device operation. The lattice constants of GaSb and InSb are equal to 6,096 and 6,479Å correspondingly [1], i.e. the irrelevance is more than 6%. This irrelevance for epitaxy of $InAs_{1-x}Sb_x$ pseudomorphic solid solutions is gradually eliminated by us by application of intermediate step buffer layers (Al, Ga, In) (As, Sb). Thus, we obtain the unrelaxed and unstrained $InAs_{1-x}Sb_x$ top epi-layers. The characteristics (composition and widths of the layers) of obtained multilayer epitaxial heterostructures $InAs_{1-x}Sb_x$ for compositions with x=0,43 (sample R811) and x=0,38 (sample R1051) are shown in fig.1.

The identification of phonon spectrum reconstruction character in thin structures of $InAs_{1-x}Sb_x$ solid solutions and homogeneity degree of $InAs_{1-x}Sb_x$ top epi-layers is the main goal of the present paper.

RAMAN SCATTERING

It is well known that two RS active phonons, which are longitudinal optical phonons (LO) and transversal ones (TO,) are characteristics for crystals of $A^{III}B^{V}$ group with cubic lattice. According to [4] the frequency of LO phonon is 242cm^{-1} and one of TO phonon is 220cm^{-1} in InAs bulk single crystals; frequency of LO phonon is 193 cm^{-1} and one of TO phonon is 185cm^{-1} in InSb.

The RS investigations in heteroepitaxial structures R811 ($InAs_{0,57}Sb_{0,43}$) and R1051 ($InAs_{0,62}Sb_{0,38}$) on confocal Raman spectrometer "Nanofinder 30" (Tokyo Instr., Japan) are carried out by us. The investigations are carried out in backscattering geometry. YAG:Nd laser with second harmonic wavelength λ = 532 nm is used as

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excitation light source. The cooling CCD-camera (-70ºC) working in the regime of photon counting is served as radiation collector, the exposure time is usual 5 min, the radiation power incident on sample is 7-9mVt, and the beam diameter is near 4 μm. The diffraction lattice having 1800 dashes per millimeter is used in spectrometer, the determination accuracy of line spectral position is not worth 0,5 cm^{-1} is used in spectrometer.

The penetration depth of laser radiation and therefore the analysis effective depth at Raman scattering can be defined from ratio $\lambda/2\pi k$ where k is extinction factor. At InAsSb system analysis by the laser with wavelength λ = 532 nm such depth is approximately near 100nm with taking into consideration the extinction factor for InAs and InSb [5]. This fact shows that using the laser given wavelength for Raman scattering, we get the information only from top layer of the investigated multi-layer covering. According to selection rules obtained from analysis of Raman scattering tensors with diamond structure at backscattering from (100) surface, the only LO phonons can be observed and the appearance of TO ones is prohibited.

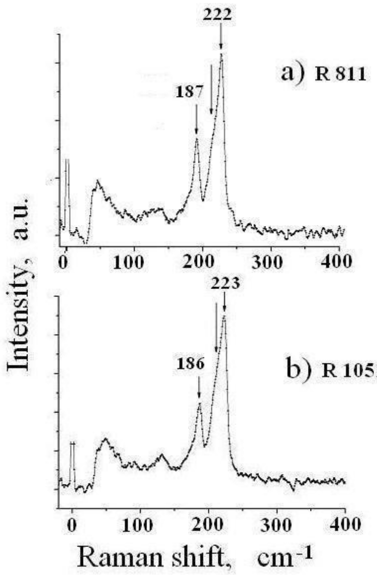

Fig. 2. Raman scattering spectra of samples R811 (a) and R1051 (b).

Raman scattering spectra in the backscattering regime at room temperature are shown in fig.2. It is obvious that the two-mode type of phonon spectrum reconstruction is character for $InAs_{1-x}Sb_x$ solid solution. The two-mode behavior of optical phonons is also established in work [6] by data of Raman scattering on $InAs_{1-x}Sb_x$ ($0 \le x \le 1$) solid solution thin films grown up on GaAs substrates by molecular-beam epitaxy method. The several phonon bands are observed in fig.2. These are: the intensive phonon band on frequencies 187 cm^{-1} ($InAs_{0,57}Sb_{0,43}$) and 186 cm^{-1} ($InAs_{0,62}Sb_{0,38}$) corresponding to longitudinal optical phonon in InSb (InSb-like LO) which is allowed band by selection rules for the given scattering geometry and asymmetric wide phonon one on 223 cm^{-1} ($InAs_{0,62}Sb_{0,38}$) presenting itself the overlapping of two bands of optical longitudinal and transversal phonons in InAs (InAs-like LO and InAs-like TO). This fact in given geometry Raman investigations of TO-phonons is the consequence of symmetry breaking of crystal lattice of epitaxial film as a result of disordering in solid state crystal lattice and small deviation comparison from backscattering geometry. It is necessary to note the high quality of GaSb bulk substrate differing by narrow spectral lines with FWHM of about 3cm^{-1} (fig.3). The frequency position corresponds to LO (235 cm^{-1}) and TO (226 cm^{-1}) RS active phonons in GaSb [4].

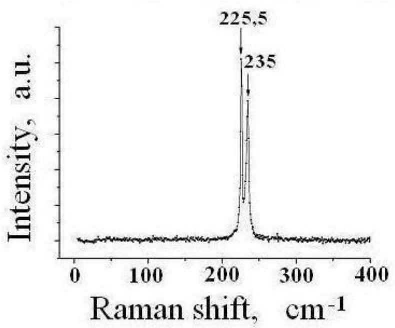

Fig. 3. Raman scattering spectra from GaSb substrate.

It is seen that the frequency 222 cm^{-1} shifts to the sides of bigger ones, i.e. to the frequences of KP active phonons character for InAs, as far as Sb atom number decrease in в $InAs_{1-x}Sb_x$ (sample R1051). The nature of observable less intensive wide bands at ~140 cm^{-1} isn't established and the additional investigations are required.

In work [6] it is experimentally established that frequences of LO and TO phonons in dependence on x composition in $InAs_{1-x}Sb_x$ solid solution change linearly as follows:

InAs-like LO ν_{L1} (cm^{-1}) = 238–32x
InAs-like TO ν_{T1} (cm^{-1}) = 219–27x
InSb-like LO ν_{L2} (cm^{-1}) = 177+12x

The high homogeneity of obtained heteroepitaxial structures is approved by investigation data of micro-RS spectra by the way of laser beam scanning on structure surface (50μm·50μm) in mapping regime. Confocal raman mapping is an highly suitable analytical tool for the study of advanced materials such as heteroepitaxial $InAs_{1-x}Sb_x$ structures.

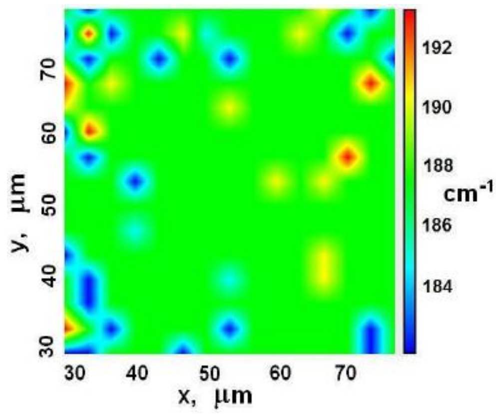

Fig. 4. Mapping of peak position of spectral line 187 cm^{-1}.

In mapping regime one can carry out the operation with each line emphasized from spectral ones by several characteristics: peak position of spectral lines, FWHM of spectral line, value of maximum intensity of spectral line, value of integrated intensity of spectral line and etc.

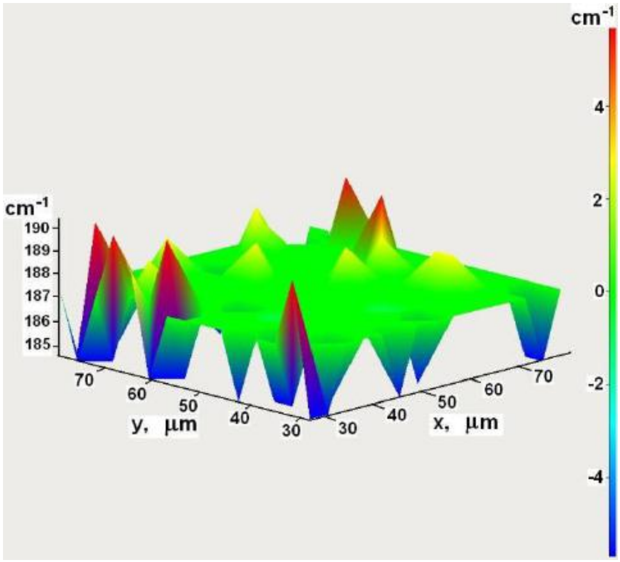

Fig. 5. Three-dimensional mapping image of peak position of spectral line 187 cm^{-1}.

The results of mapping peak position of spectral line 187 cm^{-1} in square 50µm·50µm are given in fig.4. The figure 4 gives the information approximately from 215 points (in 15 points in each direction). The peak position of spectral line in each coordinate point can be known by color ruler (on the right). For example, the areas painted in green color correspond to peak position of spectral line at 187-188 cm^{-1}, yellow and blue colors correspond to peak position at 190 and 184 cm^{-1}. Only very thin blue and red colors testify to presence of defects leading to peak position at 183 and 192 cm^{-1}. The three-dimensional visual mapping image is shown in fig.5.

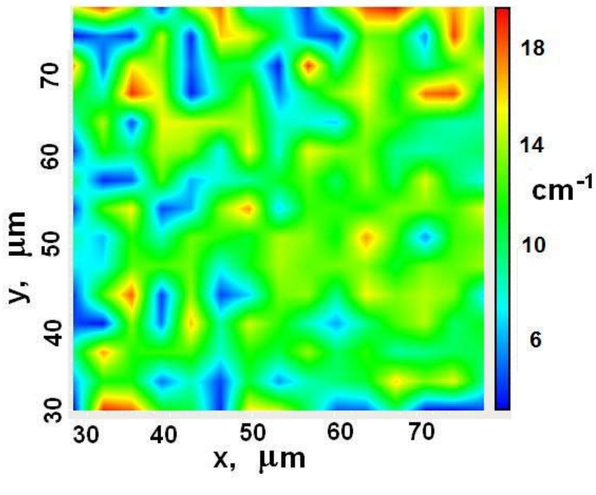

Fig. 6. Mapping of FWHM of spectral line 187 cm^{-1}.

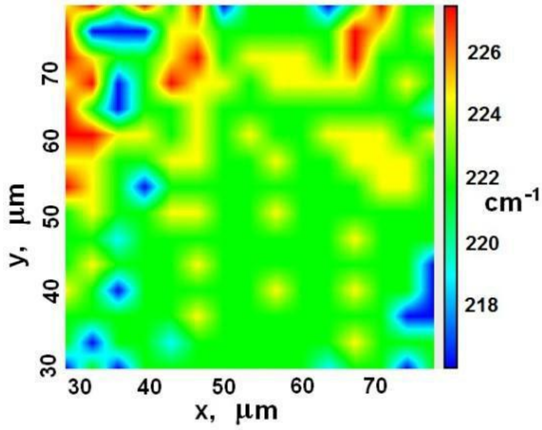

Fig. 7. Mapping of peak positions of spectral line 222cm^{-1}.

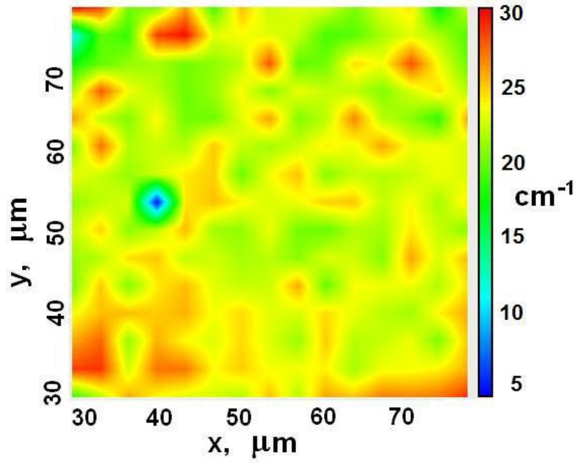

Fig. 8. Mapping of FWHM of spectral line 222 cm^{-1}.

The results of FWHM mapping (Full width at half maximum) of spectral line187cm^{-1} are given in fig.6. As it is seen FWHM mapping of spectral line 187cm^{-1} also testifies to homogeneity: the most part painted in green-bluish color shows that FWHM of spectral line 187 cm^{-1} is equal to 9-13 cm^{-1}.

The results of mapping peak position of spectral line 222 cm^{-1} are given in fig.7.The results of FWHM mapping of spectral line 222 cm^{-1} are given in fig.8, which also testify to high homogeneity of obtained heteroepitaxial structures $InAs_{1-x}Sb_x$.

CONCLUSION

The data of confocal Raman spectroscopy authenticate on two-mode type of phonon spectrum reconstruction in $InAs_{1-x}Sb_x$ solid solutions. The investigations in mapping regime testify tohomogeneity of obtained heteroepitaxial structures $InAs_{1-x}Sb_x$.

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