FLUENCE DEPENDENCE of NANOSIZE DEFECT LAYERS in ARSENIC-IMPLANTED HgCdTe EPITAXIAL FILMS STUDIED with TEM/HRTEM

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INTRODUCTION

- The most promising design of *p*–*n* junctions used in photodiodes based on $Hg_{1-x}Cd_xTe$ (MCT), relies on fabrication of local *p*–type regions in an *n*–type base with the use of implantation of arsenic.
- Ion implantation (II), however, leads to the formation of various types of radiation donor defects, so to form a required *p*–type region one needs to anneal the radiation defects and to activate the introduced arsenic atoms electrically.
- To perform an effective annealing, it is necessary to know the properties and nature of the radiation donor defects. However, the effect of arsenic implantation on the properties of MCT is typically studied after implantation into *p*–type material. This approach presumes that formation of implantation-induced defects, including electrically active ones, proceeds similarly in the 'base' layers with *p*– and *n*–type conductivity.
- **The aim of this work was to perform a comparative study with TEM/HRTEM and electrical measurements of fluence dependence of defect layers in *p*-$Hg_{1-x}Cd_xTe$ epitaxial film implanted with arsenic ions with 190 keV energy and fluences 10^{12}, 10^{13}, and 10^{14} cm^{-2} in relation to size of defects layers and radiation defects concentration.**

BF-TEM images

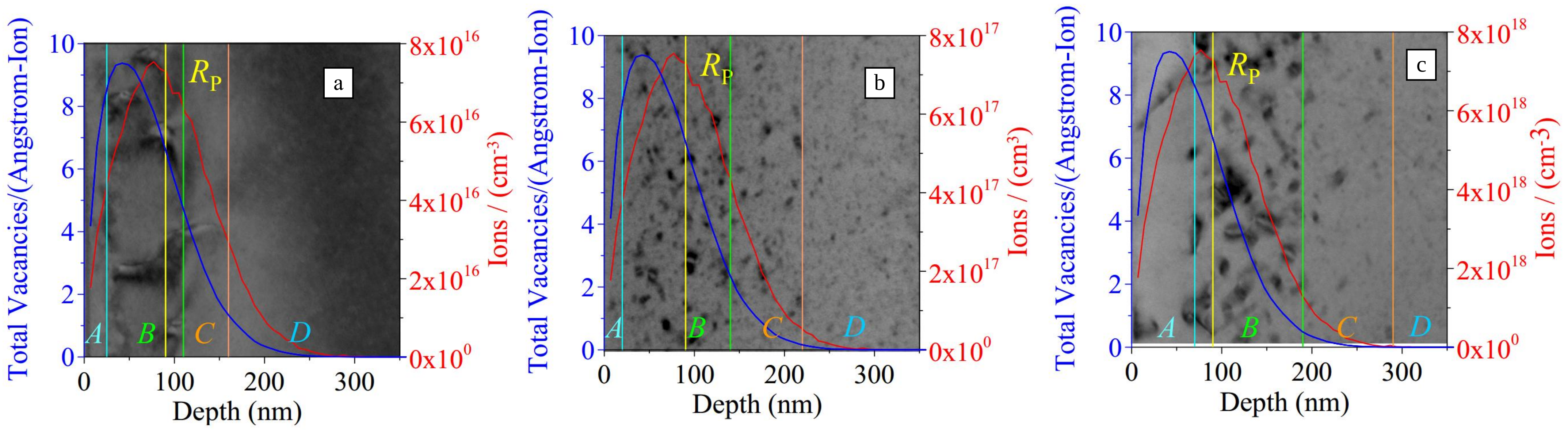


Fig. 1 Calculated (SRIM package) distributions of the implanted arsenic ions and the total number of vacancies against the background of selected fragments of the BF-TEM images of samples #1 (a), #2 (b) and #3 (c) implanted with arsenic ions with energy 190 keV and fluence 10^{12} (a), 10^{13} (b), 10^{14} (c) cm^{-2}.

Sample	Sublayers depth, nm		
	A	*B*	*C*
#1	20	90	50
#2	20	110	80
#3	70	120	100

Whole implantation-damaged layer (Fig. 1) for all samples could be divided into three characteristic sub-layers: the top sub-layers possessed a low density of structural defects; sub-layers *B* contained 'large' structural defects with high densities; sub-layers *C* contained 'small' extended defects with lower densities. These sub-layers were followed by the layers containing quasi-point defects, which could not be visualized in BF-TEM mode and appeared as a uniform background.

HRTEM radiation defects images

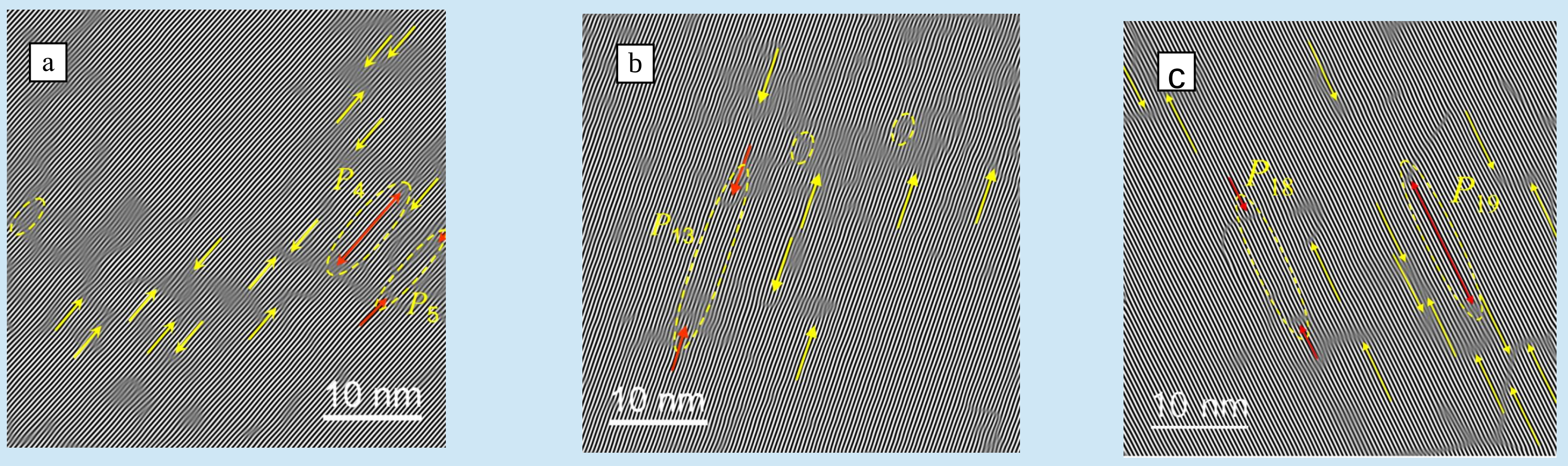
EXPERIMENTAL DETAILS

❑ In-doped film was grown by molecular-beam epitaxy at Institute of Semiconductor Physics (Novosibirsk) on (013) CdTe/ZnTe/Si substrates; *in situ* ellipsometric measurements were used to monitor film composition and thickness. The 'absorber' layer with uniform CdTe molar fraction (composition) x_a~0.22 was covered with a graded-gap protective layer (GPL) with surface x_s=0.46.

❑Indium doping provided *n*-type conductivity of the as-grown film ($n=4\cdot10^{15}$ cm^{-3}). A piece cut from the film after the growth was subjected to thermal annealing (220 ^{0}C, 24 h) in helium atmosphere at low mercury pressure. After annealing a *p*–type sample was fabricated with hole conductivity resulting from the presence of mercury vacancies, intrinsic acceptors in MCT ($p=5.1\cdot10^{15}$ cm^{-3}).

❑ *p*–type samples were implanted with As^+ ions with the energy 190 keV and fluence 10^{12} (#1), 10^{13} (#2), 10^{14} cm^{-2} (#3) and 10^{14} cm^{-2} (#4) using IMC200 (Ion Beam Services, France) machine. The microstructure of the implanted material was studied with Transmission Electron Microscopy (TEM) in bright-field (BF) and high-resolution (HRTEM) modes with the use of Tecnai G2 F20, FEI Company microscope. Thin foils were prepared using FEI Quanta 200 dual-beam focused-ion (Ga+) beam machine equipped with an OmniprobeTM lift-out system.

❑Concentration of donor radiation defects after implantation was determined by studying magnetic field *B* dependencies of the Hall coefficient and conductivity at *T*=77 K in *B*=0.01–1.5 T range and the discrete mobility spectrum analysis.



Sample	Dislocation loop size, nm		
	Sub layer*A*	Sub layer *B*	Sub layer *C*
#1	3 – 4	6 – 13	4–5
#2	4 – 8	12 – 14	8 – 4
#3	3 – 5	12 – 20	7

The characteristic size of dislocation loops in each sub-layer depends on the fluence.

Fig. 2. HRTEM inverse fast Fourier transform (IFFT) images of an area in the sub-layer B of samples #1 (a), #2 (b) and #3 (c). Red arrows and dashed ovals in the images mark dislocation loops, yellow arrows, single dislocations.

Electrical measurements

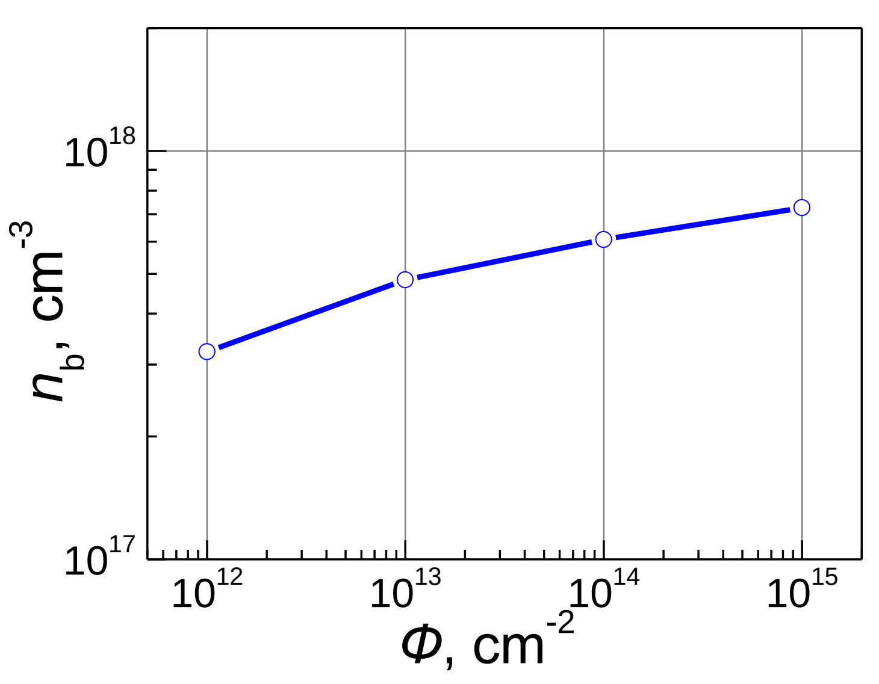


Fig. 3. Fluence dependences of bulk concentration of the low-mobility electrons induced by arsenic implantation with E = 190 keV.

The dominating contribution to the conductivity in the n^+–n–layers formed as a result of the implantation was that by the low-mobility (2500–4000 $cm^2/(V\cdot s)$) electrons. Low-mobility electrons in the implanted material are known to originate in implantation-induced extended defects, such as in donor defects representing atoms of interstitial mercury Hg_I captured by dislocation loops. The unambiguous relation between these electrons and structural defects was revealed by HRTEM in ion-implanted MCT.

Conclusions

BF–TEM studies showed that the defect layers produced by the As implantation were similar in all samples. Damaged layers could be divided into three characteristic sub-layers: the top sub-layers *A*, which possessed a low density of structural defects; sub-layers *B*, which contained 'large' structural defects with high densities; sub-layers *C*, which contained 'small' extended defects with lower densities. The thicknesses of the sub-layers were dependent on ion fluence.

HRTEM studies showed that the characteristic size of dislocation loops in each sub-layer depended on the fluence.

Electrical measurements showed that the main contribution to the conductivity in implanted structures was made by electrons with low mobility that originated from donor centers formed by trapping of interstitial mercury atoms by dislocation loops. The concentration of low mobility electron increased with the fluence increasing, which is consistent with an increase in the number of dislocation loops in the sub-layer *B* and *C* with the increase in the fluence.