ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:
https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Deadlines for submission of Experimental Reports

Experimental reports must be submitted within the period of 3 months after the end of the experiment.

Experiment Report supporting a new proposal ("relevant report")

If you are submitting a proposal for a new project, or to continue a project for which you have previously been allocated beam time, you must submit a report on each of your previous measurement(s):

- even on those carried out close to the proposal submission deadline (it can be a *"preliminary report"),*
- even for experiments whose scientific area is different form the scientific area of the new proposal,
- carried out on CRG beamlines.

You must then register the report(s) as "relevant report(s)" in the new application form for beam time.

Deadlines for submitting a report supporting a new proposal

- 1st March Proposal Round - **5th March**
- 10th September Proposal Round - **13th September**

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report in English.
- include the experiment number to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Study of the strain field induced in HgCdTe photodiodes by Sb-implantation and annealing at a sub-micronic scale	**Experiment number**: 32-02-794
Beamline: BM32-IF	**Date of experiment**: from: 16/11/2016 to: 22/11/2016	**Date of report**: 14/02/2020
Shifts: 18	**Local contact(s)**: Jean-Sébastien MICHA	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Dr Habil Philippe Ballet* - CEA-Grenoble / LETI / DOPT / STM / LMS

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Report:

The main goal of this study was to obtain the local crystal deformation induced by the implantation of antimony and to record these lattice deformations as a function of annealing conditions in order to evidence the dynamics of the diffusion/activation processes. This study provides us with all expected results and constitutes the chapter 4.2 of the successfully defended PhD thesis of A. Tuaz [1].

The ternary alloy $Hg_{1-x}Cd_xTe$ is of Zinc-Blende type and is constituted by 2 face-centred cubic sub-lattices (named A and B afterwards) offsetted by [¼,¼,¼] with the anion sub-lattice made of Tellurium while the cation sub-lattice hosts either Hg or Cd. Consequently, (hkl) reflections are only allowed if Miller indexes h, k and l have the same parity and their sum is either odd (odd indexes) or even (even indexes). Concerning their intensities, there is a major difference for even Miller indexes: (hkl) reflections with h+k+l=4n have an amplitude proportional to the square of the *sum* of atomic form factor $(f_A+f_B)^2$ while h+k+l=4n+2 have an amplitude proportional to the square of the *difference* of atomic form factor $(f_A-f_B)^2$. Consequently, h+k+l=4n reflections are strong while 4n+2 reflections are weak.

As shown in table 1 for as-implanted sample, the diffraction signal almost goes down to background level in a 500 nm deep and 8 µm wide zone situated at the centre of the image, thus perfectly localising the Sb implantation zone. Moreover, that zone is roughly 250-500 nm thick, perfectly corresponding to the expected penetration length of Sb ions: diffraction intensity reduces because of implantation-induced damages. A detailed comparison shows that the weak diffraction intensity is 1.5 time more reduced than the strong one. The proposed explanation is that misfit dislocations occur in the damaged zone, thus inducing stacking faults in the crystal that locally transform the AB atomic structure into BA structure. Therefore, the two cfc sub-lattices are no more exclusively made of cations or anions, but of a mixture of both in various proportions: f_A and f_B difference lowers. And whatever the proportion of anion/cation mixing, this does not affect strong reflections but specifically decreases weak reflections until — in the limit case where anions and cations are fully mixed-up — weak reflection are zero since $f_A=f_B$.

After annealing, we observe a restoration of the diffraction signal in the implanted zone but this restoration looks incomplete. This clearly contrasts with the case of As implanted HgCdTe structures (object of a previous thesis [2]) where after annealing, the epilayer was completely cured. We think this may be linked to the apparition of nanometric voids in the last 500 nm epilayer with a 10 times larger density for Sb (65.5 μm^{-2}) than for As (6.4 μm^{-2}). Moreover, we specifically observe for the annealed sample in the 2 µm height surface zoom, that a triangular zone appears (shown in dashed

white line) where we observe a 35% reduced diffraction intensity that exists both of weak and strong peak.
This is quite a non-expected phenomenon since – contrary to all expected diffusion processes - it seems not to be isotropic and to the author's knowledge, it is an unknown phenomenon. We also see such an effect on the 2D strain repartition under the form of a weakened strain as illustrated. We think this non-isotropic phenomenon is worth developing a new axis of research.

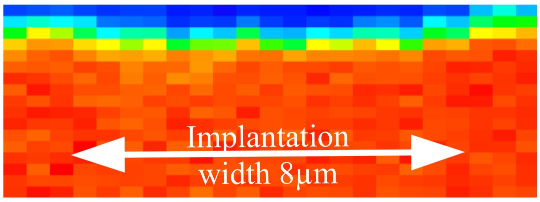
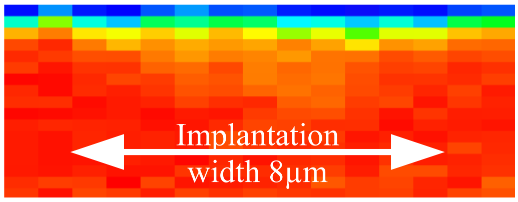
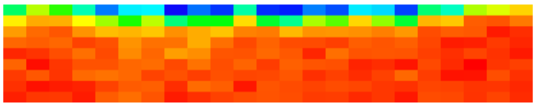
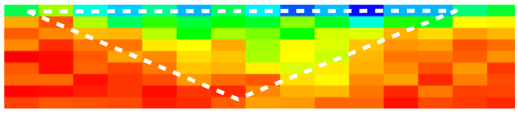
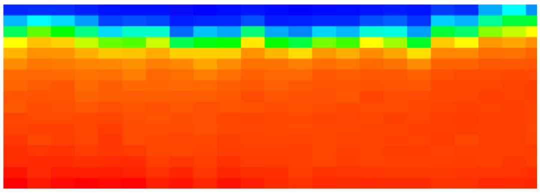
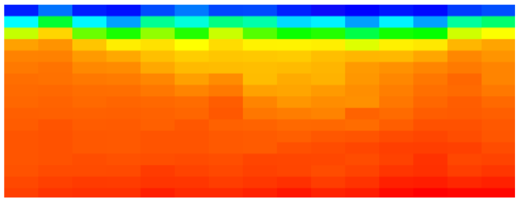
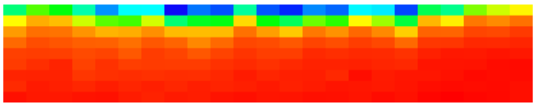
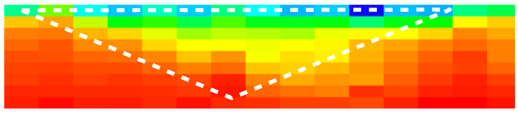
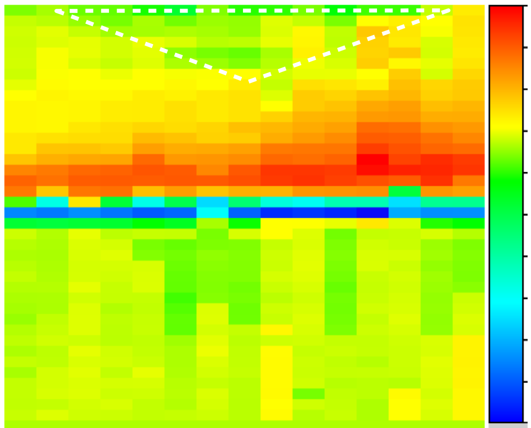
	Before annealing	After annealing
WEAK (-4 10 8) 17.5 keV 4 µm height		
Surface zoom		
STRONG (-2, 10, 8) 19.1 keV 4 µm height		
Surface zoom		
STRAIN 10 µm height strain range [-7;3.5]10^{-4}		

Table 1: Comparison of strong and weak peak intensity repartitions in the 4 µm surface of the epilayer, both in the as-implanted and annealed case. The 2D strain mesh is also presented.

Another important aspect here is that this phenomenon is width limited by the implantation: despite SIMS, RBS and MEIS have much better adapted depth resolution in the 1 nm range, their millimetric beam size is a prohibitory drawback here because it would require making an as-large implantation, and we would probably loose the width limiting phenomena. This probably explains why this phenomenon has never been observed before and why only micro-probing experiments would be relevant here.

[1] A. Tuaz, 'Investigations structurales haute-résolution de photodiodes infrarouges de nouvelle génération', phdthesis, Université Grenoble Alpes - CEA/Grenoble, Grenoble, 2017.
[2] C. Lobre, 'Compréhension des mécanismes de dopage arsenic de CdHgTe par implantation ionique', phdthesis, Grenoble, Grenoble, 2014.