ESRF	**Atomic environment of Fe following high temperature implantation in InP**	Experiment number: HS 1252 and 08-01-334
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Report:

Among transition-metal impurities, iron is of key importance in the InP-based optoelectronic and microwave applications, thanks to its peculiar electronic and optical properties. Due to its near-midgap deep acceptor level Fe acts very efficiently as an electron trap, and is therefore routinely used in bulk and epitaxial crystal growth to produce semiinsulating (SI) substrates or SI current blocking layers for vertical isolation and charge confinement in various device structures. A major drawback of Fe-related applications is due to its rather low solubility in InP. This limits the maximum concentration of substitutionally located, electrically and optically active Fe atoms attainable with equilibrium techniques to values $<10^{17}$ cm^2 before precipitation occurs. As a typical nonequilibrium technique, ion implantation may be used to overcome solubility limitations. One of the problems with Fe implantation in InP is related to its high reactivity with the implant induced defects, especially when amorphous clusters or regions are produced: the high-temperature annealing treatments necessary for the damage recovery induce strong redistribution/gettering phenomena which completely alter the implantation profile with detrimental effects on the desired electrical or optical properties. Damage-related undesired effects can be avoided by high-temperature implantation.

In this field, several important questions of fundamental character remain open and deserve careful investigation, mainly regarding the structural aspects of the ion-solid interaction. Presently, little or no knowledge exists on the microscopic status of the crystal after the high-temperature implantation process and on the relationship between the host atoms, the produced defects, and the implanted Fe impurities. It would be of particular interest to know what is the effect of the dynamical annealing processes on the final location of the implanted Fe atoms and how the latter is modified by the subsequent annealing treatments. Extracting information about the final site occupied by Fe could help, e.g., to understand why the electrically active Fe fraction after annealing treatments appears to be of the order of 10% only. The aim of this work was to study the structural relation between the InP crystal and the implanted Fe atoms after an elevated temperature (200°C) implantation process and the subsequent high-temperature annealing treatments. Thanks to the reduced damage rate during the implantation process, it is possible to introduce a relatively large amount of Fe without destroying the long-range crystallinity of the substrate and thus avoiding strong damage-related redistribution phenomena during the annealing: this allows to successfully employ structural techniques which otherwise suffer of sensitivity limitations ~with respect, e.g., to the electrical/ electronic ones and to directly compare their results with those obtained by electrical measurements.

In order to obtain a clear picture of the structure of Fe implanted in InP we have performed X-ray absorption spectroscopy (XAS) measurements on the GILDA beamline on numerous samples as a function of the implantation dose (in the range 2 – 3 10^{15} at/cm^2) and annealing conditions. Samples were implanted at 350 keV at a high temperature of 220 °C; annealing was performed in the temperature range 300 °C – 600 °C for times between 15 and 90 minutes. Due to low concentration of the Fe absorber atoms, these measurements take full advantage of the high photon brilliance of third-generation synchrotron radiation sources and of the specific instrumentation available at the GILDA beamline. Complementary characterization was performed by RBS, PIXE, TEM and HRXRD.

As an example of the XAS spectra we show in Fig. 1 the near edge region of selected samples compared to that of two Fe oxides, metallic Fe and stoichimetric Fe – P compounds. These spectra demonstrate that Fe is never present in metallic or oxidized form and some similarities with the spectra of Fe – P compounds are apparent. In Fig. 2 we show background subtracted EXAFS spectra for a representative samples, before and after annealing. An enhancement of the signal amplitude is apparent from the figure. Spectral fitting showed that in the as – implanted samples Fe is substitutional to In in the InP lattice, while annealing induces the precipitation of Fe to form Fe – P complexes with an octahedral Fe coordination.

The overall picture arising from these investigations is that the high-temperature implantation process favors the incorporation of Fe in high-symmetry sites. Conversely, the point defect flux occurring during high-temperature annealing controls the kick-out of the Fe atoms from substitutional locations, leading to the formation of Fe-P complexes.

Based on these measurements the following papers have been published:

* A. Gasparotto, T. Cesca, N. El Habra, B. Fraboni, F. Boscherini, F. Priolo, E.C. Moreira, G. Ciatto, F. D'Acapito, G. Scamarcio, "Implantation and characterization of highly concentrated Fe deep centers in InP", Mat. Sci. Eng. B **91-92**, 503 (2002).

* G. Ciatto, F. D'Acapito, B. Fraboni, F. Boscherini, N. El Habra, T. Cesca, A. Gasparotto, E.C. Moreira, and F. Priolo, "Local structure of Iron implanted InP", Nuclear Instrum. Methods **200**, 171 – 173, (2003).

* T. Cesca, A. Gasparotto, G. Mattei, V. Rampazzo, F. Boscherini, B. Fraboni, F. Priolo, G. Ciatto, F. D'Acapito, and C. Bocchi, "Atomic environment of Fe in high temperature implanted InP", Phys. Rev. B **68**, 224113 (2003).

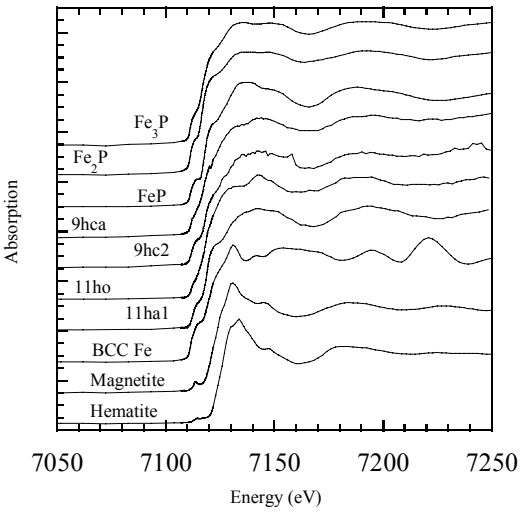

Fig. 1

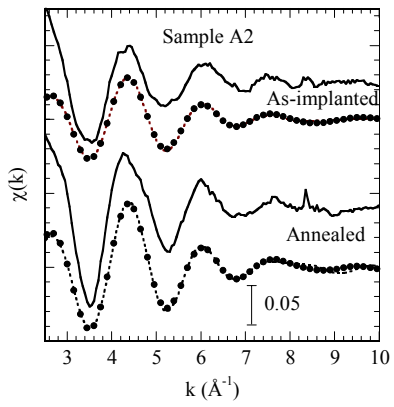

Fig. 2