Streszczenie z realizowanego projektu MI-1059

Skład grupy:

Prof. dr hab. Marek Pajek (Instytut Fizyki, Uniwersytet Humanistyczno-Przyrodniczy Jana Kochanowskiego w Kielcach)

Dr Dariusz Banaś (Instytut Fizyki, Uniwersytet Humanistyczno-Przyrodniczy Jana Kochanowskiego w Kielcach)

Dr Aldona Kubala-Kukuś (Instytut Fizyki, Uniwersytet Humanistyczno-Przyrodniczy Jana Kochanowskiego w Kielcach)

Dr Jakub Szlachetko (Instytut Fizyki, Uniwersytet Humanistyczno-Przyrodniczy Jana Kochanowskiego w Kielcach; ESRF Grenoble, Francja)

Mgr inż. Paweł Jagodziński (Politechnika Świętokrzyska)

Depth-profiling of relevant dopants implanted at low energies in Si and Ge by using synchrotron radiation based high-resolution micro-GEXRF

Y. Kayser[1], J.-Cl. Dousse[1], J. Hoszowska[1], W. Cao[1], S. Nowak[1], M. Pajek[2], A. Kubala-Kukuś[3], D. Banaś[2], P. Jagodzinski[3]

[1]Department of Physics, University of Fribourg, CH-1700 Fribourg, Switzerland
[2]Institute of Physics, Jan Kochanowski University, 25-406 Kielce, Poland
[3]University of Technology, 25-314 Kielce, Poland

Progresses in the characterization of dopant distributions in semiconductor materials, for example ultra shallow junctions in MOS transistors, are needed in order to follow the trend of shrinking down device sizes to some nanometers [1]. For reasons of device-scaling, smaller devices require shallower distributions of dopants. The method of choice to dope semiconductors is nowadays ion implantation as it presents the best control over the relevant parameters for the final distribution (laterally and in the depth direction) of the dopants, a great flexibility as well as an excellent reproducibility [2]. In order to produce the required shallow dopant profiles, the implantation energies are decreased to a few keV since this is the parameter which determines the projected range of the final dopant distribution. Alternatively, for a fixed implantation energy, shallower profiles can be produced in a Ge matrix compared to a Si matrix, due to the higher Ge density. Actual depth profiling techniques encounter problems when dealing with shallow implants close to the surface. For instance SIMS (secondary ion mass spectroscopy), although progresses have been made, has to fight with a transient region which makes it very difficult, if not impossible, to characterize the first few nanometres below the sample's surface. In addition, it is a destructive technique in contrast to GEXRF based approaches. GEXRF, like the more popular TXRF [3] method, is based on the reflection and refraction of x-rays but employs an inversed setup with respect to TXRF, i.e., the sample and the detector are exchanged [4]. AES (Auger electron spectroscopy) is very surface sensitive, but suffers from quantification problems. GEXRF has thus the potential to extend the accessibility of depth- profiling techniques towards dopant distributions on a nanometre scale. In addition, it supports simulations of dopant distributions resulting from ion implantation procedures. The present depth profiling capabilities of our setup are reported in [5]. By using a micro-focussed beam, it is possible to probe the lateral uniformity of the implantation dose with respect to the sample surface. This is not feasible with the TXRF method. Together with depth profiling, a 3D scan of the sample is thus conceivable with our synchrotron radiation based high-resolution GEXRF technique.

The aim of the experiment was to further develop and improve the high-resolution synchrotron radiation based GEXRF (grazing emission x-ray fluorescence) technique for depth-profiling. The new feature of our GEXRF setup was a polycapillary installed close to the target surface in order to focus the primary photon beam on the sample. Thus, an increase of the local photon flux and improvement in the lateral spatial resolution down to the micrometer range were observed. With this new micro-focussing GEXRF setup we have studied the distributions of relevant dopants, namely As, P, Ga, In and Sb, implanted at different energies and doses in Si and also Ge, a material which draws again an increasing interest in the semiconductor industry. The depth profile of a given dopant was obtained by measuring the dependence of the x-ray fluorescence intensity on the grazing exit angle (defined with respect to the flat target surface).

The high-resolution GEXRF measurements of the K.-lines of Si and P and the L.-lines of Ge, Ga, As, In and Sb were performed using the von Hamos Bragg-type bent crystal spectrometer of Fribourg [6] which was installed at the ID21 beamline and equipped with a TlAP (001) or an ADP (101) crystal, depending on the considered x-ray fluorescence line. The high resolution of this spectrometer, which is about 1-2 eV for the energies of interest, is really crucial for well separating the Si and Ge fluorescence lines from the dopant's fluorescence lines. A photon flux was about 10^{12} ph/s at 2.15 keV, which is above the absorption edges of the lines of interest for Si, Ge, P, Ga and As. For In and Sb a primary beam energy of 4.15 keV was required. Grazing emission conditions were realized by tilting the flat sample surfaces close to the critical exit angles which depend on the energy of the measured fluorescence line and the density, the atomic number Z and the mass number A of the substrate. In our setup, the exit angle is defined with respect to the Bragg angle of the diffracting crystal. A polycapillary installed in front of the sample focused the primary beam on a micrometer scale (<50 μm).

We have characterized the profile of the following dopants: P in Si implanted at 0.5, 1, 2, 4 keV, As in Si (0.5, 1, 2, 4, 8 keV), As in Ge (1, 2, 4 keV), Ga in Ge (1, 2 keV), In in Si (1, 2 keV) and Sb in Si (1, 2 keV). The projected ranges of the distributions vary between 1.7 and 10 nm and are within the detection depths. The implantation fluxes ranged from $5 \cdot 10^{14}$ to $5 \cdot 10^{15}$ atoms/cm2. For each implantation profile, the x-ray fluorescence was measured at 100 different exit angles from 0 to 0.05 rad.

In the performed experiment we have deduced from the synchrotron radiation based high-resolution micro-GEXRF measurements the depth profiles on a nanometer scale of different dopants of interest for the semiconductor industry, both n-type and p-type, in Si and Ge. Former experiments have shown that our method has already a high enough sensitivity for depth profiling of the considered dopants [7,8]. The use of a polycapillary increased the sensitivity of our technique and allowed depth profiling in combination with a micrometer lateral resolution. GEXRF measurements with a micro-focussed photon beam have not been reported up to now.

References:

[1] J.M. Poate, L. Rubin, Ion Implantation in Silicon Technology, Ind. Phys. 9, 12-15 (2003).

[2] W. Lerch, Ion implantation and Rapid Thermal Annealing in Synergy for Shallow Junctions, Phys. Stat. Sol. 158, 117 (1996).

[3] R. Klockenkämper, Total Reflection X-Ray Fluorescence Analysis (Wiley, New York, 1997).

[4] R.S. Becker, J.A. Golovchenko, J.R. Patel, X-ray Evanescent-Wave Absorption and Emission, Phys. Rev. Lett. 50, 153 (1983).

[5] Y. Kayser et al., Depth profiles of Al impurities implanted in Si wafers determined by means of the high resolution grazing emission x-ray fluorescence technique, Spectrochim. Acta Part B 65, 445 (2010).

[6] J. Hoszowska et al., High resolution von Hamos crystal X-ray spectrometer, Nucl. Instrum. Methods Phys. Res. A 376, 129 (1996).

[7] A. Kubala-Kukus et al., Observation of ultra low-level Al-impurities on silicon surface by high-resolution grazing emission x-ray fluorescence excited by synchrotron radiation, Phys. Rev. B 80, 113305 (2009).

[8] J. Szlachetko et al., Application of the high resolution grazing-emission x-ray fluorescence method for impurities control in semiconductor nanotechnology, J. Appl. Phys 105, 086101 (2009).