Proton implanted silicon wafers investigated by electron beam induced current measurements

S. Kirnstorfer 1,2, P. Hadley1, W. Schustereder2, J. Laven3, H. J. Schulze3

1 Institute of Solid State Physics, Technical University Graz, Austria
2 Infineon Technologies Austria AG, Siemensstraße 2, 9500 Villach, Austria
3 Chair of Electronic Devices, University Erlangen-Nürnberg, Cauerstraße 6, 91058 Erlangen, Germany

Abstract

Electron Beam Induced Current (EBIC) is an analysis method used in a Scanning Electron Microscope (SEM) to investigate buried junctions or defects in semiconductors. [1-3] During an EBIC measurement, the electron beam enters a semiconductor and generates electron-hole pairs. If the charge carriers diffuse into a region where there is a built-in electric field, such as a pn junction or a Schottky contact, charge separation will occur and a current will flow. We have used EBIC to investigate proton implanted silicon wafers with implantation doses from 1x10^{15} p+/cm² to 1x10^{17} p+/cm² and with implantation energies from 500 keV to 5 MeV. [4] The implantation introduces vacancies, silicon interstitials, and hydrogen into the crystal. The sample is then annealed in the temperature range from 350–550°C and defect complexes form. The microscopic structure of these defect complexes is not completely understood. There is a class of oxygen-vacancy defect complexes called thermal donors that are known to act as donors in silicon. Besides EBIC we used voltage contrast imaging, Schottky contacts of tungsten tips, and spreading resistance profiling (SRP) to investigate the properties of these wafers.

Voltage Contrast Imaging

Voltage contrast imaging in a scanning electron microscope (SEM) is a technique for studying potentials and potential distributions on a sample. The principle of voltage contrast is that fewer secondary electrons at a conducting surface escape when the metal is positively biased. Here we used it for visualizing a pn junction across the surface of a doped silicon wafer. We put the wafer in a sample holder, where each side of the pn junction was contacted to one of the electrodes, and applied a voltage of +10 V to -60 V across the sample.

Fig. 1: Micromanipulator installed in a FEI Quanta 200 (photograph taken by Kleindiek)

1D- and 2D-EBIC

For the EBIC measurements, silicon wafers that have been implanted with hydrogen are diced and placed so that the edge of the die is visible in the SEM. The electron beam is then scanned from the front-side to the back-side of the wafer and the current is recorded. Typical one and two dimensional EBIC measurements of the wafer are shown in Fig. 4 (a) and (b). The currents collected at the front and the back of the sample have equal magnitudes but opposite signs. The magnitude of the EBIC current can be much larger than the beam current since the high energy electrons in the beam can each generate many electron-hole pairs. A peak in the EBIC signal indicates the position of a pn-junction.

Fig. 4: (a) SEM image, (b) 1dimensional and (c) 2 dimensional EBIC image of the cross section of proton implanted silicon wafers arranged under each other

Determination of the position of the pn junction

To better visualize the defects caused by the proton implantation, a tungsten tip was placed on the silicon to form a Schottky contact. The EBIC signal was then measured as the electron beam was scanned in a two dimensional region around the Schottky contact. The Schottky contact separates electron-hole pairs that diffuse to it from the surrounding silicon. Since electron-hole pairs recombine at defects, the EBIC signal is decreased if the charge carriers have to diffuse past defects on their way to the Schottky contact.

Fig. 6: A series of two dimensional EBIC images of a tungsten tip on different positions on the cross section of the silicon wafer.