Detection of pn-junctions in very thin specimens by combining electron holography and electrical fields in an in-situ experiment

A. Lenk, B. Einenkel, H. Lichte and J. Sandino

Triebenberg Laboratory, Institute of Structure Physics, Technische Universität Dresden, D-01062 Dresden, Germany

Andreas.Lenk@triebenberg.de
Keywords: Electron Holography, Dopant Profiling, Electric Field Holder, Dielectric Constant, Thin Specimen

It has been widely demonstrated that Electron Holography allows 2D-mapping of pn-junctions by detecting changes of the local electric potential in differently doped areas [1,2]. Unfortunately, essential precondition for applying this method is an object thickness of at least 160 nm. Exact determination of presumed pn-junctions requires even higher object thicknesses [3]. This arises a problem, since chips of the current product generation contain microdevices smaller than 60 nm, too thin for a respective preparation. Therefore, the technique can only be indirectly applied at suitable test structures.

This experiment shows a possible way to detect pn-junctions even in objects that are too thin for the usual approach. To demonstrate this, a respective specimen was exposed to an external electric field of variable strength in a TEM in-situ experiment, using a specially designed electric field holder (Fig1).

A homogeneous electric field, which is given by the experiment's geometry at least in the immediate area of interest, creates a linear increase of the electric potential between the electrodes, forming a potential wedge. The slope of this wedge depends directly on the dielectric constant of the material between the electrodes and the applied voltage.

With Electron Holography, the difference between the potential wedge in the vacuum and in the object is measured. If the object consists of areas with different dielectric constants, this is reflected by different slopes of the potential wedges in the respective areas. This is further clarified by repeating the experiment for different external fields.

Subject of this experiment is a pnp-layer, epitaxially grown on an unstructured silicon wafer. First, the structure was holographically analysed at a homogeneous FIB-prepared specimen of ca. 300 nm thickness. The result is shown in Fig2a. It clearly reveals the location of two pn-junctions. Then, the same structure was prepared conventionally as a cross-section, using a broad ion beam polishing system. The resulting specimen is not homogeneously thick but typically wedge-shaped, with a thickness increasing from the wafer's surface to the regions beneath. At this specimen, however, only the deeper, i.e. thicker second pn-junction is directly visible by bendings in the measured potential profiles (Fig2b). The shallow first pn-junction is invisible, because the specimen is not thick enough in the related region.

If the profiles measured under different external electric fields are directly overlayed, they begin to diverge exactly at the presumed first pn-junction (Fig2c). This can be explained by different dielectric constants in the p- and n-doped regions of the silicon.

With this result, it has been shown that it is possible to detect pn-junctions also in very thin objects, using a combination of electron holography and an electric field holder.

1. W.-D. Rau, P. Schwander, F. H. Baumann, W. Höppner, and A. Ourmazd, Physical Review Letter **82** (1999), p. 2614
2. M.-R. McCartney, B. Frost, R. Hull, M. R. Scheinfein, D. J. Smith, E. Voelkl, Proc. Intern. WS on EH, Knoxville USA (1995), p. 189-198, ISBN 0-444-82051-5

DOI: 10.3217/978-3-85125-062-6-625 , © Verlag der TU Graz 2009

3. A. Lenk, H. Lichte and U. Mühle, Journal of Electron Microscopy **54(4)** (2005), p351

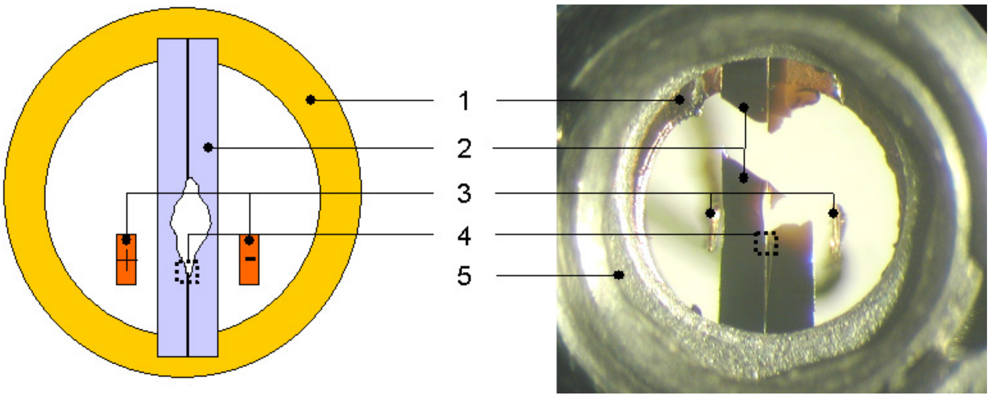

Figure 1. Arrangement for in-situ external fields at specimen, scheme (left) and experimental setup (right). A ring (1) supports the actual specimen (2). If a voltage is applied to the free-standing flat gold electrodes (3), the electron-transparent thin area of interest (4) is exposed to a homogeneous electrical field. Due to the distance between electrodes and object, no current can flow. The design of the object holder (5) allows a simple change of specially shaped specimens.

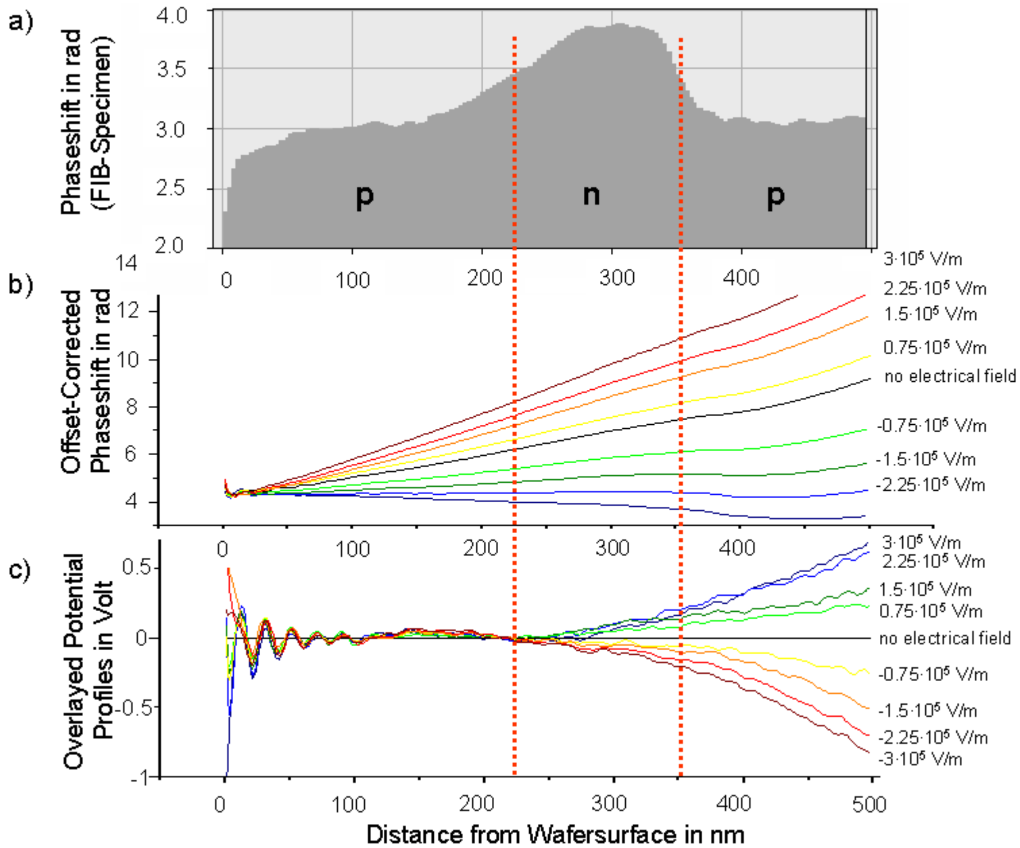

Figure 2. Comparison of the experimental result and usual holographic analysis at a thick FIB-specimen: The dotted vertical lines mark the presumed pn-junctions. **a)** Phase profile measured at the FIB-specimen. **b)** Phase profiles measured in this experiment for different external fields. **c)** Overlayed phase profiles from b). Whereas the first pn-junction can not be detected in the original phase measurement, an overlay of the profiles converges exactly at the presumed position in c). The second pn-junction can be seen directly as bendings of the phase profiles in b).

DOI: 10.3217/978-3-85125-062-6-625 , © Verlag der TU Graz 2009