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# ELECTRON HOLOGRAPHIC CHARACTERIZATION OF NANOSCALE MAGNETIC AND ELECTROSTATIC FIELDS

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In addition to improving the resolution limit of electron microscopes[1], off-axis electron holography at moderate resolution can be used to characterize electrostatic and magnetic fields[2] down to the nanometer scale. We have investigated samples with one- and two-dimensional dopant profiles and obtained maps of electrostatic potential with a sensitivity of 0.1V and spatial resolution approaching 5nm. The magnetization behavior of patterned magnetic nanostructures at high sensitivity and spatial resolution has also been studied.

In off-axis electron holography the hologram is formed after overlapping part of the electron wave that has traveled only through vacuum with the sample wave by means of a positively charged electrostatic biprism. The instrumentation required for this research includes a transmission electron microscope (TEM) equipped with a field emission gun in addition to the biprism. Digital acquisition of the hologram allows for rapid and quantitative reconstruction. The Philips CM200-FEG instrument at ASU is also equipped with an extra coil below the lowerpole piece of the objective lens that allows for magnetic samples to be examined in a field-free environment at magnifications of up to 70KX with the objective lens turned off. This electron-optical arrangement is also advantageous in terms of a convenient field-of-view for imaging dopant depletion regions in current semiconductor devices.

The semiconductor community is intensely interested in obtaining 2-D dopant profiles at the nanometer scale. For example, the ITRS Metrology 2000 Update, table 84a – " 2000 Front End Processes Technology Requirements – Near Term", lists this requirement as one with "No known solution". Electron holography has been shown to be capable, both in principle 3 and in practice 4,5, of providing high resolution (~3nm), high sensitivity (0.1V) 2-D maps of electrostatic potential in semiconductor devices. Over the past few years, we have performed holographic experiments on a variety of two-dimensional device structures as well as 1-D doped samples. Two-dimensional potential maps of transistor structures can provide essential information for accurate modeling parameters for device engineers. Figure 2 shows the reconstructed holographic amplitude and phase images from a 0.13micron transistor structure.6 Analysis of the electrostatic potential derived from the phase image can be used to determine both the junction depth and the width under the gate after process annealing. Quantitative analysis of the junction potential allowed details of the lateral diffusion of the implanted dopant to be used for comparison with process simulations.

As an example of holographic imaging of magnetic fields, Fig. 2 shows spin-valve structures consisting of two ferromagnetic layers separated by a thin non-magnetic spacer layer[7]. The shaped elements consist of Co(10nm)/Au (5nm)/Ni (10nm). The figure shows the magnetic contributions to the reconstructed phase over part of an experimental hysteresis cycle along with micromagnetic simulation. The images reveal a reduction in the number of phase contours on approaching zero applied field. The simulations show that the magnetization direction of the Ni in each element reverses well before the external field is reduced to zero as a result of the presence of the demagnetizing field of the magnetically more massive Co layer. Interestingly, the simulations were unable to replicate the vortices observed experimentally in the diamond- and elliptical-shaped elements, stressing the need for direct imaging method for magnetic element at reduced size[8].

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[8] MRM gratefully acknowleges contributions to this work and on-going collaborations with D.J. Smith, Jing Li, R. E. Dunin-Borkowski, M.R. Scheinfein and M. Gribelyuk.

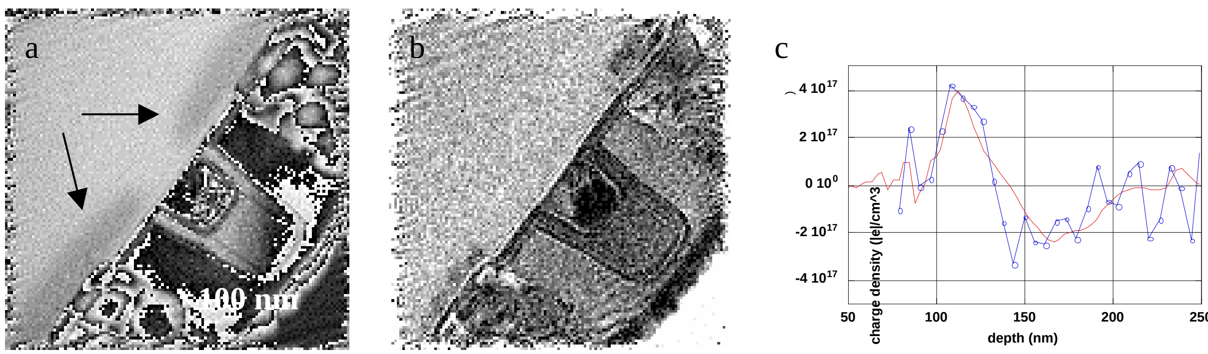


FIG. 1. Holographic reconstructed phase (a) and amplitude (b) of a 130nm p-MOS transistor structure. Contrast due to the depletion regions associated with p-n junctions is visible as darker regions (arrowed) under the Si surface in the phase image. (c) Comparison of dopant distribution and junction position derived from second derivative of hologram (open circles) with that calculated from SIMS profile (solid line).

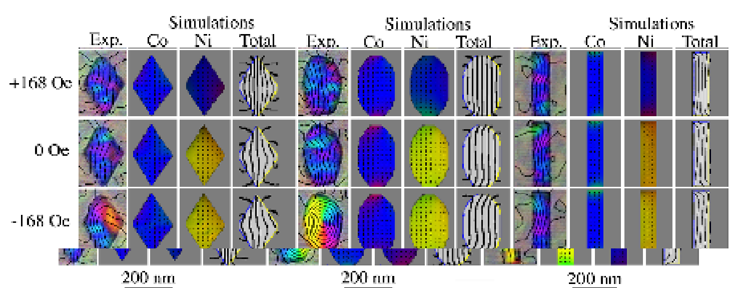


FIG. 2. Composite image of phase contours for magnetic nano-scale spin-valve structures along with simulations for the individual layers and total phase shift.

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