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Three-dimensional dopant/carrier profiling.

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With the transition from planar to three-dimensional device architectures such as fin field-effect-transistors (FinFETs) and TFET's, new metrology approaches are required to characterize the 3D-dopant and carrier distributions precisely as their positioning relative to gate edges, 3D-distribution, conformality and absolute concentration determine the device performance in great detail [1]. We present such metrologies based on 3D-Atomprobe and 3D-SSRM.

At present the Atom-probe has shown its ability to analyze dopant distributions in semiconductor and insulator materials with sub nm 3D-resolution and good sensitivity, however so far primarily on planar devices which represent less severe challenges in terms of localization and site specific sample preparation. Electrical atomic force microscopy (AFM)-based techniques such as scanning spreading resistance microscopy (SSRM) have evolved as mature techniques for the two-dimensional (2D) electrical characterization of nanoscale devices during the last decade and are considered as the method of choice for 2D carrier mapping of advanced semiconductor devices due to its sub-nm spatial resolution, 2..3 nm/decade dopant gradient resolution and high sensitivity. However, the introduction of three-dimensional (3D) device architectures such as TriGate- and nanowire-based transistors inevitably entails the need for metrology techniques capable of measuring the distribution of carriers in confined volumes in 3D.

In this paper we will demonstrate the Atomprobe methodology to extract the 3D-dopant distribution from a FINFET device and discuss the difficulties related to such an exercise.

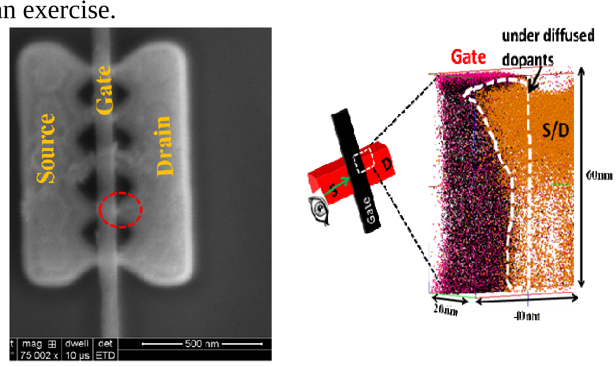


Figure 1a shows the SEM image of where a APT 3D-distrubtion is made and Figure 1b the corresponding atomic distributions of a FIN device, doped using an Arsenic plasma. We used the Atomprobe to determine the dopant under diffusion (under the gate) as well as to probe the dopant profile along the top and the side wall. The acquired 3D-profile highlights the variations in dopant under diffusion (from S/D region to Gate) on the top surface (~14nm) versus the side walls (~5nm) as the result of a non-conformal doping process..

To characterize the 3D-carrier distribution, we demonstrate two methodologies based on SSRM. As SSRM is essentially 2D, we need to introduce concepts which extend the SSRM technique towards 3D i.e. as an electrical tomography tool. The first approach generates a set of cross-sections with incremental off-set in the third dimension through a confined volume. 2D carrier profiles obtained on the individual device cross-sections are then reconstructed towards a 3D carrier distribution map.[3] This is demonstrated on a FINFET-transistor, and is facilitated by arranging several devices in a staggered array, allowing to produce a series of cross-sections with incremental setup by a single cleave. A 3D carrier distribution map is then obtained by combining the individual 2D maps. Based on this concept 3D-carrier profiles in FINFET-transistor are obtained.

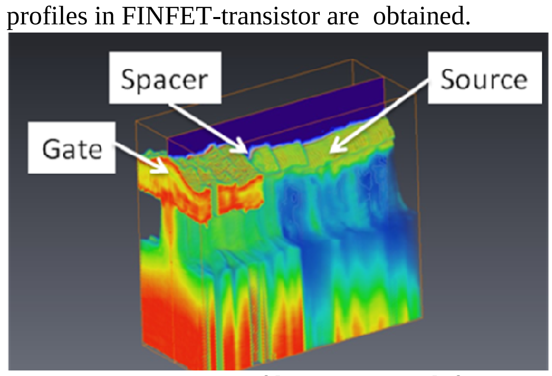
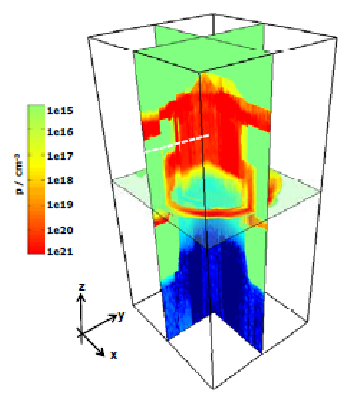
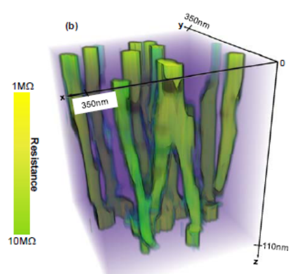


Fig 2 : 3D-carrier profile as extracted from a FINFET using SSRM-tomography [3]

Through the application of a similar concept to TFET's (figure 3) it has been demonstrated that it is necessary to study the actual device dimensions as for the TFET's diameter dependent diffusion effects can be extracted from the 3D-SSRM [4].



The second approach is based on a slice-and-view method whereby material removal by successive tip scanning combined with 2D-imaging leads to a full 3D electrical profiling. The case studies here relates to carbon nanotube (CNT)-based interconnects.[6]



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