Advanced semiconductor-oxide interfaces of ferroelectric and RRAM devices

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Devices based on ferroelectric field effect transistors (FeFET) or resistive random access memory (RRAM) stacks are currently in the focus of academic and industrial research towards steep-slope transistors, neuromorphic networks, and computation-in-memory application. Especially promising are RRAM HfO_2 or ultrathin (below 5 nm) ferroelectric $Hf_{1-x}Zr_xO_2$ (HZO) layers. Their combination with III-V semiconductor substrates such as InAs offers superior charge carrier mobility compared to Si. Our collaborators at the Nanoelectronics group of Lund University are pioneering in developing InAs nanowire-based FeFET gate-all-around [1,2] and RRAM [3,4] devices including 1 transistor 1 resistor structures integrated in a single nanowire [4]. These novel devices have in common that their performance critically relies on the quality of the semiconductor-oxide interface and that the structure and chemical composition of this interface provides additional functionality. Here, I will present in-depth studies of such interfaces using *operando* soft- and hard X-ray photoemission spectroscopy (XPS/HAXPES), complemented by other synchrotron-based methods, which are resulting in a paradigm change in the understanding of MOS structures.

For InAs/HfO_2 RRAM devices, we found that the existence of a sufficiently thick As-oxide interface layer, obtained through extended oxygen plasma pulses, below the HfO_2 film with oxygen vacancies is crucial for enabling resistive switching [4]. This is contrary to the case of conventional InAs-based MOSFETs where we previously were aiming for the perfect self-cleaning and observed complete As-oxide removal during HfO_2 deposition [5]. Furthermore, also the structure of the HfO_2/TiN top metal interface of RRAM devices is relevant, where substantial band-bending can result in strong Schottky barriers [3].

From initial *operando* HAXPES studies of FeFET devices, with applied dc bias or upon positive-up-negative-down (PUND) switching pulses, we derived the unexpected result that the applied bias does not drop across the ferroelectric HZO oxide layer, but instead only across a very thin interfacial InAs-oxide layer. Simulations explain this behavior by the defect density in the interfacial oxide. Nevertheless, the FeFETs show high polarization values and good endurance.

The close connection between state-of-the-art device development and detailed characterization of the involved materials science aspects are the key to an improved understanding of the device functionality.

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