Semiconductor-Oxide Interfaces of InAs-based Ferroelectric and Memristive Devices

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Introduction: Ferroelectric metal-oxide-semiconductor (MOS) stacks or resistive random-access memory (RRAM) devices are promising building blocks for steep-slope transistors, neuromorphic networks, and compute-in-memory applications. Devices based on ultrathin HfO2 or Hf(1-x)Zr(x) O2 (HZO) oxide layers on InAs combine scalability with superior charge carrier mobility. However, their performance and functionality critically rely on the structure, quality, and chemical composition of the semiconductor-oxide interface.

Methods: We use various types of synchrotron-based X-ray photoemission and absorption spectroscopy (XPS/XAS) to study MOS interfaces, even under device operation or during oxide layer formation (see Figure (a)).

Results: In conventional InAs/HfO2 MOS field-effect transistors, where we analyzed the role of different In and As sub-oxides and defect states both for planar and nanowire devices, we confirmed the so-called “the cleaner the better” paradigm and explored paths towards a native oxide-free interface.

Surprisingly, when investigating InAs/HfO2 RRAM devices, our XPS results revealed that a sufficiently thick interfacial InAs-oxide layer, obtained upon interface reoxidation during atomic layer deposition, significantly improved resistive switching properties (see Figure (b)).

In ferroelectric InAs/HZO-based devices, oxidation and degradation of the interface is a critical issue during a post-deposition annealing step, which is required for obtaining the ferroelectric crystal phase of HZO. Here, XPS helped to evaluate alternative annealing procedures. Finally, during operando XPS studies we observed an interlayer oxide with significant electrostatic influence and polarization switching-induced interface chemistry.

Conclusion: Advanced semiconductor-oxide interfaces play a highly active role in ferroelectric and memristive devices, and in-depth interface characterization is crucial for understanding and improving device performance.