Spatially resolved trap states and random telegraph noise in semiconductors

Megan Cowie[1], Taylor J.Z. Stock[2,3], Procopios C. Constantinou[2], Neil J. Curson[2,3], and Peter Grutter[1]

[1] *Department of Physics, McGill University, Montreal, Quebec, Canada*
[2] *London Centre for Nanotechnology, University College London, London, United Kingdom*
[3] *Department of Electronic and Electrical Engineering, University College London, London, United Kingdom*

peter.grutter@mcgill.ca

Semiconductor interfaces often have isolated trap states which modify electronic properties. Here, we study the electric susceptibility of the Si/SiO_2 interface with nm spatial resolution using frequency-modulated atomic force microscopy. We show that surface charge organization timescales, which range from 1−150 ns, increase significantly around interfacial states [1]. We conclude that dielectric loss under time-varying gate biases at MHz and sub-MHz frequencies in metal-insulator-semiconductor capacitor device architectures is highly spatially heterogeneous over nm length scales [1].

In frequency-modulated atomic force microscopy the measured frequency shift is quadratic in applied bias for metallic samples and probes. However, for semiconducting samples, band bending effects must be considered, resulting in non-parabolic bias curves. We have developed a framework to quantitatively describe a metal-insulator semiconductor (MIS) device formed out of a metallic AFM tip, vacuum gap, and semiconducting sample. We show how this framework allows us to measure dopant concentration, bandgap and band bending timescales of different types of defects on semiconductors with nm scale resolution on Si, 2D $MoSe_2$ and pentacene monolayers [2].

We also measure temporal two-state fluctuations of individual defects at the Si/SiO_2 interface with nanometer spatial resolution using frequency-modulated atomic force microscopy with single electron sensitivity. We demonstrate that two-state fluctuations are localized at interfacial traps, with bias-dependent rates and amplitudes. When measured as an ensemble, the observed defects have a 1/f power spectral trend at low frequencies [3].

Low-frequency noise due to two level fluctuations inhibits the reliability and performance of nanoscale semiconductor devices, and challenges the scaling of emerging spin based quantum sensors and computers. The presented method and insights provide a more detailed understanding of the origins of 1/f noise in silicon-based classical and quantum devices, and could be used to develop processing techniques to reduce two-state fluctuations associated with defects.

References:
[1] M. Cowie, et al., Phys. Rev. Lett. (accepted); arxiv.org/abs/2306.13648
[2] M. Cowie, et al., Phys. Rev. Materials **6**, 104002 (2022); arxiv.org/abs/2109.15275
[3] M. Cowie, et al., submitted, arxiv.org/abs/2403.07251