Scanning Tunneling Spectroscopy as a tool for the study of physical phenomena at surfaces

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In this talk, we will present the use of scanning tunnelling spectroscopy to understand the interplay between structural and other physical properties of the surface of different two-dimensional materials.

In the first example, we show that scanning tunneling spectroscopy is able to differentiate the electronic properties of single and bilayers of epitaxial graphene. We report on the observation of triangular nanostructures which result from extended stacking faults in the SiC substrate and their effects on graphene layers that are formed on top of them. Spectroscopic measurements revealed distinct electronic responses as a function of the local hydrogen intercalation. Spectroscopic signatures ranging from single- to double-layer graphene, as well as intermediate states were observed as a consequence of the (in)complete hydrogen intercalation process [1].

In the second example, we used vapor phase deposition to synthesize ultrathin germanium sulfide nano-flakes on a highly oriented pyrolytic graphite substrate. Nanostructures of variable thicknesses were characterized using scanning tunneling microscopy and spectroscopy. Tunneling currents under forward and backward biases were measured as a function of nano-flake thickness. Remarkably, we clearly observed a hysteresis pattern, which we attributed to surface ferroelectric behavior, consistent with the screening conditions of polarization charges [2].

Finally, we explored the variation in the band gap of two-dimensional nanobelts o MoO_3 after the localized application of intense electric fields using scanning tunneling microscopy and spectroscopy. A deterministic change of electronic band gap was observed in MoO_3 for negative applied biases. These changes are fully reversible and robust with respect to successive cycles for a range of applied bias compatible with common applications. This phenomenon is ascribed to changes in the surface stoichiometry due to the local action of the scanning tunneling microscopy tip [3].

[1] Self-assembled triangular graphene nanostructures: Evidence of dual electronic response, T Chagas, PHR Gonçalves, I Antoniazzi, JW González, R. Magalhaes-Paniago. **Carbon 142, 580-591 (2021)**

[2] Evidence of thickness-dependent surface-induced ferroelectricity in few-layer germanium sulfide obtained via scanning tunneling spectroscopy, RR Barreto, TC Ribeiro, GHR Soares, E Pereira, DR Miquita, GAM Safar, R. Magalhaes-Paniago, **Nanoscale 16 (11), 5794-5801 (2024)**

[3] Electronic gap redesign in electrochromic : A scanning tunneling spectroscopy study, LP Trindade, G Fontenele, EG de Oliveira, RR Barreto, LC Detoni, R. Magalhaes-Paniago, **Physical Review Materials 10 (1), 016205 (2026)**