Probing the Energy Landscape of 2D Material-Based Devices via Operando X-ray Photoemission Microscopy

Presenting Author: Debora Pierucci[1]
Co-Authors: Dario Mastrippolito[1,2], Mariorosa Cavallo[1], Erwan Bossavit[1,2], Pavel Dudin[2], Jose Avila[2], Emmanuel Lhuillier[1]
[1] *Sorbonne Université, CNRS, Institut des NanoSciences de Paris, 4 place Jussieu, 75005 Paris, France*
[2] *Synchrotron SOLEIL, L'Orme des Merisiers, Départementale 128, 91190 Saint-Aubin, France*
Contact: debora.pierucci@cnrs.fr

As two-dimensional (2D) materials are increasingly incorporated into electronic and optoelectronic devices, understanding their electronic structure under realistic working conditions becomes a central challenge. Once integrated into device architectures, these materials are no longer isolated systems but are instead in contact with metal electrodes and dielectric environments while operating under applied electrical bias, conditions under which their intrinsic properties may substantially deviate from those of pristine materials.

In this context, scanning X-ray photoemission microscopy (SPEM) [1] emerges as powerful technique to directly access to the local energy landscape and electric-field distribution in operating 2D-material-based devices. By exploiting the sub-micrometer spatial resolution of SPEM, we investigate field-effect transistors (FETs) based on single-flake transition metal dichalcogenides (TMDs) and van der Waals heterostructures under applied bias. The technique enables simultaneous mapping of the out-of-plane gate-induced field and the in-plane vectorial electric-field components across the device channel [2].

Our results demonstrate that this approach acts as a sensitive local probe of device architecture, flake geometry, thickness, and morphology, parameters that strongly influence nanoscale current pathways within the device channel [2]. The measurements highlight finite-size effects and reveal the spatial distribution of electric fields at flake interfaces [3]. Ultimately, this *operando* methodology enables a correlative description linking the bias-modified local energy landscape to the macroscopic electrical response, offering a pathway toward systematic and rational optimization of nanoelectronic devices, including, but not limited to those based on 2D materials.

References

[1] J. Avila, S. Lorcy, P. Dudin, Journal of Electron Spectroscopy and Related Phenomena, 266, 147362 (2023)

[2] D. Mastrippolito, M. Cavallo, D. Borowski, E. Bossavit, C. Gureghian, A. Colle, T. Gemo, A. Khalili, H. Zhang, A. Ram, E. Dandeu, S. Ithurria, J. Biscaras, P.I Dudin, J.-F. Dayen, J. Avila, E. Lhuillier, D. Pierucci, ACS nano, 19, 9241–9249 (2025)

[3] D. Mastrippolito, M. Cavallo, E. Bossavit, C. Gureghian, A. Colle, T. Gemo, G. Strobbia, D. De Pesseroey, M. Paye, A. Khalili, H. Zhang, J. Biscaras, J. K. Utterback, P. Dudin, J. Avila, E. Lhuillier, D. Pierucci, Nano Letters 25, 29, 11340-11346 (2025)

Figures

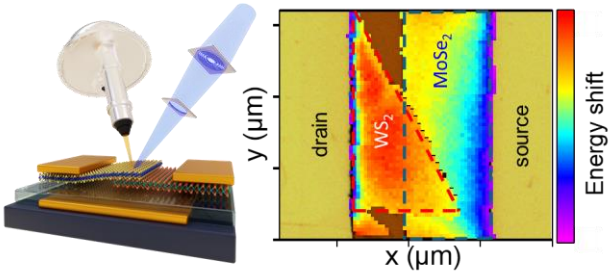

Figure 1: Left: Schematic of the FET, whose channel consists of a $WS_2/MoSe_2$ heterostructure spatially probed by SPEM. Right: Energy-shift map revealing the gate-induced energy variation within heterostructure under an applied gate bias (V_{GS} = +5 V is applied; VDS = 0 V).