Quantitative imaging of surface potential: From molecules on metals towards charge density waves on 2D materials

S. Anchamkudy[1,2], J. Lorenz[1,3,4], H. Thake[5], A. Karimi[1], R. Temirov[1,2], R. J. Maurer[5,6,7], C. Wagner[1], F. S. Tautz[1,3,4], F. Lüpke[1,2,3]

[1] Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany
[2] II Physikalisches Institut, University of Cologne, Germany
[3] Jülich Aachen Research Alliance (JARA), Germany
[4] Institut für Experimentalphysik IV A, RWTH Aachen University, Germany
[5] Department of Chemistry, University of Warwick, United Kingdom
[6] Department of Physics, University of Warwick, United Kingdom
[7] Faculty of Physics, University of Vienna, Austria

In this poster, I will discuss Scanning Quantum Dot Microscopy (SQDM) technique and its important results along with our recent advancements in broadening its application to 2D materials. SQDM is an extension of non-contact atomic force microscopy technique that uses charge state of a molecular quantum dot (perylene tetracarboxylic dianhydride (PTCDA)) attached to a tip to probe surface dipoles [1]. Developed at Peter-Grünberg-Institute (PGI-3) in Forschungszentrum Jülich, SQDM has been applied to molecular adsorbates, adatoms, defects, and atomic assemblies on the Ag surface [2,3] - and provided valuable benchmarks for theory where metal-organic hybrid systems are particularly challenging. Our recent results on measuring PTCDA molecules deposited on Ag (111) show the higher sensitivity of this technique. We could identify two preferred adsorption orientations (<1-10> and <11-2>) of PTCDA which differ by 30 degrees from each other showing distinctly different surface dipoles (-0.51 D and -0.65 D respectively). We also measured PTCDA deposited on Pb (111) and found that the PTCDA molecule has more than five times larger dipole when it is on Pb (111) compared to when it is on Ag (111). This difference can be attributed to significantly different charge transfer and adsorption height. Building on this established sensitivity of SQDM to surface potential, we extend the application of SQDM to investigate charge density waves (CDWs) in 2D materials. Although charge density variations with different CDWs in 2H-$NbSe_2$ and 1T-TaS_2 have already been imaged through scanning tunneling microscope, a quantitative mapping of surface potential variations by these CDWs are not done. On the way to this goal, we could already successfully deposit PTCDA molecules on $NbSe_2$ and our scanning tunneling experiments show clean PTCDA island with herringbone structure. Due to strong inter-molecular interactions, big islands are formed even with shorter deposition time. Currently we are optimizing the controlled picking up of PTCDA from the $NbSe_2$ surface to use it as the probe for executing SQDM technique.

References:
[1] C. Wagner, M. F. Green et al., Phys. Rev. Lett. 115, 026101 (2015).
[2] R. Bolat, J. M. Guevara et al., Nat Commun 15, 2259 (2024).
[3] C. Wagner, M. F. Green et al., Nat. Mater. 18, 853 (2019)

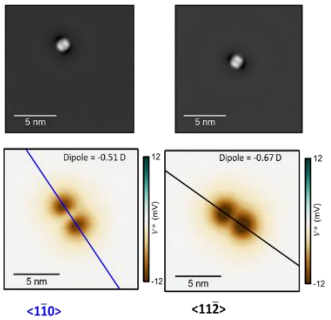

Fig. 1: SQDM results of PTCDA dipole on Ag (111) showing orientation dependence. Top two are the STM images of PTCDA molecules orienting in <1-10> and <11-2>. Bottom plots show the corresponding surface potential with the dipole values mentioned on the upper right corner.