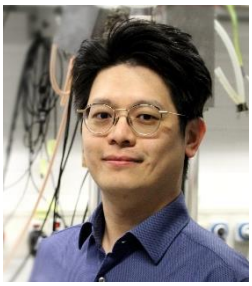
Engineering Molecular Quantum States: From Single-Molecule Luminescence to Artificial Quantum Lattices



Tzu-Chao Hung

Institute of Experimental and Applied Physics and Halle-Berlin-Regensburg Cluster of Excellence CCE, University of Regensburg, Regensburg, Germany.

How can atomic-scale structure and interactions be harnessed to engineer quantum states? Scanning probe microscopy (SPM) provides a unique platform for addressing this question by resolving individual molecules, probing their excitation pathways, and constructing artificial structures with tailored electronic properties. In this talk, I will discuss two approaches: controlling light emission from individual molecules and engineering electronic states in artificial quantum lattices.

First, I will explore how molecular charge states and excitation pathways govern single-molecule luminescence. Combining scanning tunneling microscopy (STM) and spectroscopy with STM-induced luminescence, we demonstrate bipolar electroluminescence from individual zinc phthalocyanine molecules, revealing distinct emission processes under opposite bias polarities. I will then show how the local environment can be exploited to activate Q-band emission from nickel phthalocyanine, whose fluorescence is normally quenched by rapid nonradiative relaxation. These studies illustrate how charge injection and energy-transfer processes can be harnessed to control molecular excitation and relaxation, enabling light emission from otherwise non-emissive molecular excited states.

Moving from individual molecules to engineered molecular architectures, I will present the bottom-up construction of covalently bonded phthalocyanine-based Lieb-lattice structures through on-surface synthesis. Combining bond-resolved atomic force microscopy, differential conductance mapping, density-functional theory, and tight-binding modelling, we reveal strong intersite electronic coupling and connectivity-governed quantum states, including connectivity-enforced degeneracies associated with characteristic localized states. By exploring structures with increasing dimensionality, we investigate the evolution of electronic states in extended molecular architectures.

Together, these studies establish complementary routes to engineering quantum phenomena at the atomic scale: controlling excitation and relaxation pathways in individual molecules and designing molecular architectures in which lattice topology determines electronic states. They illustrate how SPM can serve as an atomic-scale laboratory for investigating and controlling quantum states, from molecular light emission to artificial quantum matter.