Towards Quantum Computing with Spins on Surfaces

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There is a strong international research effort in the area of quantum information science. Here, the concepts of quantum coherence, superposition and entanglement of quantum states are exploited. These concepts were originally shown with photons as well as atoms and ions in vacuum traps. Over the past two decades, many advances at studying such quantum coherence in solid-state and molecular architectures have evolved [1].

In this talk we will focus on quantum-coherent experiments in Scanning Tunneling Microscopy (STM). STM enables the study of surfaces with atomic-scale spatial resolution and offers the ability to study individual atoms and molecules on surfaces. To study qubits with STM, we recently learned how to combine STM with electron spin resonance [2,3]. Spin resonance gives us the means to quantum-coherently control an individual atomic or molecular spin on a surface. Using short pulses of microwave radiation further enables us to perform qubit rotations and learn about the quantum coherence times of our spins [4]. Finally, we will demonstrate multi-qubit operations with spins on surfaces and discuss their performance measures [5]. Future directions for improvements will wrap up the talk.

1. Andreas J. Heinrich, William D. Oliver, Lieven M. K. Vandersypen, Arzhang Ardavan, Roberta Sessoli, Daniel Loss, Ania Bleszynski Jayich, Joaquin Fernandez-Rossier, Arne Laucht, Andrea Morello, “Quantum-coherent nanoscience”, *Nature Nanotechnology*, **16**, 1318-1329 (2021).
2. Susanne Baumann, William Paul, Taeyoung Choi, Christopher P. Lutz, Arzhang Ardavan, Andreas J. Heinrich, “Electron Paramagnetic Resonance of Individual Atoms on a Surface”, *Science* **350**, 417 (2015).
3. Yi Chen, Yujeong Bae, Andreas Heinrich, “Harnessing the Quantum Behavior of Spins on Surfaces”, *Advanced Materials* **2023**, 2107534 (2022).
4. Kai Yang, William Paul, Soo-Hyon Phark, Philip Willke, Yujeong Bae, Taeyoung Choi, Taner Esat, Arzhang Ardavan, Andreas J. Heinrich, and Christopher P. Lutz, “Coherent spin manipulation of individual atoms on a surface”, *Science* **366**, 509 (2019).
5. Yu Wang, Yi Chen, Hong T. Bui, Christoph Wolf, Masahiro Haze, Cristina Mier, Jinkyung Kim, Deung-Jang Choi, Christopher P. Lutz, Yujeong Bae, Soo-hyon Phark, Andreas J. Heinrich, *Science* **382**, 87 (2023).

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