A Low Temperature STM System for the Study of Quantum and Spin Electronic Systems*

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We describe an experimental system with the goal of providing new measurement capabilities for the study of quantum and spin electronic systems on the nanometer scale. The physical information desired in such systems includes: the quantized electron energy distributions arising from spatial or magnetic confinement, the spatial extent of electronic wavefunctions, the role of electron-electron interactions in the presence of confining boundaries, the exact physical structure of the system, the shape of the confining potentials, and finally, the physics of electron transport on nanometer length scales.

Several experimental challenges are posed in the study of electronic systems confined to nanoscale dimensions. Cryogenic temperatures are required to obtain high resolution in separating quantized energy level structures, ultra-high vacuum systems are necessary to study samples without contamination, and scanned probe techniques are needed to obtain measurements with atomic resolution. To meet these measurement challenges we have constructed a scanning tunneling microscope (STM), operating in the temperature range from 2-150 K, that is coupled to multiple MBE fabrication systems, as shown in Fig. 1. The microscope is a self-contained module that is translated between the room temperature system and the cryostat. It includes 3 axes of coarse motion between the tip and sample, a 3-axis scanner for fine motion, tip and sample exchange systems, and an optical system to view the tip-sample junction when located in the cryostat. In ultra-high vacuum, the STM is lowered into the cyrostat and locked into a copper cone which is cooled via He exchange gas to isolate it from the boiling He. Three stages of vibration isolation and an acoustic isolation room serve to isolate the microscope system from external noise sources. A sample temperature of 4.3 K is reached in our design when cooling with 4.2 K He. We expect to reach 2.3 K using a lambda refrigerator in the lower part of the cryostat. Figure 2 shows a typical STM measurement of the Cu(111) surface, demonstrating atomic resolution at 4.3K. To study magnetic effects, the STM system contains the capability of applying magnetic fields up to 10 Tesla normal to the sample

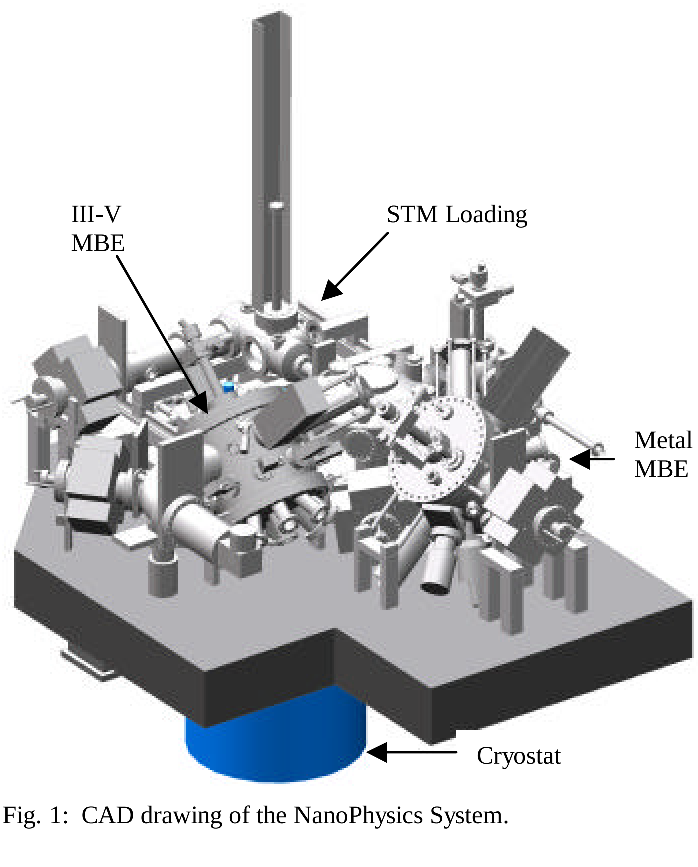

Fig. 1: CAD drawing of the NanoPhysics System.

surface to observe magnetic quantization in 2D electron gas systems, and a rotating vector field of 1.5 Tesla to observe magnetic tunneling effects.

Equally challenging to the measurement methodology is the fabrication of quantum electronic systems. The STM is part of a facility that includes separate MBE fabrication systems for III-V semiconductor growth and magnetic and superconductor material growth with transfer of samples to the STM system under ultra-high vacuum. In addition to these traditional fabrication techniques, we are developing an autonomous atom assembler to fabricate quantum structures atom-by-atom on a large scale. One of our current projects includes the study of the Kondo effect in single magnetic impurity atoms on noble metal (111) surfaces. The noble metal (111) surfaces contain a 2D surface state that has a partial band gap in the surface Brillion zone. STM images of this surface display constructive interference produced by the scattering of the surface state electrons from step edges and defects, as shown in Fig. 3.

Current projects focus on the physics of magnetic impurities in non-magnetic host materials, spin polarized tunneling effects in superconductor-ferromagnetic systems, and confined electron systems, such as in the quantum hall devices. In this poster, we will describe the design of the overall NanoPhysics system, its components, and performance to date.

*This work is supported in part by the Office of Naval Research.

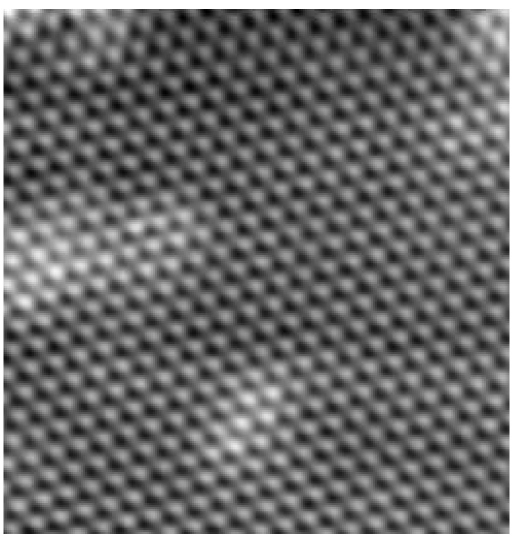

Fig. 3: Atomic resolution STM image, 6x6nm, of the Cu(111) surface obtained at 4.3 K. The grayscale range is 0.02 nm.

Fig. 2: STM image, 50x50nm, of the Cu(111) surface obtained at 4.3 K showing constructive interference produced by the scattering of the 2D surface state from step edges and defects.