The α-Ga (010) Surface Investigated by Room and Low Temperature Scanning Tunneling Microscopy and Helium Atom Scattering

Natalya Pertaya

A dissertation submitted for the degree
of Doctor of Natural Science at the
Department of Physics of the
Free University Berlin

May 2004

First referee Prof. Dr. K.-H. Rieder

Second referee Prof. Dr. K. Horn

Date of defense 11th of June 2004

Content

Introduction

The surface of a crystal can exhibit significantly different qualities as compared to the bulk. Electronic surface states and lattice vibrations localized in the topmost layers are common phenomena on a multitude of materials. The interaction between them can result in a new groundstate altering structural and electronic properties. Such a charge density wave has been observed and investigated in this work for the first time on a Ga(010) surface. Gallium is a commonly used material in semiconductor compounds and belongs to the little investigated category of semimetals. Strong electron-phonon coupling and a pseudogap at the Fermi energy are characteristic properties of semimetals. The surface of Ga(010) exhibits a unique thermal stability and a surface state renders it more metallic than the bulk. The low melting point of 30° C requires extra attention in the experiments. Upon cooling below only 235 K the surface ungoes a reconstruction. In the present work the surface has been imaged for the first time in the low temperature phase with scanning tunneling microscopy (STM) and the unit cell was determined in detail. The presence of a charge density wave is not expected apriori on the Ga(010) surface, but was identified unambiguously with tunneling spectroscopy. Surprisingly two domains form well ordered parallel stripes. An extensive helium atom scattering study (HAS) and measurements with STM at room temperature complement this investigation.

Next to surface measurements the instrumental setup and thorough optimization of a STM for the operation at room temperature was a major part of this work. Since the invention of the STM in 1983 by Binnig and Rohrer (Nobelprize in 1986) and atomic force microscope (AFM) nearly two decades ago, these scanning probe microscopes have been established to be of the most important techniques in the investigation of surfaces. During the past 20 years many different setups of the STM have been realized. Successful and widespread types of the STM scanners are the linear-motor type and Besocke-beetle type. Desirable is a setup which combines high-quality imaging and sufficient stability. The speed and the resolution of the scanner are limited by its mechanical resonances which are triggered by external noise sources, thermal activation, and a feed-back loop. Thereby one needs to distinguish between low-frequency noise in the range of a few Hz caused typically by intrinsic vibrations of buildings and air ventilation and high-frequency noise caused by the electronic noise and the triggered mechanical resonances. Both of the noise sources can be effectively reduced with an optimized scanner setup built up during this work. Furthermore the quality of STM images and the applicability of the STM for spectroscopy and manipulation purposes rely upon the time-dependent response of the used piezo ceramics resulting in creep, hysteresis and thermal drift. In this work the Besocke-beetle STM scanner setup was optimized (for the operation at room temperature) by using a new type of the piezoelectric elements – *shear stack piezoelectric elements*. This resulted in very high resonance frequencies and overall stability - the resonance frequencies shifted up by more than one order of magnitude as compared to commonly used tube piezos. This scanner was then implemented in an ultra high vacuum (UHV) system, the setup of this system was part of the present work.

Manipulation of atoms, small molecules and big molecules have been achieved with a low temperature STM starting a decade ago. But more interesting and promising for future direction is the manipulation of atoms and molecules at room temperature. For molecular manipulation at room temperature several conditions need to be fulfilled: Low thermal mobility of the molecule, strong intramolecular bonding and a delicate bonding of the molecule to the surface. A candidate satisfying these conditions is the C_5H_5 radical adsorbed on a Ag(111) surface. Furthermore a major requirement to the STM setup for manipulation experiments is its high stability. Such an ultrastable STM was built up in the present work. A remarkable row-like arrangement of the C_5H_5 radicals was observed resulting from radical-radical interaction. Detailed images revealed an appearance resulting from a localized conductivity in the molecule and the adsorption geometry. Here calculations assisted the clarification of the imaging mechanism. Additionally manipulation experiments of the C_5H_5 radicals showed a stronger bond to the Ag(111) surface than on the Ag(001) surface.