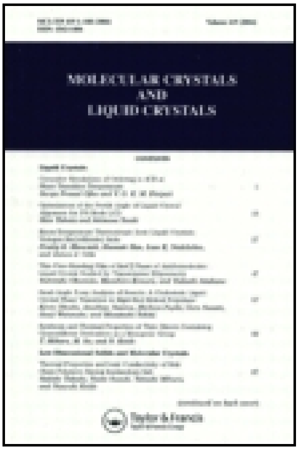

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Developing High Resolution Electrical Probing System Based on Atomic Force Microscopy

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Version of record first published: 24 Sep 2006

Mol. Cryst. Liq. Cryst., 1997, Vol. 294, pp. 91–94
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DEVELOPING HIGH RESOLUTION ELECTRICAL PROBING SYSTEM BASED ON ATOMIC FORCE MICROSCOPY

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Abstract We have developed an electrical probing system based on a conducting atomic force microscope (AFM), which has great versatility and accuracy in acquiring nanometer-scale spatially resolved electrical information of samples, involving local I(current)-V(voltage) and I-s(distance) characteristics, simultaneous current and topography mapping, etc. together with the conventional AFM function. It is particularly powerful in evaluation of the electrical properties of nanosized materials and devices.

INTRODUCTION

Nanometer-sized materials and structures have attracted great attention as potential building blocks for future generation electronic devices.[1,2] Using the scanning probe microscopy (SPM), it has become a routine-like laboratory work to create quantum dots and wires, and nanometer-scale patterns.[3,4] Undoubtedly evaluation of the electrical properties like I-V characteristics of such nanosized materials is of equally importance from both fundamental and technological point of view. Most of the conventional techniques have lost their competency for this purpose because of the lack of spatial resolution. In this regard, scanning tunneling microscopy (STM) and scanning tunneling spectroscopy (STS) as atomic level resolution techniques have been widely used to perform spectroscopy on single atoms, and to study the electrical properties of metal contacts on the atomic scale.[5,6] However for some circumstances the atomic level resolution is too high to reflect the desired property, e.g., the "bulk" I-V characteristic of a nanoparticle rather than that of a few atoms on its top surface. The existence of tunneling gap in STM/STS measurement may also make the explanation complicated.[7] In this paper, we present an AFM-based electrical probing system. The reasons for using AFM are: (1) the feedback system does not interfere with the electrical measurement because of the use of optical feedback mechanism; (2) under proper force load, mechanical rather than tunneling contact can be built between tip and sample, thus allowing a straightforward measurement of electrical properties. Equipped with a conducting tip and an electrical source-measurement apparatus, our system has a great flexibility on the measuring functions, the types of samples, and the sample environments such as in air, in vacuum, and even in liquid with satisfactory spatial resolution.

SYSTEM SETUP

Figure 1 shows the block diagram of our system, which is established on a Nanoscope III AFM (Digital Instruments (DI) Inc., Santa Barbara, CA, USA). Commercial silicon or silicon nitride tip and cantilever (DI, with force constant ranging from 0.01 to 1 N/m) are made conductive by squentially sputtering on 10 nm titanium and 100 nm gold. A HA-150 Potentiostat (Hokuto Denko Inc, Tokyo, Japan) biases the tip and sample externally, detects the current and sends signal to the SPM controller for imaging or to a server computer for sampling and storing. These three parts of the system are connected through a Signal Access Module (DI, not shown) which facilitates the wiring and operating much.

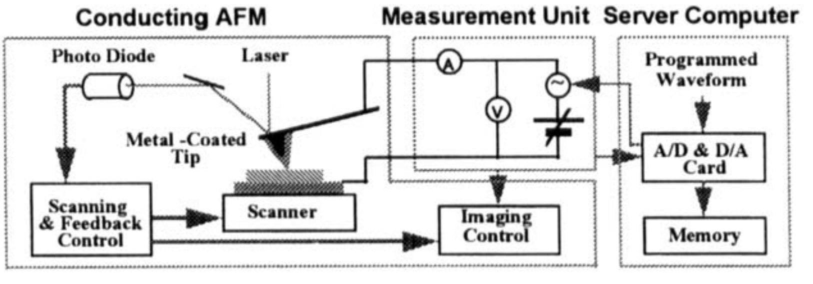

FIGURE 1 The Block diagram of the AFM-based I-V probing system.

The system measures current ranging from 1 pA to 10 mA, with a sensitivity of 0.1 pA. In most cases, current is limited below 10 μA by inserting a resistor (several megaohms) in the circuit in series with the tip to prevent tip and sample from destruction. The bias voltage is generated by the server with any desired waveform between -10V and +10V (vs. sample). The spatial resolution is proved to be mainly determined by the radii of the tips, typically around tens of nanometers. For instance, with gold-coated silicon tips, we investigated a series of individual gold nanoparticles having dimensions of 100 nm to 10 nm in diameter immobilized on substrate surfaces using self-assembling technique, and got clear topography images and stable I-V characteristics.

At this stage, three main current measurement modes are available in our system. On *scanning* mode, when the bias voltage is fixed, simultaneous topography and current-mapping images can be acquired. Shown in Figure 2 is the example of this operation, which was obtained with a metal grating. Clearly the metal-coated lines gave higher current, in nice aggreement with the topography image.

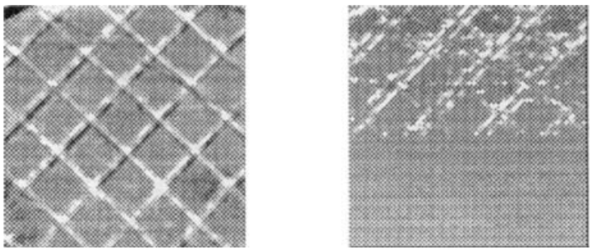

FIGURE 2 Simultaneous topography and current-mapping images obtained on a metal grating with 1μm spacing.

On *point-detection* mode, the X-Y scanning is stopped and the probe tip is located on a predetermined position above sample surface. Then the local I-V characteristic can be obtained with fixing the z movement of tip. Figure 3 shows the I-V dependence of n-doped silicon measured in this way, which is characteristic of a metal (tip) - semiconductor (Si) junction. A variant of this operation mode is, gradually moving the tip toward sample surface and measuring the current-distance dependence on a specific location, which can be used to investigate the local deformation properties of sample.

The third mode combines the former two, i.e., during X-Y scanning, I-V curves are simultaneously collected on each group of pixels, similar to the current imaging tunneling spectroscopy (CITS) mode in STM operation.

It should be pointed out that although conducting AFM has been used on many occasions, for example, to fabricate nanostructures [8] and to perform current mapping, few studies have been done on directly measuring the I-V properties using it. With all above operation modes, our conducting AFM system can actually perform most functions of STM except for the different feedback mechanism. If required, the differential current to a preset value can be switched into the AFM controler as feedback signal so to make the system a real STM, which allows for the simultaneous measurements of forces and force gradients along STM constant current contours.[9]

We have examined a variety of samples to demonstrate the capability and reliability of our electrical probing system. Besides those shown above, given in Figure 4 is another example, which demonstrates the bistable conductivity feature of an organic film. The sample was a 40nm ultrathin film of 1,4-Phenylenediamine and 4'-nitro-1,1-dicyanostyrene co-deposited on HOPG by ionized cluster beam deposition(ICBD), which exhibited electronic donor-acceptor behavior as proven from absorption spectroscopy study. Along with the bias voltage scanning, the film conductivity oscillates reversibly between two different values, with one being more than three orders larger than the other one, demonstrating the potential of such hybrid films in ultrahigh density information storage.

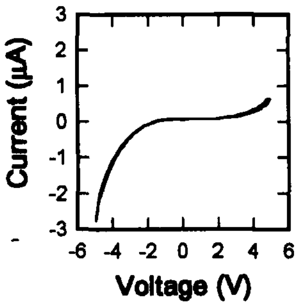

FIGURE 3 I-V characteristic obtained on a metal (gold coated tip) - silicon (n^+, 0.015 Ω· cm) junction.

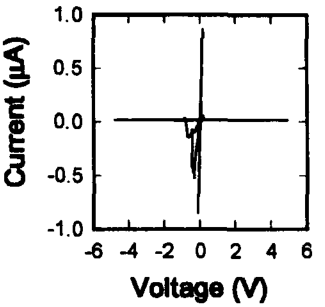

FIGURE 4 Bistable conductivity property of co-deposited film of 1,4-Phenylene-diamine and 4'-nitro-1,1-dicyanostyrene on HOPG.

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