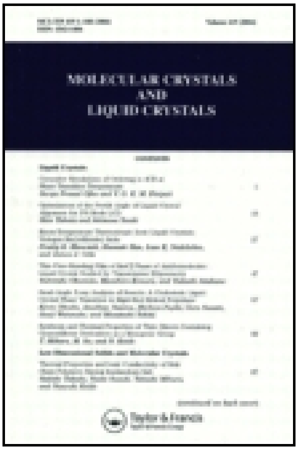

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Fabrication of PdIr-Coated Conductive Atomic Force Microscope Tip and its Application in Nanofabrication

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Fabrication of PdIr-Coated Conductive Atomic Force Microscope Tip and its Application in Nanofabrication

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We report a new, conductive AFM tip, which is fabricated by thermal evaporation of 20–30nm PdIr alloy onto commercial silicon nitride cantilevers. With well-controlled evaporation conditions, a tip with nice electrical conductivity, good mechanical and chemical stabilities has been prepared. Thus fabricated AFM tips were used to measure electrical properties of materials with spatial resolution higher than 2nm, and to fabricate nanostructures on Zn-doped p-type GaAs (100) and chromium surfaces via field-induced oxidation.

Keywords: AFM tip; Pd-Ir; Nanofabrication

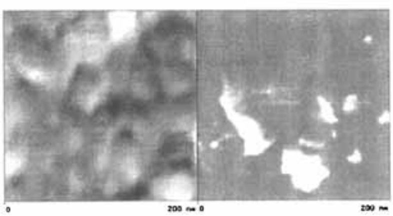
INTRODUCTION

Conductive AFM tips have been instrumental in the study of the electrical properties of materials on nanometer scale[1-3], and in the fabrication of nanostructures and nanodevices by field-induced processes[4-9]. In addition to heavily doped silicon tips[9], many different types of conductive AFM tips have been fabricated using surface coatings such as Ti[4], Au[1], AuTi[1], AuCr[5], Pt[9], W[1], Cr[7], NiCr[6] and NbN[2].

The requirements for high-performance conductive AFM tips are small tip radius, good electrical conductivity, as well as good mechanical, chemical and electric field stabilities. Each kind of realistic tips has its own limitations, and none seems to be all purpose. For instance, silicon tips and tips coated with metals such as Ti, Cr, W, etc may form oxides readily when exposed to air, especially in the presence of an electric field. The oxides cause the surfaces to be somewhat nonconductive [1,2,4]. The tip coatings may be worn out easily after several scans if the coating metals are too soft, e.g. Au, Ag. If the difference in thermal expansion coefficients between tip and the coatings is too large, stresses in the coatings may warp the cantilever, e.g. Al, Ag, and Au. With coatings having small threshold fields for field evaporation, the coatings may be deposited onto substrate surface when a strong electric field is imposed[8]. Furthermore, large tip radii, due to thicker coatings and larger particle sizes of coatings, may result in larger magnification factors of the imaged features[2] in imaging as well as larger minimum linewidth that can be written[4] in lithography.

In this paper, we report the fabrication of a new type of conductive AFM tips, which were fabricated by thermal evaporation of a 20-30nm thick layer of PdIr alloy onto commercial silicon nitride cantilevers. With well-controlled evaporation conditions, the coating resulted in very little increment in tip radius because of small particle size and coating thickness. The particle size of the coating was about 3nm measured by STM. The SEM pictures showed that a homogeneous and dense coating was formed on the tip. We will demonstrate the high performance of the fabricated PdIr AFM tips in electrical measurements and nano-oxidation studies.

RESULTS AND DISCUSSION



a) b)

FIGURE 1. a) 200nm × 200nm topographic image of sputtered gold film on silicon (Z range 20nm), performed with a PdIr-coated Si_3N_4 probe; b) simultaneously acquired current image at a 500mV bias (Z range 1μA).

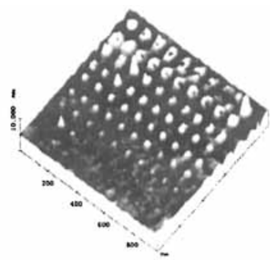


FIGURE 2. Nanodots fabricated by AFM local oxidation of GaAs (Pulse: 3~11V for 0.5s).

With a modified Nanoscope III AFM system (Digital Instruments)[10], the PdIr-coated Si_3N_4 tips were used to simultaneously measure the topography and current at a constant voltage for a gold surface in air. Fig.1a shows the 200nm × 200nm topographic image of a sputtered gold on silicon. Fig.1b gives the simultaneously acquired current map at a 500mV tip/sample bias. Since the current image was obtained in contact mode AFM, the image contrast directly reflects the different conductivity of gold surface. For instance, the smallest discernible bright spot is ~2nm, originating from the surface region having nice electrical conductivity. As is shown in current image, the surface is highly inhomogeneous in conductivity, suggesting the occurrence of surface contamination in air. This is consistent with the fact that the gold surface has a large surface free energy and thus organic molecules in air adsorb on it spontaneously.

The PdIr-coated tips were also used to fabricate nanostructures on Zn-doped p-type GaAs(100) by AFM anodic oxidation in 35~50% ambient humidity. Fig.2 shows the typical results, which were obtained by applying pulse across tip and substrate to induce local oxidation of GaAs surface. With pulse duration of 0.5s and a voltage varying from 3V to 11V, we studied the dependence of nanodot dimension on the pulse voltage. As shown in Fig.2, the lateral dimension of the dots increases remarkably as the bias voltage increases, while the height of the dots increases more moderately. Two types of dots were formed in response to different pulse voltage. With low pulse voltage, the dots were mound-like, while under high pulse voltage the dots were ring-like with the dot center being lower than the edge region. This suggests that the oxidation rate of GaAs not only depends on the strength of electric field, but also on the concentration of O^-. Under low voltage, the dot shape is determined by the distribution of electric field, which leads to mound-like structure. Under high voltage, the electric field under the tip is strong enough and the oxidation of GaAs is mainly determined by the concentration of O^-. In this case, the diffusion of oxygen will become the rate-determining step. Because of the shielding effect of AFM tip, oxide layers would be formed more easily surrounding the tip where the electric field is still larger than the threhold value and the ring-like structure is created.

In addition, we also used heavily doped silicon tip to conduct the localized oxidation of GaAs and obtained similar results. This suggests that

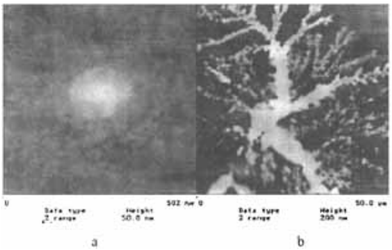


FIGURE 3. a) Nanoscale dot fabricated by local oxidation of Cr; b) Fractal structure fabricated by local oxidation of Cr.

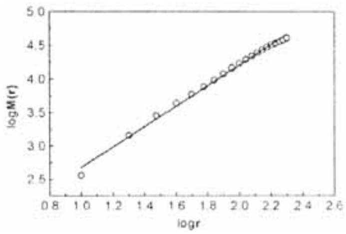


FIGURE 4. The logarithmic dependence of pixel distribution function **M**(**r**) on scale **r**

the resulted nanostructures by PdIr tip are originating from localized oxidation of GaAs, rather than a field induced evaporation of PdIr tip itself.

Figure 3a shows the AFM image of a nanodot fabricated on 20nm chromium film on mica using the PdIr tip by applying a pulse of +10V for 10s in 35% ambient humidity. The size of this nanodot is 140nm in width and 12nm in height. When the pulse voltage was increased to 30V, the dot size becomes 100μm in width and 300nm in height.

Interestingly when we applied a voltage 15V on the Cr film for 15min, a leaf -like nanostructure was created as shown in Fig. 3b. We calculated the fractal dimension of the structure using the method described in Ref. 11. Fig.4 shows the logarithmic dependence of pixel distribution function **M(r)** on scale **r.** Linear fitting of the data gives the Hausdorf dimension D=1.52. We believe that the fractal formation of Cr oxides is the direct reflection of easy diffusion of oxygen through the boundaries of Cr grains.

We found that the PdIr-coated Si_3N_4 tips have excellent mechanical and chemical stabilities. No discernible damage was observed by SEM after long time use for I-V measurements and repeatedly applying voltages of ±30V between tip and sample for nanofabrication.

In summary, a new type of conductive AFM tips has been fabricated using PdIr as the coating. These PdIr-coated Si_3N_4 tips have excellent stability, good conductivity and relative small tip radii, which have been shown to be suitable for measurements of electrical properties on a nanometer scale, and for fabrication of nanostructures by field-induced chemical oxidation of GaAs and Cr.

Acknowledgments

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