Platinum Silicide probes: A novel approach to manufacture highly conductive AFM probes with small radii and high wear resistance

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ABSTRACT

Conventionally, conductive Atomic Force Microscopy (c-AFM) probes are either made by depositing a conducting material such as a metal, an alloy or a doped diamond layer onto a ready-made AFM probe or, by depositing one of those materials into an inverted pyramid anisotropically etched into silicon followed by a subsequent tip and cantilever release process. However, none of those technologies allow fabricating probes featuring low wear rate and reliable conduction together with the requirement of small tip radii.

In this work, c-AFM results using a newly developed cantilever with platinum silicide (PtSi) tip are presented. Those tips have small radii, conductivity close to commercial PtIr coated probes but have an outstanding mechanical wear-out behaviour and sustained electrical contact quality.

Keywords: Conductive-mode AFM, platinum silicide, cantilever, probe

1 MOTIVATION

Atomic Force Microscopy (AFM) [1] is a widely used technology to image the topography in high resolution on both conducting and insulating surfaces. One of the extensions of AFM is the conductive or electrical measurement mode (c-AFM). Today the main c-AFM methods are Scanning Capacitance Microscopy (SCM) [2], tunneling AFM (TUNA) [3] and Scanning Spreading Resistance Microscopy (SSRM) [4,5] which allow to measure a wide range of electrical properties on various materials with nanometer-scale resolution.

In these applications, there is a significant need for reliable conductive AFM probes. Various kinds of probes for c-AFM have been studied up to now. They are typically made either by depositing a metal, an alloy or a doped diamond layer [6] onto a ready-made AFM probe or alternatively, by depositing one of those materials into an inverted pyramid anisotropically etched into silicon followed by a subsequent tip and cantilever release process (similar to the fabrication of molded silicon nitride (SiN) probes). The primary disadvantages associated with the former technique are an increased tip radius due to the additional layers and a fast wear-out behavior of metal coatings. The abrasive resistant diamond needs a certain thickness to form a closed layer (100 nm and more) whereupon the conductivity is about an order of magnitude worse than that for metal coated probes (e.g. 30 nm PtIr). On the other hand, using molding techniques, it is challenging to reliably produce sharp probes [7]. Today, the common standard for c-AFM applications is either the use of diamond coated silicon probes (Fig. 1a) or platinum coated silicon probes (more precisely $Pt_{0.95}Ir_{0.05}$ because of its greater hardness, Fig. 12b) or diamond coated silicon probes (Fig. 3).

2 SILICIDE PROBES MANUFACTURING

The process to form a silicide probe consists of first depositing a metal onto a standard silicon probe followed by a thermal annealing step to create the silicide layer [8]. A solid silicide tip apex is created due to a volumetric excess of metal at the very end of the tip apex. Compared to

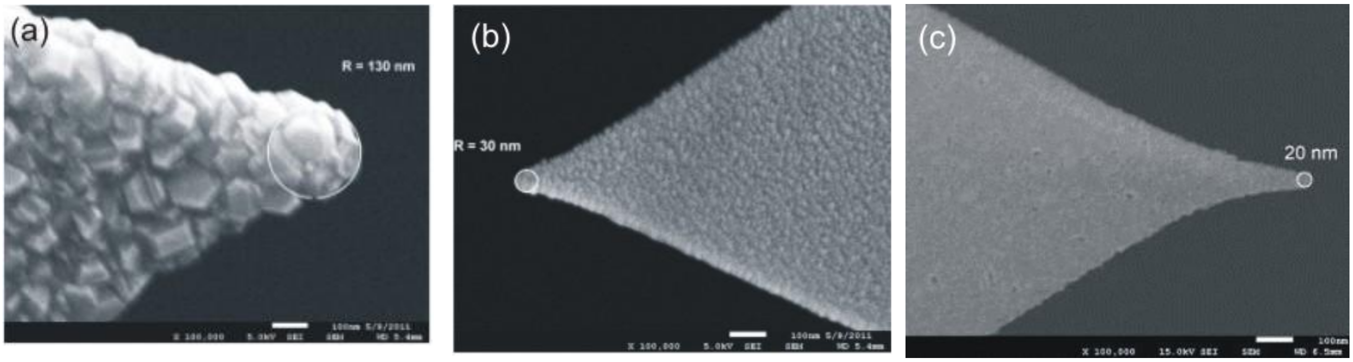

Figure 1: SEM micrographs of a (a) commercial diamond coated silicon probe [11], (b) a commercial PtIr coated silicon probe [11] and (c) a platinium silicide probe.

the silicon tip radius, the silicide tip radius is increased due to a volume increase [9] but significantly smaller than the radius of the original metal coated tip. The process used to manufacture the PtSi probes described in this paper is based on [10] in which more details can be found. Figure 1c is showing the SEM image of a readily processed PtSi tip.

3 CONDUCTIVITY AND WEAR EXPERIMENTS

3.1 Degradation of conduction and mechanical wear of PtSi probes

A hard amorphous carbon surface was imaged in c-AFM mode with a PtSi probe. During the scan, the cantilever deflection was regulated at 100 nm and bias voltage of 1V was applied. Figures 2 shows conduction (2a-b) and topography images (2c-d) of the first image and after a total tip travel distance of 1m. Despite this extreme long usage, the quality of the electrical contact is still excellent whereas the tip radius has increased from about 12 nm initially (Fig. 2e) to about 50 nm (Fig. 2f).

3.2 Mechanical wear: comparison of PtSi and Si probes

Standard silicon and PtSi probes were used under identical conditions (contact mode, loading force = 100nN) on a diamond like carbon surface for a distance of 10mm. The figure 3 (a: silicon tip, b: PtSi tip) show overlays of SEM micrographs of identical tips before and after scanning. The silicon tip has a much larger loss of material (wear) at the tip apex compared to the platinum silicide tip..

3.3 Degradation of conduction: comparison of PtSi and PtIr probes

A titanium nitride surface was imaged in TUNA mode (loading force 1µN, bias voltage -0.25 V) either with a commercial PtIr and a newly developed PtSi probe. Initially, the maximum current measured during the scan was -1.25 µA (system limit) with both probes. After 20 images (13 mm scanning), the PtIr probe shows a drastic reduction in conductivity (Fig. 4a) whereas for the PtSi probe the degradation of conductivity is substantially less (Fig. 4b).

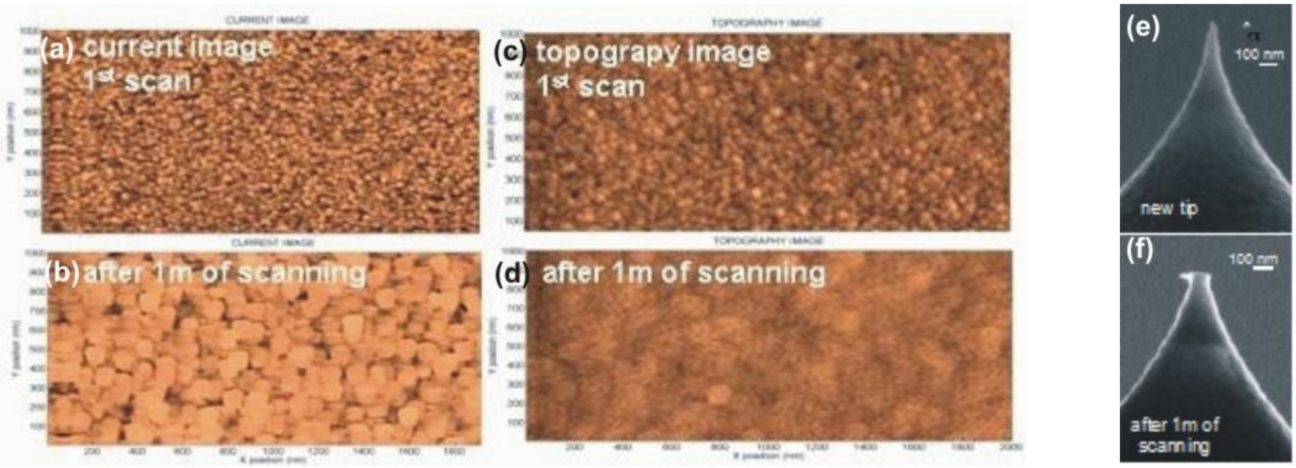

Figure 2: Conductivity (a, b) and topography (c, d) images on amorphous carbon. SEM images of the PtSi probe (e: new state, f: after usage) used for this experiment.

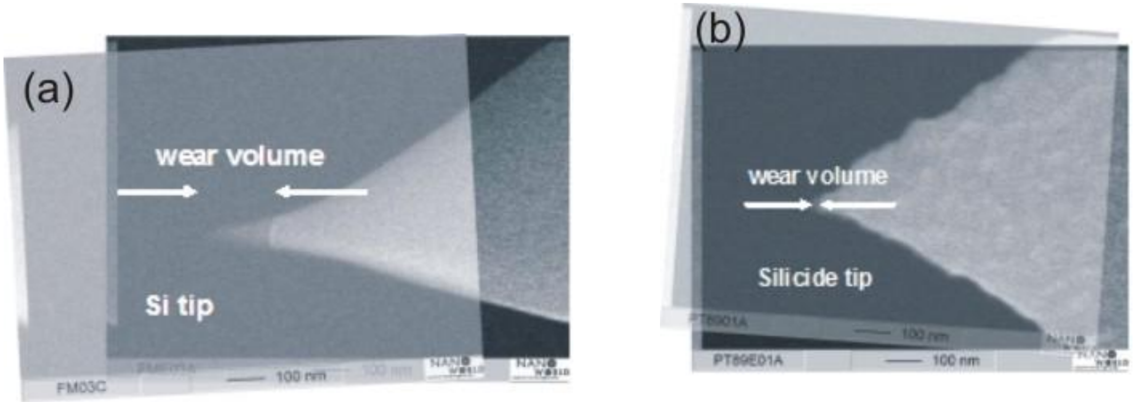

Figure 3: Overlaying SEM images of a (a) silicon and (b) a PtSi tip before and after scanning.

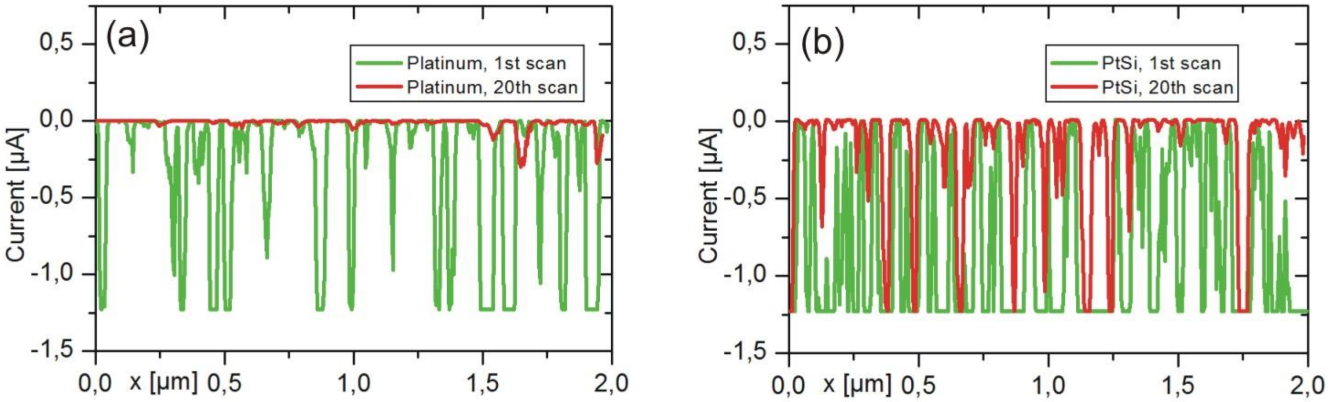

Figure 4: Cross sections of current images (1st scan, 20th scan) of (a) a commercial PtIr probe and (b) a PtSi probe.

4 CONCLUSION

Platinum silicide AFM probes have been fabricated by a process that involves platinum deposition onto a silicon tip and a subsequent thermal annealing step. The PtSi probes do have tip radii far below conductive diamond probes and smaller than conventional PtIr probes. The mechanical wear of the PtSi probes is significantly lower than of uncoated silicon probes. At comparable tip radii, the degradation of conductivity is substantially lower compared to PtIr probes. PtSi probes have been successfully used for scan distances up to one meter without significant loss in conductivity.

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