SPM Local Oxidation and In-situ Characterization Using AFM Probes in Multiple Modes

W. Hu, J. A. Bain and D. S. Ricketts
Carnegie Mellon University, Pittsburgh PA
ricketts@ece.cmu.edu

Scanning-probe (SPM) tip-based nanofabrication is an emerging area of device fabrication that leverages the atomic precision of SPM metrology to write and/or modify structures[1]. While much work has been done for both AFM and STM modalities, little fabrication has been demonstrated that uses both modalities to form a series of nanoscale features. In this work, we demonstrate the successful implementation of a compliant AFM probe in tip-oxidation using multiple modes: contact-AFM mode for imaging and for coarse oxide feature writing in an insulating field, STM mode for fine feature oxide writing and conductive AFM mode for in-situ electrical characterization.

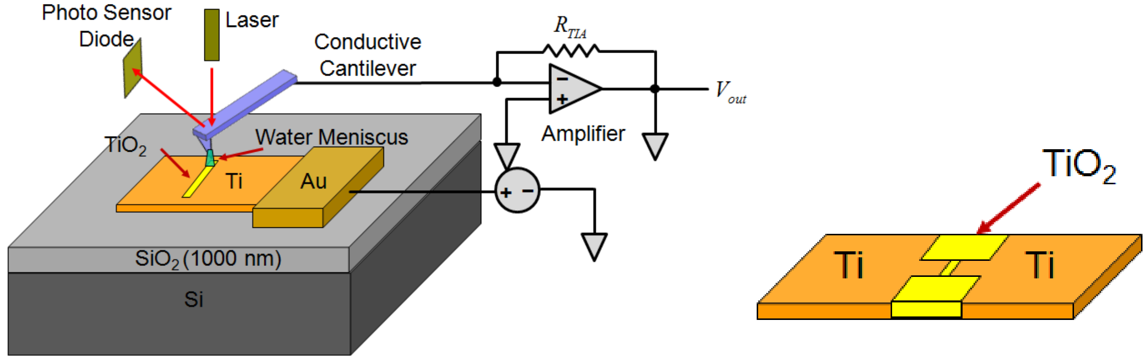
To demonstrate the multiple modes achieved on a single AFM probe, we deposited an 8 nm thick Ti films on a SiO_2 (1 μm)/Si substrate using an electron beam evaporator at a base pressure of 5×10^{-10} torr. Ti layers were patterned into 2 μm wide strips using photolithography (liftoff). All Ti strips were electrically connected at one (common) end, which contained a sputtered Au contact pad with a thickness of 200 nm. The common end provides bias for oxidation as well as conductive AFM imaging (C-AFM).

Tip-based nano-oxidation was performed in an ambient atmosphere at room temperature with relative humidity of 20-25% using a RHK scanning probe system (Troy, MI, USA). The experimental setup is shown in Figure 1 where we write a TiO_2 oxide barrier to form a lateral MIM junction [Fig. 1(b)]. The procedure is as follows. First, a conductive AFM cantilever was used to locate the Ti strip in contact AFM topographic mode. Second, the AFM probe was navigated to the center area of Ti layer and was then used to oxidize an 800 nm line across the Ti strip in STM mode at the speed of 10 nm/s and current setpoint of 1.5 nA and Ti bias of +3.5 V relative to tip. Third, the control system was changed back to contact AFM mode and the probe was used to oxidize two square areas at the ends of the previously STM-oxidized line at the speed of 1 μm/s with the Ti biased at +10 V. These square areas were large to ensure the oxidation was across the entire Ti strip in order to form a metal-oxidation-metal junction. Finally, the sample was biased at -1 V relative to the tip and scanned in contact AFM mode to allow a map of current to be collected. A negative imaging bias insures that no oxidation of the Ti takes place during imaging. This final step allows us to investigate the electrical fidelity of our written structures, and if necessary, re-write our structures [Fig. 2(b)].

Figure 2 shows the tip-oxidation results using a diamond coated conductive AFM probe (20-80 N/m stiffness) in the multiple modes. Figure 2(a) and 2(c) show the topography and current image separately. In order to compare the STM oxidation and AFM oxidation, a second oxidation line was produced by the same probe in AFM mode at speed of 10 nm/s while the Ti strip was biased at +10 V [Fig. 2(b) and 2(d)]. We could see that AFM oxidation line [left in (b)] is wider than STM oxidation line [right in (b)]. The current decreased dramatically after the AFM oxidation line was produced, which means AFM oxidation leads to a more resistive oxidation junction. There are four main advantages of implementing multiple modes of conductive AFM probes in SPM based nanofabrication: (1) smaller tip-oxidation features are produced using STM mode. Oxidation lines thinner than 20 nm were obtained by using Pt coated AFM probes (0.4-4.4 N/m stiffness) in STM mode [Fig. 3]; (2) AFM mode allows tip operation on electrically isolated features and insulating substrates, allowing fabrication at the interface of conducting/insulating regions, e.g. strip edge; (3) conductive AFM enables in-situ electrical characterization during the nanofabrication; and (4) using compliant AFM probes will allow individual actuation for use in future arrays[2], which will significantly increase throughput in nanofabrication.

---

[1] E. S. Snow and P. M. Campbell, *Appl. Phys. Lett.*, vol. 64, p.1932, 1994.
[2] W. Hu, Y. Tang, Y. Zhang, J. Gu, S. Tamaru, J. A. Bain, L. R. Carley, R. F. Davis, G. K. Fedder and D. S. Ricketts, Proceeding of the Workshop on Technologies for Future Micro/Nano Manufacturing, Napa, 2011.



(a) (b)

Figure 1 (a) A schematic of the experimental apparatus used in this work. A conductive AFM (C-AFM) cantilever was employed in the AFM, C-AFM, and STM modes. The feedback signal while in the AFM and C-AFM modes is the optical deflection signal, while the feedback signal in STM mode is tunneling current. (b) Structure of tip-oxidized lateral MIM junction.

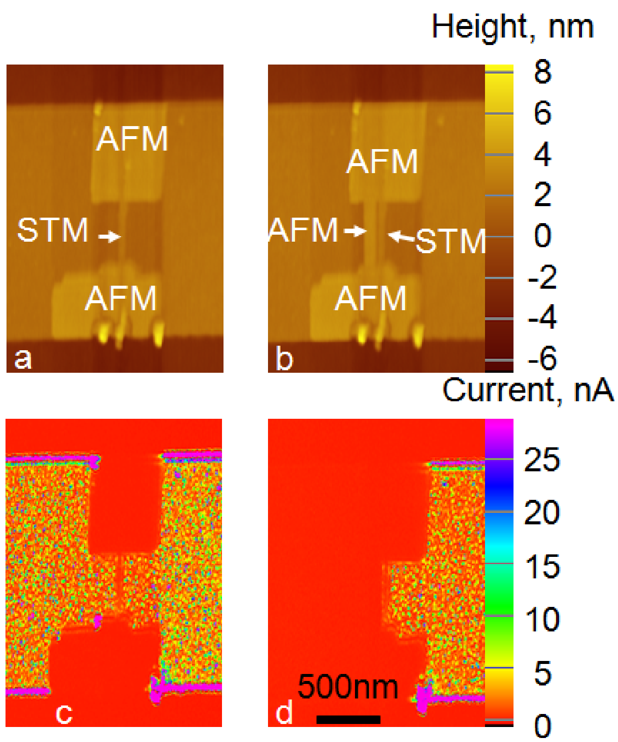


Figure 2 AFM (conductive) images of Ti strip after tip-oxidation on it. (a) Topography image of Ti strip with tip-oxidation features. The oxidation line in the center is produced by using the conductive AFM probe in STM mode while the two square oxidized areas are produced in contact AFM mode. (b) Topography image of the Ti strip after a second oxidation line was added by using the same AFM probe in contact AFM mode. (c) Current image corresponding to (a). (d) Current image corresponding to (b). It is clear that in this example the AFM mode leads to a more resistive junction.

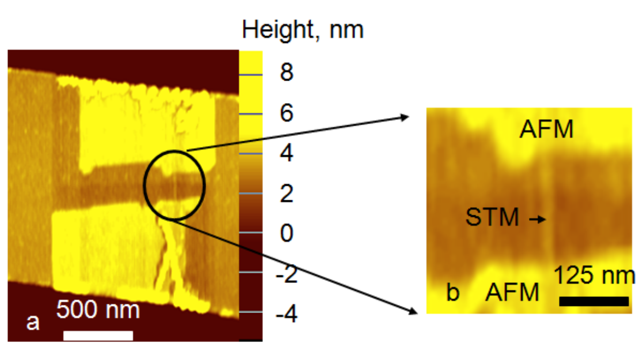


Figure 3 (a) AFM image of a Ti strip after tip-oxidation by using a Pt coated conductive AFM probe (0.4-4.4 N/m stiffness) in both AFM and STM modes. The thin line in the center was the oxidation line produced in STM mode while the two big pads at its ends were oxidized in contact AFM mode. The width of the oxidation line is thinner than 20 nm. (b) Zoomed in image of the STM oxidation line.