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Atomic Force Microscope Tip Induced Anodic Oxidation

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Introduction

The versatility of an atomic force microscope (AFM) as an imaging and spectroscopic tool is well known. Apart from producing atomic resolution images, the AFM with its sharp tip can also be used in other applications such as nano-grafting and nanolithography. Various nanolithographic techniques include nano-positioning of molecules and tip induced anodic oxidation. AFM tip induced anodic oxidation is a technique widely used to obtain fine features smaller than the conventional electron beam lithography.

The Technique

The AFM tip induced oxidation process is based on negatively biasing the tip with respect to the substrate under ambient conditions. Substrates commonly used are semiconductors or metals that form stable oxides. When the AFM tip is brought close to the surface, water from the ambient humidity forms a droplet between the tip and substrate, as shown in **Figure 1**. To drive the anodic oxidation, a voltage, typically between 5 and 15 V, is applied between the tip and substrate. Since the anodic oxidation process requires an electrical current, both the tip and substrate must be conductive. Conductive tips are commercially available, and are made from a highly doped semiconductor, or are metal coated. In the anodic oxidation process, the applied voltage induces a high electrical field between the tip and the substrate that ionizes the water droplet and the OH– ions produced provide the oxidant for the chemical reaction.

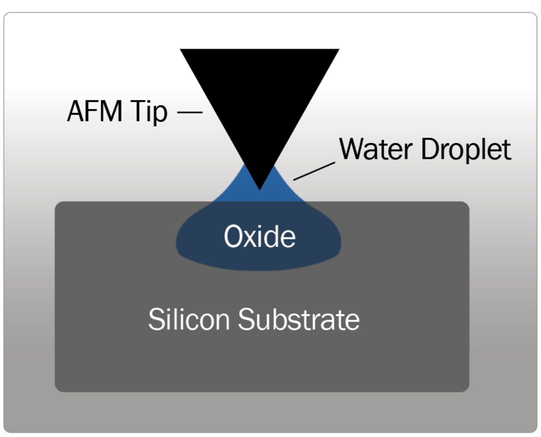

Figure 1: *AFM anodic oxidation*

The polarity of the applied voltage is important, since it determines whether the OH– ions go to the tip or substrate. To oxidize the substrate, the tip voltage must be negative. If a positive voltage is applied to the tip the OH– ions are drawn to the tip, oxidizing it and eventually breaking the electrical circuit. With the proper tip voltage, the substrate is locally oxidized, and by moving the tip in contact mode or non-contact mode across the surface, a line is drawn. Since the area oxidized on the surface depends on the size of the water droplet, the lateral resolution of the AFM oxidation process depends strongly on the humidity in the air. To achieve reproducible linewidths the humidity must be controlled. The lower the humidity, the smaller the lines, and we have obtained our best results at a humidity of between 50 and 70%. Apart from the humidity, the factors influencing the lateral resolution and oxide thickness are the tip voltage, speed of writing and tip-substrate separation.

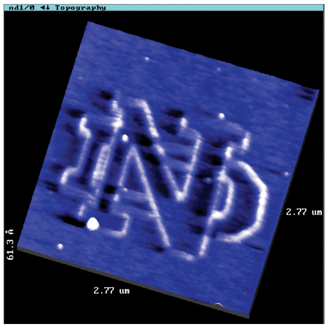

Figure 2: *Notre Dame logo written on a Ti substrate with humidity of 65% and a tip voltage of 9.0 Volts. The logo was laid-out using lithographic routines provided by the RHK controller.*

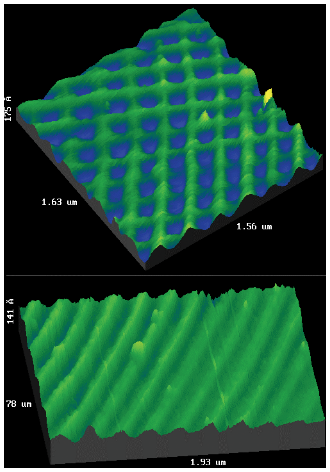

Figure 3: *Thin lines written on Ti Substrate with a voltage of 8.0 Volts and 50% humidity.*

The AFM anodic oxidation system used in the Electrical Engineering Department at Notre Dame uses an RHK SPM 1000 controller with a Molecular Imaging PicoSPM AFM. We have performed oxidations of silicon and titanium using both contact and non-contact mode. The following figures show results from some of these experiments.

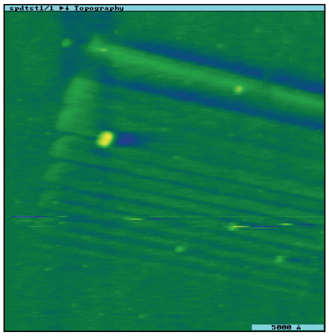

Figure 4: *Lines written on Ti substrate with a tip voltage of 8.0 V and 60% humidity at different writing speeds. The smallest features on this figure are approx. 10-20 nm.*

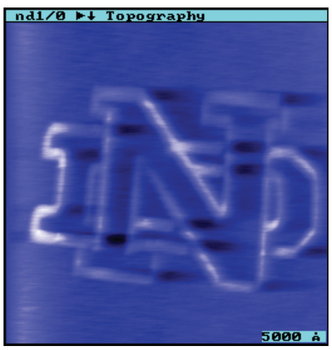

Figure 5: *ND logo on a Si substrate with tip voltage of 12 V and humidity of approximately 60%*

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