Localized Thermal Modification of Surfaces via Electron Bombardment from an STM Tip

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Directed fabrication of nanostructures is of interest both for emerging devices as well as a method to investigate materials at the nanoscale. Extensive work has been done using the scanning tunneling microscope (STM) to both image and modify surfaces [1]. A subdiscipline of previous efforts was focused on using DC currents to heat the substrate [2]. In this work we demonstrate that short duration (≈ 1 μs) pulses have sufficient energy to modify the surface. At predetermined locations on the sample surface, a voltage pulse is applied between the tip and surface, resulting in a large tunneling current relative to the nominal scanning current. The region of the surface under the electron beam experiences a rise in temperature with an estimated time constant of ≈ 1 ns.

Two different metallic films were used in the experiments: Au and Pt. Both were sputter deposited to a thickness of 100 nm on a Si substrate; 5 nm Ti was used as an adhesion layer for Au, and 5 nm Cr was used for Pt. Experiments were performed in an RHK UHV STM with a base pressure of 5×10^{-10} Torr. Identical voltage pulses were applied on a 4x4 grid of regularly spaced points superimposed on the scan area, and a series of images were acquired for increasing pulse voltage heights. Veeco Pt/Ir tips (prepared by mechanical shearing) were used, and the STM data was acquired at a sample bias voltage of +2 V relative to chamber ground and setpoint current of 1 nA.

The onset of surface modification for both materials occurs at a voltage of 5.3 V but not at every location. Estimates of the emission current for these values of voltage is 3 μA based on a combination of measurement and modeling as described in [3]. We attribute the surface modification to melting since no marks were observed below a threshold of 5.3 V. The fact that only a subset of the 16 pulse locations resulted in a mark is consistent with the large range of current values at each voltage in 3; if the current was too low, the surface would not melt. Assuming a tunneling beam diameter of 3 nm, current of 1 μA, and the threshold current brings the surface just to the melting temperature, an estimate of the effective thermal conductivity of the Au would be 1.5 W m^{-1} K^{-1} and the Pt would be 0.9 W m^{-1} K^{-1}. These values are far below that of the bulk films, but are consistent with predictions of reduced thermal conductivity at the nanoscale

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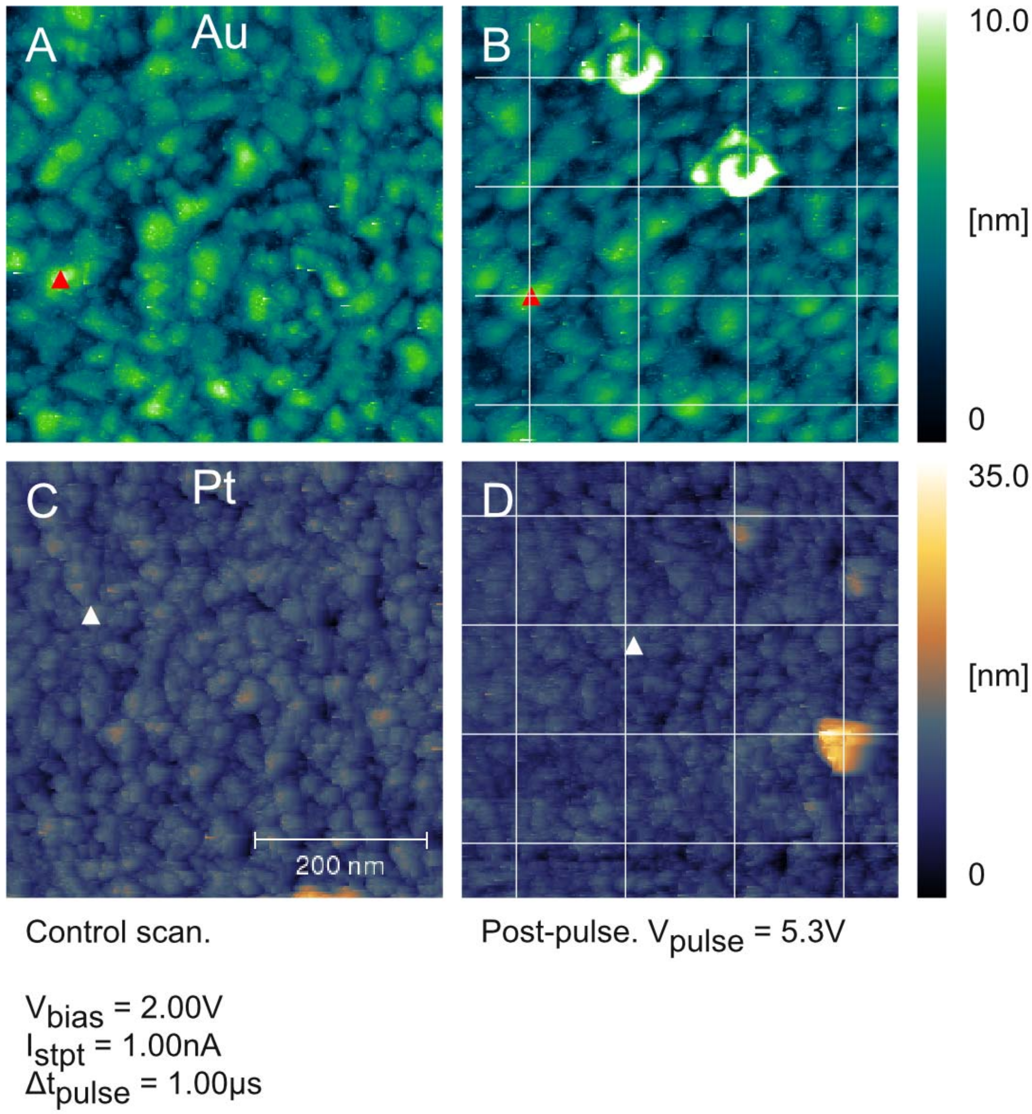

Figure 1: Sequences of STM micrographs showing nanostructure formation on Pt and Au. A-B depicts Au, and C-D Pt. Figs. A and C are taken before pulses were applied. Figs. B and D are taken after a pulse height of 5.3V and include grid locations (intersections) of pulse points. Red/white registration markers indicate features which are common throughout the sequence. All images are the same lateral scale.