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Study of Photon Emission from Microstructures Using Scanning Tunneling Microscopy

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SCIENTIFIC PERSONNEL

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RESEARCH FINDINGS

To investigate how light interacts with various structures on the nanometer scale, photon emission from the tunnel junction of an STM was monitored. An optical fiber, placed at the end of the STM tip, as shown in Fig. 1, was used to collect the light which was then focused onto a cooled photomultiplier tube where photon counting was employed to measure the photon signal. High levels of emission (about 4000 cps) were observed from Au surfaces in air using Au tips and the variation of the photon emission as a function of position was recorded in what is conventionally referred to as a photon map. The striking similarity observed between these photon maps and the topographical images of the Au samples seems to result from the influence of the varying tip/sample geometry on photon emission.

The experimental system (see Fig. 2-3), employed a state-of-the-art air scanning tunneling microscope (Nanoscope II) and an Arlunya Image Processor which handled the photon maps. The use of a Au tip was instrumental in producing photon emission since experimentation with both PtIr and W tips proved unsuccessful in generating photon emission. We propose that when the Au tip scans the Au sample, the tip effectively cleans itself as atoms from the tip are deposited onto the sample and alternately, atoms from the surface adhere to the tip, thus creating an uncontaminated region on the end of the tip.

Photon emission from Au covered polystyrene spheres and from a Au grating are displayed in Fig. 4 and 5. Each a these samples possess large surface roughness, corrugation ranging from 30-75 nm high, and the surface features of the topography are clearly reproduced in the photon maps. Namely, the crevices between the polystyrene spheres and the grooves of the grating are visible in the photon maps. Emission from the STM arises as electrons tunneling from the tip excite local surface plasmons which are concentrated in the region immediately below the tip, and as these plasmons decay, a fraction of the energy from the collective electron oscillations is channeled into radiation. We find that the coupling of the surface plasmons with the electromagnetic field is controlled, to some extent, by the geometry of the tip/surface system and features, such as bumps and pits, alter the plasmon modes that are generated and effect the coupling of the localized electron oscillation with the radiation field. In the case of the Au covered polystyrene spheres and the Au grating, the cracks and grooves in the topography seem to weaken the coupling and reduce the energy transferred from the plasmon into radiation.

Another emphasis of our research is nanolithography, a technique in which the STM tip has been used to alter the surface of the sample and generate small structures like bumps and pits on the sample surface. Photon emission from these structures has also been observed and Fig. 6 displays the topography and photon emission maps of a Au dot deposited on a Pt foil with the application of a -4.5 V, 150 nsec voltage pulse to the tip. Emission from the Au dot, but not from the Pt substrate, was observed, most likely indicating the positive influence of the self cleaning property of the Au tip/Au sample system. Figure 7 shows the topography and photon emission maps of a Au dot written on a Au thin film using in this case a 3.5 V, 150 nsec pulse.

An increased emission level is observed from the Au dot, most likely due to the enhanced coupling of the photon emission with the surface plasmon at a bumped feature.

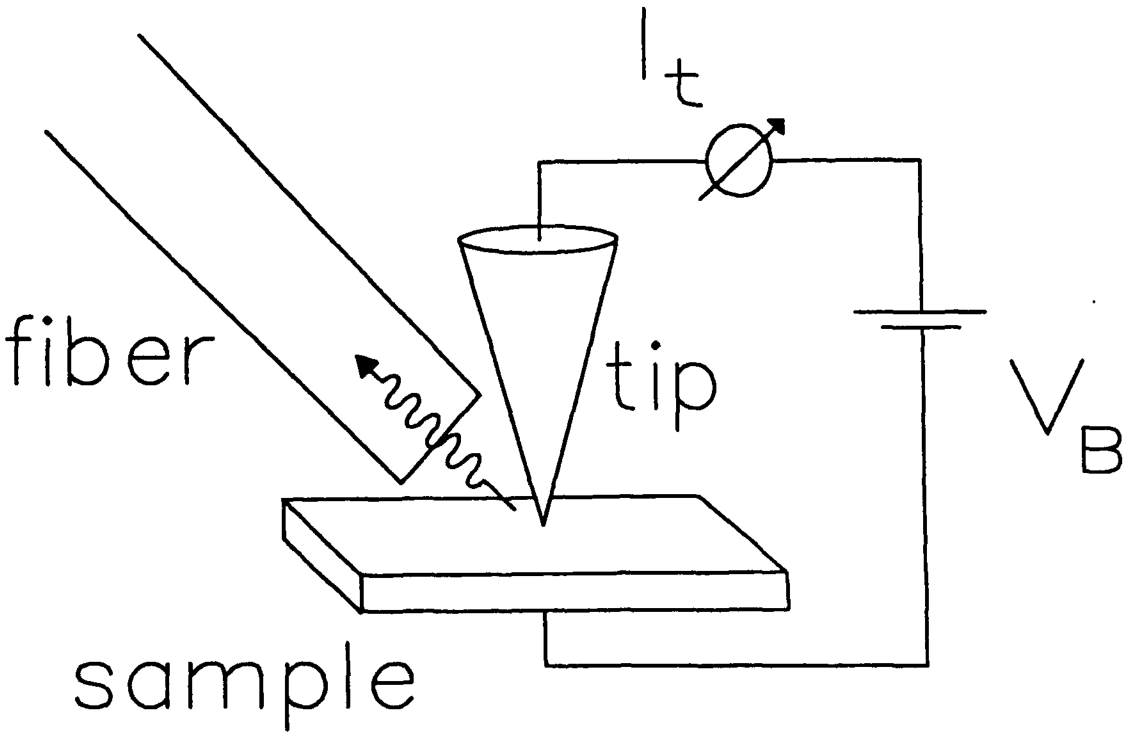


Figure 1: Diagram of the STM tunnel junction with the large core (1 mm) optical fiber positioned to collect photon emission. The fiber has a Numerical Aperture of 0.5 and is directed at an angle of 40° with respect to the sample plane.

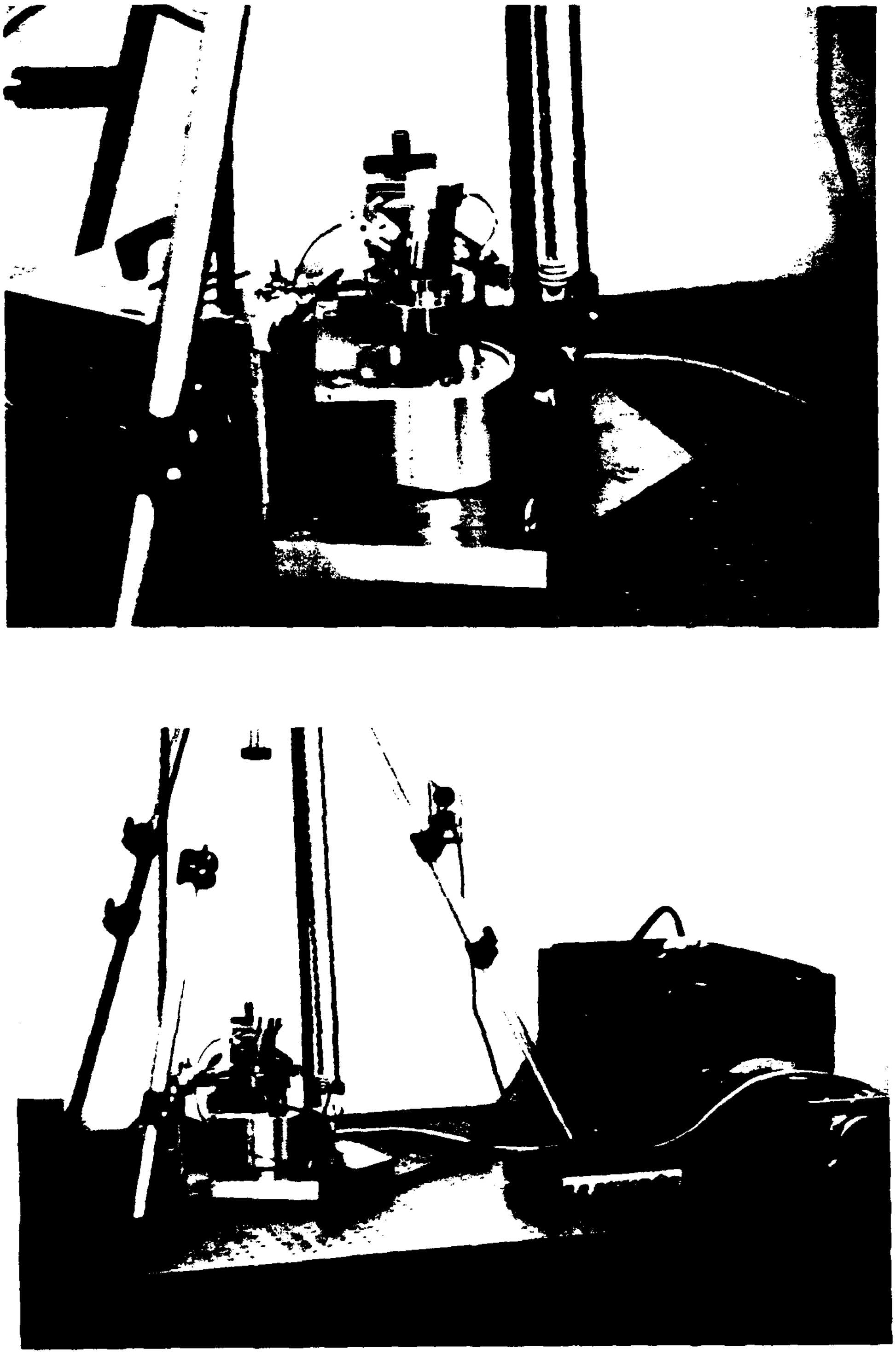


Figure 2: The experimental system including the Nanoscope II STM head and the optical fiber. The lens focusing the output of the fiber onto the PMT is located inside the black box which shields the PMT from stray light and the PMT is housed in the stainless steel cooler on the right.

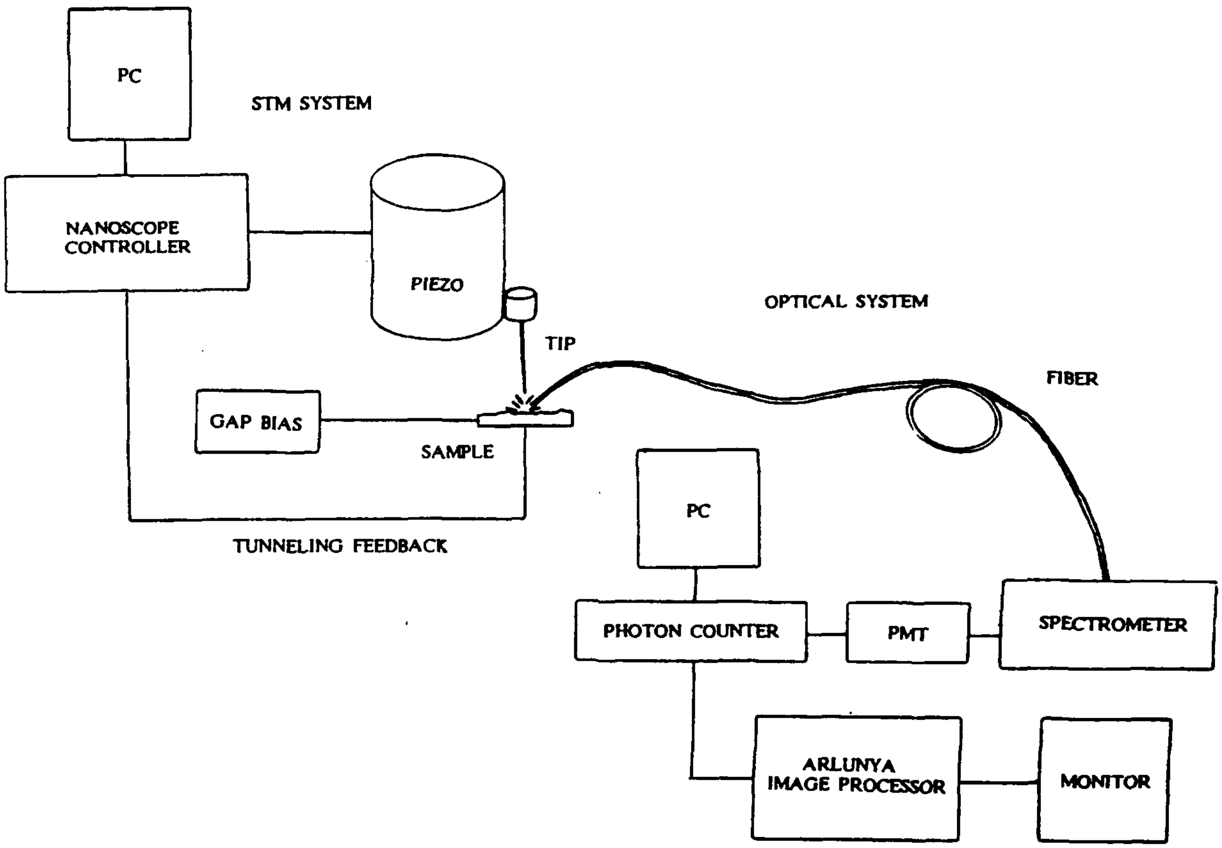
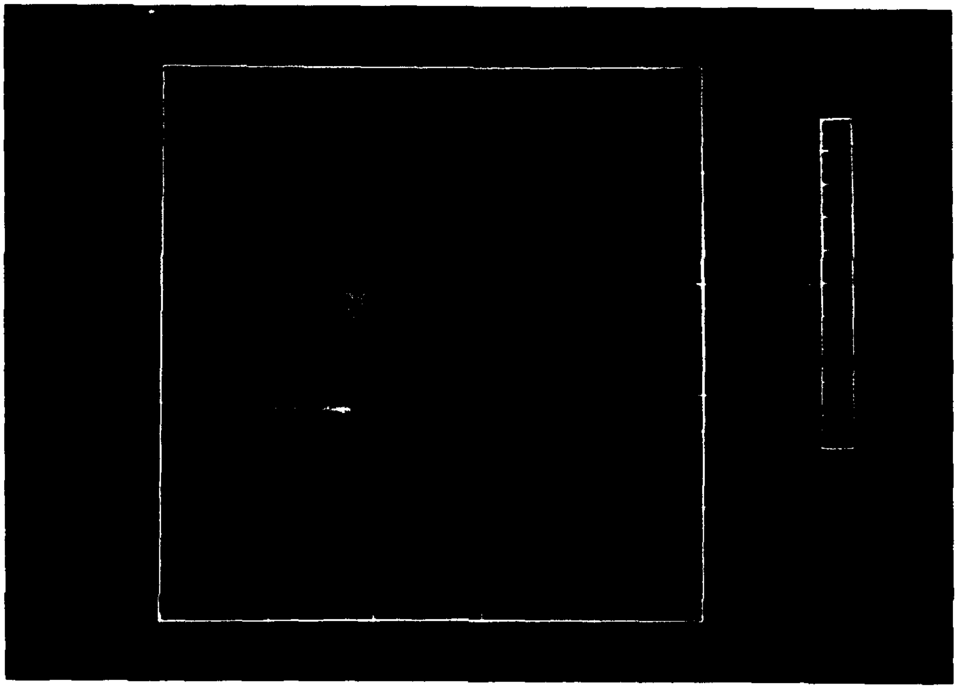


Figure 3: Schematic of system designed to monitor photon emission from the tunnel junction of an STM. The photon signal as a function of tip position is monitored as the tip is scanned across the sample and a photon map is produced using the Arlunya system.



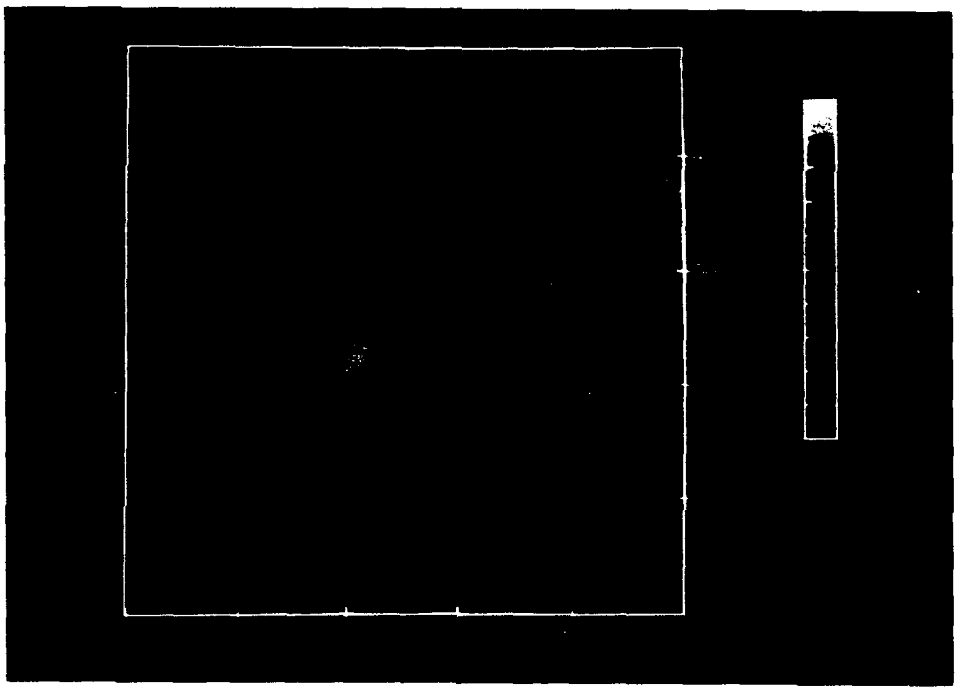


Figure 4: Topography and photon emission map of Au covered polystyrene spheres. A layer of polystyrene spheres was deposited on a Au sputtered mica substrate. A 30 nm Au film was then sputtered on the polystyrene spheres. The average diameter of the synthetic spheres was 87 nm. The tunneling current was 1 nA and the bias voltage was 1.8 V when the photon map was created.

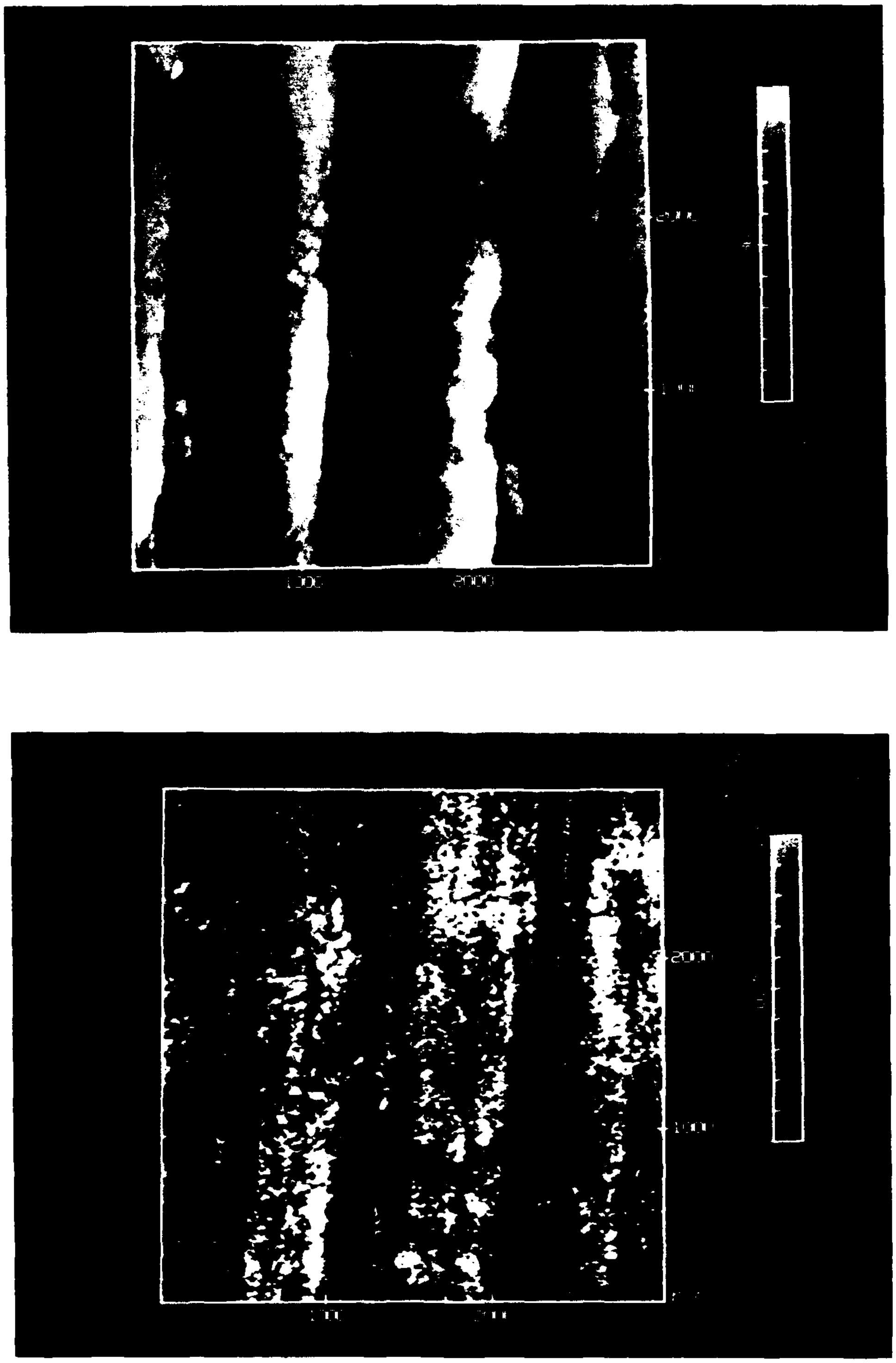


Figure 5: Topography and photon emission map of Au grating. The periodicity of the grating is 1000 nm and the height of the ruling is about 75-100 nm. This photon map was produced with a bias voltage of 2.0 V and a tunnel current setting of 1 nA.

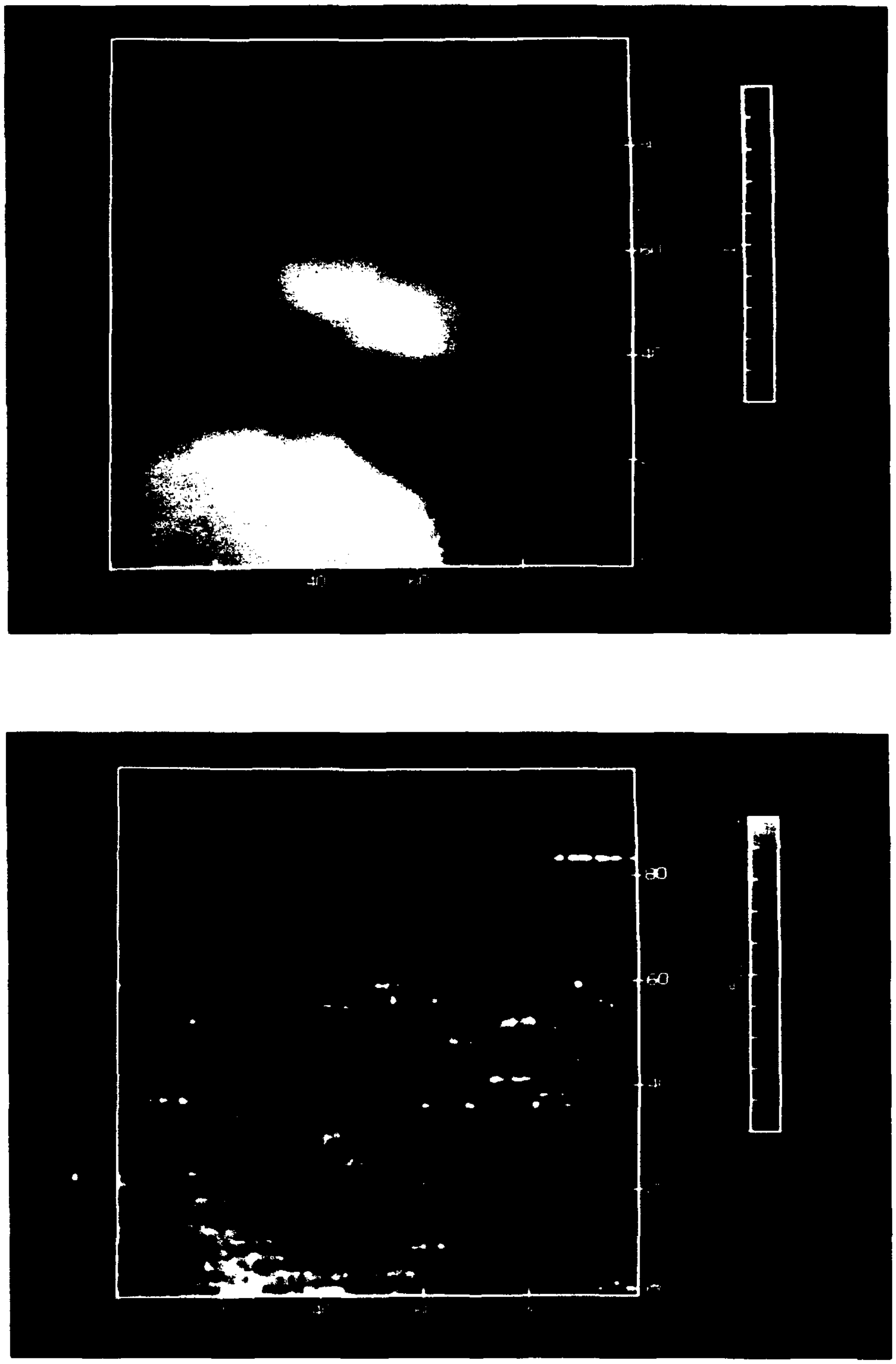


Figure 6: Topography and photon emission map of Au dot deposited on Pt foil. A 4.5 voltage pulse applied to the sample was used to write the dot. The tunneling current was 10 nA and the bias voltage was 1.8 V when the photon map was recorded.

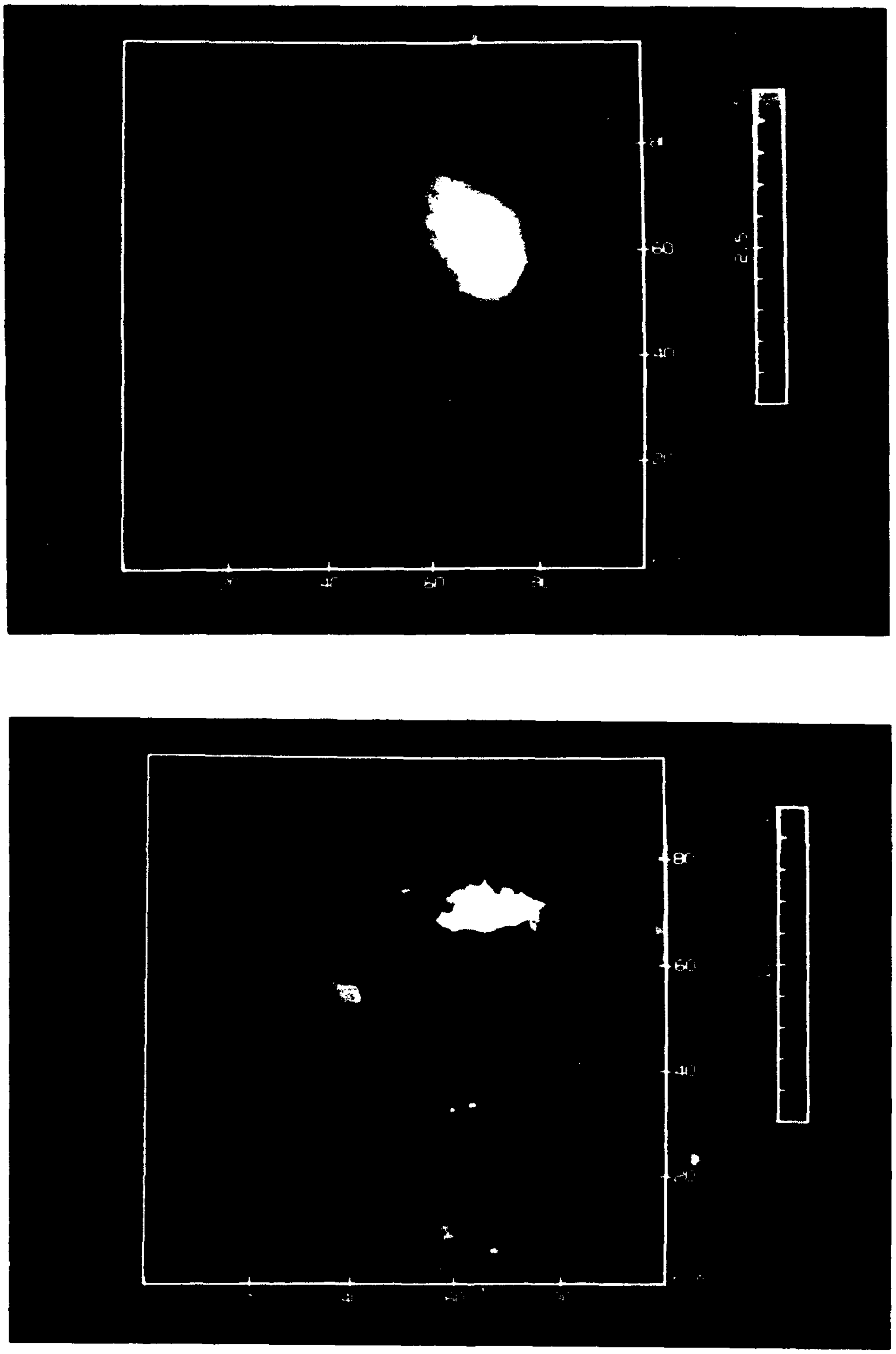


Figure 7: Topography and photon emission map of Au dot deposited on film. The 56 nm Au film was grown on a mica substrate at 339°C to ensure large flat crystalline regions. The Au dot was deposited with a 1.8 V voltage pulse. The photon emission map was produced with a bias voltage of 2.0 V and a tunnel current setting of 12 nA.

Related Recent Publications

M.J. Gallagher, S. Howells, L. Yi, T. Chen, D. Sarid, "Photon Emission from Gold Surfaces in Air Using Scanning Tunneling Microscopy," Surf. Sci. (submitted, 1992).

S. Howells, M. Gallagher, T. Chen, P. Pax, D. Sarid, "Oxidation Effects on Cleaved Multiple Quantum Well Surfaces in Air Observed by Scanning Probe Microscopy," Appl. Phys. Lett. (submitted, 1992).

T. Iwabuchi, C. Chuang, G. Khitrova, M.E. Warren, A. Chavez-Pirson, H.M. Gibbs, D. Sarid, M. Gallagher, "Fabrication of GaAs Nanometer Scale Structures by Dry Etching", SPIE **1284**, 142 (1990).