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Controlled Growth and Positioning of Metal Nanoparticles via Scanning Probe Microscopy

E. Silva-Pinto*, A. P. Gomes, C. B. Pinheiro, L. O. Ladeira, M. A. Pimenta and B. R. A. Neves

Departamento de Física, Universidade Federal de Minas Gerais, UFMG, Ave. Antonio Carlos, 6627 Belo Horizonte, MG, Brazil, email: elissp@fisica.ufmg.br
* Corresponding author.

Abstract – An innovative process enabling both the controlled growth and positioning of metal nanoparticles (NPs) is reported. Using scanning probe microscopy (SPM) techniques, metal NPs are directly grown in the region of interest via the reduction of metallic ions in a polymer matrix induced by a properly biased SPM tip. The metallic nature of these NPs is established via X-ray diffraction and surface-enhanced Raman spectroscopy experiments. Some initial applications of this process, such as the decoration of carbon nanotubes with metal NPs, are also briefly demonstrated and discussed.

Metal nanoparticles (NPs) are an essential constituent of many processes that take place on the nanoscale: from inorganic catalysis to biosensor development [1-5]. For some of these proposed processes to become a reality (i.e., a technological application) a few barriers must be overcome. Commonly, a missing feature is the ability to control both the growth and positioning of the metal NPs. Even though conventional chemical and electrochemical growth routes yield enormous amounts of NPs, placing these particles in their position of interest has been revealed to be a good challenge, and some approaches to achieve this goal have been reported [4,5].

This work reports on a process of SPM-induced (and controlled) reduction of metal ions to metal nanoparticles on a polymer matrix. Gold, silver, nickel, and rhodium NPs have been successfully grown with the developed process using their respective salts/halides ($HAuCl_4$, $AgNO_3$, $NiCl_2$, and $RhCl_3 \cdot 3H_2O$) dissolved to a thin-film polymer matrix. Poly(vinyl pyrrolidone), PVP, and poly(vinyl alcohol), PVA, were both successfully employed throughout this work. The reduction is reached when a biased SPM metallic tip is brought into contact with the polymeric film surface (with metallic ions dissolved at the film). The control of relevant parameters (precursor concentration, bias voltage, pulse duration, and humidity) enables the accurate growth and positioning of a single NP or the growth of large dendrites formed by thousands of NPs (figures 1 and 2). The metallic nature of these NPs is established via X-ray diffraction.

Some initial applications of this process, such as enhanced of Raman spectrums (SERS – Surface-Enhanced Raman Spectroscopy) and decoration of carbon nanotubes with metal NPs, are also briefly demonstrated and discussed. The decoration of carbon nanotubes shows the possibility of controlled positioning of NPs (figure 2). Many other applications of both the SPM-induced reduction process and the controlled growth and positioning of NPs may be derived from the present work.

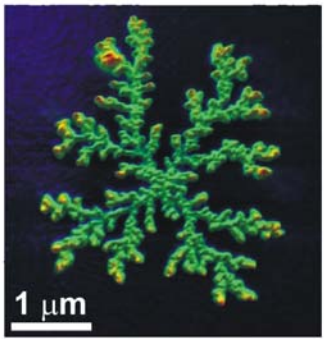

Figure 1: AFM image of a large Ag NP dendrite grown in a high concentration PVP/$AgNO_3$ matrix.

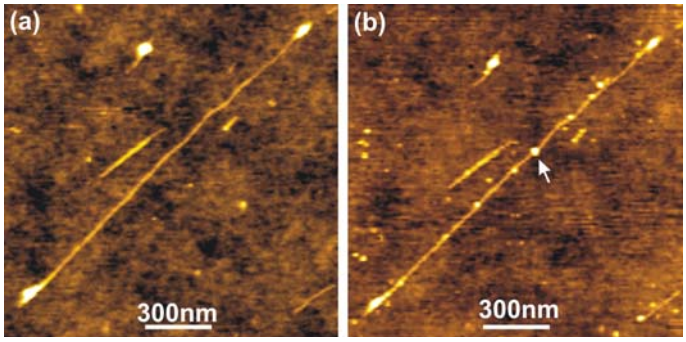

Figure 2: (a) AFM image of single-walled carbon nanotubes on the SiO_x substrate. (b) AFM image of the same region after the central nanotube has been decorated with Ag NPs .

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