EVIDENCE FOR LOCAL FERROMAGNETISM IN HOPG BY MAGNETIC FORCE MICROSCOPY

M. I N. da Silva, M. A. Cotta and Y. Kopelevich.
Universidade Estadual de Campinas, Instituto de Física Gleb Wataghin, Departamento de Física Aplicada, Laboratório de Pesquisa em Dispositivos, C.P. 6165, 13081-970 Campinas, SP, Brazil.

E-mail: mnsilva@ifi.unicamp.br

http://www.ifi.unicamp.br

Characterization at the microscopic and nanoscopic scale is of great importance for the understanding and development of new materials. In this work magnetic characterization of HOPG samples - they were synthesized at temperatures T~2700-3000^{o}C and pressure P~10-30MPa - by Scanning Probe Microscopy (SPM) is presented.

The magnetic properties of three HOPG samples were investigated using Magnetic Force Microscopy (MFM). The experiments were done in air using a Digital Instrument MultiMode Scanning Probe Microscope with a Nanoscope III controller and an extender electronic box. TappingMode ultra sharp Si tips coated with Cr/Co thin film was used to EFM experiments.

Figure 1(a) shows the topographic images of the HOPG1 surface acquired using atomic force microscopy (tapping mode). One can see atomic planes forming the surface along with corrugations which create regions with different heights on the plan surface. Figures 1(b) is the MFM image of the same region in figure 1(a); the tip-surface separation is 15 nm. Figure 1(b) shows magnetic contrast corresponding to the ferromagnetic regions. We believe that these ferromagnetic regions are due to a strong topological disorder necessary to stabilize ferromagnetism and frustrate antiferromagnetic order.

Our experimental evidences indicate such patterns as magnetic in nature, thus a quantitative analysis of the signal strength patterns was carried out. By comparing minimum and maximum shifts with a reference point on the same sample, it was possible to obtain numeric values to the average maximum signal strength for all samples. Figure 2 shows three series of points, each related to each sample (HOPG1, HOPH2, and HOPG3), in a plot of frequency as a function of tip-surface separation. It can be seen that the each set of data presents a steady increase of frequency shift with decreasing separation. In order to understand these results, a simple model for the magnetic interaction between tip and sample was applied [1]. The fairly good fitting of the experimental points shown in figure 2 corroborates the idea, extracted from the several different experiments we have carried out, that the patterns are, indeed, of magnetic nature only. The magnetization values obtained from our frequency shifts with this model, at specific regions of the surface, are 3 orders of magnitude lower than ferrous materials.

References:

[1] D. Sarid, *Scanning Force Microscopy*; Oxford University Press: New York **1991**.

Figures:

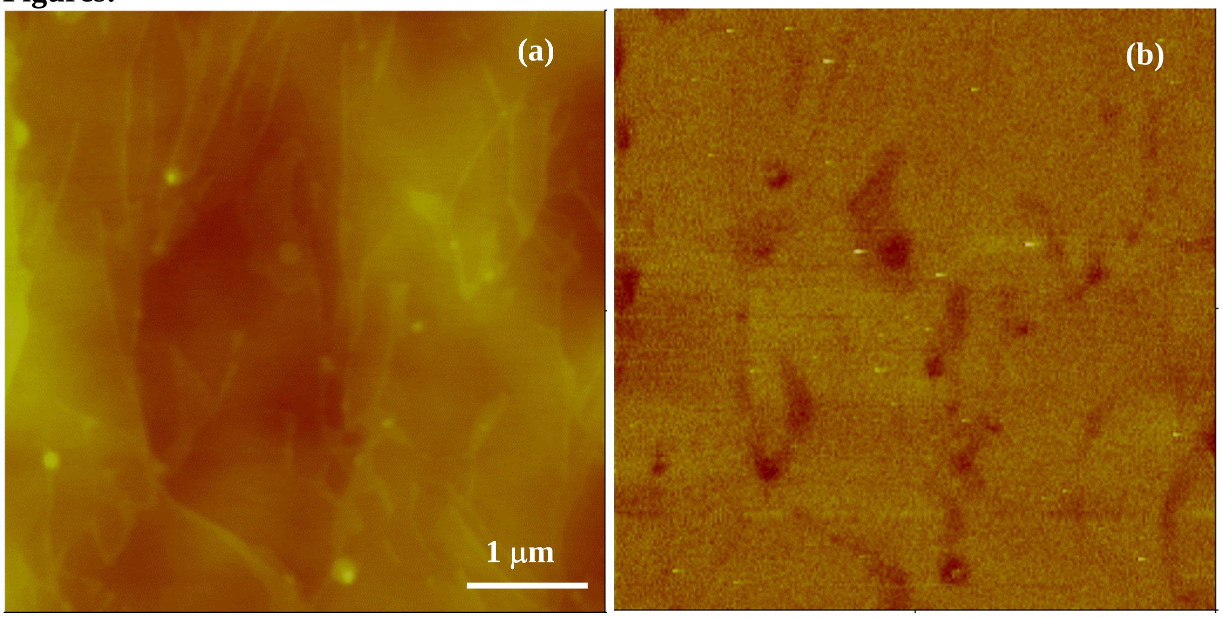

Figure 1- MFM Images for HOPG1 sample: (a) Topographic, Z scale is 60 nm, and (b) frequency image, z scale is 10 Hz. The tip-surface separation was 15 nm.

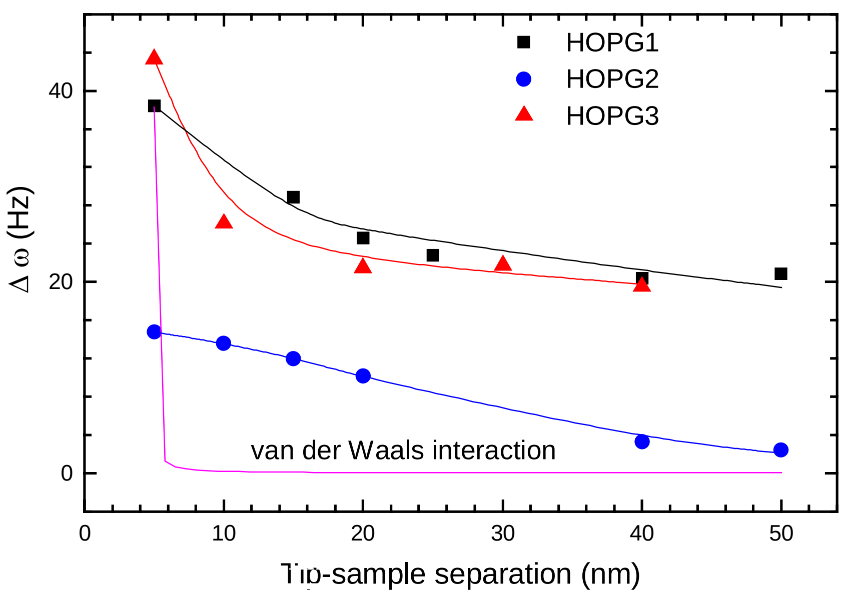

Figure 2- Average maximum frequency shift as a function of the tip-surface separation for HOPG1, HOGP2, and HOPG3 samples.