GROWTH OF LOW-DIMENSIONAL MAGNETIC NANOSTRUCTURES ON AN INSULATOR

Z. Gai, G.A. Farnan, J. P. Pierce, and J. Shen

Solid State Division, Oak Ridge National Laboratory, PO Box 2008,
Oak Ridge, TN 37831-6057, USA
E-mail: gaizn@ornl.gov

Iron nanometer-scaled dots, wires and ultrathin films have been successfully prepared on an insulating NaCl (001) single crystal surface by electron beam deposition using different growth conditions. *In-situ* noncontact atomic force microscopy (NC-AFM) shows that the heights and lateral sizes of the dots and the widths of the wires are very uniform. The dispersions of the height and lateral size distributions of the Fe dots are hardly affected by increasing the dosage of Fe atoms. The films are atomically flat and are formed due to a high nucleation density achieved through a low temperature growth procedure.

Introduction

In well-defined nanostructures, confinement of electrons in less than three dimensions results in magnetic, electronic and transport properties that are dramatically different than those of conventional bulk materials. When studying these characteristics and the correlation between magnetic and transport properties, it is necessary to grow magnetic nanostructures on a common insulating or semiconducting substrate. We report here on the successful growth of nanometer-scaled Fe dots, nanowires, and ultrathin films with the same amount of deposited material on the same insulating substrate, a cleaved NaCl(001) surface, under different growth conditions.

Experimental

The experiments were performed in an ultrahigh vacuum (UHV) system equipped with electron beam sources, laser molecular beam epitaxy and an *in-situ* Omicron variable-temperature UHV beam deflection Atomic Force Microscopy (AFM) / Scanning Tunneling Microscopy (STM) with cooling and heating facilities to cover a temperature range from 13 K to 1500 K. The noncontact mode AFM (NC-AFM) was used to study the surface morphology in this work. The NaCl single crystal substrates were loaded into the UHV chamber immediately after being cleaved in air. The substrates were annealed to 530K for one hour to remove surface contamination prior to further experiments. The Fe was deposited from an electron beam evaporation source at a rate of 0.04 ML/min (1ML is equivalent to the nominal surface atomic density of bcc Fe (110), 1.7×10^{15} atoms/cm^2). The dots and nanowires were grown at an elevated temperature of 530K, while the ultrathin films were prepared with a substrate temperature below 30K. AFM images acquired at the deposition temperatures and room temperature showed similar morphologies, which means the nanostructures are stable as the samples are cooled or heated to room temperature from the growth temperatures.

Results and discussion

The cleaved NaCl(001) surface shows monolayer-high steps and large terraces with no adsorbates. Fig. 1 (a), (b), and (c) show representative NC-AFM images along with the line profiles of the three nanostructures, dots, wires, and ultrathin film, respectively. Note that the amount of Fe in these three images is the same (1.7ML nominal thickness).

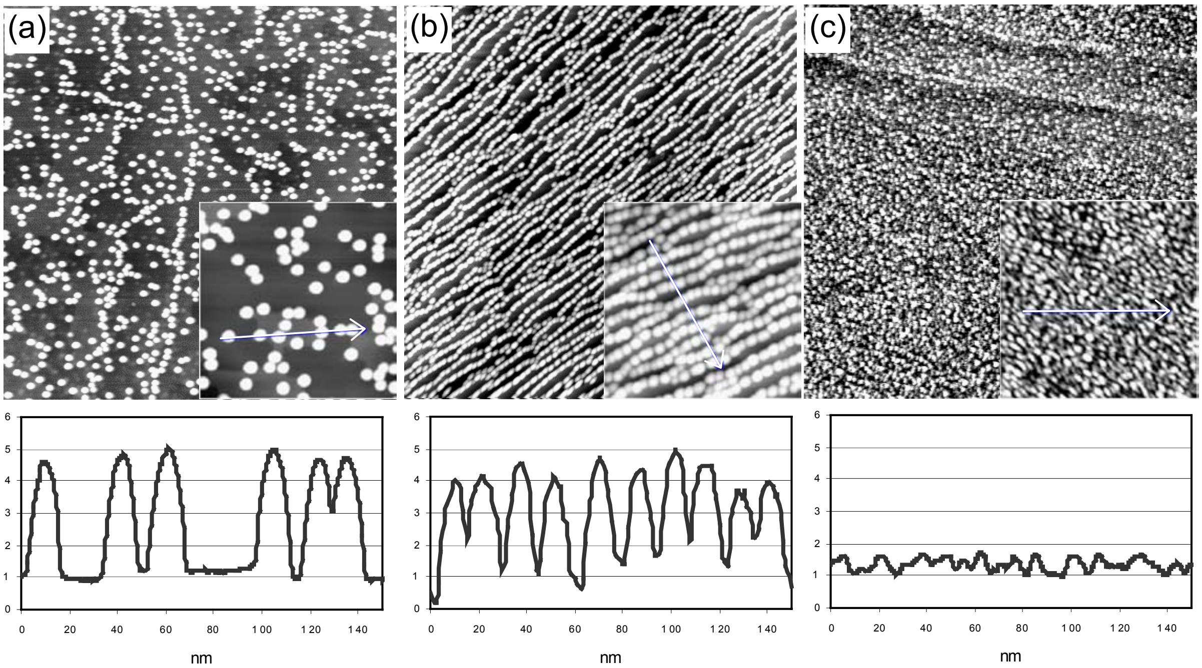

Fig. 1 (a), (b) and (c) (750 nm × 750 nm) Fe nanometer scaled dots, wires, and ultrathin films on the NaCl (001) surface and their line profiles along the white arrows (150 nm long) in the insets (200 nm × 200 nm). Fe coverage θ_{Fe} = 1.7 ML for all three structures.

The dots are randomly arranged on the large terraces; the size and height distribution of the dots are very narrow, the dispersions of the distributions of the diameter and height are less than 10%. The island densities decrease with increasing coverage. This indicates that the growth of the dots is in the coalescence regime. But contrary to the broadening of the distributions in normal coalescence growth, the widths of the size and height distributions remain the same at all coverages.

The wires are typically 15 nm wide, 2 nm high, and almost parallel to each other, with less than 15 nm spacing. We observe the extension of wires to lengths of several microns. The Fe wires are formed by nanometer-sized Fe dots, which are aligned along the upper terraces of the step edges of the NaCl(100) surface. The orientations of the wire arrays are governed by the substrate step directions. The heights and widths of the wires can be controlled by varying the Fe dosages.

The growth of ultrathin Fe films on NaCl is hindered by the large difference of the surface free energies between Fe and NaCl. We overcome this obstacle with so called “reentrant layer-by-layer growth” at low temperatures. The resulting film is atomically smooth; the corrugation of the film is of the order of the height of a single atomic step of the substrate. Histogram analysis indicates that the layer fillings for the 1.7 ML film are 97%, 60%, and 10% for the 1st, 2nd, and 3rd layer, respectively.

Conclusion

In conclusion, iron dots, nanowires, and ultrathin films have been successfully prepared on top of a cleaved insulating NaCl (001) surface. This identifies an ideal system for comparative studies of the electronic transport and magnetic properties of low-dimensional structures.