Surface reconstruction and induced uniaxial magnetic fields on Ni films

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ABSTRACT

Metal ceramic interfaces are important in applications as diverse as magnetic storage media to support catalysts. Understanding the relation between the films structure and its properties is very important for applications. For example the lattice mismatch between substrate and epilayer during heteroepitaxial growth induces strain as well as defects on the structure of the films that in turn affect the magnetic properties.

We have previously shown that it is possible to obtain epitaxial (001) and (111) Ni films grown on MgO substrates. [1] In particular we observed that the crystalline quality of the films improved considerably after 10 nm of film growth and annealing of the films indicated significant reduction of the surface roughness. In addition, after annealing (001) Ni films we observed nano-patterning of the surface through self-assembly of periodic “stripes”.

We will now present our analysis of the magnetic properties of these films, in particular the azimuthal dependence of the magnetization reversal, using MOKE, and we will attempt to correlate our findings with the surface characterization obtained with STM.

INTRODUCTION

The magnetic anisotropy, of epitaxial thin films is dominated by the crystallographic structure of the metal/substrate interface as well as the surface quality. For many practical applications (e.g. spin-dependent tunneling devices, [2]) the roughness at the surface must be very small in order to ensure the integrity of the subsequent epilayers. Thus, we have considered the growth of magnetic films on MgO substrates, which can be prepared with very smooth surfaces. [3]

Theoretical studies have indicated that for Ni films grown on MgO substrates, Ni is expected to strongly interact with MgO [4]. Various researchers have studied the orientation of Ni films on MgO substrates under various growth conditions [5], and some reports indicate that Ni may form an epitaxial relationship with Ni[001]//MgO[001] and Ni(010)//MgO(010) for films deposited using dc sputtering on MgO substrates held at 100 ^{o}C [6]. There are also reports on epitaxial growth of fcc metals on surfaces with hexagonal surface symmetry such as MgO (111) [7]. Sandstrom et al. [8] have shown that at growth temperatures between 300 ^{o}C and 400 ^{o}C it is possible to grow smooth <111> oriented single domain epitaxial films on MgO substrates, utilizing dc magnetron sputtering in an ultra high vacuum (UHV) chamber.

We have reported previously that we have been able to grow epitaixal and smooth Ni films on MgO using MBE. [1] Here we report on our preliminary studies on the magnetic switching behavior of these thin films, in particular in the (001) orientation.

EXPERIMENTAL DETAILS

The Ni films were grown in an MBE VG 80M system with a background pressure <5 x 10^{-11} torr. Ni was evaporated from a 99.9999 % pure source. The deposition rate was 0.5Å/sec. The substrates used in the experiment were 0.5 mm thick, 1 x 1 cm^2 pre-polished MgO (001), which were heat-treated in UHV at 800°C for 1 hr. The combination of flat polished substrates and the UHV heating cycle to allow the surface layers to regain crystalline order has been proven to permit growth of single crystal metal films as well as exhibiting sharp reflection high-energy electron diffraction (RHEED) from the MgO surface.

Prior to initiating the growth, the substrate temperature was lowered to the appropriate deposition temperature for metal growth. Heat transfer was by direct radiation between the heater and MgO substrate. The RHEED patterns were recorded continuously during deposition and during subsequent annealing of the films. The surface morphology of the as-deposited and annealed films was determined in-situ with scanning tunneling microscopy [(STM) RHK model STM100]. Our films were typically 10-15 nm thick and the surface morphology of the "as deposited" film was mounded. [Fig. 1(a)] The structural characterization of the films is extensively discussed elsewhere. [1]

We have previously observed that when annealing epitaxial metallic thin films at a temperature 1/3 of the bulk melting point (K) mass transport mechanisms favor surface diffusion thus further enhancing the surface smoothness. [9] Our present studies have shown that in the case of Ni films the surface smoothness is indeed improved with annealing (from 0.5 nm rms to 0.2nm rms). In addition, in the case of (001) Ni, the surface also exhibits periodic "stripe" nano-patterning. [Fig. 1(b)] This periodic stripe nano-patterning is not present in (111) Ni films grown and annealed under the same conditions, [Fig. 1(c)] and therefore the possibility of surface contamination with residual gases to explain it in the (001) films, although not impossible, is unlikely. To understand the periodicity observed in the stripes, we have considered the possible effect of strain. The lattice misfit between MgO and Ni is 16%. However, it has been postulated [6] that an in-plane super-cell matching (commensuration) between the film and substrate with a_0(Ni) x 6 = 2.0446nm and a_0(MgO) x 5 = 2.1066 nm will reduce the misfit to ~0.8%. The critical thickness needed to relieve such a small strain may be quite large.

Figure 1. Epitaxial Ni films MBE grown on MgO. (a) (001) Ni film MBE grown on (001) MgO at 373K, not annealed; (b) the same Ni film annealed at 573K (note the "stripe" surface reconstruction); (c) epitaxial (111) Ni film MBE grown on (111) MgO and annealed at 573K, note the absence of surface reconstruction. Bottom scale: 10 nm. [1]