TEXTURE AND GRAIN SIZE OF PERMALLOY THIN FILMS SPUTTERED ON SILICON WITH Cr, Ta AND SiO_2 BUFFER LAYERS

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ABSTRACT

We have investigated the structural properties of $Ni_{80}Fe_{20}$ thin films sputtered on silicon with Cr, Ta and SiO_2 buffer layers using transmission electron microscopy. We observe a decrease of the grain size when Ta and SiO_2 underlayers are used instead of Cr. Permalloy films deposited on Ta layers are strongly (111) textured while those grown on Cr and SiO_2 are mostly randomly oriented. The results are discussed with respect to the nanostructure of both Ta, Cr and SiO_2 underlayers and in relation to the variation of the magnetic softness observed in this system.

INTRODUCTION

The recent interest in thin magnetic thin films and multilayers has stimulated the need for a precise knowledge and control of their structural characteristics like texture, interface roughness and grain size. Permalloy ($Ni_{80}Fe_{20}$) thin films and heterostructures are of great interest for magnetoresistive devices [1-3]. In particular, the low field magnetoresitive behavior of these layered systems may be advantageous for high density magnetic recording. In this system, in plane coercivity as low as 0.1 Oe have been measured under optimized conditions. However this property is strongly dependent on the growth conditions. Parameters like film thickness, texture and grain size can be invoked in order to explain the variation of coercivity observed in that kind of system [4-7]. For films with thicknesses below 100 nm, the nature of the underlayer deeply affects the structural characteristics responsible for the observed magnetic properties.

In order to clarify the structural aspects connected to their magnetic properties, we present a Transmission Electron Microscopy study of $Ni_{80}Fe_{20}$ films deposited on various buffer layers. For this purpose, we have investigated Cr and Ta metallic buffers. In these systems the coercive field, Hc, can be reduced from 1.0 to 0.1 Oe when Permalloy is sputtered on a Ta instead of Cr [8]. Although Ta and Cr crystallize both in the bcc phase, they exhibit different melting points. This should affect the atomic surface mobility during the growth and influence the microstructure. In addition, we have studied the influence of a well known amorphous underlayer like SiO_2 which has already been used to generate randomly oriented metallic films [7]. An interesting feature of this underlayer is that it leads to an intermediate value of the coercive field ($Hc \approx 0.5$ Oe).

EXPERIMENT

$Ni_{80}Fe_{20}$ films, 250 Å thick, were deposited on Cr, Ta or SiO_2 buffer layers on (100)Si in a high vacuum sputtering system with a base pressure of 5.10^{-8} Torr [8]. The Silicon substrate was chemically etched in HF then rinsed in deionized water prior to the growth. RF magnetron was used for deposition of Cr and Ta at a deposition rates of 2.2 Å/s. The SiO_2 buffer layer, 1200 Å thick, was grown ex-situ by thermal annealing of silicon at 1050°C under dry oxygen atmosphere. It was degreased, but not etched, prior to the growth. The $Ni_{80}Fe_{20}$ films, 250 Å thick, were then deposited using the RF diode configuration at a deposition rate of 1Å/s. A magnetic field of $\approx$ 50 Oe was applied in the plane of the substrate during the deposition, in order to induce a uniaxial anisotropy in the permalloy layer. A cap layer of Cr or Ta was then

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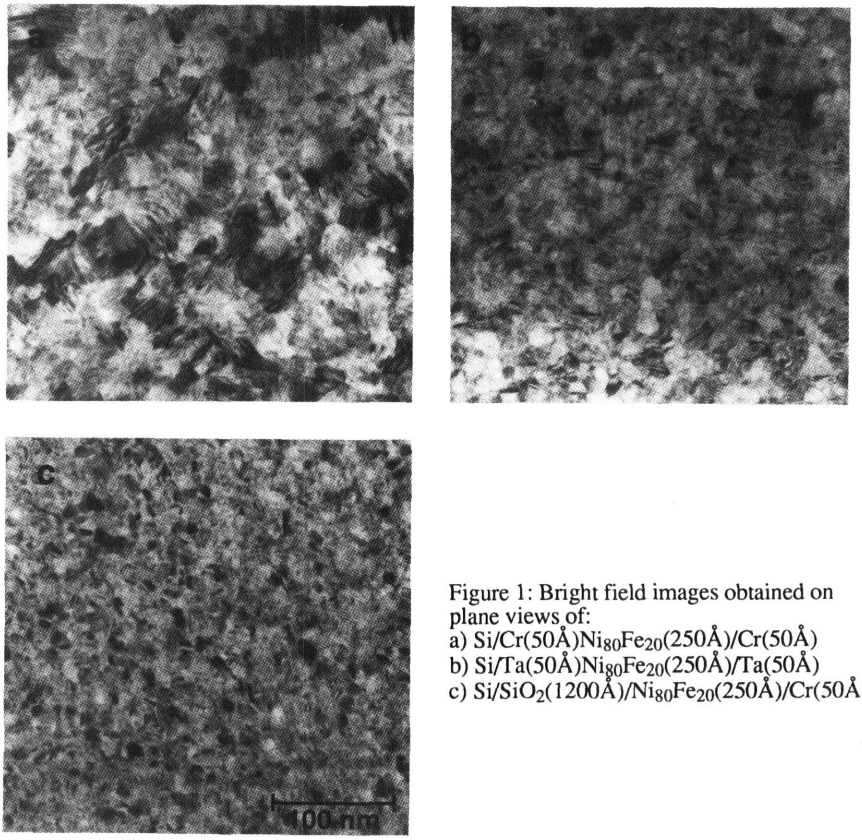

Figure 1: Bright field images obtained on plane views of:
a) Si/Cr(50Å)$Ni_{80}Fe_{20}$(250Å)/Cr(50Å)
b) Si/Ta(50Å)$Ni_{80}Fe_{20}$(250Å)/Ta(50Å)
c) Si/SiO_2(1200Å)/$Ni_{80}Fe_{20}$(250Å)/Cr(50Å)

deposited to prevent the oxidation of the permalloy layers.The substrate temperature was close to 300°C for all the investigated films.

TEM experiments were performed on plane views and cross sections prepared by polishing and dimpling followed by argon milling performed with a beam incidence of 15° and using a liquid nitrogen cooled stage equipped with a sector speed control. The observations were performed using a Topcon 002B microscope operated at 200 kV. It was fitted with a Cs=0.4 mm pole piece giving a resolution of 1.8 Å. Nanodiffraction experiments where performed using a probe size of about 30 Å and a half convergence of 4 mrd.

RESULTS

Grains size and texture of the Permalloy films

In both cases the $Ni_{80}Fe_{20}$ films are found polycristalline with the fcc structure. For Permalloy films deposited on Cr, the lateral size of the grains measured on plane views is about 300-500 Å (Figure 1.a). Some columnar growth is visible in the bright field images obtained on cross sections as previously reported [10]. The ring related to the (111) reflection observed in the electron diffraction pattern show that most of the grains are randomly oriented (Figure 2.a).

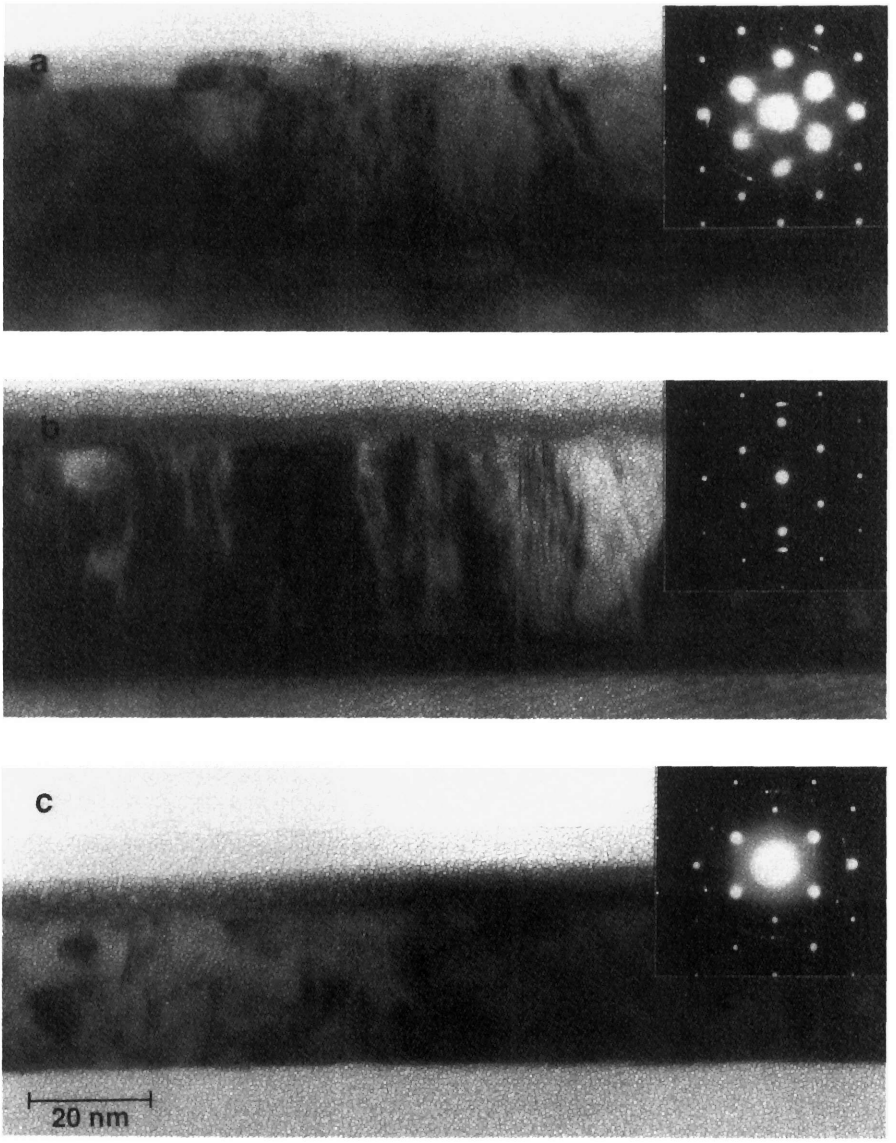

Figure 2: Bright field images and electron diffractions obtained on cross-sections of a) Si/Cr(50Å)/$Ni_{80}Fe_{20}$(250Å)/Cr(50Å), b) Si/Ta(50Å)/$Ni_{80}Fe_{20}$(250Å)/Ta(50Å) and c) SiO_2(1200Å)/$Ni_{80}Fe_{20}$(250Å)/Ta(50Å)

However, some residual preferential orientations are not excluded. Similar results are observed when Cr is replaced by Fe.

The films deposited on a Ta buffer layer appear to be very different in terms of grain size and texture. Their lateral dimensions are smaller (≈ 100-200 Å), with no particular lateral shape. They exhibit a clear columnar structure as shown in cross-section observations (Figure 2.b). A strong (111)fcc texture is observed with the texture axis parallel to the growth direction (Figure 2.b). The top surface is apparently wavier than the one on Cr and SiO_2 buffers presumably due to the columnar growth.

In the case of a SiO_2 buffer layer, grains with small lateral dimensions are observed (≈ 50-150 Å)(see Figure 1.c). Although their sizes are almost comparable to the one observed with Ta buffers, they do not exhibit the kind of columnar shape noticed previously (Figure 2.c). Furthermore, like for Cr buffer layer, no clear texture is observed.

Structure of the Cr and Ta buffer layers

Electron diffractions on plane views show the bcc structure of the Cr buffer layer. The (200)bcc and (211)bcc reflections are clearly seen whereas the (110)bcc contribution was not resolved from the (111)fcc of $Ni_{80}Fe_{20}$. The grain size, measured on high resolution images on cross sections (Figure 3.a), is larger than 40 Å. A close examination of the high resolution images shows a clear structural coherency between the Cr layer and the upper permalloy layer. This is illustrated in Figure 3.a where we can see the continuity of the lattice fringes from the Cr grains into the upper Permalloy (the lattice spacing measured in that case is about 2.05 Å which corresponds to both the (110) and (200) reflections of Cr an $Ni_{80}Fe_{20}$). Thus in the case of a Cr buffer layer the growth mode of $Ni_{80}Fe_{20}$ is monitored by the different orientations of the grains in the buffer.

The case of the Ta buffer layer appears somewhat complicated. Electron diffractions on plane views show only one broad ring related to Ta with a lattice spacing of 2.35-2.45 Å. This can be attributed to either the (110) reflection of the bcc phase (2.34 Å), either to the (202) reflection of the ß phase (2.35 Å) [11,12]. We have not detected other reflections. High resolution observations performed on cross sections show small grains, ≈ 15 Å large, embedded in an "amorphous like" layer (Figure 3.b). This is confirmed by nano-diffraction experiments which show, in addition to diffraction spots related to small Ta grains and to residual contributions from the Si substrate, a ring centered around 2.4 Å (insert of Figure 3.b). This suggests that the Ta buffer layer is partially amorphous. However, it is difficult to definitively conclude about the exact crystallization state of this buffer. A close inspection of the images reveal that the (111) oriented Permalloy grains are nucleated at the interface with the underlayer and apparently without any relationship with the Ta crystallites.

DISCUSSIONS

Our results illustrate the importance of nucleation films on the structure of Permalloy thin films. We show that Cr and Ta buffer layers exhibit very different crystallization states. This is probably in relation with the different melting point values noticed for these metals (1875°C for Cr and 300°C for Ta). A lower atomic mobility is expected far below the melting point which, combined with the relatively low temperature of the growth (300°C), inhibits the crystallization process and probably explain the quasi amorphous structure of the Ta underlayer [13]. On the other hand, the atomic mobility is higher for Cr and this favors the nucleation and growth of well crystallized grains.

In the case of Cr, the properties of $Ni_{80}Fe_{20}$ films are directly monitored by the buffer. However, Cr and $Ni_{80}Fe_{20}$ crystallize in their bulk stable structure. The texture observed with Ta suggests that it is somehow correlated to the "amorphous like" structure of the buffer. However, very different results are observed on SiO_2. The growth mode of thin films deposited on amorphous surfaces has been extensively studied in the past [14]. The orientation of the

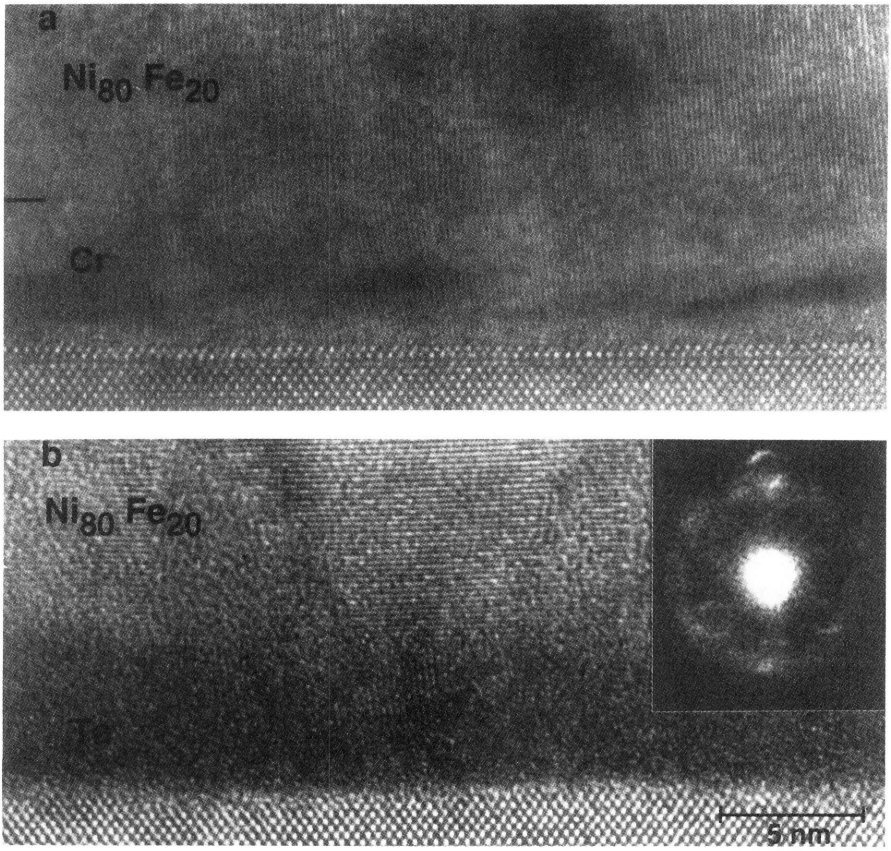

Figure 3: High resolution images of the interface Si/buffer/$Ni_{80}Fe_{20}$ for a) Cr and b) Ta. A nanodiffraction pattern of the Ta layer is shown in insert of b).

crystallites are found to be due (i) to formation of nuclei with special orientations (nucleation orientation) or (ii) to the preferred growth of crystals with special orientations (growth orientation). An tentative explanation of our results can be found in the preparation processes which strongly differ for Ta and SiO_2. The thermal oxide is fabricated *ex-situ* and this probably favors the creation of a lot of nucleation sites, due to contamination, with different orientations of nucleation which lead to randomly oriented grains (Figure 2.c). On the other hand, these nucleation sites are not present in the case of a Ta buffer grown *in-situ*. Thus, the (111) texture observed on the Ta buffer layer should be more likely related to the kinetic of the growth (growth orientation). This is consistent with previous reports of a preferential growth of face-centered cubic metals along the [111] axis [14]. However, the adsorption of atomic species on metals is known to give rise to long range ordering due to the delocalization of the electronic bond and this could also be the origin of the preferential growth observed on Ta. Further investigations are necessary to clarify that point.

Both grain size and preferential orientations of the films have been assumed to influence the magnetic softness. Weak coercivities are generally observed for small crystals where the exchange interaction between the neighboring crystals reduces the effective anisotropy [15]. The growth with preferential orientations is also known to deeply affect the magnetocrystalline anisotropy and magnetostriction [7]. In our study, the highest coercive field (Hc≈1 Oe) is obtained with large and mostly randomly oriented grains (Cr case). The lower coercive field (Hc≈0.1 Oe) is obtained on films with a preferential orientation (Ta case) whereas smaller grains, but randomly oriented (SiO_2 case), lead to higher coercivity (Hc≈0.5 Oe). The lowest coercivity obtained on Ta buffers is thus mostly related to the (111) preferential orientation observed with this underlayer. In that case, the magnetization lies in the (111) plane a configuration which reduce the magnetocystalline anisotropy and suppress the sources of local anisotropy fluctuations [8].

CONCLUSIONS

Our results show that the grain size and texture of $Ni_{80}Fe_{20}$ thin films are strongly affected by the underlayer. Cr and Ta buffer layers are found to exhibit very different crystallization states. Cr buffer is shown to monitor both the grain size and the absence of texture of the upper Permalloy layer. This contrasts with the results obtained with Ta which is found mostly amorphous and leads to columnar and textured permalloy grains whereas no preferential orientations are observed with SiO_2. Both grain sizes and texture are found to affect the coercive field of the Permalloy. However, the preferential orientation observed on $Ni_{80}Fe_{20}$ sputtered on Ta appears to be the dominant parameter responsible for the observed weak coercivity.

This work was supported in part by a Brite Euram grant from the European Economic Community. The authors would like to thank C. Chenu for the preparation for the TEM sample, Dr. P. Alnot for stimulating discussions and Dr. F. Plais for the fabrication of the SiO_2/Si films

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