STRUCTURAL AND MAGNETIC PROPERTIES OF Fe / Au THIN FILMS AND MULTILAYERS

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ABSTRACT: *The Fe/Au systems including single Fe films grown on gold, sandwich structures containing magnetically coupled Fe layers, multilayered systems and monoatomic superlattices. Many novel interesting phenomena like perpendicular anisotropy or oscillating interlayer coupling have been found. On the other hand, it is difficult to find any other systems for which so many contradicting papers have been published. This discrepancy is due to a complicated growth mode of iron on gold, which is very sensitive on the preparation of the Au substrate and the growth conditions. In this paper we gave a review of structural and magnetic properties of Fe/Au systems.*

Keywords*:* *Fe/Au system- Magnetic - Anisotropy - Monoatomic*

1. INTRODUCTION

The Fe/Au systems including single Fe films grown on gold, sandwich structures containing magnetically coupled Fe layers, multilayered systems and monoatomic superlattices, are one of the most extensively studied magnetic/nonmagnetic metal combinations. Many novel interesting phenomena like perpendicular anisotropy or oscillating interlayer coupling have been found. On the other hand, it is difficult to find any other systems for which so many contradicting papers have been published. This discrepancy is due to a complicated growth mode of iron on gold, which is very sensitive on the preparation of theAu substrate and the growth conditions. In this paper a review of structural and magnetic properties of Fe/Au systems will be given. The discussion will be limited to the data, where the preparation conditions are well documented or the structural information allow classifying the system.

Among the iron film systems, Fe/Au (001) is of special interest because of the good lattice match of bcc Fe (001) to the primitive unit mesh of the Au (001) surface and because of the surfacetant action of Au atoms. Bulk Fe lattice constant a_{Fe}=2.866A differs by only 0.6% from that one of the quadratic surface unit mesh of fcc-Au (001) asurf,Au = a_AP12.4.078AN2 = 2,884A. The expected orientation of the bcc-Fe over layer on Au (001) is shown in Fig.l.

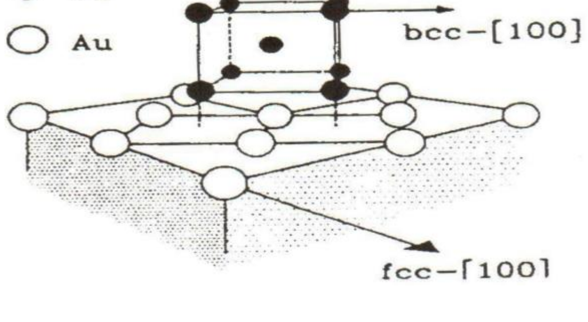


Figure (1): Schematic sketch of the orientation of a bcc unit cell of Fe on the (001) surface of fcc-Au.

2. METHODOLOGY:

By simple energetic arguments a layer-by-layer Fe growth on Au (001) should not be expected because Fe does not wet Au (y_{Fe}=2.55 mJ/m^2 and y_{Au}=1.55 mJ/m^2). Contrary to this, a layer growth was concluded from the evolution of Auger signals with deposition time [2]. To explain the layer-by-layer growth, it has been suggested that a gold over-layer "floats" on the surface duringFegrowth, modifying the surface energy balance and keeping the Fe film flat [2]. Au atoms were found on top of a Fe film as thick as 20 ML, at 230°C growth temperature [1]. Jiang et al **[1 1]** investigated the first monolayer of Fe films on an Au (001) using high resolution LEED. They did not report on Au segregation below 0.6 ML Fe and the observed features of LEED spots are attributed to Fe islands. They found that the island density stays almost constant up to —0.6 ML and for coverages higher than —0.6 ML, island coalescence occurs. It was not clear at what Fe coverage the Au segregation to the surface begins. Other papers [6,3,9] gave also the evidence that growth at room temperature leads to epitaxial bcc Fe films. The segregated Au layer, which is already formed in submonolayer Fe films through an atomic Fe-Au place exchange mechanism, is also present at the surface for thick (40 ML) Fe films, although it remains ordered as an epitaxial surfactant layer only for films up to —5 ML thick. Growth at elevated temperature leads to apparently better quality epitaxial films [2], but it is suspected that Au dissolves in the Fe layer [18].

Important information on film structure, in view of surface anisotropies, is the interlayer spacing, which was measured by many authors as shown in Table (1). The data are spread beyond the experimental error but most of them indicate that the interlayer distance between the surface Au layer and the first Fe layer is not far from the average value of bcc-Fe and fcc-Au (001) layer spacing which ia 1.74 $\dot{A}$.

Table (1): Interlayer spacing between the surface Au layer and the first Fe layer d_{Au-Fei} and between first and second Fe layers

d_{Au-Fel} [$\dot{A}$]	$d_{Fel-Fe2}$ [$\dot{A}$]	Source	Remarks
1.71 0.03	-	[Lie92]	sub-ML Fe
1.85 0.03	-	[Beg93]	sub-ML Fe
1.71 0.04	1.59 0.04	[Opi97]	2 ML Fe
1.67 0.02	1.43 0.03	[Ken92]	15 ML Fe

Not much is reported on the role of the Au reconstruction in the growth of Fe. Au (001) surface exhibits a complicated reconstruction which can be explained by forming of a quasi-hexagonal Au monolayer. Details of this problem will be discussed in the experimental part. Here it is only to note that the STM studies of Herman et al. [7] indicate that the process of the place exchange between Fe and Au is facilitated by the excess of Au atoms present in the reconstructed (001) layer. They observed that the Fe deposit locally removes the reconstruction, and 0.2 ML Fe destroys it entirely. They conclude also that the Fe atoms are buried below the Au monolayer starting from the lowest coverage. The magnetic properties of Fe(001) films on Au(001) are strongly structure dependence. As expected, the formation of interface alloy influences interface anisotropy, enhanced magnetic moments or reduced Curie temperature. Nevertheless, Fe(001)/Au monolayer present a coherent picture, in particular when prepared at room temperature or below.

Dun et al. [4] found that thin Fe films on Au (100)-including one monolayer-exhibit long-range ferromagnetic order. The temperature dependence of the magnetisation showed a second-order phase transition at a thickness-dependent Curie temperature. The onset of magnetic long-range takes place at very low coverage, in the range between 0.6 and 0.9 ML. T_c for 1 ML was around room temperature and for thickness larger than 1 ML, the bulk value is rapidly approached. Already for 2.5 ML T_c could not be recorded because of inter-diffusion and/or clustering at elevated temperatures.

Contradicting data, dependents on the film structure concern the magnetic anisotropy. In-plane [2] and perpendicular [6] magnetisation is reported for the RT grown monolayer Perpendicular anisotropy is stronger if Fe is grown at 100 K, a then the out of plane easy axis is observed up to 2.8 ML. There is no direct confirmation of enhanced magnetic moments Fe (001) films.

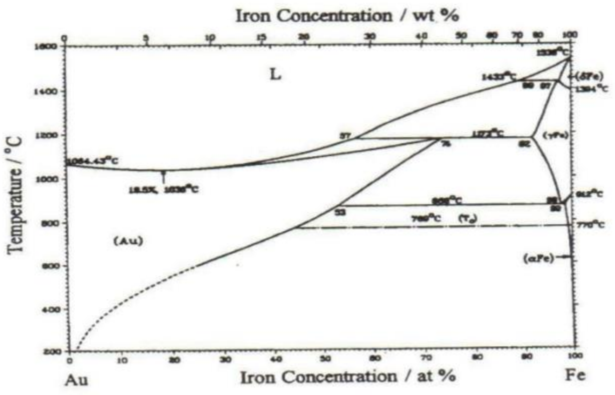
More data on magnetic properties can be collected from studies of Au/Fe multilayered systems. They attracted considerable attention due to giant magneto resistance [8], perpendicular anisotropies [12] combined with magnetic moment enhancement and oscillatory exchange coupling [9].

3. RESULTS:

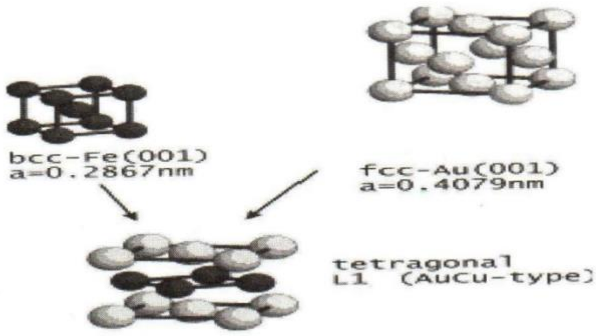
An important new contribution to physics of magnetic multilayers came from monoatomic multilayers in which thickness of a single Fe layer does not exceed few atomic layers. The Au-Fe binary system has a peritectic-type reaction and neither intermediate phase nor inter-metallic compound exists in the equilibrium phase diagram (Fig. 2a) [15], but the interatomic distances and atomic arrangement in the (001) planes allow to construct the ordered alloy artificially (Fig. 2b)Takanashi et al [21] proposed a method to prepare **Ll_0** Fe-Au ordered alloy by alternate monolayer deposition of Fe and Au using MBE. X-ray diffraction for prepared FeAu films proved existence of the $L\ 1_0$superlattice line, but its intensity indicated that the order parameter is rather low. Even so, it has been demonstrated that monoatomic superlattices are effective way to combine a high magnetic moment with high Curie temperature and high perpendicular interface anisotropy. Such combination was predicted also theoretically [20,22] and the experimental and theoretical data are compiled in Table (2).

Table (2): Comparison of the theoretical predictions [Shi96[1], Wan98[2]] with experimental results [Tak95[3], Rie99[4]] for Fe/Au monoatomic superlattices

Structure	Theory[1,2]	Experiment[3,4]
	c=3.57A. c/a=0.86 - 0.92	**c=3.83A c/a=0.96 S=0.3 — 0.5**
Magnetic moments	2.7611B	2.5 0.3 R_s
Curie temperature		>460K
Anisotropy	out of-plane	out of-plane



(a)



(b)

Figure (2) : (a) Equilibrium phase diagram of Au-Fe system,
(b) tetragonal Ll_0 type ordered structure compared with the crystal
Structure of bcc Fe and fcc Au.

From the calculation it follows that the tetragonal Ll0 ordered FeAu is stable with large tetragonality. The electronic density of states of the tetragonal L 1_0 ordered FeAu for c/a = 0.87 is presented in Fig (3) [20]. The large splitting between spin-up and spin down DOS peaks explains the large Fe magnetic moment (order of 2.7514). The magnetic moment of Fe increases slowly from 2.4714 to 2.9714 as the ratio c/a increases from 0.74 to 1. The trend of enhancing the magnetisation in Fe layers results from weakening the correlation between Fe layers as their interlayer separation increases.

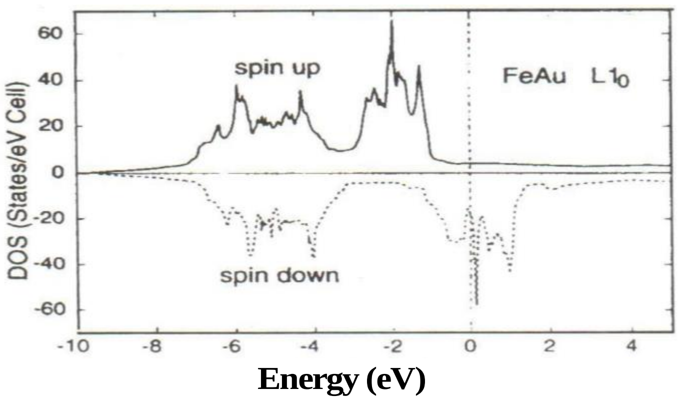


Figure (3): The total electronic DOS of spin up and spin down for the tetragonal Llo ordered FeAu.

4. CONCLUSION:

Recently, Riedling et al. [Rie99] investigated the temperature dependence of the magnetization reversal process in Au/Fe monoatomic multilayers with Fe monolayers separated by Au layers ranging from 1 to 6 ML. At high temperature, the magnetization curves were well described by an alternating stripe domain structure with free mobile domain walls, and at low temperature by a thermal activation model for the domain wall motion. By increasing the distance between Fe layers both, the surface anisotropy and T_c are reduced. Similar observation was made by Yamazaki [23] for polycrystalline Fe/Au multilayers and surprisingly, the coupling between Fe monolayers was observed up to 20 nm spacing between them.

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