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Correlation of electrical and magnetic properties of thin iron films on silicon

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Abstract. It is demonstrated that evolution of magnetic structure of iron film grown on silicon surface manifests itself in Hall measurement results. We present Hall and longitudinal voltage data obtained during iron growth for the range 0 – 3.5 nm. A film growth mechanism explaining the behavior of the results is proposed.

Introduction

The process of growth of thin iron film on silicon surface is paid much attention in last decades. This complex multi-component system represents fundamental interest and promises perspective applications, such as integration of high-dense magnetic memory in silicon technology and injection of spin-polarized electrons into silicon.

It has been shown by XPS and STM methods that at the first stages of film formation a thin (0.2-0.3 nm) layer of silicide forms then small islands grow on top of it [1]. Information on evolution of physical properties of the films during the growth process contributes to better understanding of the film growth. It has been shown that for the thickness range of (0-0.3nm) the film is stretched and for 1.5 nm it is compressed [2]. Onset of spontaneous magnetization is observed at room temperature for the thickness of ~0.6 nm. During the growth, easy magnetization axis changes its direction three times: from [111] at 0.6 nm to [1 -1 0] at 0.85-1.0 nm and to [1 -2 1] at 2.5 – 2.9 nm [3-5].

It is interesting to study the relation between the magnetic and electro-physical properties of the film and its dependence on the film thickness. In this work evolution of the measured Hall voltage and longitudinal voltage (proportional to the resistivity) during iron film growth on Si(111) is studied. The results are related to the behavior of magnetic properties.

1. Experimental

Experiments were carried out in two UHV chambers with the base vacuum 2×10^{-10} and 1×10^{-9} Torr. The first chamber is equipped with Auger electron spectroscopy and original unit for Surface Magneto Optic Kerr Effect (SMOKE) measurements [6]. The second one has LEED and original Hall [7] units. The samples ($15\times5\times0.35$ mm^3) were cut from p-type Si wafer (10 Ohm·cm). The substrates were heated at 600 ^{0}C for 4-8 hours, then cleaned by a few flashes at 1250^{0}C. Iron was deposited in small portions of 0.2 nm at the rate 0.1 nm/min, followed by measurements after each deposition. After the experiments the samples were studied by ex situ Atomic Force Microscope SOLVER P47.

2. Results and discursion

The voltages measured by our 6-tip Hall unit, taking into account the distance between the tips (~5 mm), are not the parameters of the film itself but represent some effective values attributed to the 3-layer system sketched in Fig. 1. It includes the underlying layers of the substrate, the above mentioned thin silicide layer and the film that at the early stages of growth consist of islands. Evolution of U_H and U_ρ during iron deposition allows to separate and interpret the consequence of film growth stages. During the measurements, the most of current flows in the underlying

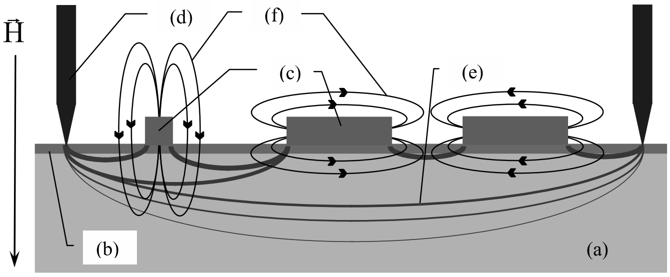

Fig.1. Schematic view of investigated system: a - silicon substrate, b - thin silicide layer, c - islands, d - Hall unit tips, e - current lines (thicker lines symbolize higher current density), f - magnetic field lines.

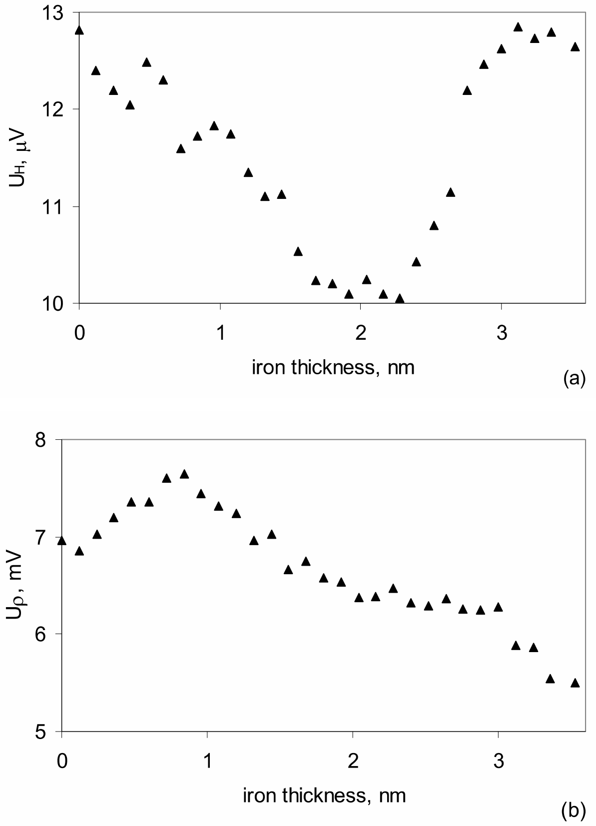

Fig.2. Dependences of Hall voltage (a) and Longitudinal voltage (b) versus iron thickness. Measurement error less than 7%.

silicon layer (Fig. 1); thus, the measured value of U_H depends on magnetic field, concentration and mobility of carriers in this region. The depth of this region can vary during the experiment. As Fig. 1 illustrates, increase of the area occupied by metal islands results in concentration of current in the shallower region of the substrate.

It is essential that the magnetic field of ferromagnetic islands has effect on the measured value of U_H since it contributes to the external field applied and has influence on the carriers' mobility since it curves their trajectories. Simple estimations show that at the depth of 10 nm under the surface the absolute value of the field of an island of the radius 10nm and height of 4 nm is of the order of 1000 Oe (the external field applied is 75 Oe). It is noteworthy, the field of a magnetic dipole is essentially non-uniform. This field increases with growth of the island's volume.

Fig. 2 (a) and (b) represent the dependences of Hall U_H and longitudinal U_ρ voltages on the amount of the deposited iron. To explain the curves presented in Fig. 2, a few phenomena related to the electrophysical properties of the system should be considered: changes in its phase content, the contact phenomena that can cause enrichment/depletion effects, evolutions of stress and ferromagnetic properties. Taking into account the arguments given in previous paragraphs, the behavior of U_H and U_ρ presented in Fig. 2 (a) and (b) is explained on the basis of our SMOKE measurements and the other data on Fe/Si system existing in the literature. The model of the iron film growth on Si(111) surface is presented. It is in agreement with the data obtained by other methods.

Thus, it is shown that measurements of electrophysical parameters can give valuable complementary information on the mechanism of film growth.

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