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Structure Features of the Nanocrystalline Ni Films Formed by Ion Sputtering Technique

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Abstract—Thin nanocrystalline Ni films with a thickness of ~340–360 nm are synthesized by ion sputtering on single crystal Si(111) substrates under high vacuum conditions. X-ray diffraction, scanning electron microscopy with microanalysis, vibration magnetometry and differential thermomagnetic analysis are used to study structure, magnetic phase composition, and magnetic properties of the initial and thermally annealed Ni films. It is found that, under certain deposition modes, the initial nickel films at room temperature have a saturation magnetization by an order of magnitude lower than that of nickel, and after thermal annealing at a temperature of 723 K, they exhibit magnetic anisotropy perpendicular to the surface. It is shown that the reduced value of the saturation magnetization is associated with a significant (3%) tensile deformation of the crystal lattice of nickel. It is found that the perpendicular magnetic anisotropy in the annealed films is due to the presence of tensile macro-stresses because of the differences in the thermal expansion coefficients of the film and the substrate.

Keywords: ion sputtering, nanocrystalline nickel films, structure, magnetic properties

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1. INTRODUCTION

It is difficult to overestimate the importance of thin films in modern high-tech technologies, which include optics, micro- and nanoelectronics, magnetic storage devices, a wide variety of sensor devices. The relevance of fundamental and applied research in this area is currently only increasing, since the requirements for the complex of structural and physical characteristics of thin films, methods of their synthesis and control of their properties increase. The aforesaid also applies to films of magnetic materials, which are the basis of traditional or modern trends, such as spintronics [1, 2], straintronics [3], and the industry of superdense recording and storage of information.

A large number of methods for the deposition of thin films have been developed and, undoubtedly, they largely determine the structural and physical characteristics of thin films. Earlier, we found that nanocrystalline iron films formed by ion sputtering in certain modes exhibit a number of features in structural parameters and magnetic properties [4]. It was found that the lattice constant of iron films obtained by this method is 2–3% higher than the tabulated values for α-Fe. In terms of magnetic properties, films exhibit perpendicular magnetic anisotropy (PMA), which depends on the deposition modes and disappears after thermal annealing of the films in vacuum at relatively low annealing temperatures (723 K). In addition, the Curie temperature of the films is ~20° lower than that of α-Fe. The reasons for such significant deviations in the structural parameters and magnetic properties of iron films obtained by this method are not entirely clear. There are several mechanisms responsible for the appearance of PMA in thin magnetic films, and which of them is realized in our case, it was not possible to establish in that study. More detailed studies of iron films deposited under various conditions, which are described in [5], testify in favor of the mechanism associated with micro-stresses and magneto-elastic effect.

Another example is ZnO nanocrystalline films formed by the same method of ion sputtering of a zinc target in an oxygen atmosphere. Like nanocrystalline iron films, they have a lattice constant 2–3% higher than that of bulk samples [6].

Thus, one of the features of the method used by us for the formation of thin films is that, in certain deposition modes, nanocrystalline films have structural parameters significantly exceeding the standard values.

In this context, of interest are thin films of other ferromagnetic metals formed by ion sputtering. This article presents the results of studies of thin nickel