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The Ability of Quantum Dots Formation in Thin Nanostructured Amorphous Films

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In the last years an interest in field of quantum dots devices creating has been increased. In this work the nanocrystallite with Frank-Kasper structure was examined as the quantum dot in amorphous film. An ability to create all-inorganic Quantum Dots Light Emission Device may be considered for $Tb_{30}Fe_{70}$, $Co_{80}C_{20}$, $Fe_{86}Mn_{13}C$ *and* $Co_{50}Pd_{50}$ *films.*

The self-organisation of atomic structure in $Tb_{30}Fe_{70}$, $Co_{80}C_{20}$, $Fe_{86}Mn_{13}C$ *and* $Co_{50}Pd_{50}$ *films, which possess large values of perpendicular magnetic anisotropy (PMA) constant* ($K_{\perp} \sim 10^6$ *erg/cm*^{3})*, were investigated by methods of electron diffraction and transmission electron microscopy, including the method of bend contours. The crystallization of the films proceeds in an explosive way forming different dissipative structures from initial nanocrystalline state. In previous works [2, 3] it was shown that after crystallization* ($T_{ann} \sim 260$-330 °C) *the atomic structures of* $Tb_{30}Fe_{70}$, $Co_{80}C_{20}$, $Fe_{86}Mn_{13}C$ *and* $Co_{50}Pd_{50}$ *films are tetrahedrally close-packed Frank-Kasper structures. In this work the structural model of thin film at mesoscale and its correlation with magnetic and optical properties is proposed.*

Keywords: dissipative structures, explosive crystallization, bend contours, quantum dots.

Introduction

The creation of new materials with unique properties is a conclusive element of new technology development. The structures arising during self-organization process are known as "*dissipative structures*". The term "*dissipative structures*" was introduced by I. Prigogine [4]. These structures appear in nonlinear open systems spontaneously. The corresponding processes are the result of the considerable remoteness from equilibrium conditions. Strong internal bends of crystalline lattice in thin solid films and solid bulk materials with high concentration of elastic stresses were observed in [5, 6]. Due to the temperature gradients and pressure the hydrodynamic and thermal effects during competing create the complex structures including periodic, quasiperiodic and chaotic structures.

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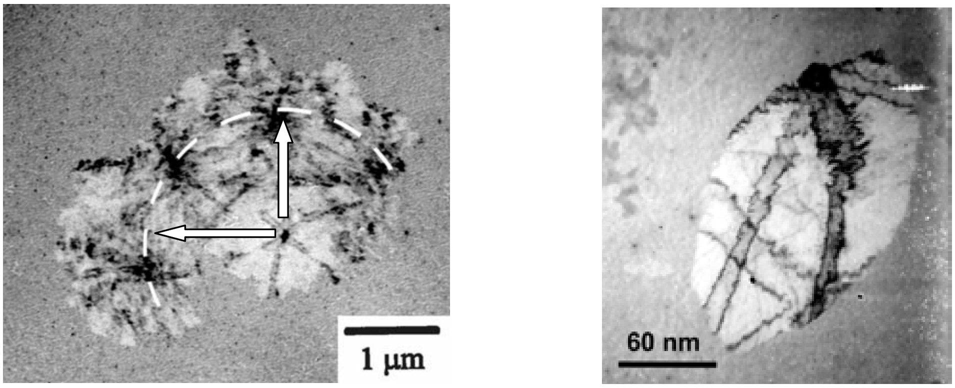
1. Methods and Results

We investigated the structure and magnetic properties of $Tb_{30}Fe_{70}$, $Co_{80}C_{20}$, $Fe_{86}Mn_{13}C$ and $Co_{50}Pd_{50}$ nanocrystalline films with strong PMA [2, 7]. The films were examined in the initial state and after annealing at vacuum. The film samples were prepared by thermal explosive evaporation at vacuum (residual pressure about 10^{-5} Torr) and magnetron sputtering at vacuum (residual pressure about 10^{-6} Torr) onto different substrates (glass, crystalline, amorphous silicon, fused silica, NaCl, CaF_2, MgO, and LiF). The microstructure and phase composition of the films were analysed using PRÉM-200 and JEM-100C transmission electron microscopes. The chemical composition of the films was checked by X-ray fluorescent analysis. PMA constant K was determined by the torsion magnetometer at room temperature in magnetic fields with strengths up to 17 kOe.

In this article we bring results gained by using electron diffraction and transmission electron microscopy methods [2, 7]. Examples of rotation effects are shown on Fig. 1. The self-organisation of atomic structure in $Co_{50}Pd_{50}$ and $Co_{80}C_{20}$ films, possessing large values of the PMA constant ($K_{\perp} \sim 10^6$ erg/cm^3).

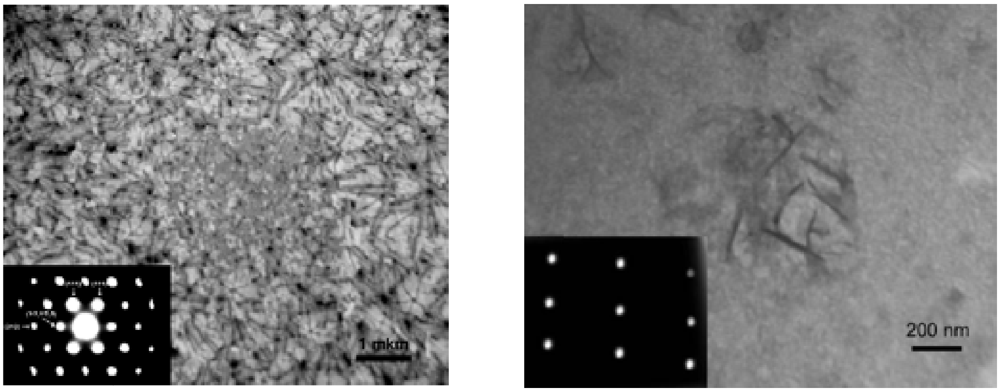
On electron microscopy image of Co-Pd film (Fig. 1(a)) explosive crystallization propagated in periodic turbulent regime is observed. The presence of rate gradients during the movement of nanoparticle groups relative to each other provided aligning action on every nanoparticle. The anisotropic distribution of particles relative to their orientation in volume is established under the action of simultaneous effect of orientating flow forces and disorientating movement [8]. As a result, the phenomenon of explosive crystallization with the formation of pseudomonocrystals, both periodic and quasiperiodic, was observed.

The crystallization of films occured by an explosive way is forming the large variety of structures from initial nanocrystalline state to dendrit, fractal, lens (with hyperbolic and elliptic ombilica morphology), Hele-Shaw cells, shock-wave fingers, Teilor vortex. The scale invariance took place in these formations. On Fig. 2 it is shown that after crystallization ($T_{ann} \sim 260$-330 °C) the atomic structures of $Fe_{86}Mn_{13}C$ and $Co_{50}Pd_{50}$ films are forming tetrahedrally close-packed Frank-



(a) (b)

Fig. 1. (a) The electron microscopy image of a Co-Pd film with bend contours. Periodic turbulent regime was formed under the action of electron beam of transmission electron microscope; (b) Bright-field TEM image of a $Co_{80}C_{20}$ film with individual quantum dot in amorphous matrix with bend-contours aroused at explosive crystallization under the action of electron beam of transmission electron microscope during investigation



(a) (b)

Fig. 2. (a) Bright-field TEM image showing the dark quantum dots on the surface of Co-Pd film after interaction with an electron beam and the picture of electron microdiffraction; (b) Bright-field TEM image showing the dark quantum dots on the surface of Fe-Mn-C film after interaction with an electron beam and the picture of electron microdiffraction; formation of bend-contours and monocrystal inclusions are visible

Kasper structures [7]. Such a kind of atomic structures is usual for Tb-Fe alloys but is unknown for Co-Pd alloys.

The correlation of nanocrystalline film structure with their magnetic characteristics in the process of transition from the disorder to their regular structure is researched. The other problem considered in this work is a decrease of saturation magnetization in nanocrystalline films of $Co_{50}Pd_{50}$ and $Fe_{86}Mn_{13}C$ with tetrahedral close-packed Frank-Kasper structures.

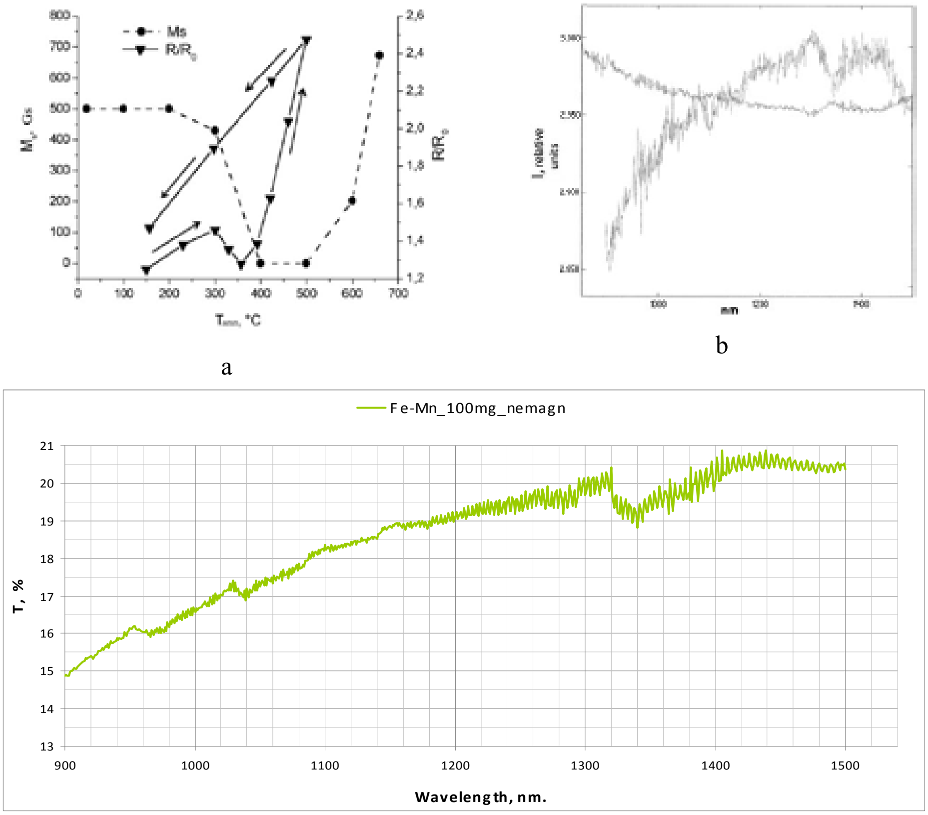
The dependence of saturation magnetisation (Fig. 3) at annealing temperature shows decreasing of temperature over the range 300° to 400°C. Probable reason of saturation decrease is significant magnetostriction. The behavior of temperature coefficient of electrical resistivity indicates structural reconstruction. The optical and structural properties of these nanoobjects (quantum dots – QD) essentially differ from the properties of initial material states (See Fig. 1 (b)). One of the directions using such properties of nanocrystalline materials is creation of displays of new generation on quantum dots (QD).

Based on the bend-contours analysis using transmission-electron micrographs the evaluations of internal tensions in the investigated films were made. This bend-contours analysis indicated also considerable effective bending of crystalline lattice (~70°/mkm). It is shown that the peculiarities of the atomic structure of the films should cause large magnetostriction effects. It is supposed that the formation of large values of PMA constant is defined by the magnetostriction anisotropy.

The torsion angle θ of crystal plane d_{hkl} was determined using distances between bend contours W on electron microscope images [1]:

$$\theta = \frac{360}{\pi W} \arcsin\left(\frac{\lambda}{2d}\right) \qquad (1)$$

the electron wavelength λ was equal to 0.037 Å, the radius of curvature r was determined by equation from [5]:



a

b

c

Fig. 3. (a) The dependence of (M_s) – saturation magnetisation and (R/R_0) – relative electrical resistivity at annealing temperature (T_{ann}) in nanocrysnalline films $Co_{50}Pd_{50}$; (b) Spectra of optical absorption and transmission from nanocrystalline film of Co-Pd. At wavelength about 1300 nanometers distinct peaks with exciton nature can be observed; (c) The spectrum of absorption from thin film $Fe_{86}Mn_{13}C$ contains distinct peak on wave length of 1320 nanometers

$$r = \frac{Wd_{hkl}}{\lambda} \tag{2}$$

The torsion angle and curvature radius of crystal could be contributed to the equation:

$$\theta = \frac{360 \cdot d_{hkl}}{\pi \cdot r \cdot \lambda} \cdot \arcsin(\frac{\lambda}{2 \cdot d}) \tag{3}$$

According to [8], rotation instability of atomic lattice is possible at shift deformation. In the case when we have one variable value parameter and two directing, we would get assembling catastrophe. In the case of two variable value parameters and three directing, the ombilic catastrophes are observed, that is so-called pseudomonocrystal shape ombilics. In the case of others combinations of parameters the shapes of tore, helix, fractal are realized. All mentioned above shapes were observed in our experiments.

Analysis of the bend extinction contours in the films was performed according to the procedure described in [5]. For presented studied films, the elastic stress is estimated at ~10^{11}N/m^2. In the case when the stress in the film does not exceed the elastic limit, PMA constant is approximately equal to ~10^7 erg/cm^3. However, dark-field electron microscopic research of these films revealed a plastic flow, which indicates a rotational effect, i.e. rotation of film regions with 1 μm size about. Consequently, stresses arising during the formation of the crystal structure substantially exceed the elastic limit and can make a considerable contribution to PMA due to magnetostriction effects. The possibility of elastically-magnetic recording of information was shown in [9] and it can be the example of Fe-Tb film. The recording was possible because the temperature gradient during recording by laser beam caused the pressure gradient in the film. The authors [9] didn't take into consideration changing of viscosity, assuming that heating is negligible. However, it was shown in [10] that *shear components of tension* provided strong influence on the distribution of uniaxial anisotropy along a thin magnetic film. The intensification of magnetostriction effects by the substrate bending during evaporation of film was reported in [10]. The bending was not more than 5°/μm. With the help of bend contour analysis it was shown that in our experiment the inner bend in film material could be 10 times more. The magnetostriction constant of Fe-Tb is equal to $2{\cdot}10^{-3}$, that is 1000 times more than in [11]. Therefore, the effects related to varying of anisotropy field depending on rotation shifts would be much higher in our films.

2. Conclusions

In this work the nanocrystalline films with Frank-Kasper structure were examined as the quantum dots. An ability to create all-inorganic Quantum Dots may be considered for $Co_{80}C_{20}$, $Tb_{30}Fe_{70}$, $Fe_{86}Mn_{13}C$ and $Co_{50}Pd_{50}$ films. Advantages of all-inorganic Quantum Dots representing in [12].

In our opinion, there are sufficient reasons to conclude that the features of explosive crystallization processes in metal films with a nonequilibrium structure can be described in the framework of the modern STZ theory based on the excited-atom model [11].

The uniaxial magnetic anisotropy in film materials having large constant of magnetostriction is able to change its sign and value due to inner stress gradients created by dissipative structures. The data summarized in this paper have demonstrated that in nanocrystalline films of metal alloys exists possibility of the quantum dots creation in the form of nanocrystallites with Frank-Kasper structure. The appearance of this quantum dots one can connecting with spectrum of absorption, which shows visible distinct peaks at wavelength in the area of 1300 nanometers, apparently, connecting with exciton optical transition.

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References

[1] *Bolotov I.E. and Kolosov V.Yu.* // Phys. Status Solidi, A 69 (1982) P. 85.

[2] *Kveglis L.I., Jarkov S.M., Bondarenko G.V., Yakovchuk V.Yu., Popel E.P.* // Physics of the Solid State 44 (2002) P. 1117.

[3] *Zhigalov V.S., Frolov G.I., and Kveglis L.I.* // Fiz. Tverd. Tela (St. Petersburg) 40, 2074 (1998).

[4] *Nicolis G., Prigogine I.* // Exploring complexity, New York (1989).

[5] *Kolosov V.Yu., Thölen A.R.* //Acta Materialia 48, 1829 (2000).

[6] *Korotaev A.D., Tyumentzev A.N., Litovchenko I.Yu.* // Phys. Met. and Metall., V. 90. P.S36 (2000).

[7] *Kveglis L.I., Jarkov S.M., Staroverova I.V.* // Physics of the Solid State 43 (2001) P. 1543.

[8] *Poston Tim, Stewart Ian* // Catastrophe theory and its applications, London (1978) P. 608.

[9] *Berman G.P., Seredkin V.A., Frolov G.I., Yakovchuk V.Yu.* // Amorphous film alloys of transition and rare-earth metals, 1988, L.V. Kirensky Institute of Physics SB RAS, Krasnoyarsk.

[10] *Belyaev B.A., Izotov A.V., Lexikov A.A.* // Zavodskaya laboratoriya, V.67. No.9. 2001. P.23.

[11] *Langer J.S., Lemaitre A.* // Physical Review Letters 2005, V.94. №17. PP 175701.

[12] *Caruge J.M., Halpert J.E., Wood V., Bulovic V., Bawendi M.G.* // Colloidal quantum-dot light-emitting diodes with metal-oxide charge transport layers, Nature Photonics, April 2008.

Возможность формирования квантовых точек в тонких наноструктурированных аморфных пленках

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В последние годы большой интерес привлекают исследования, связанные с устройствами, работающими на квантовых точках. В данной статье нанокристаллиты со структурами Франка-Каспера исследованы как квантовые точки в аморфных пленках. Возможность создания эмиссионных устройств на полностью неорганических квантовых точках может быть рассмотрена для $Co_{80}C_{20}$, $Tb_{30}Fe_{70}$, $Fe_{86}Mn_{13}C$ и $Co_{50}Pd_{50}$ пленок.
Самоорганизация атомной структуры $Co_{80}C_{20}$, $Tb_{30}Fe_{70}$, $Fe_{86}Mn_{13}C$ и $Co_{50}Pd_{50}$ в пленках, которые обладают высокими значениями константы, перпендикулярной магнитной анизотропии (ПМА) $K_{\perp} \sim 10^6$ эрг/см^3, исследованы методами электронной дифракции и просвечивающей электронной микроскопии, включая метод изгибных контуров. Процессы взрывной кристаллизации аморфных пленок формируют различные диссипативные структуры из нанокристаллических зародышей. В предыдущих работах [2, 3] было показано, что после кристаллизации ($T_{отжига} \sim 260$-330 °C) атомная структура $Tb_{30}Fe_{70}$, $Co_{80}C_{20}$, $Fe_{86}Mn_{13}C$ и $Co_{50}Pd_{50}$ была определена как тетраэдрически плотно упакованная структура Франка-Каспера. В этих работах структурные модели тонких пленок, созданные для микро- и мезомасштабов связываются с магнитными и оптическими свойствами пленок.

Ключевые слова: диссипативные структуры, взрывная кристаллизация, изгибные контуры, квантовые точки.
