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Effect of stripe domain structure orientation on secondary electron yield

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Spatial and angular distributions of secondary electrons emitted from a uniaxial Co film surface with magnetization normal to the surface have been calculated. The electron energy has been chosen within 2 to 5 eV range (the main maximum of the energy spectrum) and at 100 eV (Auger electrons). It has been shown that the regular stripe domain structure must result in an anisotropic spatial distribution of electrons escaped from the surface and reduced secondary electron yield at small escape angles. This phenomenon is similar to the escape blocking effect at the interaction of accelerated particles with single crystals.

Рассчитаны пространственные и угловые распределения вторичных электронов, эмитированных с поверхности одноосной пленки Co с намагниченностью, перпендикулярной поверхности. Энергия электронов выбиралась в интервалах 2–5 эВ (основной максимум энергетического спектра) и 100 эВ (Оже электроны). Показано, что наличие регулярной полосовой доменной структуры должно приводить к анизотропии пространственного распределения электронов, покинувших поверхность и уменьшению выхода вторичных электронов при малых значениях углов вылета. Это явление аналогично эффекту блокировки выхода при взаимодействии ускоренных частиц с монокристаллами.

Charged particles are used widely to study the surface magnetic properties [1]. Both the scattering and transmission of the particles and the secondary electrons and photons are considered, as well as their polarization is taken into account [1–3]. The use of charged particles makes it possible to observe magnetic domains and walls thereof, as well as to study the domain boundary structure. Recently, a particular attention is drawn to the studies of domain structures and collective phenomena therein [1, 4]. In this connection, of interest is to study the specific features of the charged particle motion near the domain structures (DS). The presence of regular DS in uniaxial magnetic films may result in such peculiarities in the charge particle scattering as the entrance blocking, channeling, and multiple scattering [5, 6]. The electron channeling in bulk single crystals was first reported in [7].

The purpose of this work is to study the effect of the stray magnetic fields in a stripe DS (SDS) on the spatial distributions of secondary electrons and the effect of the emitted electron velocity orientation (in relation to DS) on those distributions.

The angle reading scheme is shown in Fig. 1(a), where the OY axis is directed along the stripe domain boundary. The initial velocity orientation of an emitted electron is set by the polar (δ_0) and azimuthal (φ_0) escape angles that define the electron motion direction as is emitted immediately from the film surface. The electron velocity orientation as it is withdrawn at a distance exceeding the action area of the SDS stray field is referred to as the final orientation that is defined by angles δ_t and φ_t where the index t defines the number of calculated trajectory. The electron motion direction and the magnetization directions in the domains are indicated by arrows. The SDS stray fields were calculated using the magnetic charge method; into account taken were the fields of a block consisting of 20 infinitely long domains being the particle nearest neighbors. In the course of trajectory calculation, the block was displaced dynamically following the particle. The electron trajectory was defined by the Lorentz force and determined by numerical solving the motion equations.

The electron energy values were selected in two ranges, (i) slow electrons, E_0 of 1 to 5 eV, that corresponds to the main maximum in the energy spectrum of secondary electrons emitted due to electronic or ionic irradiation of the surface [8], and (ii) fast electrons, $E_0 = 100$ eV, that corresponds to the Auger electrons emitted by surface atoms. The slow electron colliding with the surface was considered to be absorbed, so its trajectory was not taken into account in the final distribution. In the case of a fast electron collision, the following approximations were used: the scattering was considered to be a specular one, the energy loss was set by the relationship $E_n = kE_{n-1}$ where E_n and E_{n-1} are energy values prior to and after the collision with the number n, $k = 0.9$. In the final distribution, no account was made for the trajectories of fast electrons which lost their energy down to values corresponding to slow electrons due to multiple collisions with the surface. The value and distribution of fields generated by SDS is defined by the film saturation magnetization M and the SDS period P_0 ratio to the film thickness h. The typical SDS sizes in real materials are within limits of 100 μm to 50 nm [9] while the P_0/h ratio may be within a range of $0.5 < P_0/h < 15$ [10, 11]. The calculations are shown for $P_0/h = 10$, $h = 1$ μm, $4\pi M = 17600$ Gs (cobalt). For Auger electrons, such conditions correspond to the ratio $R_L/P_0 = 0.4$ where R_L is the Larmore radius in a homogeneous field of strength $4\pi M$.

Since the amplitude of the SDS stray fields drops sharply as the distance from the film surface increases, those fields were assumed to be zero at distances exceeding P0. The emission point position (Z = 0) was selected at random within the SDS period, the initial velocity direction was selected also at random within intervals $0° < \delta_0 < 90°$ and $0° < \varphi_0 < 360°$, all directions being considered to be equiprobable. To construct the distributions, statistics of 125000 trajectories was accumulated.

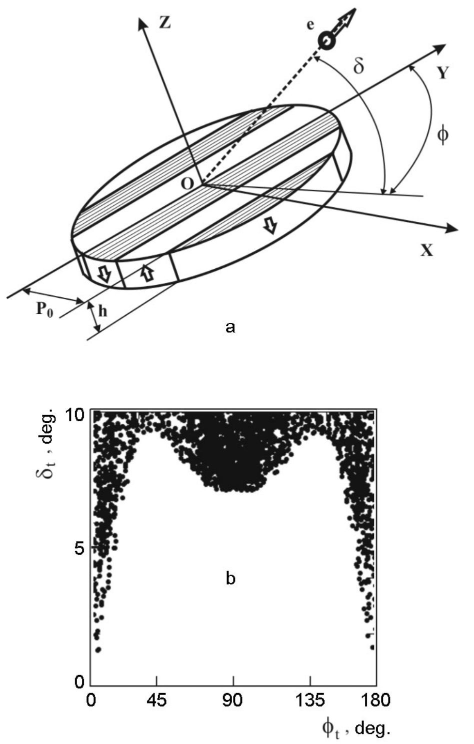

Fig. 1. Scheme of angle reading and the problem geometry (a); spatial distribution of emitted electrons for the main maximum of energy spectrum (b).

Consideration of calculated trajectories of emitted particles shows that the presence of stray fields of a regular DS must result in an anisotropic spatial distribution of electrons leaving the surface. Since main effects of the SDS are manifested at small δ_0 angles [5, 6], let the $\delta_t(\varphi_t)$ spatial distribution region at $\delta_t < 10°$. Fig. 1b shows the $\delta_t(\varphi_t)$ distribution for slow particles. Note that, due to complex trajectory shape at the particle motion in the SDS stray fields, the $\delta_t(\varphi_t)$ distribution region at $\delta_t < 10°$ can include the points corresponding to electrons emitted in all the initial directions. A point presence in the $\delta_t(\varphi_t)$ distribution means that there is an electron with the velocity direction corresponding to the δ_t and φ_t angles at a significant distance from the sample. It is seen from Fig. 1b that the $\delta_t(\varphi_t)$ distribution is strongly inhomogeneous and includes a region where no points are presented, thus, there are no electrons with corresponding escape directions in the flow of emitted particles. The presence of such a

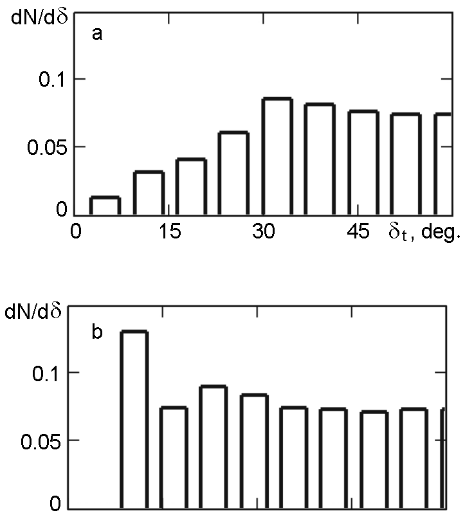

Fig. 2. Distribution in polar escape angle for electrons from the main maximum of energy spectrum along domain boundaries (a) and perpendicular thereto (b).

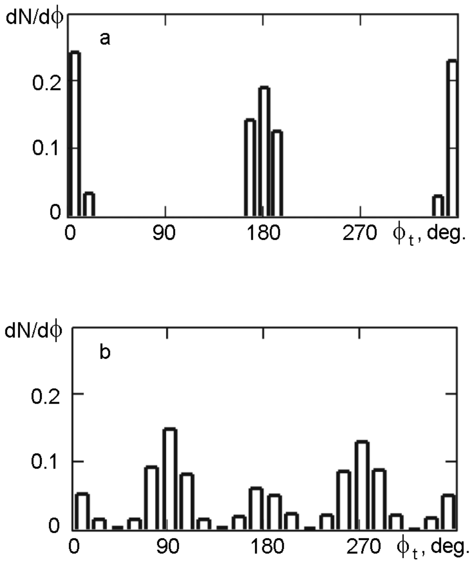

Fig. 3. Distributions in azimuthal escape angle: δ = 5° (a), δ = 8° (b).

region evidences that when electrons are emitted in the stray fields of a regular domain structure, a phenomenon (escape blocking) must be observed similar to the escape blocking effect at the interaction of accelerated particles with single crystals [12]. A rather sharp border is seen to separate the angular escape intervals that are accessible (contain points) and inaccessible (no points in the $\delta_t(\varphi_t)$ dependence) to the secondary electron escape. The position of that border depends unmonotonously on the angle φ_t. At $\varphi_t = 0°$ and $\varphi_t = 180°$ (the escape directions along the DS domain boundaries (DB)) as well as at $\varphi_t = 90°$ (the escape direction perpendicular to DB), there are local minima of the blocking angle intervals $\Delta\delta$. In the $0° < \varphi_t < 360°$ interval, the $\Delta\delta$ dependence of φ_t is defined by the SDS symmetry. Note that for fast electrons, the $\delta_t(\varphi_t)$ distribution is similar to that shown in Fig. 1b. The difference consists in the $\Delta\delta(\varphi)$ change amplitude and the position of maxima in that dependence. So, for slow electrons, the maximum value of the blocking angle interval $\Delta\delta(45°) = 9.3°$ while for fast ones, the maximum is observed at $\varphi_t = 15°$, $\Delta\delta(15°) = 3.5°$.

In Fig. 2, presented are the $dN/d\delta$ distributions in polar escape angle of particles from the main maximum of energy spectrum, the particle being emitted in the direction of DB (Fig. 2a, $\varphi_{t0} = 180°$) and perpendicular thereto; the distributions are constructed within the $\varphi_{t0} \pm 5°$ range. These distributions show distinctions in the formation of escape blocking region at different observation directions. It is seen from Fig. 2a, the electron emission probability along domain boundaries varies smoothly as the polar escape angle decreases, the maximum escape probability corresponding to larger δ values. In the direction perpendicular to DB, the calculations evidence a sharp jump of the escape probability as δ increases, the maximum in the $dN/d\delta$ dependence lying at small escape angle values. Such distinctions may be associated with possible focusing of particles as those move along the domain boundaries; in this case, the SDS stray fields draw the trajectories to the domain boundary [5].

The distributions in the azimuthal escape angle for different values of polar one are shown in Fig. 3. Both distributions demonstrate a non-monotonous dependence of the escape probability on the φ angle. At small δ values, 5° ± 2° (Fig. 3a), the escape occurs only along DB. Increase of δ up to 8° makes possible the particle escape also in the direction perpendicular to DB. At the further δ increase, the calculation demonstrates the escape possibility in any directions and a smoothing of the $dN/d\varphi$ dependence. A maximum in the $dN/d\delta$ dependence at $\delta = 10°$ and its manifestation in the $dN/d\varphi$ one can be considered as a peculiar focusing of the emitted particle flow along the direction perpendicular to DB. To estimate the effect value, the capture angles into the channeling regime along DB were calculated for 300 eV electrons [5]. The choice of the energy value is associated with possibility of classical scattering description at the estimations. The estimations have shown that, at the used SDS parameters, a particle moving along a DB is captured into the channeling regime at $\delta_0 \simeq 3°$. This value is close to the angular blocking range described above. Thus, in spite of low absolute values of the escape blocking ranges, those effects are relatively strong. It is to note that calculations at other P_0/h ratio values give similar results, the only difference consisting in the characteristic angle values.

Thus, the presence of stray fields of a stripe domain structure with magnetization perpendicular to the sample surface must result in a decreased emission probability of secondary electrons at small escape angles. This phenomenon is similar to the escape blocking at the charged particle motion in single crystals. The escape blocking interval at the particle emission in the presence of SDS depends on the particle flow orientation with respect to domain boundaries.

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Вплив орієнтації смугової доменної структури на вихід вторинних електронів

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Розраховано просторові та кутові розподіли вторинних електронів, що емітовані з поверхні одновісної плівки Co з намагніченістю перепендикулярною до поверхні. Енергію електронів вибрано у інтервалах 2–5 еВ (основний максимум енергетичного спектра) та 100 еВ (Оже електрони). Показано, що наявність регулярної смугової доменної структури має приводити до анізотропії просторового розподілу електронів, які вийшли з поверхні та зменшенню виходу вторинних електронів при малих кутах вильоту. Це явище є аналогічним до ефекту блокіровки виходу при взаємодії прискорених часток з монокристалами.