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THE CRITICAL FLUCTUATIONS OF MAGNETIZATION AND SPUTTERING OF FERROMAGNETICS

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ABSTRACT

The sputtering yield of magnetics is a strong function of the ratio of the correlation radius of magnetization fluctuation of the characteristic radius of the cascade of moving target atom i.e is eventually much dependent on target temperature. The temperature intersvals, where a definite type of sputtering (ferro or para) prevails, are presented. In particular, the temperature interval near the magnetic phase transition point is studied. The consequences of the hypothesis of the universal character of the critical phenomena are applied to sputtering of magnetics and analyzed in brief.

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1. Temperature dependence of the correlation radius of magnetization fluctuations

The second-kind phase transitions are known [1,2] to be characterized by the so called "parameter of order", namely, by a certain macroscopic mean value which vanishes identically above the phase transition temperature. In case of magnetics, the vector of spontaneous magnetization of a sample is the parameter of order. As the sample temperature approaches the critical point T_c, the system begins to exhibit the anomalously large fluctuations of the parameter of order, i.e. the critical fluctuations [1,3,4], with a very high relaxation time. By the term "fluctuation", it is meant here a local deviation of the parameter of order from its mean value taken throughout the sample bulk. The critical fluctuations are not statistically independent. The correlation radius of fluctuations is a quantitative measure of their statistical dependence. As applied to magnetics, the correlation radius of the magnetization fluctuations, roughly speaking, determines the size of the space region where the spins are correlated, i.e. identically oriented on the averag.

We are interested in the long-wave fluctuations of magnetization because they are used to determine the phase transition. In this case we may treat a continuous field of the magnetization fluctuations, which is a function of coordinate (and time), and disregard the discreteness of the spin lattice. In other words, we are interested in the fluctuations whose characteristic length of spatial variations is much in excess of the lattice parameter.

According to the fluctuation theory for magnetic phase transitions of the second kind [1], the correlation radius of magnetization fluctuations varies with temperature T as [5];

$$r_c \approx C \left| \frac{T_c}{T_c - T} \right|^{\nu} , \qquad (1)$$

where : T_c is the temperature of magnetic phase transition; C is the radius of direct spin interaction (of the order of lattice constant) ; and ν is the critical index. The values of ν vary from 0.5 to 0.7 [6].

It should be noted that formula (1) is an asymptotic one, namely, it states that the correlation radius becomes infinite following a power law when the temperature approaches the critical point unlimitedly :

$$r_c \sim \tau^{-\nu} \qquad (2)$$

where $\tau = \left| \frac{T_c - T}{T_c} \right|$. Formula (2) has been derived in terms of continuous approximation for isotropic field of fluctuations, and it essentially determines the order of magnitude of r_c . The proportionality constants in (2) above and below T_c may, generally, differ from each other.

The present-day theory of phase transitions fails to permit any definite conclusion concerning the validity of the power-law function (2) at high values of τ . The only thing that may be safely asserted is a monotone decrease of r_c with increasing τ on either sides from T_c. However, within an accuracy sufficient for our purposes, the dependence $r_c(\tau)$ may be considered to be a power law for all τ and symmetric with respect to the point $\tau = 0$, while the interatomic distance may be taken to be the proportionality factor C.

According to the theory of critical phenomena [3,5, 6], ν is determined by the dimension of space, the geometric properties of the parameter of order (scalar,vector, tensor), and the symmetry group of the Hamiltonian. For example, the Landau theory for phase transitions [2],which is based on the self-consistent mean field approximation, corresponds to ν = 0.5. The Hamiltonian of the anisotropic Heisenberg magnetic [7] is given by :

$$\mathcal{H} = - J \sum_{\vec{r},\vec{r}'} (\vec{S}_{\vec{r}} \vec{S}_{\vec{r}'} + q S^Z_{\vec{r}} S^Z_{\vec{r}'})$$

It practically describes all of the magnetic structures of interest to us, and leads to the values of ν ranging from 0.6 to 0.7 (depending on the sign of q).

Fig. 1 shows the temperature dependence of the correlation radius of magnetization fluctuations at various values of ν .

To solve the appropriate kinetic equations [8], we have to know the mean values of the scalar product of the spins located at different points of space. In case of a two-atomic collisions in a cascade, one of the atoms has of spin $\vec{S}$ and energy E during motion. It may be assumed within sufficient accuracy [9], that the atom with spin $\vec{S}$ is moving from the point $\vec{r}$ which was at a distance r' from an atom spin $\vec{S}'$, the mean free path of the atom with energy E in the target matter is $\lambda(E)$. Thus, we have to know the mean value of the scalar product of spins $\langle \vec{S}\vec{S}' \rangle$ located at distance

$$\lambda(E) = \left| \vec{r} - \vec{r}' \right| .$$

By definition, the mean value of $\langle \vec{S}(\vec{r}) \; \vec{S}(\vec{r}') \rangle$ is a two-spin correlator [10]. In the symmetric phase above T_c, the two-spin correlation function in the continuous isotropic approximation is determined by the well-known

Ornstein-Zernike asymptotic formula [5]:

$$\langle \vec{S}_{\vec{r}} \vec{S}_{\vec{r}'} \rangle = \frac{G}{|\vec{r} - \vec{r}'|} \exp\left\{ - \frac{|\vec{r} - \vec{r}'|}{r_c} \right\}, \quad (3)$$

where G is a normalizing constant.

In the asymmetric phase below T_c, a long-range order appears in the system and expression (3) takes the form :

$$\vec{S}_{\vec{r}} \vec{S}_{\vec{r}'} = \langle \vec{S} \rangle^2 + \frac{G}{|\vec{r} - \vec{r}'|} \exp\left\{ - \frac{|\vec{r} - \vec{r}'|}{r_c} \right\} \quad (4)$$

where $\langle \vec{S} \rangle^2 = \left[\frac{M(\tau)}{M(1)} \right]^2$; M is the spontaneous magnetization.

According by, the mean scalar product of spins of two colliding atoms in a cascade is given by :

$$\langle \vec{S}\vec{S}' \rangle = \exp\left\{ - \frac{\lambda(E)}{C} \tau^{\nu} \right\}, \quad T > T_c \quad (5)$$

$$\langle \vec{S}\vec{S}' \rangle = \exp\left\{ - \frac{\lambda(E)}{C} \tau^{\nu} \right\} + \left[\frac{M(\tau)}{M(1)} \right]^2 \left(1 - \exp\left\{ - \frac{\lambda(E)}{C} \right\}\right),$$

$$T < T_c. \quad (6)$$

The second term in (6) allows for the long-range order, and the first term corresponds to the short-range order. Fig. 2 shows the temperature dependence of $\langle SS' \rangle$ for various paths λ. It is seen that the spins are parallel near the critical point T_c and near T = 0 and that the spin orientation gets chaotic above T_c. Below T_c the value of $\langle \vec{S}\vec{S}' \rangle$ exhibits a minimum whose depth and position depends on λ .

2. The dependence of the sputtering yield on the ratio of the cascade radius to the correlation radius of magnetization fluctuations

In contrast to the theory of equilibrium phase transitions of the second kind, where the correlation radius of fluctuations is the sole characteristic length, the sputtering of magnetics involves another characteristic parameter of length, namely, the radius of the cascade region of moving atoms which contributes to sputtering.It should be expected that the characteristic length of the cascade is primary ion free path [9] and depends weakly on temperature. Obviously, the sputtering yield will vary as a function of the cascade radius-to-correlation radius ratio. The process of sputtering in various temperature intervals may be presented as follows :

(1) In case, the temperature is much higher than the critical point, the fluctuation correlation radius is much smaller than the dimension cascade and we deal with the paramagnetic phase sputtering determined mainly [11] by the binding energy of surface atoms in paramagnetic state;

(2) As the temperature decreases, the correlation radius increases and becomes equal to the cascade radius at a certain temperature $T_2 > T_c$. In this case all spins are correlated in the cascade region and the character of sputtering at temperatures $T_c < T < T_2$ corresponds to the sputtering of ferromagnetic phase ;

(3) As the temperature decreases further to pass by T_c , the correlation radius becomes once more equal to the cascade radius at a certain temperature $T_1 < T_c$ and decreases afterwords. However, the effect of the long-range order must be allowed for here. As a result, the character of sputtering at $T_1 < T < T_c$ will be intermediate between the ferro- and para- magnetic phase scattering, but closer to the ferro-sputtering;

(4) The correlation radius decreeases with further decrease of temperature. This would have result in the complete chaotisation of spins in the cascade regions and, hence, to produce a type of paramagnetic phase sputtering, But in this case, the role of the long-range order becomes significant, so we have again an intermediate character of sputtering which is however closer to the para-sputtering;

(5) In the low-temperature range, we deal with the pure ferromagnetic type of sputtering;

(6) The highly important temperature interval of 20 - 30° width, namely, the region of surface phase transition, is located in the immediate proximity to the magnetic phase transition point.

The variations of spin orientations and the atomic shifts are known to be related to each other [12] in that the spin orientation variations are accompanied by atomic shifts, and vice versa. Bound magnetielastic waves exist in magnetically ordered crystals. Therefore, the large--scale critical fluctuations of spin density are accompanied by the respective fluctuations of elastic stresses. In the vicinity of magnetic phase transition, the irradiated target surface is permanently in a stressed state, which gives rise to the experimentally observable changes in the morphology of the surface of magnetic [13,14] (the surface phase transition) and by the variations of the sa saturation vapour pressure [15-17] and of the rates of absorption and chemical reactions [18,19]. The surface phase transition gives rise to a change in the form of the potential barrier. The barrier curvature increases, and as a result [20,21], the sputtering yield increases by 1.5-3 times in this temperature interval.

According to the fluctuation theory of phase transition, the cirtical behaviour of magnetics is of universal character, that is , it is determined by the dimension of space, the tensor dimension of the parameter of order, and the symmetry group of the spin-Hamiltonian. It should be expected, therefore, that the temperature dependence of the sputtering of the magetics, for which the parameters of order exhibit the same geometric properties and the spin-Hamiltonian symmetry group is also the same, will be qualitatively identical. For example, the qualitative pattern of sputtering of nickel, whose parameter of order is a three-dimensional vector and magnetic structure corresponds to the Heisenberg three- dimensional model, will be the same as the patterns of heavy rare-earth metals sputtering.

Therefore, the qualitative dependence of lanthanide sputtering will be repeated for the transition metals of iron group target. Hence, they would be of the same Hamiltonian symmetry and the same dimension of the parameter of order.

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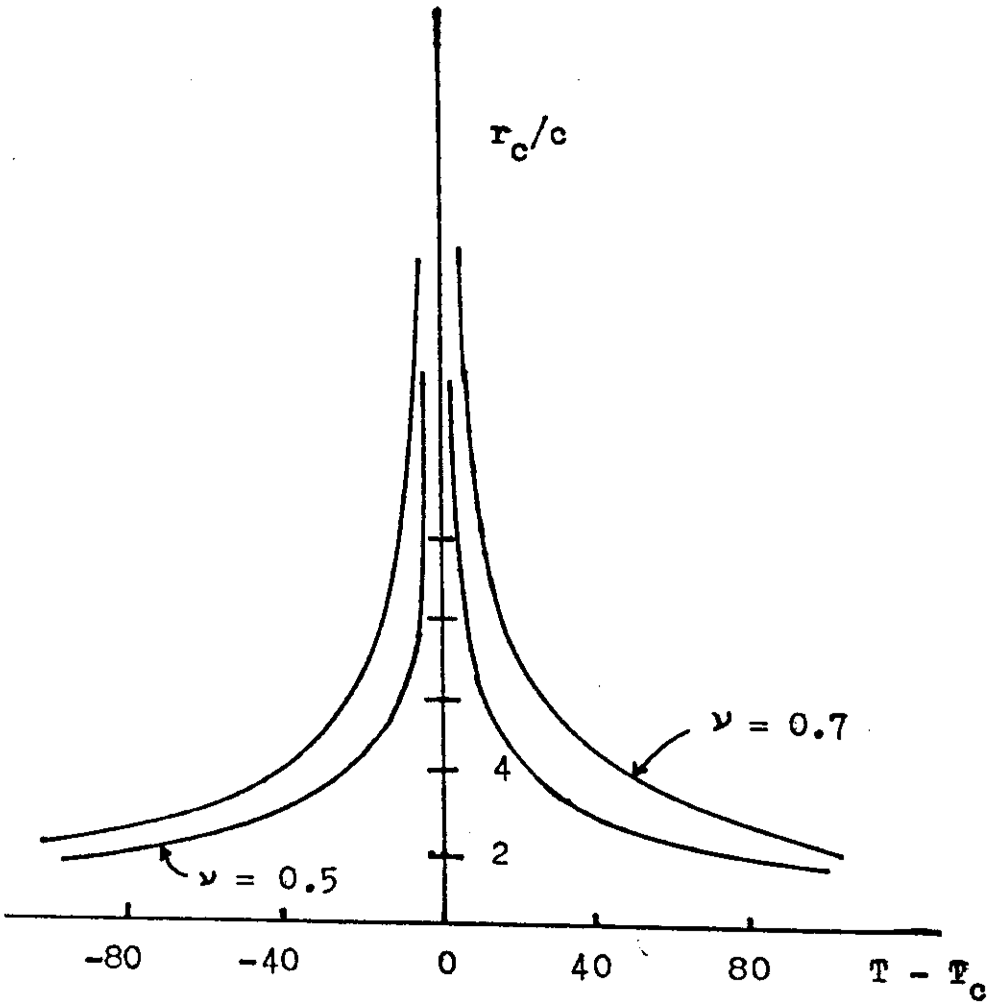

Fig.1. The temperature dependence of the correlation radius of magnetization fluctuations at various values of the critical index ν.

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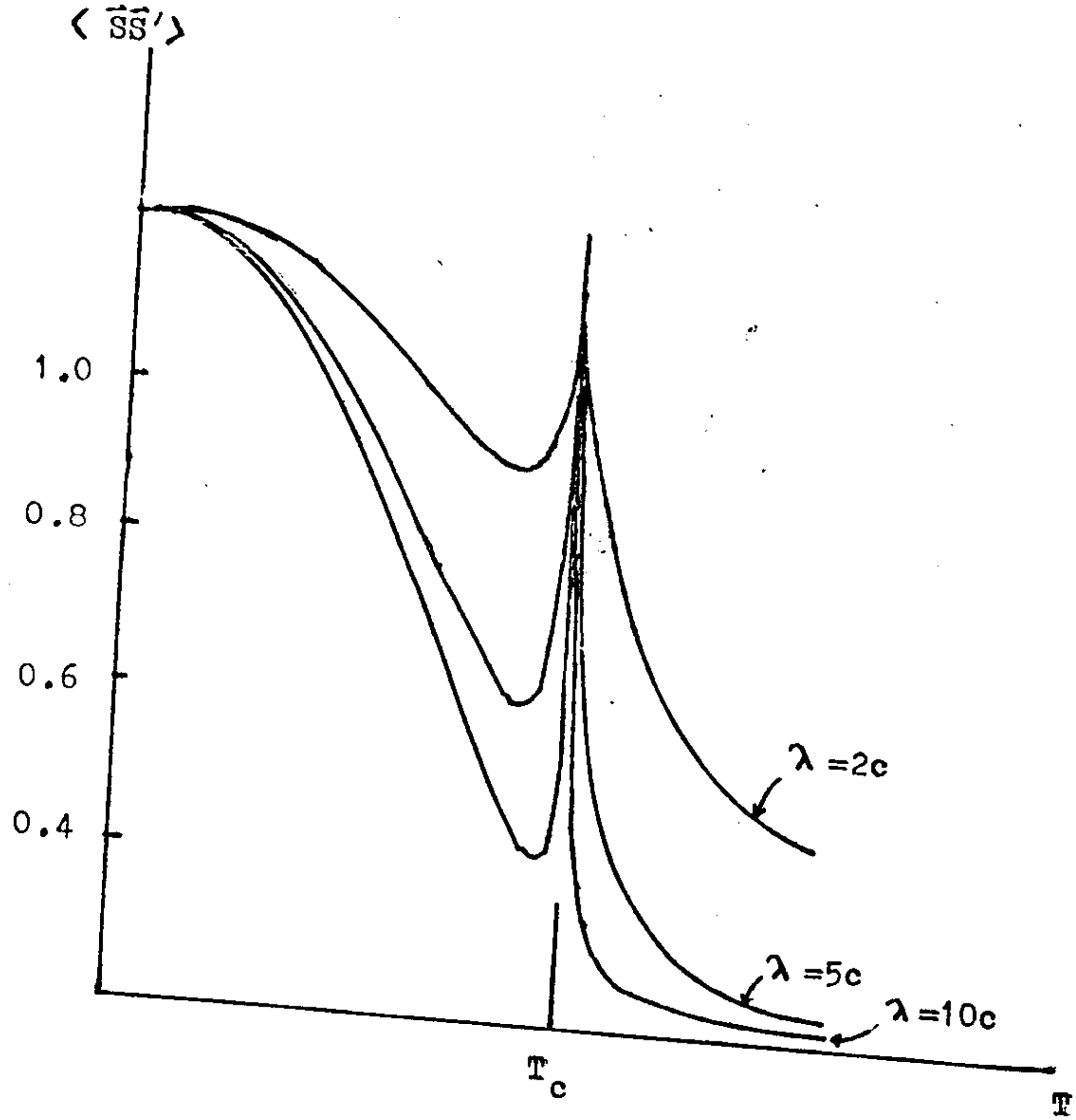

Fig. 2. The temperature dependence of $\langle \vec{S}\vec{S}' \rangle$ at various values of λ .

التغيرات الحرجة للمغناطيسية والتطاير للمواد الفيرومغناطيسية

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يعتبر معامل التطاير للمواد الفيرومغناطيسيه داله قوية للنسبة بين نصف القطر المقارن للتغيرات المغناطيسيه ونصف القطر المميز للذرات الهدف الزجزاجية المتحركه ، اى يعتبر داله لدرجة حرارة الهدف ٠ ثم تم عرض فترات الحراره حيث تسيطر نوعية معينة من التطاير (فيرواو بارا) ولقد تم على وجه الخصوص دراسة فترة الحراره بالقرب من نقطة التحول المغناطيسى وتم باختصار تحليل تسلسل الفروض للسلوك العام المطبقه على ظاهرة التطاير الحرج للمغناطيسيات٠