The effect of the surface field on the phase diagrams of a transverse Ising thin film

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Within an effective field theory (EFT), the phase diagrams of a transverse Ising thin film (TIM) has been investigated. The effects of the Ω_s on the critical temperature are discussed by including the modification of surface exchange interaction. The phase diagrams are also determinated as function of the transverse field for different values of the film thickness n and for same value of Δ_s

I-INTRODUCTION

De Gennes [1] to explain the phase transition of hydrogen-bonded ferroelectric such as KH2PO4 have introduced the transverse Ising model (TIM). This model has been applied to several physical systems and studied by a variety of techniques. Recent developments in the fabrication of thin films have revealed some novel physical properties in the study of ferroelectrics films [2-4]. They have also stimulated many theoretical studies of (TIM) in thin film geometry. By modifying the exchange interaction and the transverse field at the surface, Wang and al [5] successfully extended the transverse Ising model to the study of surface and size effects in ferroelectrics films. Karevski et al [6], have studied the random transverse Ising spin chaine according to a distribution of the transverse field governed by a low of type $K^{-\alpha}$ (K being the distance from the surface and a α constant).

Very recently, the phase diagrams of a transverse Ising thin film is investigated by the use of two theoretical frameworks, namely the standard mean field theory (MFA) and the effective field theory (ZA) [7]. In this work, the effects of the ration p ($p=\frac{\Omega_s}{\Omega}$) between the bulk and surface transverse fields on the critical temperature are discussed by including the modification on surface exchange interaction.

The aim of the present work is to investigate the phase diagrams of the amorphization of the spin-1/2 transverse Ising thin film. In this work, the modification of both surface exchange interaction Js and surface field from the bulk values J and Ω has been introduced. Namely, $\Omega_n=\Omega_s\exp(-n)$ and $J_s=J(1+\Delta_s)$.

The outline of this work is as follows. A brief formulation of the effective field theory (ZA), which is based on the introduction of a differential operator [8], is given in section II. In section III the numerical results are given and discussed. In section IV we give conclusion.

II- FORMULATION

We consider a transverse Ising thin film with a thickness n (n ≥ 3) consisting of a simple cubic lattice in which each layer is parallel to the (001) surfaces. The Hamiltonian of the system is given by

$$H=-\sum_{(ij)} J_{ij} S_i^z S_j^z - \sum \Omega_i S_i^x \qquad (1)$$

Where S_i^z and S_i^x are the components of the spin operator, Ω_i represents a transverse field and J_{ij} is the exchange interaction between nearest-neighbor atoms. J_{ij} takes the value J_s if sites i and j are on the surfaces and J otherwise. The exchange interaction J_s is defined as

$$J_s=J(1+\Delta_s) \qquad (2)$$

All the couplings J_S and J are assumed to be randomly distributed according to the independent probability distribution functions $P(J_s)$ and P(J) respectively given by

$$P(\overline{J}_s)=\frac{1}{2}\left[\delta(\overline{J_s}-J_s-\Delta J_s)+\delta(\overline{J_s}-J_s+\Delta J_s)\right] \qquad (3)$$

$$P(\overline{J})=\frac{1}{2}\left[\delta(\overline{J}-J-\Delta J)+\delta(\overline{J}-J+\Delta J)\right] \qquad (4)$$

In order to clarify the effect of the surfaces on the physical properties in the film, let us assume that the transverse field Ω_i can take the Ω_s at the two surfaces and $\Omega_s\exp(-n)$ in the bulk layers.

By the use the differential operator technique [8], the surface magnetization m_s (for L=n=1 and L)) and each layer magnetization m_n (2 ≤ n ≤ n-1) are given by

$$m_s=\left[\langle\cosh(J_sD)\rangle_r+m_s\langle\sinh(J_sD)\rangle_r\right]^4 \left[\langle\cosh(JD)\rangle_r+m_i\langle\sinh(JD)\rangle_r\right]F_s(x)\Big|_{x=0} \qquad (5)$$

(i=2 or i=L-1)

$$m_n=\left[\langle\cosh(JD)\rangle_r+m_n\langle\sinh(JD)\rangle_r\right]^4 \left[\langle\cosh(JD)\rangle_r+m_{n+1}\langle\sinh(JD)\rangle_r\right] \left[\langle\cosh(JD)\rangle_r+m_{n-1}\langle\sinh(JD)\rangle_r\right]F_s(x)\Big|_{x=0} \qquad (6)$$

Here, the functions $F_s(x)$ and F(x) are defined by

$$Fs(x)=\left(\frac{x}{y_s}\right)\tanh(\beta y) \text{ and}$$

$$F(x)=\left(\frac{x}{y}\right)\tanh(\beta y)$$

where

$$y_s=\left(x^2+\Omega_s^2\right)^{1/2},\ y=\left(x^2+\Omega_s^2\right)^{1/2}$$

Near the transition temperature, the magnetization in each layer is very small and we can linearize the coupled equations. This leads to the matrix equation from which the phase diagram can be determined. The formulation has been discussed previously in Ref. [9], and will not be reproduced again here

III- NUMERICAL RESULTS

From the formulations given in section II, we can obtain numerically the phase diagrams in an Ising thin film with a certain n, changing the values of Ω_s, Δ_s and n.

The results show that there can be two phases, a film ferromagnetic phase (F) which means that the magnetisation (M) in the film is not equal to zero, and a film paramagnetic phase (P) which corresponds to M=0.

Figure 1 shows the phase diagram of (TIM) selecting some values of n, and taking a fixed values of Δ_s and δ ($\Delta_s=0$, $\delta=0$). The film critical temperature T_{cf} decreases with increasing Ω_s and reduces to zero at a critical value Ω_c. This has been closely related to the universal features found in [10]. The critical Ω_c increases when the value of n increases. This behavior is similar with that observed in the Ref.[11] for n < 7. However, when the value of n becomes larger than 7 (n > 7),T_{cf} is independent of the value of Ω_s. This is a new characteristic phenomena.

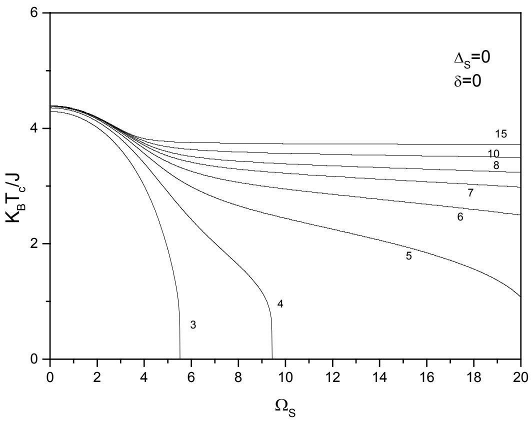

FIGURE 1: Transition temperature in a transverse Ising thin film as a function of Ω_s for various values of thickness (n=3,4,5,6,7,8,10,15) and for ($\Delta_s=0$, $\delta=0$).

To point out the effect of the disorder parameter δ on the critical field Ω_c, we have plotted T_{cf} as function of Ω_s taking $\Delta_s=0$ and $\delta=1$ (figure 2). The behavior is qualitatively similar with that observed in figure1. Moreover, for a fixed value of n, Ω_c decreases when the structural factor δ increases. In order to prove this result, we have plotted Ω_c as function of n taking first $\delta=0$ and then $\delta=1$ (figure3).

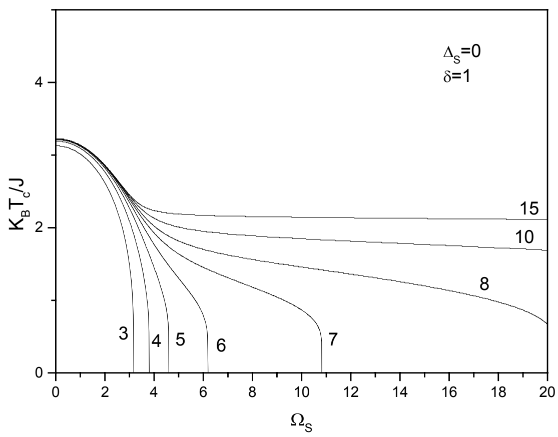

FIGURE2:Transition temperature in a transverse Ising thin film as a function of Ω_s for various values of thickness (n=3,4,5,6,7,8,10,15) and for ($\Delta_s=0$, $\delta=1$)

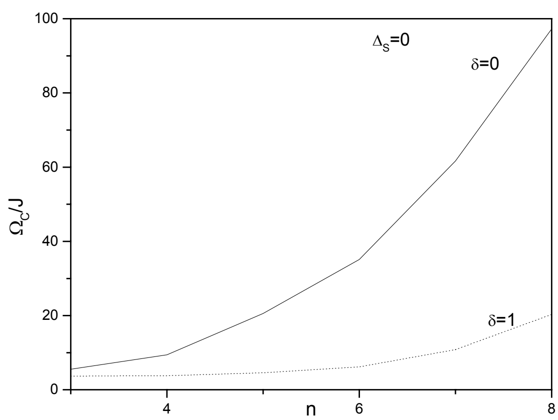

FIGURE 3 phase diagram $\left(\frac{\Omega_C}{J},n\right)$ plane for $\Delta_s=0$, $\delta=0$ and $\delta=1$

In order to see the effect of Δ_s on Ω_c, we have plotted Ω_c as function of Δ_s for some values of n (figure 4). This figure show that Ω_c increases linearly with augmenting Δ_s for all the n values.

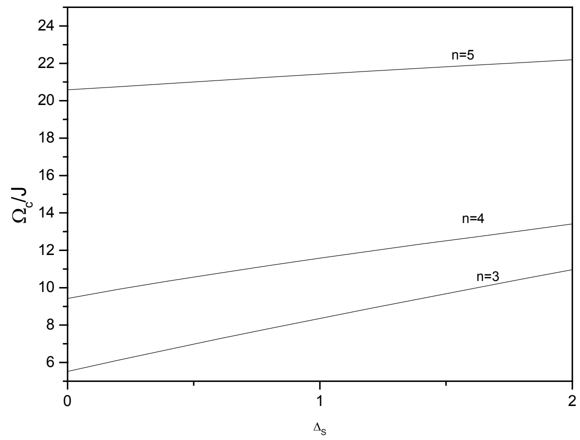

FIGURE 4 phase diagram in $\left(\frac{\Omega_C}{J}, \Delta_S\right)$ plane for n=3,4,5

IV CONCLUSION

We have studied the critical behavior of (TIM). In this work, the modification of both surface exchange interaction Js and surface field from the bulk values J and Ω has been introduced. The T_{cf} decrease with increasing Ω_s and reduces to zero at a critical value Ω_c. Moreover, for a fixed value of n, Ω_c decreases when the structural factor δ increases. The effect shows a linear behavior of Ω_c for all any thickness values n.

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