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Chiral symmetry breaking in FAXY model with roughness exponent method

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HIGHLIGHTS

- We investigate chiral symmetry breaking in the FAXY model.
- Spin configurations are mapped to surfaces of a solid-on-solid growth model.
- The film roughness is maximum at critical temperature.
- The critical temperature is determined by using properties of the film surface.
- The roughness exponent is found to be greater than one near the critical point.

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ABSTRACT

Chiral symmetry breaking in the frustrated antiferromagnetic XY (FAXY) model on a two-dimensional triangular lattice is investigated. The roughness exponent method is used instead of the standard Metropolis method. Spin configurations are mapped to adatoms on a solid-on-solid (SOS) growth model. Statistical properties of the grown film surface are analyzed. Results show that the chiral transition can be indicated by the sharp increase in the roughness of the film morphologies. The critical temperature at the transition can be identified either by the peak of the noise-reduced interface width (W^*) or the peak of the noise-reduced roughness exponent (α^*). The critical temperature and exponent (ν) obtained here are consistent with those obtained from conventional methods.

1. Introduction

In the past decades, kinetic roughening of film surfaces generated by growth models has been one of the most attractive subjects studied in computational, theoretical, and also experimental statistical physics [1–7]. Its behavior seems to occur in a wide range of physical systems, which reflects its universality. In order to study physical properties of the systems, some parameters must be introduced. The standard tools used in growth models are the roughness (W) and its exponents: growth exponent (β), roughness exponent (α) and dynamical exponent (z) [1]. Once the exponents are determined, the universality of the systems is classified.

It had been shown [8,9] that W, β_w and α obtained from mapping spin configurations to rough surfaces of a solid-on-solid (SOS) growth model can be used to detect transition points of spin models. In addition, the exponents can also be used to verify the validity of its universality classes by considering scaling relations between growth and spin models. This approach was introduced by de Sales et al. [10]. They considered cellular automata (CA) and then mapped the CA configurations to surfaces of a SOS model. By using the roughness exponent method, the CA universality classes can be classified more

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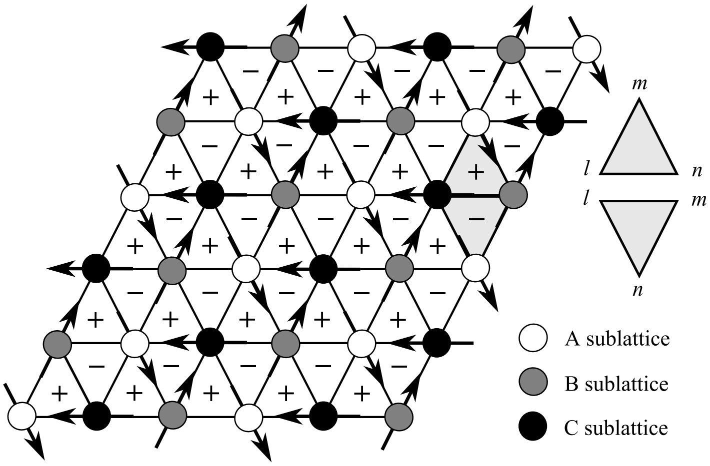

Fig. 1. The FAXY model with $N = 6 \times 6$ sites. The circles refer to spins in A, B and C sublattices, the $\pm$ signs denote the chirality at each elementary triangle, and the shaded triangles refer to up- and down-triangle i, respectively.

precisely. Later, Atman et al. [11,12] showed that β_w can be used not only to detect the Domany–Kinzel cellular automaton (DKCA) phases, but also to test scaling relations of critical exponents between growth and DKCA models. In spin models, Redinz and Martins [8] studied the q-state (with $q = 2$, 3, and 7) Potts and $p = 10$ clock models. The results showed that α and ϵ^* (characteristic length) sharply change near critical points. For the clock model, the intermediate phase or spin-wave phase was also found [9]. Furthermore, Brito et al. [13] studied the Ising chain with long-range interactions and found the value of α to peak near critical points, resulting in super-roughening. The detailed study was extended to q-state Potts, spin-1 Blume–Capel (BC) models, and two-dimensional XY models [9].

In studies of spin systems, frustrated spin models have received much attention. It describes an array of Josephson junctions under an external field [14]. Some of the interesting models investigated via the simulation methods are the fully frustrated XY model [15–18], the frustrated antiferromagnetic XY (FAXY) model [19–21] and the frustrated antiferromagnetic six-state clock model [22,23]. These models have a rotational $U(1)$ symmetry and an additional reflection Z_2 symmetry or chiral symmetry that can be broken at critical temperatures through the Kosterlitz–Thouless and an Ising-like transition temperatures, T_{KT} and T_I, respectively. Since systems with the $U(1)$ symmetry are expected to belong to the KT universality class, therefore the Z_2 symmetry has been the subject of interest in these models. It has been found that the Z_2 symmetry (with the critical exponent, $\nu < 1$) may not belong to the Ising universality class [16,17,19–21,23]. Others [18,22] argue that it is the finite size effect and $\nu = 1$ in the limit of $L \to \infty$, so the results are still controversial.

We, therefore, investigate the FAXY model on a two-dimensional triangular lattice. The chiral configurations are mapped (like a walk process) to rough surfaces of a SOS growth model, for which the roughness exponent method will be used. The aims of this study are to study the chiral symmetry breaking of the FAXY model and to provide simulation details of this model, since frustrated models have not been much studied using this method. In Section 2 we describe the spin models, simulation details, and representation formalism. Results and discussion are presented in Section 3. Finally, we conclude our study in Section 4.

2. Models and methods

The Hamiltonian of the lattice spin model is given by

$$H = -J \sum_{\langle ij \rangle} \mathbf{S_i} \cdot \mathbf{S_j} = -J \sum_{\langle ij \rangle} \cos(\theta_i - \theta_j), \tag{1}$$

where $\langle ij \rangle$ denotes a sum over all neighbor spin pairs, J is a coupling constant, $\mathbf{S_i}$ is a spin variable, and θ_i is an angle of $\mathbf{S_i}$ with respect to an arbitrary direction. In the FAXY model, the chirality at each elementary triangle is defined as

$$\kappa_{\triangle_i, \nabla_i} = \frac{2}{3\sqrt{3}} [\sin(\theta_m - \theta_l) + \sin(\theta_n - \theta_m) + \sin(\theta_l - \theta_n)], \tag{2}$$

where $\triangle_i$ and ∇_i denote up- and down-triangle i, respectively (see Fig. 1). The staggered chirality which plays a role of spin-like variable of the Z_2 symmetry is given by

$$\kappa_i = \frac{1}{2}(\kappa_{\triangle_i} - \kappa_{\nabla_i}). \tag{3}$$

According to the method [10], a positive-state of κ_i at site i and at time t' is equivalent to deposition of an atom on the film surface while a negative-state leads to an evaporation of an atom. Local height at site i and at time t, then, is the