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Reply to "Domain-growth kinetics of systems with soft walls"

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On the basis of computer-simulation results for three different models with soft domain walls it is argued that the zero-temperature domain-growth kinetics falls in a separate universality class characterized by a kinetic growth exponent $n \simeq 0.25$. However, for finite temperatures there is a distinct crossover to Lifshitz-Allen-Cahn kinetics, $n \simeq 0.50$, thus suggesting that the soft-wall and hard-wall universality classes become identical at finite temperatures.

In their Comment on the work by one of us[1] on the domain-growth kinetics of systems with soft domain walls, van Saarloos and Grant (vSG)[2] raise basically two points: (i) rescaling of the time scale used in our zero-temperature computer simulations resulting in logarithmically slow growth, and (ii) possible crossover to Lifshitz-Allen-Cahn[3] kinetics at finite temperatures.

In response to these points we argue in this reply, on the basis of comparative model studies[4-6] and recent unpublished results,[7] the following.

(i) There are no indications of logarithmically slow zero-temperature growth in simulation studies of soft-wall models. All models, independent of the details, lead to the same zero-temperature kinetic exponent, $n \simeq 0.25$. At late times, the growth may be slowed down due to finite-size-induced slab effects wellknown from Ising models.[8] We suggest that the prediction of vSG may be obscured by the one-dimensional nature of their calculation. Furthermore, we argue that one of the assumptions underlying the Allen-Cahn law may not hold for the soft-wall models at zero temperature.

(ii) Recent results on the finite-temperature kinetics of the soft-wall models[7] indeed indicate that the Allen-Cahn law is recovered at finite temperatures, in agreement with our previous results for the herringbone model,[5] the study by Milchev, Binder, and Heermann[9] of the ϕ^4 model, and the experimental study pointed out by vSG of the growth kinetics in smectic films.[10]

Three two-dimensional soft-wall models with continuous single-site variables (spins or rotors) will be referred to in the following. They are conveniently labeled by their number p of degenerate ordered ground states: the $p = 2$ model,[1,2] the $p = 4$ model[4] and the $p = 6$ herringbone model.[5] vSG concentrate on the $p = 2$ model. Concerning point (i), they study the model in a simple limit where it reduces to a one-dimensional problem. While their arguments about the ln$t$ rescaling of the Monte Carlo time scale imposed by the particular dynamics employed in Ref. 1 are undoubtedly correct in *one dimension* as well as for certain special geometries of the domain-wall network (we have verified the slowing down of growth for linear domain walls along the lattice directions[7]), we do not be-

lieve that the argument holds for a random *two-dimensional* network with curvature. It is essential for the domain-wall motions that the model Hamiltonian contains the original next-nearest-neighbor couplings[1] which are disregarded in the calculation by vSG. In fact, we find that the argument of vSG is pertinent for slab configurations. The slowing-down effects due to finite-size-induced slab configurations also inhibit the growth in the soft-wall models at late times, quite similar to what is found in Ising models.[8] Extensive studies of all three soft-wall models at zero-temperature show no signs of slowing down in the time regime where finite-size effects have been eliminated,[1,4,5,7] and the striking result is that the same value of the growth exponent, $n \simeq 0.25$, is found in all cases studied. Moreover, the wide-wall limit of anisotropic high-p Potts models gives the same result.[6]
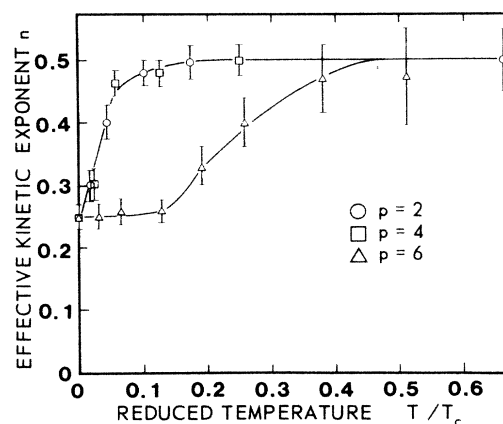

FIG. 1. Effective late-time growth exponents vs reduced quenching temperature T/T_c for three different soft-wall models. p denotes the number of degenerate ordered domains of the model. The solid lines are drawn as guides to the eye. The late-time region in the computer simulations is taken as the time range over which an asymptotic growth behavior has established itself in systems containing up to 200^2 particles. The time of crossover t_c to the late-time behavior depends on the model, t_c being smaller the smaller the value of p.

Turning now to point (ii), our results from finite-temperature growth kinetics of all three soft-wall models[5,7] indeed show (Fig. 1), in accordance with the suggestion by vSG, that there is a crossover to the Allen-Cahn law with $n = 0.50$, independent of the actual degree of the domain-wall softness. These findings indicate that the hard-wall and soft-wall domain-growth kinetics fall in the same universality class at finite temperatures. This is moreover consistent with the finite-temperature Allen-Cahn kinetics found for the soft-wall ϕ^4 model[9] and interestingly enough with the finite-temperature electric-field quenching experiments on smectic films by Pindak, Young, Meyer, and Clark.[10] These experiments even showed that the kinetic exponent is independent of the width of the wall.

The question remains: What causes the difference between the hard-wall and soft-wall kinetics at zero temperature? We believe that a key to answering this question may be the observation that the $n = 0.25$ exponent for the various soft-wall models is found to be independent of the actual degree of softness or wall thickness. Thus is appears that the relevant property of the soft-wall models is not that the walls are soft as such and how soft they are, but rather their capacity of softening, in particular soften-ing locally, in response to high curvature. This observation hints at a possible breakdown of the basic assumption underlying the Allen-Cahn theory[3,2] regarding the inverse proportionality of wall width and surface tension. Inspection of snapshots of domain-wall networks generated in computer-simulation studies of the soft-wall models[7] shows that, in regions of high curvature the walls not only move but also soften, thus impeding the growth. These observations call for a new theory of zero-temperature soft-wall domain-growth kinetics which accounts for the additional effect of domain-wall softening in response to curvature.

Finally, it is now obvious that the $T = 0$ limit may not be very interesting in an experimental context as far as the asymptotic growth behavior is concerned. Still, it represents a well-defined mathematical limit whose properties may, as Fig. 1 suggests, have influence on the crossover behavior at low but finite temperatures.

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