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# Random-Like Deposition Model of Surface Growth Kinetics*

WANG Wei
*Department of Physics and National Laboratory of Solid State Microstructure, Institute for Solid State Physics, Nanjing University, Nanjing 210093; and Center for Advanced Studies in Science and Technology of Microstructures, Nanjing 210093*

Hilda A. Cerdeira
*International Centre for Theoretical Physics, Trieste, Italy*

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*The surface growth kinetics of random-like deposition model with two kinds of particles (A and C) is studied. The scaling behavior of the surface width is obtained for various deposition probabilities of particle C and system sizes. We also found a change of different morphologic structures which results from the diffusion of particle C.*

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A rich variety of natural and industrial processes, such as crystal growth, vapor deposition, chemical dissolution, corrosion, erosion, fluid flow in porous media and biological growth, lead to the formation of complex surfaces and interfaces. Recently, there has been considerable interest in the study of the morphology of such phenomena, not only because of its potential technological importance, but also due to its manifestation of interesting non-equilibrium statistical physics at fundamental levels.[1] A novel feature is the existence of scaling[2,3]: $W(L,t) = L^{\alpha} f(t/L^{z})$, where $W(L,t)$ is the rms roughness of the surface, or the surface width on length scale $L$ at time $t$, $z = \alpha/\beta$ is the dynamic exponent, and the scaling function $f(x) \sim x^{\beta}$ for $x \ll 1$ and $f(x) \sim$ const for $x \gg 1$. Various models used for the study of surface phenomena only concern the growing of one kind of particle.[1] However, in the growing of real materials one may take into consideration of different particles depositing on these structures such as alloys or impurities. Thus, in the growing system, there may exist different interactions for different particles. The growing mechanism will also be changed.

In previous work,[4] we proposed a random-like deposition model of two kinds of particles growing on a $d$-dimensional substrate. In this letter, we discuss the diffusion effects by means of the dynamical scaling behavior of the surface width. We consider the deposition of two different kinds of particles, A and C, onto a $d$-dimensional substrate. The particles are allowed to fall straight down randomly, one at a time, onto a growing surface and stick where they land or diffuse to another position. A site is chosen randomly, and then with probability $1 - P$ (or $P$) a particle A (or particle C) is deposited on the surface of the aggregate depending on the conditions: Firstly, the deposition occurs when the particle on the top of the chosen site is particle A, or if the particle on the top of the chosen site is particle C and one of the nearest

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neighbors is particle A (one unit higher than the top of the chosen site). Secondly, if the deposited particle is particle C, it is allowed to diffuse to its neighbors until it is located at a minimal height. However, there is no such diffusion for particle A. The rules are depicted in Fig. 1.

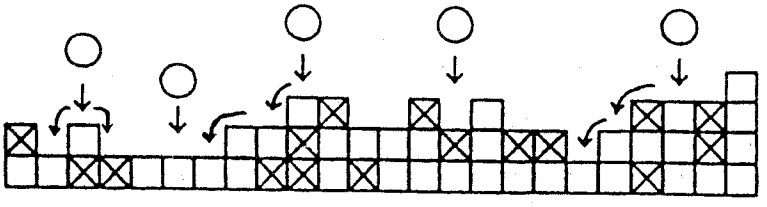

**Fig. 1.** Random-like deposition model. The circles represent the falling particles (A or C), the squares represent particle A and the squares with a cross denote particle C. The down arrows show the falling and the right and left arrows show the positions where the falling particle will stick.

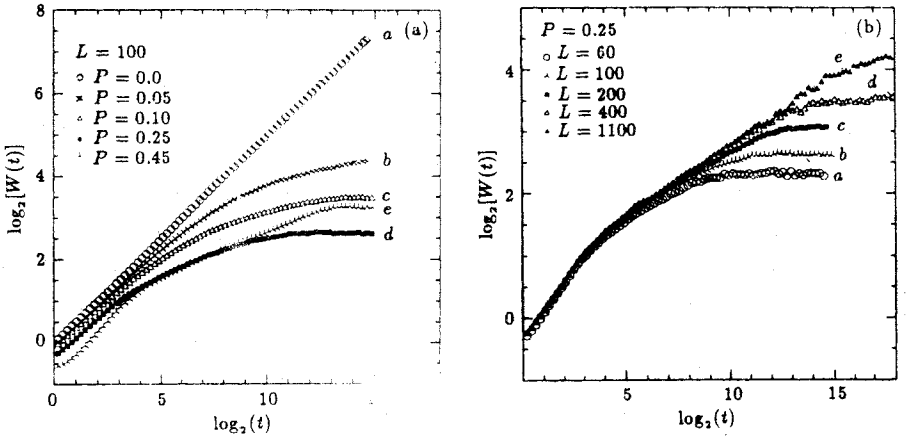


**Fig. 2.** The $\log_2$–$\log_2$ plots of the surface width $W(t)$ against $t$. (a) With different probability $P$ and same system size $L = 100$; (b) with the same probability $P = 0.25$ and different system sizes.

The physical motivations of our model might be two-fold as follows. Firstly, our model may represent the chemical reactions which take place in the surface of the growth of materials. For example, we model the following reaction process: A + B = C. Particle A and particle B are active, and once particle A is touched by a particle B the combination produces a reactant C which is no longer active. The particle A is chosen with a probability $1-P$, and the particle B with $P$, i.e., the reactant C is produced with the probability $P$. Thus, in these systems, some of the surface sites continue to react while some sites do not. We introduce naturally the diffusion only for C particles since they have less interacting "bonds" with other particles and they can move more freely to a place with lower height just like most of the diffusion processes studied by other authors.[1] Secondly, this model can also represent a growing interface of a material with low concentration of impurities. Our model mimics the role of the impurity atoms as follows. An impurity atom C is introduced with a probability $P$ while it has less active bonds for other atoms A.

The substrate is a strip with the width $L$ (in the $X$ direction). The aggregation is in the $Y$ direction. A periodic boundary condition is used in the $L$ direction. Figure 2(a) shows a plot of the surface width $W$ as a function of time for different deposition probability $P$. The system size is $L = 100$ and the statistical average is found by averaging over 100 or 250 runs. Curve $a$ shows the trivial case, random deposition of only one kind of particles (particle A). The width of the surface is proportional to the square root of time $t$, $W \sim t^{1/2}$, independent of dimension.[2] There is also no saturation width, that is no steady state. When $P \neq 0$ once a particle C is deposited on a column, its growth will strongly depend on the local structure of the surface and the scaling behavior changes. From curves $b - f$, we see that there exists a steady state for various deposition probabilities of the particle C. The growth of the aggregation is divided into three stages. Firstly, at early times (for $\log_2 t < 4$), the width grows with a power of time, $W \sim t^{1/2}$ due to the random deposition process. Secondly, the width grows with a power of time $W \sim t^{\beta}$ with $\beta \simeq 0.25$. Finally, there is a saturation values of the width. Figure 2(b) shows the surface width as a function of time for different system sizes with $P = 0.25$. From this figure, we see that the scaling behavior is similar to Fig. 2(a). Thus, we can scale the saturation surface width $W(t = \infty)$ with the system size $L$ for different probability $P$. We get a scaling $W(t = \infty) \sim L^{\alpha}$ with $\alpha = 0.44 \pm 0.01$. From $\alpha \simeq 0.44$ and $\beta \simeq 0.25$, we can conclude that our model belongs to the Edwards-Wilkinson (EW)'s universality class[5,6] for which $\alpha = 0.5$ and $\beta = 0.25$. The deviation of our exponents is due to the weak nonlinearity of the special diffusion depending on the local geometry of the growing surface. As a note, we cut curve $e$ just at the saturated value, i.e., $\log_2 W(t = \infty) = 4.15$.

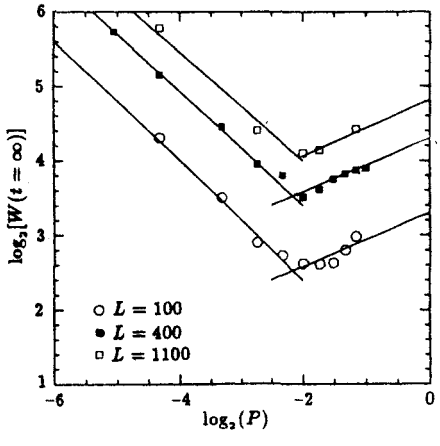


**Fig. 3.** The $\log_2$-$\log_2$ plot of the saturation value $W(t = \infty)$ against the probability $P$.

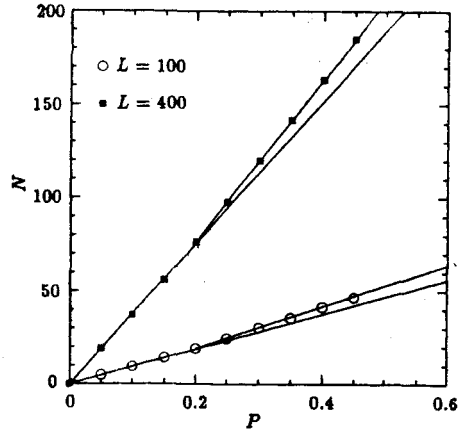


**Fig. 4.** The concentration of particle C on the surface vs the probability.

The scaling of the saturation width with the probability $P$ is plotted in Fig. 3. We can see that there are two different scaling regions: below and above a probability $P_c \simeq 0.25$, the scaling exponents are different. For small $P$, the depositions of particle A occur more frequently and the A particles form a lot barriers which enable the surface to be locally rough. This rough surface makes the diffusion of particle C more limited and only within a small range. However, for large $P$, particle C is more easily to diffuse and can travel to a large distance, which makes

the surface more smooth. Thus, morphologically, in the region $P < P_c$ the surface appears rough down to short length scales. When $P > P_c$, the surface is dominated mainly by relatively large terraces. In order to verify the above discussion, we have also counted the concentration of particle C on the surface, $N_c$, as shown in Fig. 4. We can see that there exists a change of the slope of the relationship between $N_c$ and $P$. Actually, this phenomenon is somewhat like a phase transition found by Family *et al.* in a restricted solid-on-solid surface growth.[7]

It is worthy to make a few remarks : (1) Our model is similar to the solid-on-solid model but with two kinds of particles. (2) Comparing the present work with our previous one,[4] the particle C, or the reactant C (in the chemical reaction A + B = C) and the impurity C, is considered as possessing diffusion because we assume that it has less interacting bonds for other particles. Due to the thermal activity, it may move more easily than particle A which has more interacting bonds and could be tightly bonded by others. This is the physics of our assumption for the diffusion. (3) In the presence of diffusion, there is a change of the morphologic structures and the values of $\alpha$ and $\beta$ are also different corresponding to that of in Ref. 4. The intersection of curves $d$ and $e$ results from the above reasons. (4) In this work, the diffusion length is limited to be 20 lattice spaces, i.e., $l_{cd} = 20$, which is rather large. Thus, our model may describe the case of high temperature in practice. Our next work is to build an EW-like stochastic equation[5] but with a weak nonlinear diffusion term. This is in progress and will be presented elsewhere. (5) The scaling in Fig. 3 seems not to be exact, however, it does give us some senses below and above $P = 0.25$. Nevertheless, more work is needed to be done for larger systems which could minimize the finite-size effects. (6) There is a threshold probability, $P \simeq 0.55$, with which the growth will stop because of all the surface sites being covered by particle C.

In conclusion, we have presented a study of the surface kinetics with diffusion for a two kind of particles deposition model, random-like depositing on a (1+1)-dimensional substrate, in this letter. The scaling behavior of the surface width is obtained for various deposition probabilities of particle C and the system sizes. In addition, we also found a change of different morphological structures.

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