Quasi-stable PDF of velocities of accelerated metal clusters on graphite before joining an island

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Neutral mass-selected clusters are deposited with low initial energy on the graphite substrate. The flux of clusters is uniform and constant during the experiment. After deposition the clusters start to diffuse on the surface. Moving clusters meet each other and stick together thereby forming islands. The islands grow by capturing new clusters. This process is shown in the Fig. (1).

The anomalously high diffusion coefficients for different metallic clusters have been discovered in experiments[?] ,[?] . The hypothesis that each cluster is accelerated arises from the fact that the initial velocity is low and the diffusion is fast. It has been shown that the properties of the graphite substrate are most probably responsible for the effect, since fast diffusion has been observed for different metallic clusters. This fact is explained using the model of Fermi acceleration and is supposed to be the result of the interaction of clusters with a part of graphite layer called 'flake', that is involved in thermal motion as a whole[?] . A thermodynamic interpretation of Fermi acceleration in billiards was presented in[?] .

The effect of the motion of flakes on cluster dynamics can be described as a noise. This equilibrium noise depends on temperature. On the contrary, the motion of a cluster is far from equilibrium. The energy of the chaotic motion of a cluster is increasing in time. Time-dependent probability distribution of the cluster velocity is calculated in work[?] using Langevin equation, and the corresponding PDF is not Maxwell. The accelerated motion of the cluster is terminated at a boundary of an island. The contradictory character of the problem of cluster dynamics under influence of flake fluctuations is as follows. Fermi mechanism results in the superdiffusion. The diffusion constant should increase with measurement time. However, experiments yield time-independent diffusivity. Therefore, either the experimental results are incorrect or the theory is not relevant. To solve the contradiction we introduce an ensemble of moving clusters. This ensemble consists of a constant (on average) number of clusters in the approximation of slow growth of islands. Such an ensemble is an open system: new slow clusters arrive in the system due to deposition and fast clusters depart from the system being captured by islands. The motion of ensemble of clusters is stable and characterized by the stationary probability distribution. Thereafter, we can estimate an mean velocity and effective temperature of the cluster ensemble. The long lifetime of the quasi-equilibrium state makes it possible to assume that a local equilibrium principle is satisfied and that an effective temperature characterizing this state can be introduced.

We analyse factors that influence the effective temperature. A decrease in this temperature results from cluster capturing by islands. The higher the velocity of a cluster, the higher the probability that this cluster will arrive to the island boundary and join the island. We consider conditional probability distribution of velocities under condition that the cluster has not reached the boundary yet and is still moving. Thus, we come to such a quasistable state of a system in which the velocities of the particles are limited.

An increase in the effective temperature is caused by Fermi acceleration. We introduce the age of each cluster, which is a time interval from the cluster deposition to the moment of observation. To obtain stationary PDF of velocities of clusters in ensemble, we average the time-dependent PDF of one Fermi-accelerated cluster using probability distribution of ages of clusters.

We describe a nonequilibrium state in conventional terms of equilibrium thermodynamics, which are convenient for application of the results in the production of the thin films.

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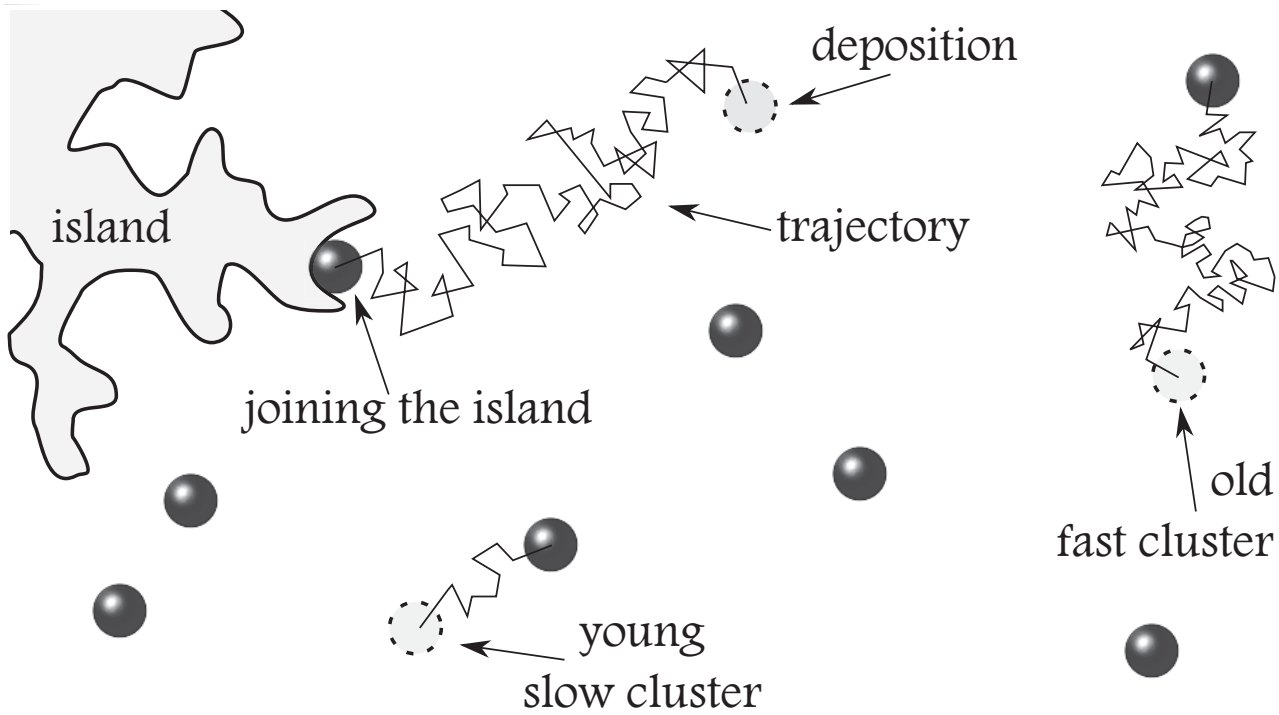

FIG. 1. The process of deposition, diffusion and aggregation of clusters that results in the formation of islands.

[1] P. Jensen, Rev. Mod. Phys. **71**, page 1695 (1999).
[2] A. Perez, P. Melinon, V. Dupuis, et al., Int. J. Nanotechnol. **7**, page 523 (2010).
[3] A.K. Krasnova and O.A. Chichigina, Moscow University Physics Bulletin **67**, page 48 (2012).
[4] A. Loskutov, O. Chichigina, and A. Rjabov, Int. J.Bifurcation Chaos **18**, page 2863 (2008).
[5] A.V. Kargovsky, E.I. Anashkina, O.A. Chichigina, A.K. Krasnova, Phys. Rev. E **87**, page 042133 (2013).