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STOCHASTIC RESONANCE IN ADATOM DIFFUSION ON CRYSTAL SURFACES *

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The *stochastic resonance* phenomenon consists of an increase in the response of a nonlinear dynamical system to a periodic signal when an optimal amount of noise is added to the system. Equivalently one can think of the phenomenon as the appearence of a modulation frequency, determined by the noise intensity and absent if noise is absent, for which the response is optimal. Stochastic resonance has been predicted and observed in physical, geophysical, and biological systems [1, 2, 3, 4] and represents an interesting example of noise-induced coherence.

Brownian diffusion of adsorbed atoms on crystal surfaces with a periodic potential is a physical manifestation of thermal noise. In this case the jump rate follows an exponential activation law at low temperatures, and the diffusion coefficient can thus become vanishingly small at very low temperatures. If such a Brownian particle is coupled to a weak externally applied (electric) field, its motion will still be restricted to one potential well if the energies involved in the applied field are small compared to the energy barriers between wells. The simultaneous presence of both a small periodic driving and a small amount of thermal fluctuations is, however, the classical combination leading to stochastic resonance: one can expect that the small response to the small applied field will be greatly amplified if noise intensity and modulation frequency match a stochastic resonance criterion. This has been reported by Gang *et al.* [6] in the one-dimensional case. The purpose of our work is to analyze the influence of additional factors present in a real two-dimensional physical system but absent in the overdamped one-dimensional situation such as in Ref. [6]. Two such important factors are: (a) the geometry of the activation paths, and (b) the presence of nonnegligible inertial effects. The combination of these two factors has been shown to play an important role for the diffusion process in the absence of an external field [5].

We model the Brownian motion of an adsorbed atom in a spatially periodic potential created by the crystal atoms, and in the presence of an oscillating electric field, by the following Langevin equation:

$$M\ddot{\mathbf{x}} + \eta\dot{\mathbf{x}} + \nabla U(\mathbf{x}) = \mathbf{E}\sin(\omega t + \phi) + \vec{\xi}(t). \tag{1}$$

Here M is the mass, η is the friction coefficient (we neglect memory effects), $\mathbf{E}$ is the electric field vector. $\vec{\xi}$ is stochastic thermal noise, with correlations given by the temperature T:

$$\langle \xi_x(t)\xi_x(t')\rangle = \langle \xi_y(t)\xi_y(t')\rangle = 2k_B T\eta\delta(t-t'),\ \langle \xi_x(t)\xi_y(t')\rangle = 0. \tag{2}$$

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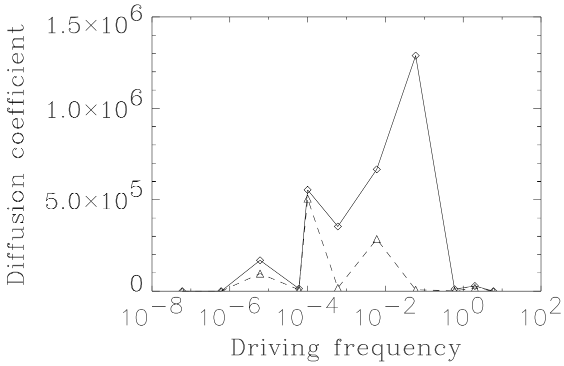

FIG. 1. *Diffusion coefficient in the field direction (solid) and in the orthogonal direction (dashed) as a function of the frequency of the external field.*

The potential $U = U(x, y)$ gives the conservative forces of the surface on the adatom. The relevance of bidimensionality depends strongly on the *separability* or *non-separability* of the potential U. A potential is separable if it can be written as sum of potentials depending on a single coordinate. An example of non-separable potential is the one on the (110) surface of a BCC crystal [5]. The physically important effect comes from the fact that in the separable case the steepest descent directions at the saddle point between minima join these minima, at variance with the non-separable case. This influences the possibility of multiple jumps which are more frequent in the separable case if inertia is present [5].

We have performed simulations of Eq. (1) in several potentials at temperatures such that there is no activation in the absence of an external field in the simulation time scales (10^6 times the oscillation frequencies at the potential wells). $\mathbf{E}$ is applied in the x direction and we calculate the diffusion coefficients D_x and D_y in the field direction and in the direction orthogonal to it as a function of the driving frequency. An example of the preliminary results is shown in Fig. 1, corresponding to a non-separable potential. The stochastic resonance phenomenon leads to enhanced activation and diffusion in a wide range of frequencies including the inverse of the Kramers time for single barrier crossing: ($\omega \approx 10^{-4}$). We stress that the diffusion coefficients are virtually zero in the absence of external field for this temperature value, and that the field does not induce jumps in the absence of noise.

Discussion of the influence of the geometry of the different potentials, appearence of long jumps in the separable case when inertia is present, and behavior of the velocity autocorrelation function will be reported elsewhere.

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