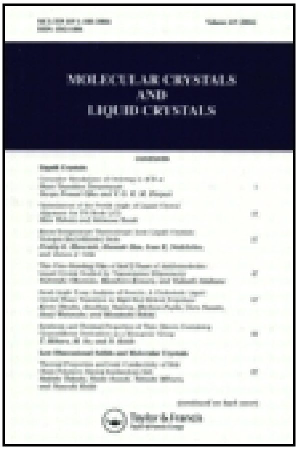

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Dynamical Threshold Behavior of A Sliding Charge Density Wave

J. B. Sokoloff [a]

[a] Physics Department, Northeastern University, 360 Huntington Avenue, Boston, MA, 02115, U.S.A.
Version of record first published: 20 Apr 2011.

To cite this article: J. B. Sokoloff (1985): Dynamical Threshold Behavior of A Sliding Charge Density Wave, Molecular Crystals and Liquid Crystals, 121:1-4, 91-94

To link to this article: http://dx.doi.org/10.1080/00268948508074838

Mol. Cryst. Liq. Cryst. 1985, Vol. 121, pp. 91-94
0026-8941/85/1214-0091/$10.00/0

DYNAMICAL THRESHOLD BEHAVIOR OF A SLIDING CHARGE DENSITY WAVE

J.B. SOKOLOFF
Physics Department, Northeastern University, 360 Huntington Avenue, Boston, MA 02115, U.S.A.

Abstract It is argued that the existence of a dynamical threshold field [i.e. the value of the electric field such that when the applied field is reduced to this value the charge density wave (CDW) stops sliding] requires that the sliding of the CDW at low center of mass velocity occurs as local sudden jumping motion reminiscent of "stick-slip" friction. Using this model, it is argued in the weak impurity limit that the static threshold field is greater than the dynamic threshold field.

Charge Density Waves (CDW's) in $NbSe_3$ are set in motion for electric fields above a threshold value E_t. When the field is then lowered below a value E_{td} (the dynamical threshold field) CDW motion ceases. It will be argued here that since E_{td} is determined by dissipative processes whereas E_t is not, E_{td} will be less than E_t. This is in agreement with the hysteresis found in the nonlinear conductivity by Gruner and Zettl and by Tessema and Ong.[1] Furthermore, it will be shown that smooth adiabatic motion of the CDW cannot occur for slow speed motion for this would require $E_{td} = 0$. Consider the generalized Fukuyama-Lee model to describe the CDW's motion[2]

$$\ddot{\phi}(\vec{r}) + \gamma\dot{\phi}(\vec{r}) - \alpha\nabla^2\phi(\vec{r}) = F_i(\vec{r})\sin[\vec{Q}\cdot\vec{r} + \phi(\vec{r})] + f, \qquad (1)$$

where ϕ, γ, and $\vec{Q}$ are the phase, damping constant and wave vector of the wave, and $F_i(\vec{r})$ is the force due to impurities. To simplify the arguments we discretize $\vec{r}$, and (1) becomes

$$\ddot{\phi}(\vec{r}_j) + \gamma\dot{\phi}(\vec{r}_j) + \Sigma_{\vec{a}}\,[\phi(\vec{r}_j) - \phi(\vec{r}_j + \vec{a})\,] = + F_i(\vec{r}_j)\,\sin[\vec{Q}\cdot\vec{r}_j + \phi(\vec{r}_j)] + \vec{f}. \qquad (2)$$

where $\vec{F}_i$ $\vec{Q}$ and $\vec{f}$ are along the z-axis and $\vec{a}$ runs over the 6 vectors of length a along the ±x, ±y, and ±z axes. Let $\vec{F}_i(\vec{r}_j)$ be $\vec{F}_o$ if $\vec{r}$ contains an impurity and zero otherwise. Transforming to a frame in which the CDW is stationary and the impurities are moving, equation (2) is modified by adding a term $\vec{Q} \cdot \vec{v}t$ to the argument of the sine and adding a constant term $\gamma\vec{v}$ to the left hand side of the equation, where $\vec{v}$ is the mean center of mass velocity of the wave.

The mean force of friction of the moving wave F_{fric} is defined by

$$\vec{F}_{fric} \cdot \vec{v} = \frac{1}{Q}\frac{1}{T}\int_{-T/2}^{T/2} \Sigma_j \langle \dot{\phi}(\vec{r}_j)\, F_i(\vec{r}_j)\, \sin[\vec{Q} \cdot \vec{r}_j + \phi(\vec{r}_j) + \vec{Q} \cdot \vec{v}t] \rangle + \gamma v^2, \tag{3}$$

where T is a long time and < --- > signifies an impurity average. Solving for ϕ from equation (2) using the "phonon Green's function" for the left hand side of (2) and substituting in (3), we obtain the results of Sneddon, Cross, and Fisher[3] if we neglect ϕ in the argument of the sine in equations (2) and (3), and identify F_{fric} with the external field.

If we assume adiabatic motion [i.e. motion in which ϕ depends on $\vec{r}_j$ and t as $\vec{r}_j + \vec{v}t$] the sine in equations (2) and (3) also has this dependence on r_j and t. Then $\vec{F}_{fric}$ is given by

$$\vec{F}_{fric} \cdot \vec{v} = \frac{1}{2}C|F_o|^2\, \Sigma_{\vec{k}} \int |B(\omega)|^2 \frac{\gamma\omega^2\, d\omega}{(\omega^2 - \omega_o^2(\vec{k}))^2 + \gamma^2\omega} \tag{4}$$

where $B(\omega)$ is the time Fourier transform of the sine. Since

$$B(\omega) = \Sigma_{\vec{k}}\, A(\vec{k})\big|_{\omega = -\vec{k} \cdot \vec{v}} \tag{5}$$

where $A(\vec{k})$ is the spatial Fourier transform of the sine, and since $A(\vec{k})$ falls to zero for large $\vec{k}$, equation (4) shows that F_{fric} approaches zero as v approaches zero.

Computer simulations[4] show that motion near threshold takes place by local regions of the wave becoming unstable and jumping rapidly while most of the wave does not move. A model for this is

$$\sin[\vec{Q} \cdot \vec{r}_j + \vec{Q} \cdot \vec{v}t + \phi(\vec{r}_j)] = \Sigma_p\, f(\vec{r}_j - \vec{r}_p)\Delta(t - \tau_p), \tag{5}$$

where f and Δ are functions peaked about zero argument and $\vec{r}_p$ and τ_p are the center in space and time of the region. Substituting equation (5) into equations (2) and (3) gives to 1st order in the impurity concentration C,

$$F_{fric} \sim C|F_o|^2 \int d\omega |\Delta(\omega)|^2 \omega^{3/2} \qquad (6)$$

The width of Δ(ω) in time is ∼ (F_{fric} / γ), where ℓ is the Lee-Rice length (the assumed size of the domain.) Then from (6)

$$F_{fric} \sim C(F_{fric})^{3/2} \ell^3 . \qquad (7)$$

Writing $\ell \sim \varepsilon C^{-1/3}$, where ε >> 1 for weak impurities and ∼ 1 for strong impurities, we find from (7)

$$E_{td} \sim F_{fric} \sim C\varepsilon^{-9} \qquad (8)$$

Since the Lee-Rice depinning field[5] [i.e. the field needed to break loose a domain], which we identify with the static threshold field is given by

$$E_t \sim \frac{1}{\ell^{3/2}} = \frac{C^{1/2}}{\varepsilon^{3/2}} \text{ , Then}$$

$$\frac{E_{td}}{E_t} \sim \frac{1}{C^{1/2}\varepsilon^{9/2}}$$

Hence in the weak impurity limit for low concentrations, $E_{td} < E_t$. In a one dimensional model, the same arguments yield $E_{td} > E_t$, implying that an applied field between E_{td} and E_t in strength will depin a single domain but will not cause motion of the CDW as a whole which was found in computer simulations done on one dimensional models.[4]

REFERENCES

1. G. Gruner and A. Zettl, Phys. Rev. B26, 2298 (1982).
   G.X. Tessema and H.P. Ong. Phys. Rev. B27, 1417 (1983).
2. R.A. Klemm and J.R. Schrieffer, Phys. Rev. Lett. 51, 47 (1983).
3. L. Sneddon, M.C. Cross and D.S. Fisher, Phys. Rev. Lett. 49 292 (1982).

4. J.B. Sokoloff, Phys. Rev. B23, 1992 (1981); J. de Physique (Colloque) C3, 1667 (1983); L. Pietronero and S. Strossler, Phys. Rev. B28, 5863 (1983).
5. P.A. Lee and T.M. Rice, Phys. Rev. B19, 3970 (1979).

ACKNOWLEDGMENTS

I would like to thank the Department of Energy and the National Science Foundation for their financial support.