# CHARGE DENSITY WAVE PHASE SLIPPAGES IN INHOMOGENEOUS ELECTRIC FIELD

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Abstract. *It is shown that in a nonuniform electric field larger than the threshold field the charge density wave (CDW) breaks into dynamically correlated domains divided by phase slips. This division starts above some critical value of field gradient, dependent on the sample length, and causes the splitting of narrow band noise (NBN) frequencies.*

## Introduction

The conversion of the collective transport into the ohmic single-particle one is the process which inevitably occurs locally in real CDW systems. Wherever the CDW stops, i.e. at boundaries of specimen, contacts, strong defects etc., this conversion is complete and proceeds via the repetitive slips of phase (PS) by $2\pi$,[1] which are transversely correlated and form cores of dynamic dislocation lines. It was proposed that this process is the source of narrow band noise[2] and related phenomena.[3] In this work we consider the motion of CDW in the weakly inhomogeneous electric field. It will be shown that the PSs may then occur in the interior of the system, dividing it into a finite number of dynamic domains. The accompanying time scale is defined by the frequency of periodic repetition of these PSs, which is usually much smaller than the NBN frequency.

## Numerical results

The nonlinear CDW dynamics which includes strong variations of the amplitude can be treated by the Landau-Ginzburg type of equation proposed by Gor'kov[1]

$$\partial\Delta/\partial t - \partial^2\Delta/\partial x^2 + iE(x)\Delta - \Delta + |\Delta|^2\Delta = 0 \quad . \qquad (1)$$

This equation is appropriate for the regime of small relaxation time $\tau$, i.e. $\tau T_P^0 \ll 1$, where $T_P^0$ is the bare transition temperature. The length and time scales are here chosen to be the correlation length $\xi$ and $(T_P^2\tau)^{-1}$ respectively. The units for the amplitude of the complex order parameter $\Delta$ and the electrical field $E(x)$ are $T_P$ and $T_P/e\xi$ respectively. Note that in these units the characteristic values of experimental electric fields are of the order $E \sim 10^{-3} - 10^{-4}$.

Due to the numerical limitations we keep only the longitudinal variations in eq.(1). The transverse correlations give a complete topological structure of PS configurations,[4] but do not affect substantionally the conclusions of the present analysis.

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Far from any barrier and in the uniform electric field $E_0$, eq.(1) has a solution $\Delta(x,t) = \exp(iE_0 t)$ which represents the uniform CDW motion with the velocity proportional to $E_0$. However if E is not uniform the CDW velocity varies from one part of the system to another, i.e. the collective charge accumulates locally. This charge has to be evacuated via PSs, just like in cases of local CDW stoppage mentioned above. In order to find the possible regimes as well as time and space scales for this process, we assume a linear dependence of the electric field $E(x) = E_0 + E'x$, and at first choose boundary conditions $\Delta(x=0,t) = \Delta(x=L,t) = 1$ which impose the stoppage of CDW at the edges of the segment (0,L).

The summary of the numerical calculations is presented in Fig.1. For the gradients $E'$ smaller than the critical value $E'_{c1}(L)$ the whole segment remains

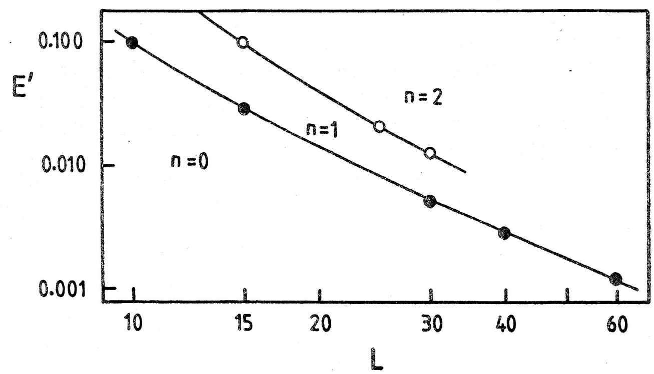


Fig.1. The regimes with n bulk PS centers in the (L,E ) diagram. Only first two critical lines $E'_{cn}(L)$, n=1,2 are drawn.

coherent, with the common frequency of NBN slippages at two edges. Its value corresponds to a mean value of electric field in the segment, in agreement with the conservation of charge in the CDW. Above $E'_{c1}(L)$ the frequencies of PSs on two edges, $\omega_0$ and $\omega_L$ respectively, start to differ. Simultaneously the generation of PSs with the rate $\omega_L - \omega_0$ starts at $x = L/2$, dividing so the segment into two dynamically correlated domains. By increasing further $E_L$, one meets a series of critical values $E'_{cn}$ at which the number of bulk PS centers increases succesively by one. The rates of n bulk PSs are equal and given by $\omega_1 = \omega_2 = \ldots = \omega_n = (\omega_L - \omega_0)/n$.

The division into domains stops when an appropriate lower value of domain length is reached. E.g. for $E_0 = 1.0$ (Fig.1) the bulk PSs cannot be generated for $L < L_0 \simeq 4.7$. The right side of Fig.1 is however more interesting since, when extrapolated to larger values of L, it corresponds to the experimentally realizable segments. In this limit one gets for n = 1

$$E'_{c1} \simeq 2.3\, L^{-\alpha}, \qquad \alpha \simeq 1.9 \tag{2}$$

and similar power laws for n > 1. Taking into account characteristic values for the correlation length and the critical temperature, $\xi \sim 150$Å and $T_P \sim 60$K, the results (2) suggests that for segment lengths 0.1-1 mm the division to two domains and the splitting of NBN lines could occur for $\Delta E_{c1} = E(L) - E_0$ in the range 10 - 100 mV/cm.[5]

The electric field E(x) in eq.(1) is measured from the bulk threshold field $E_T$. The latter can be spatially varied in a controlled way by imposing a finite temperature difference $\Delta T$ on sample ends. Applied to $NbSe_3$ at $T \le 50$K, the above estimation of $\Delta E_{c1}$ allows for the corresponding range of temperature differences $\Delta T \simeq$ 3-5K, for which the onset of the splitting of NBN frequencies was observed.[6,7]

## Dynamical bistabilities

The further point to be considered is the way in which the number of dynamical domains from Fig.1 changes from n to n+1, as e.g. the gradient $E'$ increases. In this respect the boundary conditions become irrelevant, so that we replace the previous choice by the free ends defined by $\Delta(0,t) = \exp(iE_0 t)$; $\Delta(L,t) = \exp(iE_L t)$ Then the segment (0,L) is divided into domains already for arbitrary small differences $E_L - E_0 = E'L$. By increasing $E'$ the PS center at x=L/2 splits at a critical value $E'_{c1}(L)$ into two symmetrically positioned centers. They move towards opposite ends of the segment as $E'$ further increases.

The transition from n=2 to n=3 is however much less regular. By approaching $E'_{c2}(L)$ the positions of two side PS centers start to oscillate stohastically with the intermittent time scale much larger than $2\pi/(E'L)$. Finally at $E'_{c2}(L)$ three PS centers are stabilized at fixed positions, one in the middle and two at each side of the segment. The stabilization in the regime of intermittency is very sensitive to small time fluctuations of e.g. electric field, and also show the dependence on the direction in which $E'$ changes. In other words each crossover line in Fig.1 is in fact a narrow range of bistability. This usual property of nonlinear dynamic systems was perhaps manifested in measurements which showed unstable fluctuations between single and splitted NBN frequency lines.[8-10]

## Conclusion

The dynamic CDW domains formed due to smooth inhomogenities in the electric field are semimacroscopic in size. Thus, the presence of inherent strong defects on the similar scale, as well as a nonmonotonous dependence of $E_T(x)$ and other factors may lead to various more complex splittings of NBN spectra. These possibilities are discussed elsewhere.[5] Regarding the dynamic character of domains, it has to be pointed out that the breaking of CDW coherence occurs only during short time intervals of PSs in which the amplitude $|\Delta|$ collapses to zero. This is an example of slow time modulations which, besides the line splitting, lead also to a satellite structure i.e. to a widening of NBN lines.

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