DYNAMICAL INTERACTION BETWEEN BOTH CDWs IN $NbSe_3$

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ABSTRACT

We report measurements of the upper threshold field of $NbSe_3$ under pressure in the temperature range 25 K - 120 K. At the temperature of the second transition T_2, which is pressure dependent, the threshold field of the first CDW strongly decreases, which is interpreted as a dynamical interaction between the two CDWs.

$NbSe_3$ is a well-known compound undergoing two independent charge density wave (CDW) transitions at T_1 (145 K) and T_2 (59 K) [1,2].

Previous measurements made on the variation of the first threshold field E_{c_1} versus temperature seemed to indicate a saturation at low temperature ; an other group [3] nevertheless reported different temperature behaviour for E_{c_1}. To study the divergence of E_{c_2} near T_2 we have performed [4] experiments of E_{c_2} and E_{c_1} close to T_2. We have reported that in the temperature range where fluctuations can be observed near T_2, E_{c_1} decreases slowly before reaching a constant value ; but at this time no data have been recorded below 45 K.

The variation of E_{c_1} near T_2 could be correlated either with the absolute value of the temperature or with the absolute value of T_2. To distinguish between these two possibilities we decide to apply pressure in order to change T_2.

Here we report careful four terminal measurements of the threshold field E_{c_1} under pressure ($P < 8$ kbar) in the temperature range 25 K - 120 K. The determination of E_{c_1} is made by the measurement of the differential resistance $\frac{dV}{dI}$; at low temperature this method becomes less and less accurate, so we determine E_{c_1} from broad band noise measurements [Fig. 1]. Nevertheless due to heating problems our range of temperature is limited at 25 K.

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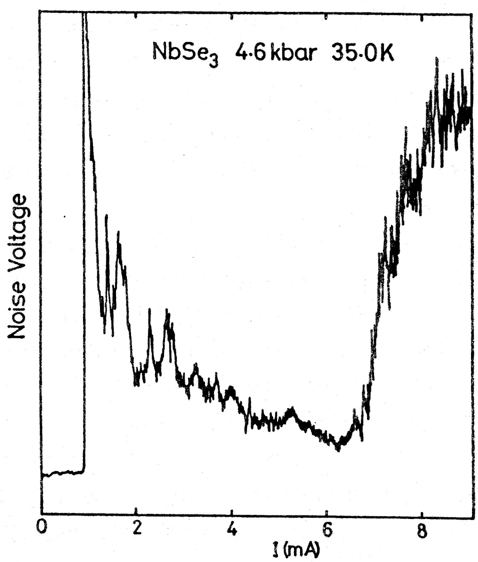

Fig. 1 - Broad band noise as a function of the dc current at 4.6 kbar and 35 K. The two sharp increases allow the determination of E_{c1} and E_{c2}.

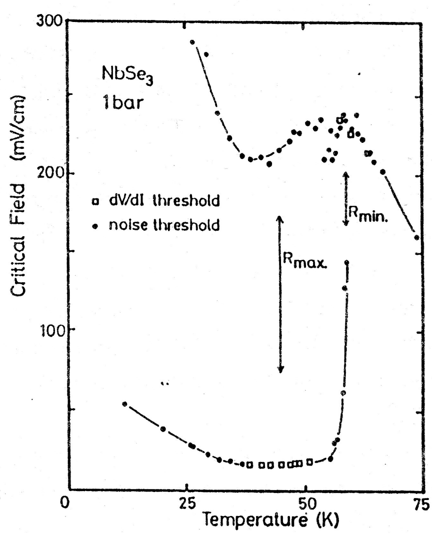

Fig. 2 - Temperature dependence of E_{c1} and E_{c2} at normal pressure. R_{min} and R_{max} corresponds to the temperature where the resistance is minimum and maximum near T_2.

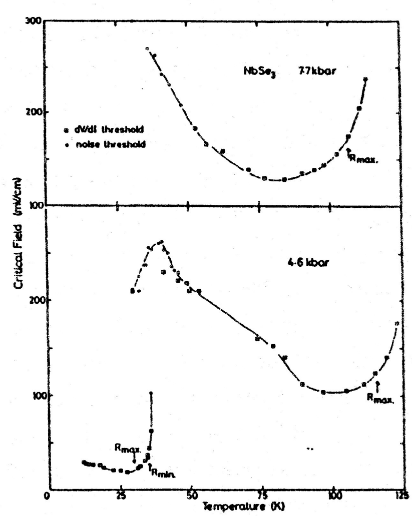

Fig. 3 - Temperature dependence of E_{c1} at two pressures and E_{c2} at 4.6 kbar.

The crystals were mounted on an araldite disc in a beryllium-copper clamp capable of retaining pressures up to 11 kbar at 300 K, resulting in about 7.5 kbar at 4.2 K. Pressures were measured at room temperature and nitrogen temperature with a pressure cycled manganin resistance located near the sample. The fluid used was an isopentane-methyl 2-pentane mixture. A loss of between 3 and 4 kbar was measured between the pressure at room temperature and that at nitrogen temperature. The resistance of the sample was measured by four probes.

For these preliminary measurements we have applied only three different pressures (1 bar, 4.6 kbar, 7.7 kbar). The amplitude of the variation of T_1 and T_2 with pressure is in agreement with previous measurements [5]. In Figures 2 and 3 we have drawn the variation of E_{c_1} with temperature for three different pressures. At 1 bar we can observe in the Figure 2 the similar kind of temperature dependence for E_{c_1} as in previous measurements [4], but for T less than 30 K, E_{c_1} still increases. When the pressure is applied, the maximum in E_{c_1} follows the decrease in T_2 (Fig. 3) and when the second transition is suppressed, for P = 7.7 kbar (Fig. 3), the maximum in E_{c_1} disappears. The strong correlation between the maximum in E_{c_1} and the formation of the second CDW at T_2 suggests the existence of a dynamical interaction between the two CDWs. Such a decrease in threshold field has been observed in orthorhombic TaS_3 around T = 130 K which is the temperature where the longitudinal component of the distortion vector locks to a commensurate value. This effect has been explained in terms of a coupling between CDWs in two different types of chains. In $NbSe_3$ two independent CDWs appear on different types of chains ; a possible locking between the two CDWs has been considered when it was noted that twice the sum of both wave vectors is in the vicinity of a lattice reciprocal wave vector [6,7]. The phase locking described by a fourth-order term in the CDW amplitudes may lead to a very small perturbation such a small gap enhancement at T_2. Fleming clearly demonstrated that $q_1 + q_2$ is not a commensurate value [8]. Morever, recent careful measurements of the temperature dependence of q_1 with a synchrotron X-ray source has detected no variation of q_1 at T_2 [9]. All these measurements seem to rule out any kind of static interaction between the two CDWs at T_2. Up to now no accurate measurements of q_1 and q_2 have been made under electric field. We notice on Figure 2 that the decrease of E_{c_1} takes place between T_2 and T_M, where T_M is the temperature of the maximum of resistance. In this temperature range where the gap of the second transition begins to open, we expect a rather important back flow of normal electrons which at a second order could affect the viscosity and the critical field of the first transition ; in that case we would have a dynamical interaction between the two CDWs.

Maki [10,11], incorporating the thermal fluctuations of the phase of CDW order parameter into the Fukuyama-Lee-Rice theory, has calculated the temperature dependence of the threshold field at low temperature (e.g. $T < \frac{T_c}{2}$). In the strong pinning limit the threshold field is given by :

$$E_T^S(T) = E_T^S(0)\, e^{-T/T_o} \frac{\Delta(T)}{\Delta(0)} \frac{\rho}{\rho_S(T)} \tag{1}$$

where $\Delta(T)$ and $\rho_S(T)$ are respectively the temperature dependent order parameter and condensate density, and T_o is a parameter proportional to $\xi = v_F/T_c$. The equation (1) predicts a minimum in E_T at $T = T_c - \frac{T_o}{2}$ if $T_o << T_c$ and a thermal activated behaviour in the low temperature range.

In the weak pinning regime the calculation of Maki gives :

$$E_T^W(T) = E_T^W(0)\left[\frac{E_T^S(T)}{E_T^S(0)}\right]^{\frac{4}{4-D}}$$

where D is the dimensionality of the CDW.

The Maki's theory can also describe the pressure dependence of the threshold field [10]. In the hypothesis where the most important effect of the applied pressure is to reduce the anisotropy in the Fermi velocities η along the crystallographic axis, so η increases with pressure this implies that E_T decreases like η^{-2} in the weak pinning regime while T_o increases like η^2 (in the weak and strong pinning regime).

The analysis of our data at the first transition gives for T_o the value of 82 K and 50 K, respectively for pressures of 4.6 kbar and 7.7 kbar. For the second transition T_o was at 1 bar 18 K and 33 K at 4.6 kbar. The discrepancy in the sense of variation of T_o with pressure between the first and the second transition could result from different variation of η with the pressure. A recent analysis of previous data have shown that for the second transition T_o is close to 10 K so the high value of 18 K observed at normal pressure in the present experiments is perhaps due to the unrealeased pressure.

REFERENCES

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1 J. Richard and P. Monceau, Solid State Commun. **33** (1980) 635.

2 J.C. Gill, J. Phys. F **10** (1980) L81.

3 R.M. Fleming, Phys. Rev. B **22** (1980) 5606.

4 J. Richard, H. Salva, M.C. Saint-Lager and P. Monceau, J. Physique **44** C3 (1983) 1685.

5 A. Briggs, P. Monceau, M. Nunez-Regueiro, J. Peyrard, M. Ribault and J. Richard, J. Phys. C : Solid State Phys. **3** (1980) 2117.

6 V. Emery and D. Mukamel, J. Phys. C **12** (1979) L677.

7 R. Bruinsma and S.E. Trullinger, Phys. Rev. B **22** (1980) 4543.

8 R.M. Fleming, C.H. Chen and D.E. Moncton, J. Physique **44** C3 (1981) 1651.

9 H. Moudden, private communication.

10 K. Maki, Phys. Rev. B Rapid Commun. **23** (1986) 2852.

11 K. Maki and A. Virosztek, Phys. Rev. B **39** (1989) 9640.