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Memory effects and peak effect in type II superconductors

G. Pasquini[a,b,*], D. Luna[a], B. Eismann[a,c], V. Bettachini[a], V. Bekeris[a,b]

[a] *Physics Department, FCEyN, UBA, Buenos Aires, Argentina*
[b] *CONICET, Argentina*
[c] *Ecole Normale Superieure, Paris, France*

Abstract

A large amount of experimental and theoretical work has been devoted to understand memory effects (ME) in the solid vortex lattice (VL) but has remained, however, controversial until now. In the vicinity of the anomaly known as the peak effect (PE) both the VL mobility and the measured critical current density are found to be dependent of the dynamical history of the sample, in both low T_c (LTS) and high T_c (HTS) superconductors. Experiments in $YBa_2Cu_3O_7$ (YBCO) crystals have shown that the mobility of the VL increases after assisting the system with a symmetric AC field (or current) of moderated amplitude. On the other hand, after an asymmetric AC field assists vortices, the VL becomes less mobile. These features indicate that ME in these samples cannot be ascribed to an equilibration process, but probably are related to the organization of the lattice after nearest neighbor re-accommodation or induced plastic VL deformation. Recently, we have shown evidence that in YBCO the PE is a dynamic anomaly observed in the non-linear response, and is absent in the Labusch constant derived from the linear Campbell regime. However, this behavior seems not to be extensive to other systems as the traditional LTS $NbSe_2$. In this work, the AC response in the PE region of $NbSe_2$ and YBCO samples are presented and compared. Very salient differences both in the linear and non-linear response as well as in the ME characteristics indicate that a different physics governs the PE phenomena in each case.

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Keywords: Vortex lattice; Memory effects; Peak effect; High and low T_c superconductors vortex lattice

1. Introduction

The diversity of vortex lattice (VL) phases in high T_c superconductors (HTS) and its complex dynamical behavior has been subject of continuous scrutiny, and has encouraged to revisit the physics of VL in low-T_c superconductors (LTS). Particular attention has been directed towards understanding driven lattices in the vicinity of the peak effect (PE) which refers to an anomalous non-monotonous dependence of the critical current density J_C with both temperature and magnetic field [1]. In this region, memory effects (ME) have been reported, both in low [2] and in high T_c materials [3–5]. The main purpose of the present work is to qualitatively compare the PE and ME in moderate anisotropic HTS and LTS type II superconductors, particularly in the well-known $YBa_2Cu_3O_{7-x}$ (YBCO) and $NbSe_2$ (NS) crystals, in AC susceptibility experiments.

The first qualitative difference regards the nature of the PE, we have found recently in YBCO crystals that in the linear Campbell regime, where vortices move inside their effective pinning wells, the PE is not present [6]. The correlation between the peak in J_C (or dip in mobility) and pinning seems mainly related to the dynamics of the VL and not to a sudden change in pinning potentials [6].

Here, we show that interestingly, these features are different in $NbSe_2$ crystals. The PE is very steep in the non-linear response and is present in Campbell regime, suggesting that in this LTS a structural change from an ordered to a disordered phase is probably the origin of the dip in mobility.

On the other hand, in both HTS and LTS systems, mobility of the VL is increased after assisting it with a temporarily symmetric (e.g. sinusoidal) AC field [2–5].

*Corresponding author. Physics Department, FCEyN, UBA, Buenos Aires, Argentina.
E-mail address: pasquini@df.uba.ar (G. Pasquini).

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The most invoked mechanism is an equilibration process assisted by the AC magnetic field [7]. However, experiments in twinned [5] and untwinned [8] YBCO single crystals indicate that this framework does not apply. A VL free from bulk field gradients assisted by an asymmetric AC field of similar amplitude (e.g. sawtooth) becomes less mobile [5]. Moreover, mobility is also reduced if a temporarily symmetric AC field forces vortices into large excursions [9]. Probably, the repeated interactions between neighbors facilitates the healing of topological defects, while temporarily asymmetric AC fields or large vortex excursions promote their creation [10,11]. In contrast, in this work, we find that in $NbSe_2$ crystals VL mobility increases indistinctly of the waveform of the AC shaking field, in agreement with the invoked equilibration process.

The paper is organized as follows. In Section 2, we describe the experimental array and the different experimental protocols that outline the dynamic history of the VL. Results and discussions are presented in Section 3 and conclusions are drawn in Section 4.

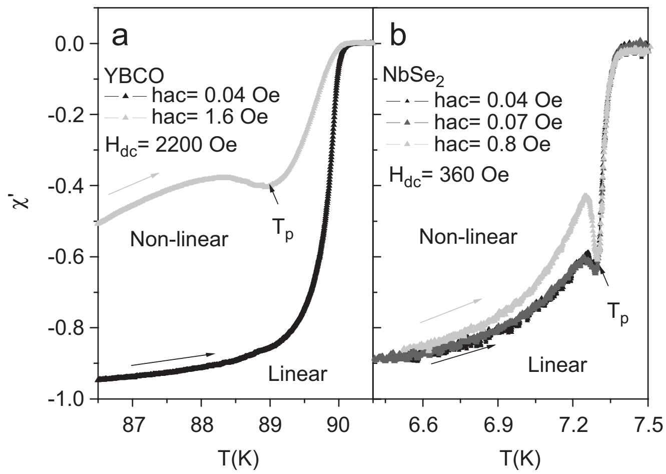

Fig. 1. $\chi'(T)$ $ZF_{AC}CW$ curves for the non-linear (gray) and linear (black) regimes. Indicated is the peak temperature T_p. (a) YBCO crystal where the PE is absent in the linear response. (b) $NbSe_2$ crystal where the PE is observed in both regimes. Two linear low AC amplitude curves are shown.

2. Experimental

Twinned YBCO crystals and $NbSe_2$ crystals have been examined. Global AC susceptibility, $\chi' + j\chi''$ was measured with the mutual inductance technique. Magnetic DC field, provided by a magnet, was aligned out of the twin boundaries in the case of YBCO samples, and parallel to the c-axis in the case of the NS samples. All measurements were performed at 30 kHz with the AC field parallel to the c-axis in both samples, and curves were normalized to a total step $\Delta\chi' = 1$ between the normal and superconducting response at $H_{DC} = 0$. The measuring field amplitude ranged from 0.04 to 1.6 Oe to examine the linear and non-linear response. The samples were always cooled in DC field avoiding magnetic gradients, but the response was examined for different AC field protocols: $F_{AC}CC$, $F_{AC}CW$ and $ZF_{AC}CW$. In the first case, the sample is measured on cooling from T_C. The $F_{AC}CW$ curve is obtained on the following warming. In the third case, the sample is cooled from the normal state to a low initial temperature with no AC applied field, and is measured on warming. Notice that the difference between the last two protocols is the way the sample was cooled prior to the measurement.

We have also examined the effect of shaking AC fields. The sample was $F_{AC}CC$ to a target temperature. A symmetric (sinusoidal) AC waveform, $h_{AC}{\sim}3.5$ Oe and $f = 30$ kHz was applied during ~1 min and then turned off before the measurement began. This procedure is denominated Sym protocol. An Asy protocol consists in applying an asymmetric (sawtooth) AC waveform of the same amplitude, frequency and duration immediately following the Sym protocol.

3. Results and discussion

Fig. 1(a) shows typical $\chi'(T)$ $ZF_{AC}CW$ curves for a twinned YBCO crystal, for $h_{AC} = 1.6$ and 0.04 Oe, at $H_{DC} = 3000$ Oe aligned 20° out of the twin planes. The low-amplitude Campbell regime [6] (black) shows a monotonic T dependence, i.e. no PE is observed in the curvature of the effective pinning wells, while in the highly non-linear regime that tests VL mobility (gray), the PE is observed at T_p. Arrows indicate the temperature sweep. Earlier work [6] reported that the PE in YBCO crystals does not seem related to an abrupt enhancement in pinning, but is dominated by dynamical phenomena. Fig. 1(b) shows results for the $NbSe_2$. The non-linear response ($h_{AC} = 0.8$ Oe) is plotted in gray. The linear Campbell regime for two small h_{AC} amplitudes (0.04 and 0.07 Oe) is plotted in dark gray and black symbols. The PE is very steep in the non-linear regime and visible in the linear response, indicating that a structural VL transition may occur at T_p.

We address now the thermo-magnetic hysteretical behavior in both samples. Fig. 2 shows $F_{AC}CC$ (black line), $F_{AC}CW$ (black symbols) and $ZF_{AC}CW$ (gray symbols) $\chi'(T)$ curves, for YBCO and NS in upper and lower panels. In YBCO crystals the measuring AC field in the $F_{AC}CC$ protocol, penetrates completely the sample at high temperatures and enhances VL mobility [11]. $F_{AC}CW$ response is almost reversible (the VL has been already ordered by the AC measuring field during the cooling process).

Consistently, the $ZF_{AC}CW$ protocol, for which the lattice has not been shaken by an AC field, results in a lower $\chi'(T)$ indicating a more disordered and less mobile lattice.

For the LTS sample, the hysteretical response is of a different nature. Both warming curves ($F_{AC}CW$ and $ZF_{AC}CW$) are coincident and the $F_{AC}CC$ curve shows lower VL mobility. The VL seems to order at low T with the increase of vortex interactions against pinning.

Finally, the effect of the AC shaking fields is reported in Fig. 3. The YBCO was field cooled (black symbols) down

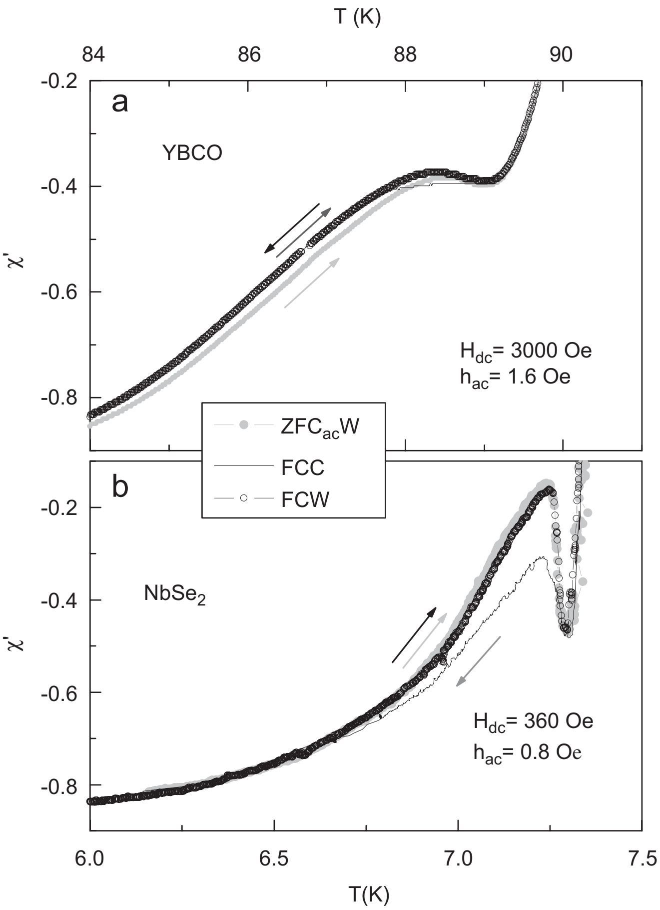

Fig. 2. $F_{AC}CC$ (black line), $F_{AC}CW$ (black symbols) and $ZF_{AC}CW$ (light gray symbols) curves are shown. In YBCO (top panel) $ZF_{AC}CW$ VL has the lowest mobility. In NbSe2, (lower panel) the $F_{AC}CC$ lattice is the less mobile (see the text). Arrows indicate the temperature sweep.

to a fixed temperature T (Point A). Then the Asy (open triangles, C) and Sym (open squares, B) protocols were performed. Both protocols were repeated two or three times at this fixed T, and finally, after the last Sym protocol, the sample was warmed (open squares). The asymmetric shaking leads to less mobile VL, whereas the symmetric shaking promotes mobility [4–6,11]. These confi-gurations are robust and repetitive. One can go from point C to point B, or vice versa, by properly applying a symmetric or asymmetric AC field, as explained above.

Now, we turn to Fig. 3(b) where a similar experiment was performed in the LTS sample. The application of the Sy or Asy protocol at point A leads indistinctly to an ordered VL at point B. It seems that the metastable disordered phase at A is equilibrated by the AC perturba-tion to the ordered phase at B. On further warming the measured susceptibility remains higher until reaching VL melting. We found no AC shaking waveform that would lead to a low-mobility configuration, starting from point B. Full arrows indicate the temperature sweep.

4. Conclusions

We presented AC susceptibility results in HTS and LTS crystals, in the vicinity of the PE, and we show evidence that the dynamics of the VL has different behaviors in these materials. The PE is absent in the linear regime for the HTS sample, but is observed in the LTS crystal. This evidences that the PE may have a dynamical character in YBCO and a static nature in $NbSe_2$. Additionally, $F_{AC}CC$, $F_{AC}CW$ and $ZF_{AC}CW$ responses were examined. A dynamical reordering caused by the shaking movement

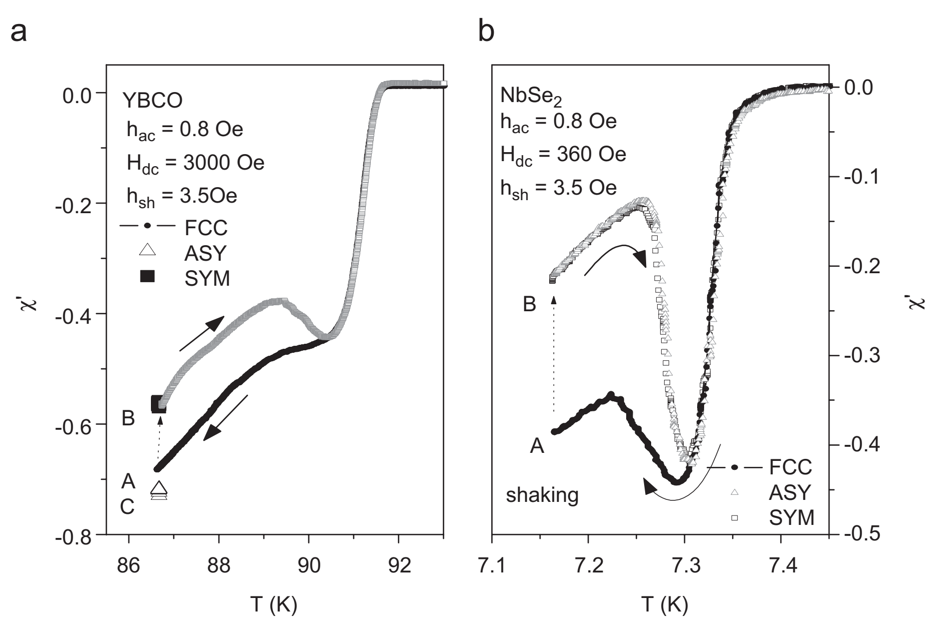

Fig. 3. (a) YBCO was $F_{AC}CC$ to A (full symbols). Sym protocol led to B (open square) and Asy (open triangle) to C. A warming curve after Sym protocol is shown (gray). (b) As in (a) but for $NbSe_2$. Warming curves are shown for coincident Sym and Asy protocols. Full arrows indicate the temperature sweep.

induced by the applied AC field during the cooling process dominates in the HTS sample. In the LTS crystal, however, the increase of elastic interactions against pinning at low temperatures dominates vortex dynamics.

The VL in YBCO crystals is organized by its oscillatory dynamical history in different VL configurations characterized by different mobility. Symmetric vortex shaking promotes repeated interactions between neighbors and heals lattice defects while asymmetric shaking tears the VL and makes it more pinned. In contrast, $NbSe_2$ samples show that AC shaking below the PE leads, indistinctly of the applied waveform, to a more mobile VL, in accordance with an equilibration process. What are the relevant interactions responsible for these differences is yet to be examined.

References

[1] W. De Sorbo, Rev. Mod. Phys. 36 (1964) 90;
A.I. Larkin, Yu.N. Ovchinnikov, J. Low Temp. Phys. 34 (1979) 409.

[2] W. Henderson, E.Y. Andrei, M.J. Hig-gins, Phys. Rev. Lett. 81 (1998) 2352;
Z.L. Xiao, E.Y. Andrei, M.J. Higgins, ibid 83 (1999) 1664;
Y. Paltiel, et al., Nature (London) 403 (2000) 398.

[3] D. Stamopoulos, M. Pissas, A. Bondarenko, Phys. Rev. B 66 (2002) 214521.

[4] S.O. Valenzuela, V. Bekeris, Phys. Rev. Lett. 84 (2000) 4200;
S.O. Valenzuela, V. Bekeris, Phys. Rev. B 65 (2002) 060504.

[5] S.O. Valenzuela, V. Bekeris, Phys. Rev. Lett. 86 (2001) 504.

[6] G. Pasquini, V. Bekeris, Supercond. Sci. Technol. (2006) 19.

[7] X.S. Ling, et al., Phys. Rev. Lett. 86 (2001) 712;
P. Chaddah, Phys. Rev. B 62 (2000) 5361.

[8] G. Pasquini, D. Luna, V. Bekeris, G. Nieva, Memory effect in the dynamics of the vortex lattice in YBCO crystals: the role of correlated disorder, Proceeding SLAFES 2006, Puebla, Mexico, November 2006, to be published in Revista Mexicana de Física.

[9] A.J. Moreno, S.O. Valenzuela, G. Pasquini, V. Bekeris, Phys. Rev. B 71 (2005) 132513.

[10] J. Higgins, S. Bhattacharya, Physica C 257 (1996) 232.

[11] S.O. Valenzuela, Phys. Rev. Lett. 88 (2002) 247003.