Coherent Voltage Oscillations in Superconducting Polycrystalline Y$_1$Ba$_2$Cu$_3$O$_{7-x}$

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Abstract. We have investigated the voltage response of superconducting polycrystalline bulk Y$_1$Ba$_2$Cu$_3$O$_{7-x}$ (YBCO) material to a bidirectional square wave current with long periods and dc current by means of the evolution of the voltage-time ($V$–$t$) curves near the critical temperature. In a well-defined range of amplitudes and periods of driving current, and temperatures, it was observed that a non-linear response to bidirectional square wave current rides on a time independent background voltage value and manifests itself as regular sinusoidal-like voltage oscillations. It was found that the non-linear response disappears when the bidirectional current was switched to dc current. The spectral content of the voltage oscillations analyzed by the Fast Fourier Transform of the corresponding $V$–$t$ curves revealed that the fundamental harmonics is comparable to the frequency of bidirectional square wave current. The coherent voltage oscillations were discussed mainly in terms of the dynamic competition between pinning and depinning together with the disorder in the coupling strength between the superconducting grains (i.e Josephson coupling effects). The density fluctuations and semi-elastic coupling of the flux lines with the pinning centers were also considered as possible physical mechanisms in the interpretation of the experimental results.

1. Introduction

Experimental studies reveal that the vortex state in a type-II superconductor can reorganize itself due to magnitude and the type of the modulation of the driving current [1-4]. One of these studies which considers a de-twinned single crystalline sample of Y$_1$Ba$_2$Cu$_3$O$_{7-x}$ (YBCO) has revealed that the asymmetrical square wave currents cause slow voltage oscillations on long time scales [1,2]. Kwok et al. [3] have shown that the voltage response of a single crystalline sample of YBCO below the melting line to an ac sinusoidal type current evolves in the form of a dynamic instability which appears as regular oscillations in time. In this study, we investigate the influence of symmetric bidirectional square wave (BSW) current with long periods ($P_1$) on the flux dynamic in a polycrystalline sample of YBCO.
2. Experiment

YBCO sample has been prepared from the high purity powder of Y$_2$O$_3$, BaCO$_3$ and CuO by using the conventional solid state reaction. dc electrical resistivity measurements have been carried out using standard four point method, and performed in a closed cycle refrigerator. During the experiments, the temperature stability better than 10 mK have been maintained. The commercial current source Keithley-6221 and Keithley-2182A are used to form such bidirectional square wave currents with long periods and to read low voltage levels with large precision, respectively. The YBCO sample whose results are presented in this work has the zero resistance at ~ 92 K with a transition $\Delta T_c$ of about 3 K at $H=0$.

3. Results and discussion

Figures 1a-1c show the voltage response of YBCO measured at $T=86$ K to a BSW current with different amplitudes of 10, 11, and 12 mA at zero magnetic field, respectively. The period ($P_I$) of the drive for each $V$ - $t$ curve illustrated in Fig.1 is 20 s. It is seen that, after the voltage rise corresponding to the first half cycle of BSW current, regular voltage oscillations evolve nearly in the form of sinusoidal-type and ride on a time independent background voltage value which rises slightly as the amplitude of BSW current increases.

![Figure 1a-c](image-url)

Figure 1a-c. Voltage oscillations measured for a bidirectional square wave (BSW) current with different amplitudes at $T=86$ K at zero field. The period $P_I$ of BSW is 20 s.

Figure 2a and 2c represent the $V$ - $t$ curves measured at $T=81.5$ K for a BSW current with amplitude of 45 mA and different periods of $P_I = 10$ and 40 s, respectively. For this temperature range, the repetitive regular voltage oscillations appear after the fine adjustment of the amplitude of BSW current. In Fig.2a, at around $t = 160$ s, the BSW current was switched to $+45$ mA dc current for the rest of the relaxation process. After switching of BSW current to dc one, the regular voltage oscillations disappear and a relative decrease in the amplitude of measured voltage which is similar to a noise pattern is observed. Inset in Fig.2b illustrates the first derivative of the $V$–$t$ curve in Fig.2a to demonstrate the oscillations better and remove the background voltage. Figure 2b and 2d show the Fast Fourier Transform (FFT) of the $V$ - $t$ curves given in Fig.2a.
and Fig.2c to determine the spectral content of the oscillations. The periods (P_{FFT}) found from FFT of Fig.2a and Fig.2c are 11.7 s and 46.5 s, respectively.

**Figure 2.** Voltage oscillations at T = 81.5 K for different periods (P_{I}) of BSW with an amplitude of 45 mA. (a) P_{I}=10 s. (b) The Fast Fourier Transform (FFT) of the V–t curve in Fig.2a. The inset shows the first derivative of the V–t curve in Fig.2a. (c) P_{I}=40 s. (d) FFT of the V–t curve in Fig.2c. First peaks are the fundamental frequencies and the small ones represent the other harmonics.

In order to understand the origin of the coherent voltage oscillations to a BSW current, we consider that the moving entity which causes measurable dissipation is the self-magnetic flux (SMF) lines induced by the transport current. Self-field B_{s} can be calculated by using the expression B_{s} = μ_{o}γ J [5], where μ_{o} is the permeability of free space (μ_{o} = 4πx10^{-7} H/m), γ is the geometric parameter of the sample and given as γ = wd/(w+d), w is the width, d is the thickness of the sample. The slab considered for the transport measurements was in dimensions of length l ~ 4 mm, width w ~ 0.1mm, and thickness d ~ 0.2 mm. Thus, the self-field is found as ~ 0.2 mT for a transport current of 45 mA. As the measured dissipation (i.e., V ~ 10^{-6}-10^{-7}) is considered, it can be suggested that the effective field inside the sample (i.e., B_{s}) is quite weak and does not suppress the superconducting order parameter sufficiently.

The V–t curves given in Fig.1 and Fig.2 reveal that the measured voltage [V(t)] remains positive despite the polarity change. We suggest that V(t) comprises of two terms, one (V_{0}) is the time independent background and the other [δV(t)] is the time dependent part which can be positive and negative due to the polarity change. Thus, it can be written as V(t) = V_{0} ± δV(t). In Fig.2a, the average amplitude of oscillations is about 0.15 μV and it is less than the background voltage value of ~ 0.5 μV. Thus, the voltage oscillations can remain positive although the drive is bidirectional.
The origin of coherent oscillations can be attributed to different mechanisms. One of them is the dynamic competition between pinning and depinning together with the relaxation effects during the time evolution of voltage response [3,4]. We suggest that the majority of SMF lines which are in motion drifts slowly and tries to traverse the sample, but, does not entirely leave it. In this case, the SMF lines remain in an oscillating mode and move forth and back. The coherent voltage oscillations suggest that the interaction between SMF lines and pinning centers could be semi-elastic rather than elastic coupling. In this description, the oscillating mode can be closely related to the defective flow of SMF lines in which some of them are moving and the others remain pinned i.e., non-uniform flux motion. In single crystalline YBCO sample, Gordeev et al. [1-2] showed that the temporal asymmetry in square wave current and its periodic reversal are essential to observe such regular oscillations. On the other hand, Kwok et al. [3] attributed the observation of the oscillatory instability in single crystal YBCO sample to the strong competition between the driving and pinning forces and correlated it to the elasticity of the vortex solid and the long time relaxation effects.

We note that the values of $P_{\text{FFT}}$ are comparable to that of BSW given in corresponding figures. On the other hand, the relatively small peaks which appear in Fig.2d correspond to the other harmonics accompanied to fundamental frequency. This finding suggests the presence of a dynamic physical case, which resembles the driven charge density waves (CDWs) by an external drive [1,6-8]. The system of weakly pinned vortices is similar to the pinned CDWs state.

4. Conclusion

In this study, the time evolution of sample voltage ($V$–$t$ curves) was measured for a BSW current with different amplitudes and periods at different temperatures. The coherent voltage oscillations were correlated to the defective flow of current induced self-magnetic flux (SMF) lines in a multiply connected network, and semi-elastic coupling of SMF lines with pinning centers.

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References

[1] Gordeev S N, de Groot P A J, Oussena M, Volkozup A V, Pinfold S, Langan R M, Gagnon R, and Taillefer L 1997 Nature 385, 324-326.  
[2] Gordeev S N, de Groot P A J, Oussena M, Langan R M, Rassau A P, Gagnon R, and Taillefer . 1997 Physica C 282-287, 2033-2034.  
[3] Kwok W K, Craptree G W, Fendrich J A, and Paulius L M 1997 Physica C 293, 111-116.  
[4] Henderson W, Andrei E Y, and Higgins M J 1998 Phys. Rev. Lett., 81, 2352-2355.  
[5] Kiliç A, Kiliç K, and Senoussi S 1998 J. Appl. Phys., 84, 3254-3262.  
[6] Hall R P and Zettl A 1984 Phys. Rev.B 30, 2279-2281.  
[7] Coppersmith S N and Millis A J 1991 Phys. Rev. B 44, 7799-7807.  
[8] Ringland K., Finnefrock A C, Li Y, Brock J D, Lemay S G, and Thorne R. E. 1999 Phys. Rev. Lett. 82, 1923-1926.