Comment on "Has a Josephson-Plasma Mode Been Observed in Layered Superconductors?"

The magnetoabsorption resonance in the vortex state of $Bi_2Sr_2CaCu_2O_{8+\delta}$ reported in Ref. [1] has been identified [2,3] as the Josephson plasma resonance (JPR), discussed theoretically in Ref. [4]. The main features of this resonance are as follows: (a) It is generated by the microwave electric field $\mathbf{E}_{ac}$ parallel to the c axis [2], (b) it is anticyclotronic [1], (c) the resonance field H_r drops as anisotropy increases [5], (d) the resonance shows a reentrant cusp in H nearly parallel to the *ab* plane [3,5], and (e) H_r strongly correlates with the c-axis critical current [5]. These properties are consistent with the JPR. Recently Sonin questioned the JPR interpretation and discussed an alternative explanation for this resonance: a vortex vibration mode (VVM) [6].

In this Comment we present two definite experimental evidences that confirm the JPR scenario and rule out the VVM picture. First, the fact that the resonance occurs when $\mathbf{E}_{ac} \parallel c \parallel \mathbf{H}$ contradicts the VVM interpretation, because *no Lorentz force acts on the pancake vortices in this configuration* [2]. Second, Fig. 1 depicts the temperature dependence of the microwave absorption of a $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal at 45 GHz near T_c ($T_c = 85$ K) observed by changing T at constant H; the resonance appears as a function of T. The resonance positions determined by this method exactly coincide with those [5] determined by sweeping H at constant T. What is important, as shown in Fig. 1, is that *the resonance occurs even at* $H = 0$ *as a continuation of that at* $H \neq 0$. This fact excludes the VVM interpretation but is consistent with the JPR picture quantitatively. The zero field plasma frequency near T_c is $f_{pl}(T) = (c/2\pi\lambda_{ab}\gamma\sqrt{\epsilon_0})[1 - (T/T_c)^4]^{1/2}$, where λ_{ab}, γ, and ϵ_0 are the in-plane penetration length at $T = 0$, the anisotropy factor, and the dielectric constant, respectively. At $T = 82$ K, assuming $\lambda_{ab} \simeq 2000$ Å, $\gamma \simeq 400$, and $\epsilon_0 \simeq 20$, we obtain $f_{pl} \simeq 48$ GHz, close to the microwave frequency 45 GHz. At $H \neq 0$ the resonance temperature drops because vortices decrease f_{pl} [4].

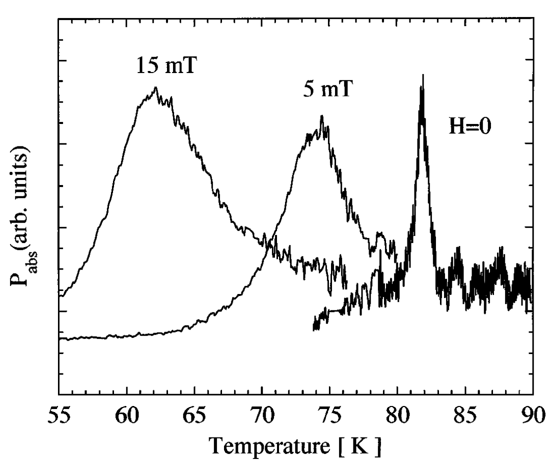

FIG. 1. Temperature dependence of the intensity of the microwave absorption at 45 GHz at $Bi_2Sr_2CaCu_2O_{8+\delta}$ ($T_c = 85$ K). Both the microwave electric field and dc magnetic field are applied parallel to the c axis, $\mathbf{E}_{ac} \parallel c \parallel \mathbf{H}$.

In Ref. [6] Sonin criticized theoretical results [4] for the effect of vortices on JPR. He argued that "they strongly overestimated this effect using the relation $\langle\cos\varphi\rangle = \exp(-\langle\varphi^2\rangle)$ which is incorrect if $\langle\varphi^2\rangle$ is large, i.e., if $\langle\cos\varphi\rangle$ is small." In fact, *such a relation is correct at any* $\langle\varphi^2\rangle$ *if* the phase difference φ *obeys a Gaussian distribution.* What is more, any one-parameter distribution function of φ tends to the homogeneous and $f_{pl} \propto \langle\cos\varphi\rangle \to 0$ as dispersion $\langle\varphi^2\rangle \to \infty$.

In Ref. [6] Sonin argued that $\langle\cos\varphi\rangle \approx 1$ because "the phase is large (i.e., $\cos\varphi$ may be small) only inside a Josephson string" (connecting nearest pancake vortices in neighboring layers), and strings are much shorter than the intervortex distance. However, as a matter of fact, in $Bi_2Sr_2CaCu_2O_{8+\delta}$, correlations in vortex positions along the c axis are very weak, i.e., *the length of strings is of the order of intervortex distance* in fields $H > 500$ G at all T.

In Ref. [6] Sonin also criticized the theoretical results [7] for the dispersion of phase collective modes in strong magnetic fields $\mathbf{H} \perp c$. It is well known that the vibrational spectrum $\omega(\mathbf{k})$ of a monoatomic lattice may be found considering one or two atoms in the unit cell. The latter approach was used in Ref. [7] to calculate $\omega(k_x, k_y, k_z)$, while the former approach was used in Ref. [6] to calculate $\omega(0, 0, k_z)$. Obviously, a gap at the Brillouin-zone boundary is absent in the spectrum obtained in Ref. [7], and at $k_x = k_y = 0$ the results coincide. Nevertheless, Sonin claims that approach [7] is incorrect.

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