Comment on "Effects of Point Defects on the Phase Diagram of Vortex States in High-T_c Superconductors in the $B \parallel c$ Axis"

Recently Nonomura and Hu (NH) presented [1] simulations of an *XY* model for a point disordered type-II superconductor using strongly anisotropic couplings $J_c/J_{ab} = (\lambda_{ab}/\lambda_c)^2 = 1/400$. They report a *vortex slush* (VS) phase at disorder strengths ϵ intermediate between the vortex solid (denoted "BG" for Bragg glass) and the vortex liquid (VL), and is separated from them by first order transitions $\epsilon_{c1}(T) < \epsilon_{c2}(T)$, respectively. The VS has neither superconducting coherence nor translational order and is distinguished from the VL by a sharp decrease in the density of dislocations in the *ab* plane. Here we clarify the nature of the VS found by NH, and argue that it is the result of an unphysical finite size effect.

We simulate NH's model using all the same parameters. Cooling to $T = 0.08$ at high $\epsilon = 0.14$ within the VL, we then slowly decrease ϵ to enter first the VS and then finally the BG. We then slowly increase ϵ back to 0.14. We use at least 3×10^7 Monte Carlo passes for decreasing ϵ, and at least 2×10^7 for increasing ϵ, comparable to NH. In Fig. 1(a) we plot our results for the longitudinal helicity modulus, Υ_c. In Fig. 1(b) we plot the structure function peak $S(\mathbf{K})$, where $\mathbf{K}$ is a reciprocal lattice vector of the vortex line lattice we find in the BG. Decreasing ϵ, we find that Υ_c rises from zero, indicating the onset of superconducting phase coherence, and $S(\mathbf{K})$ saturates to its low ϵ value, indicating formation of an ordered vortex line lattice, both at $\epsilon_{c1} \sim 0.06$. Increasing ϵ, however, we find that both phase coherence and the vortex line lattice persist to the higher value $\epsilon_{c2} \sim 0.10$. Our values of ϵ_{c1} and ϵ_{c2} are reasonably close (given likely sample to sample fluctuations) to the values reported by NH for the boundaries of the VS at $T = 0.08$. We therefore identify $\epsilon_{c1} < \epsilon < \epsilon_{c2}$ as NH's VS and conclude that it is a region with considerable hysteresis and metastability.

To get a clearer picture, we plot in Fig. 2 $S(\mathbf{K})$, computed layer by layer for the *ab* planes at different heights *z*, for several different values of ϵ as obtained when decreasing ϵ. The different symbols represent different values of $\mathbf{K}$, corresponding to vortex lattices of different orientation.

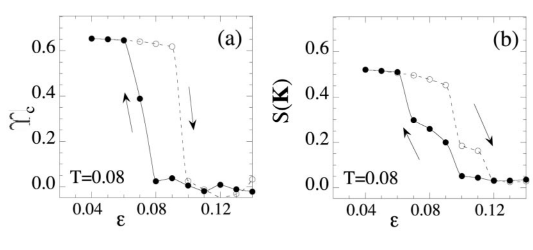

FIG. 1. (a) Helicity modulus Υ_c and (b) structure function peak height $S(\mathbf{K})$ vs disorder strength ϵ at $T = 0.08$. Solid (open) symbols are for decreasing (increasing) ϵ.

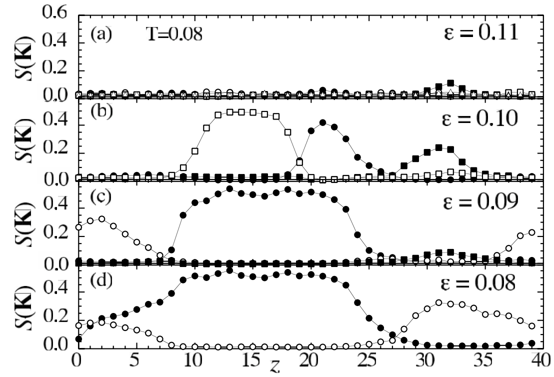

FIG. 2. Vortex structure function $S(\mathbf{K})$ computed layer by layer at heights *z*, for several different ϵ, upon decreasing ϵ. The different symbols correspond to different values of $\mathbf{K}$, representing different vortex lattice orientations.

We see that vortices in most planes have ordered into a 2D vortex lattice; however, the orientation of this lattice varies in different layers. Decreasing ϵ, the thickness of aligned layers increases, until below ϵ_{c1} in the BG, a single orientation fills the system.

For a particular random realization and system size *L*, it is possible that the above state is, indeed, more stable than an ordered vortex line lattice for a region of ϵ. However, this cannot remain true as *L* increases. For an ordered vortex lattice of size *L* and thickness $L_z \sim L$, the most energy that can be gained by adjusting to a particular set of random point pins scales as $\epsilon J_{ab} L^{3/2}$. The energy cost by having a mismatch of vortex lattices between two adjacent planes scales as $J_z L^2$. As *L* increases, the energy cost wins out and the vortex lattices align for all layers. Thus, while we cannot rule out the possible existence of a VS phase, the state found by NH, which we show to consist of ordered but misaligned layers, should not be taken as evidence for such a phase.

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P. Olsson[1] and S. Teitel[2]
[1]Department of Theoretical Physics
Umeå University
901 87 Umeå, Sweden
[2]Department of Physics and Astronomy
University of Rochester
Rochester, New York 14627, USA

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[1] Y. Nonomura and X. Hu, Phys. Rev. Lett. **86**, 005140 (2001).

