Supplementary material to the paper

Flux pattern transitions in the intermediate state of a type-I superconductor driven by ac field

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Supplementary Material 1: Flux patterns as a function of time

For low density flux tube state, the flux patterns keep creeping with time. We image the flux patterns as a function of time up to 2 hours. In figure s1, we present the dynamics of the LDFTS as a function of time. Figure s1a was imaged at $T=6.9$ K and $H=2.5$ Oe after zero-field-cooling. (b)-(f) was recorded after waiting for 3, 6, 10, 120 and 150 minutes respectively under the same parameters. Clearly, the flux tubes keep moving inside the sample.

Figure s1: (a) Vortex patterns measured after ZFC for $T=6.9$ K and $H=2.5$ Oe. (b) -(f) are measured at the same scanning area after waiting for 3, 6, 10, 120 and 150 minutes respectively.
Supplementary Material 2: Flux phase diagram

We systematically imaged the flux patterns in one scanning area through both flux penetration and expulsion processes at various temperatures and applied fields. A phase diagram is constructed as shown in figure s2. For flux penetration process after zero-field-cooling, the intermediate state can mainly be divided into four parts with different flux structures: a) Meissner state (no flux); b) Flux tube state; c) Coexistence of flux tube and stripe state; d) stripe state. However, when accessing flux expulsion process by field-cooling, the phase boundaries (dashed lines) are shifted to lower fields.

We have found that there exists an overlapped area (between $H_{ST}$ and $H'_{ST}$ lines) on the phase diagram, where the flux patterns show flux tubes when performing flux penetration and stripes (or stripes + flux tubes) when performing flux expulsion procedures. Considering the results presented in our manuscript that the stripe pattern upon flux expulsion (e.g. figure 6b) represents a more stable state due to the pinning, we suggest that the overlapped area in the phase diagram represents the superheated metastable flux tube state. When shaking the flux tube patterns in this area with high enough ac fields, these patterns will restructure into the stripe state. Therefore, we can define the area between $H_p$ and $H'_{ST}$ as low density flux tube state (LDFTS) and the overlapped area between $H'_{ST}$ and $H_{ST}$ as high density flux tube state (HDFST) as discussed in the manuscript.

Figure s2: H-T flux phase diagram for the type-1 superconductor. The solid and dashed lines represent the phase boundaries by flux penetration and flux expulsion processes, respectively.
There is one thing need to be mentioned that for different imaging areas, since the pinning potential distributions are also different, the phase boundaries in the phase diagram are a little bit different. However, the conclusions are not affected.