Vortex phase diagrams in $R_3Rh_4Sn_{13}$ (R = Yb,Ca)

C.V. Tomy[a,*], S. Sarkar[b], S. Ramakrishnan[b], A.K. Grover[b], G. Balakrishnan[c], D.McK. Paul[c]

[a] *Department of Physics, Indian Institute of Technology, Mumbai-400076, India*
[b] *Department of CMP&MS, Tata Institute of Fundamental Research, Mumbai-400005, India*
[c] *Department of Physics, University of Warwick, Coventry CV4 7AL, UK*

Abstract

A comparative study of vortex phase diagrams in two weakly pinned low T_c superconductors, $Ca_3Rh_4Sn_{13}$ (CaRhSn) and $Yb_3Rh_4Sn_{13}$ (YbRhSn), is presented. In CaRhSn, we can witness a disorder-driven transition via the phenomenon of second magnetization peak whose field-temperature dependence is analogous to that often discussed in the context of a Bragg glass (BG) to vortex glass (VG) transition.

Keywords: Peak effect; Second magnetization peak

CaRhSn and YbRhSn are isotropic low T_c superconductors with a narrow fluctuation region in the (H, T) phase space [1]. Weakly pinned crystals of these systems are considered suitable for examining the structural and dynamic behavior of the flux line lattice (FLL) within the frame work of Larkin-Ovchinikov (L–O) collective pinning theory [2]. We present here a status report [3] on the vortex phase diagram for CaRhSn and YbRhSn through AC susceptibility and DC magnetization measurements. The novel features include the observation of the second magnetization peak (SMP) and the peak effect (PE) in isothermal DC magnetization and a pinning-induced stepwise amorphization of the FLL in isofield AC susceptibility.

Fig. 1 shows DC magnetization hysteresis loops for CaRhSn and YbRhSn. According to the critical state model, any anomaly in the critical current density (J_c) reveals itself as modulation in the hysteresis width ($\Delta M(H)$) of the magnetization loop. As per the description of the L–O theory ($J_c \propto V_c^{-1/2}$, where V_c is the correlation volume of the FLL), the anomalous modulations in $J_c(H, T)$ reflect the transformation in V_c across a phase boundary. Typical anomalous features in $J_c(H, T)$ can be clearly seen in the $M-H$ loops of the two compounds. For YbRhSn, this anomalous variation in $\Delta M(H)$ occurring near H_{c2} can be identified as the classical PE. However, the hysteresis loop for CaRhSn shows an additional anomaly in $\Delta M(H)$, well below H_{c2}. Following the nomenclature from the literature, this anomaly can be termed as the SMP, which has been ubiquitously reported in high T_c superconductors (HTSC). Like in HTSC, the loci of fields marking the onset and peak fields of the SMP in CaRhSn do not show any temperature dependence. On the other hand, the loci of fields marking the PE vary with temperature in a manner such that above 4.5 K the SMP is completely subsumed by the PE (see the inset of Fig. 1(b)). The appearance of SMP in CaRhSn is new and the first observation of its kind in any specimen of low T_c superconductors.

If the anomalous variations in $J_c(H)$ reflect the transformation in V_c, one can witness path dependence of $J_c(H)$ by tracing the minor hysteresis loops, initiated from vortex states prepared along different thermomagnetic paths. The dotted curves in Fig. 1 demonstrate the path dependence in $J_c(H)$ across the SMP and the PE regions, obtained from the vortex states prepared in the field-cooled (FC) manner. For $H < H^{on}_{smp}$, the FC-minor curves remain confined within the envelope loop (ZFC curve), but they start to overshoot as H exceeds H^{on}_{smp}. The difference between the maximum value of a

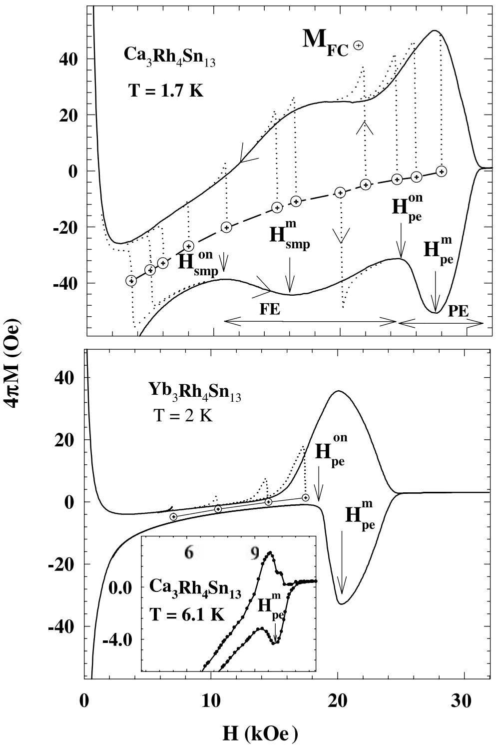

Fig. 1. $M-H$ loops for CaRhSn and YbRhSn. The onset and peak fields of the SMP and PE are identified. Inset in panel (b) shows $M-H$ loops in CaRhSn at 6.1 K, where only PE is evident. Dotted curves represent minor curves initiated from FC states.

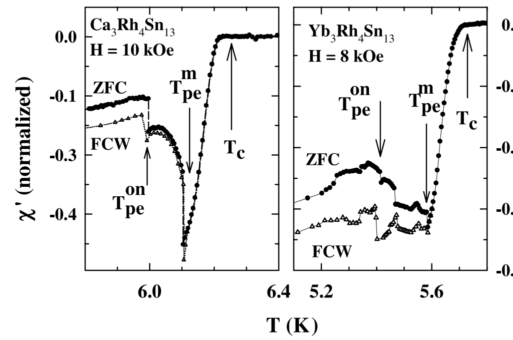

Fig. 2. Isofield $\chi'_{AC}(T)$ in CaRhSn and YbRhSn for two sample histories (ZFC and FC). The onset and peak temperatures of the PE have been identified.

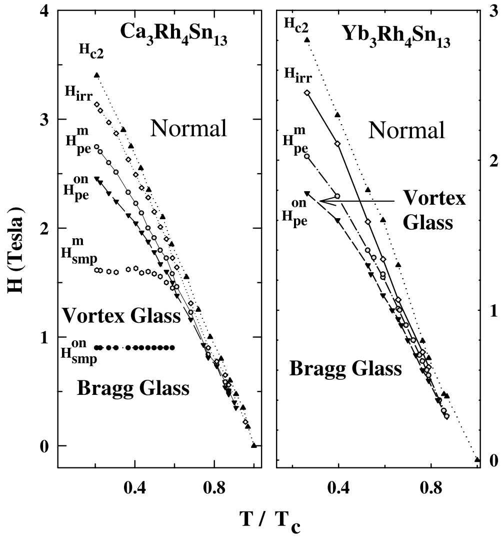

Fig. 3. Vortex phase diagrams for CaRhSn and YbRhSn. The regions, $H_{pe}^{on} < H_{pe}^{m}$, $H_{pe}^{m} < H < H_{irr}$ and $H_{irr} < H < H_{c2}$ identify shattered (Bagg/vortex) glass, pinned amorphous and unpinned amorphous, respectively.

FC-minor curve and the corresponding value on the envelope curve reflects the difference between V_c of the disordered FC state and ordered ZFC state. As H approaches H_{pe}^{m}, the FC-minor curves readily merge into the envelope loop, as expected since the metastability and memory effects disappear above the peak of the PE.

Another method to study the disorder and history dependence of J_c is the isofield ac susceptibility where the history can be traced as a function of T at a given H. Fig. 2 shows typical traces for both the compounds where the real part of the AC susceptibility (χ') is plotted as a function of T at a given H for the two thermomagnetic histories (ZFC and FC). In CaRhSn, anomalous variation in J_c consists of two discontinuous transitions at T_{pe}^{on} and T_{pe}^{m} of the PE in accordance with a stepwise amorphization/pulverization of the FLL. However, in YbRhSn, this process occurs through multiple steps, as evident from the figure. As J_c is directly related to χ' via critical state model ($\chi' \sim -1 + \alpha h_{AC}/J_c$), a larger diamagnetic response in the FC mode implies that $J_c^{FC} > J_c^{ZFC}$ in both the compounds. The difference between the ZFC and FC responses finally disappears above T_{pe}^{m}, in agreement with the DC magnetization results where the memory effects in J_c ceases above H_{pe}^{m}.

Assembling all the data from AC susceptibility and DC magnetization, a vortex phase diagram is constructed for both the compounds, as shown in Fig. 3. Note that the SMP in CaRhSn has caused the presence of a phase boundary analogous to that of a BG to VG transition across which dislocations could first permeate spontaneously. The Larkin domains in the VG region could undergo a modulation (i.e., healing) between H_{smp}^{m} and H_{pe}^{on}. Above H_{pe}^{on}, the Larkin domains pulverize through a two-step process. Since the SMP is not observed in YbRhSn, the above phase boundary is absent in the phase diagram and the fracturing proceeds through a multi-step process between H_{pe}^{on} and H_{pe}^{m}.

References

[1] C.V. Tomy, et al., Phys. Rev. B 56 (1997) 8346; C.V. Tomy, et al., Phys. C 280 (1997) 1.
[2] A.I. Larkin, Yu.N. Ovchinikov, J. Low Temp. Phys. 34 (1979) 409.
[3] S. Sarkar, et al., Phys. Rev. B 61 (2000) 12394; S. Sarkar, et al., Phys. C 356 (2001) 181.