# Superfluid Density of $CeRh_2As_2$ Probed by Lower Critical Field Studies

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The tetragonal heavy-fermion superconductor $CeRh_2As_2$ with a critical temperature $T_c = 0.35$ K exhibits an extraordinary phase diagram with two likely distinct superconducting states, low-field even-parity spin-singlet SC1 and high-field odd-parity spin-triplet SC2, when a magnetic field is applied parallel to the $c$ axis. For an in-plane magnetic field only the SC1 state is observed. Despite enormous interest in this rare multiphase superconductor, little is known about the superconducting gap structure. Certainly, the low critical temperature hinders the experimental progress in revealing the presence or absence of nodes. These difficulties are further compounded by the strong sensitivity of $T_c$ to sample quality.

Here, we report the temperature dependencies of the lower critical field $H_{c1}(T)$ determined using micro-Hall probe magnetometry. We measured single crystals of $CeRh_2As_2$ grown using Bi horizontal-flux (BHF) and conventional Bi flux (BF) methods. For several BHF samples with $T_c$ ranging between 0.21 K and 0.31 K, we found that the in-plane and out-of-plane normalized $H_{c1}(T)$ dependencies show nearly-parabolic dependence very well described by the formula originally derived in the Bardeen-Cooper-Schrieffer theory for the thermodynamic critical field of a fully gapped superconductor.

On the other hand, the $H_{c1}(T)$ results can be related to the normalized superfluid density as $\tilde{\rho}_s(T) \simeq H_{c1}(T)/H_{c1}(0)$. We found that all $\tilde{\rho}_s(T)$ curves essentially converge into one normalized dependence with a robust low-temperature $T^2$ behavior up to $0.6T_c$, regardless of sample quality [1]. This suggests a dirty $d$-wave scenario, in which nonmagnetic scatterers acting in the unitarity limit lead to a quadratic behavior of $\tilde{\rho}_s(T)$ at low temperatures [2,3]. To verify this scenario, measurements on BF samples with a smaller disorder level and the highest reported value of $T_c \approx 0.35$ K [4] will be performed. The key argument for the dirty $d$-wave scenario would be an observation of the $\tilde{\rho}_s(T)$ flattening at visibly lower temperatures.

**Acknowledgments** *This work was supported by the Polish National Science Centre NCN (Project OPUS23 No. 2022/45/B/ST3/04117).*

**References**

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