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Magnetization Studies of $Cu_{0.058}TiSe_2$ Near a Quantum Critical Point

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We study superconducting properties of highly underdoped $Cu_{0.058}TiSe_2$ single crystal by means of bulk magnetization measurements. We extract the upper critical field, H_{c2}, for magnetic field applied parallel, as well as perpendicular to the sample planes. Obtained values, $H_{c2}^{ab}(0) = 1.03$ T and $H_{c2}^{c}(0) = 0.54$ T, define a moderate anisotropy of the upper critical fields of 1.90. From the upper and lower critical fields we extract the Ginzburg-Landau parameters $\kappa_{ab}(0) = 26.3$, and $\kappa_c(0) = 12.6$ that classify $Cu_{0.058}TiSe_2$ as an extreme type II superconductor.

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1. Introduction

Cu_xTiSe_2 is a recently discovered superconductor with the coexisting charge ordered and superconducting (SC) phases for $0.04 \le x \le 0.06$ [1]. There are open questions regarding the mechanism of superconductivity [2] and the number of SC gaps in this system [3–6]. Characterization of superconductivity in optimally doped polycrystalline samples [1], slightly underdoped $Cu_{0.07}TiSe_2$ [7], and overdoped $Cu_{0.10}TiSe_2$ single crystals [8] was reported. However, few works are available that systematically study SC properties [1, 3, 6]. In this communication we report magnetization studies on highly underdoped $Cu_{0.058}TiSe_2$ single crystal with Cu concentration near the quantum critical point for the charge density wave (CDW) phase.

2. Experiment

Cu_xTiSe_2 single crystals were grown using the iodine vapor transport method in evacuated silica ampoules in a gradient furnace with the lower temperature part set to 720 °C and the temperature gradient of 80 °C/m. The energy dispersive X-ray spectroscopy (EDS) was used to establish the quantitative elemental analysis of the crystals. Magnetization measurements down to 1.8 K were performed in SQUID magnetometer and VSM option of PPMS (Quantum Design).

3. Results

The concentration of copper in the sample, established by EDS is 1.90 ± 0.04 at.%, i.e. $x = 0.058 \pm 0.0013$. The dimensions of the sample are $1 \times 1 \times 0.09$ mm^3. Figure 1 shows the reversible magnetization isotherms for $Cu_{0.058}TiSe_2$ for $H||c$ for temperatures 1.8 – 2.5 K. They were acquired as $(M_d + M_u)/2$, where M_d is the magnetization measured at decreasing, and M_u at increasing magnetic field. The inset shows the transitions from superconducting to normal state, defining the upper critical fields for different temperatures, $H_{c2}^{c}(T)$. H_{c2} at zero temperature, $H_{c2}(0)$, was extracted from the data close to T_c (not shown) using Werthamer-Helfand-Hohenberg formula [9] $H_{c2}(0) = -0.693T_c(\mathrm{d}H_{c2}/\mathrm{d}T)|_{T_c}$ and the values were found to be $H_{c2}^{ab}(0) = 1.03$ T and $H_{c2}^{c}(0) = 0.54$ T. The values are slightly lower than those for the slightly underdoped $Cu_{0.07}TiSe_2$ studied previously [7].

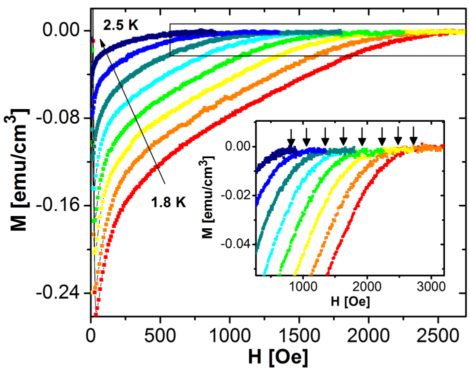

Fig. 1. Reversible $M(H)$ curves for $H||c$. The grey rectangle shows an area that is zoomed in the inset. The inset shows the transitions from SC to normal state, defining $H_{c2}(T)$.

Their ratio defines the anisotropy of H_{c2}, which is 1.90, the value somewhat higher than that for $Cu_{0.07}TiSe_2$ [7]. Furthermore, we calculate coherence lengths, $\xi_{ab}(0)$ and $\xi_c(0)$, using the anisotropic GL formulae [10] $H_{c2}^{c}(0) = \phi_0/[2\pi\xi_{ab}^2(0)]$, $H_{c2}^{ab}(0) = \phi_0/[2\pi\xi_{ab}(0)\xi_c(0)]$, where ϕ_0 is the flux quantum, $\phi_0 = 2.07 \times 10^{-7}$ G cm^2. The calculated values are $\xi_{ab}(0) = 24.2$ nm and $\xi_c(0) = 12.7$ nm.

Furthermore, we measured the first penetration field for $Cu_{0.058}TiSe_2$ for $H||c$, as well as $H||ab$. Figure 2 shows zero-field cooled (ZFC) magnetization isotherms for $H||c$ (for temperatures 1.8 K – 2.5 K) and $H||ab$ (for temperatures 1.9 K – 2.5 K). The first penetration field

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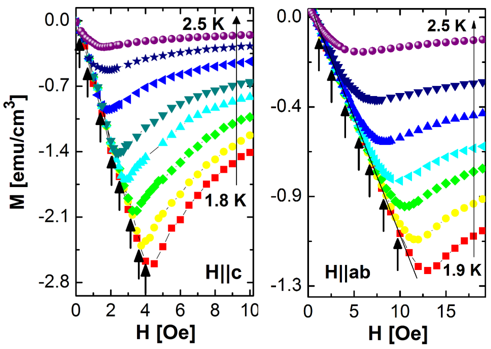

Fig. 2. Zero-field cooled (ZFC) virgin magnetization curves. Arrows indicate the first penetration fields, $H_p(T)$. *Left*: $H||c$, $T = 1.8$ K–2.5 K (0.1 K steps). *Right*: $H||ab$, $T = 1.9$ K–2.5 K (0.1 K steps).

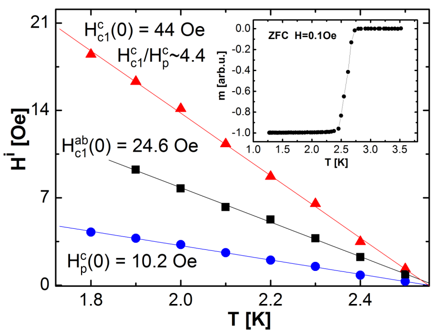

Fig. 3. First penetration field, $H_p(T)$ for $H||c$ (blue circles), lower critical field, H_{c1} for $H||c$ (red triangles) and H_{c1} for $H||ab$ (black squares). Inset: ZFC normalized $M(T)$ for $H = 0.1$ Oe, indicating a sharp SC transition with a maximum slope at ~ 2.6 K, assigned as a SC critical temperature T_c.

for each temperature is acquired as a field at which a deviation from the ideal Meissner-state screening occurs. The obtained $H_p(T)$ points have a linear dependence for both directions of the applied magnetic field (Fig. 3) and the extrapolated values are $H_p(0) = 10.2$ Oe ($H||c$) and $H_p(0) = 24.6$ Oe ($H||ab$) with the effective superconducting critical temperature $T_c \approx 2.6$ K which coincides with the maximum slope of ZFC $M(T)$ curve shown in the inset of Fig. 3. After a demagnetizing correction for $H||c$ $H^c_{c1}(0)/H^c_p(0) = 1/\tanh\sqrt{0.67b/a} \approx 4.4$, where b is the sample thickness and a is its width [11], we obtain $H^c_{c1}(0) \approx 44$ Oe. For $H||ab$, no correction is needed and therefore $H^{ab}_{c1}(0) = 24.6$ Oe. The superconducting anisotropy is temperature independent between $\sim 0.7T_c$ and T_c. Using $H^c_{c1}(0) = \phi_0[\ln\kappa_c(0) + 0.5]/[4\pi\lambda^2_{ab}(0)]$, $H^{ab}_{c1}(0) = \phi_0[\ln\kappa_{ab}(0) + 0.5]/[4\pi\lambda_c(0)\lambda_{ab}(0)]$, where $\kappa_c = \lambda_{ab}/\xi_{ab}$ and $\kappa_{ab} = \lambda_{ab}/\xi_c$, we extracted GL penetration depths $\lambda_{ab}(0) \approx 336$ nm and $\lambda_c(0) \approx 726$ nm. The ratio $\lambda_c(0)/\lambda_{ab}(0) \approx 2.16$ is somewhat higher than $\xi_{ab}(0)/\xi_c(0) \approx 1.90$. The GL numbers extracted from $H^i_{c2}(0)/H^i_{c1}(0) = 2\kappa^2_i/(\ln\kappa_i + 0.5)$ are $\kappa_{ab}(0) \approx 26.3$ and $\kappa_c(0) \approx 12.6$. They classify $Cu_{0.058}TiSe_2$ as an extreme type II superconductor.

4. Conclusions

We have studied anisotropic SC properties of highly underdoped Cu_xTiSe_2 single crystal with the copper concentration near the CDW quantum critical point by means of bulk magnetization measurements. We extracted parameters as the upper and lower critical fields for $H||ab$ and $H||c$. All these quantities are somewhat lower than those found for slightly underdoped $Cu_{0.07}TiSe_2$ [7], resulting in a SC anisotropy coefficient 1.9, that is slightly larger than 1.65 found for $Cu_{0.07}TiSe_2$. It is interesting to note that SC anisotropy of this system is the lowest among well-known SC members of transition metal dichalcogenides, as 2*H*-NbS_2 [12], 2*H*-$NbSe_2$ [13], Na_xTaS_2 [14], and 2*H*-$TaSe_2$ [15]. On the other hand, GL numbers were found almost unchanged compared to $Cu_{0.07}TiSe_2$.

Acknowledgments

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