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Magnetic phase diagram of anisotropic superconductor 2H-$NbSe_2$

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Abstract

We report the magnetic phase diagram of a clean single crystal of 2H-$NbSe_2$ and present an update on the determination of its intrinsic superconducting parameters.

Keywords: Phase diagram; Reentrant peak effect; $NbSe_2$; Superconductivity

1. Introduction

The clean single crystals of transition metal chalcogenide 2H-$NbSe_2$ (superconducting $T_c(0) \approx 7.1$ K) are considered ideal for the study of intrinsic properties of Abrikosov flux line lattice (FLL) as the transverse and longitudinal correlation lengths – over which the triangular arrangement of the flux lines prevails – are of macroscopic order [1]. The Abrikosov FLL subject to fluctuations is expected to transform to flux liquid state near normal to superconductor phase boundary ($H_{c2}(T)$) at high fields; the FLL melting curve has been predicted to have a reentrant characteristic [2] at low fields ($H \sim \Phi_0/\lambda^2$), i.e., the melting curve should move away from $H_{c2}(T)$ line and lie just above the $H_{c1}(T)$ line. A prerequisite [3] for the observation of melting curve as distinct from $H_{c2}(T)$ line (and its reentrant characteristic) in any system is the largeness of the value of its Ginzburg number, which is a measure of the ratio of thermal energy (k_BT_c) to superconducting condensation energy ($H_c^2\xi^3/8\pi$). 2H-$NbSe_2$ has an appreciable value ($\sim 10^{-4}$) of Ginzburg number, which lies in between high T_c superconductors and conventional low T_c alloys [1]. It is also a layered system for which anisotropic Ginzburg–Landau (GL) relationships are considered appropriate [3]. A quantitative comparison of experimental data with the theoretical predictions needs reliable values of superconducting parameters, like, coherence lengths $\xi^{a,c}$ and penetration depths $\lambda^{a,c}$, $\kappa^{a,c}$, etc. We present here an update [4] on the determination of the magnetic phase diagram in a clean single crystal of 2H-$NbSe_2$ for $H \| a$ and $H \| c$ via AC and DC magnetisation measurements and inter alia tabulate the revised values of $\xi^{a,c}$, $\lambda^{a,c}$, $\kappa^{a,c}$ at $T=0$ and $t(\equiv T/T_c(0))=0.97$.

2. Results and discussion

The phase diagram (see Fig. 1) comprises lower critical field lines $H_{c1}^{a,c}(T)$, the upper critical field lines $H_{c2}^{a,c}(T)$ and the peak effect (PE) lines $H_p^{a,c}(T)$.

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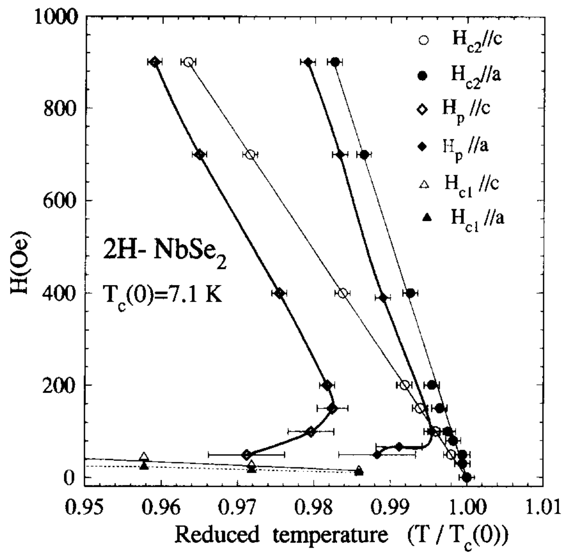

Fig. 1. Magnetic phase diagram of 2H-NbSe$_2$.

The $H_{c1}(T)$ values have been determined using deviation from linearity criterion on the isothermal $4\pi M$ versus H data recorded on a SQUID magnetometer and using a procedure described elsewhere [5]. The present values of $H_{c1}^{a,c}(0)$ are lower than those reported earlier in the literature [6], and $H_{c1}^{a,c}(T)$ data fit to the relationship $H_{c1}(0)(1-t^2)^{1/2}$. The $H_{c2}^{a,c}(T)$ values have been determined either by employing deviation from linearity criterion on isothermal normal state DC magnetisation response as the applied field values are lowered [5] or by identifying the temperatures of onset of the diamagnetic screening response in the in-phase AC susceptibility $\chi'(T)$ measurements. We find that near $T_c(0)$, the slope values $dH_{c2}^{a,c}/dT$ are smaller than those at higher fields. Using literature values [1, 6] of $H_{c2}^{a,c}(0)$ and the present values of $H_{c2}^{a,c}(t=0.97), H_{c1}^{a,c}(0), H_{c1}^{a,c}(t=0.97)$, we have estimated, using GL relationships [3], the values of $\xi^{a,c}, \lambda^{a,c}, \kappa^{a,c}$ summarised in Table 1.

The $H_p^{a,c}(T)$ lines in Fig. 1 correspond to the temperatures of anomalous negative peaks in $\chi'(T)$ data recorded at fixed H (see Fig. 2). The negative peak in a $\chi'(T)$ curve is a consequence of ubiquitous PE phenomenon in a weakly pinned FLL and is considered a fingerprint of collapse of its shear modulus [1]. The $H_p^{a,c}(T)$ curves track the respective $H_{c2}^{a,c}(T)$ curves from high H down to 200 Oe. However, at about 150 Oe, a turn around characteristic ($dT/dH > 0$ for $H < 150$ Oe) develops [4] and such a behaviour is strikingly similar to the predicted reentrant characteristic in the melting curve of a pure FLL [2, 3]. The intervortex spacing $a_0(a_0^2 = 2\Phi_0/\sqrt{3}B)$ at

Table 1
Intrinsic superconducting parameters of 2H-NbSe$_2$

$T/T_c(0)$	$H_{c2}^{a,c}$ (kOe)	$H_{c1}^{a,c}$ (Oe)	$\xi^{a,c}$ (Å)	$\lambda^{a,c}$ (Å)	$\kappa^{a,c}$
0	145, 56	128, 380	77, 27	1065, 4550	49, 14
0.97	1.51, 0.745	18, 27	666, 328	3055, 6830	10, 4.6

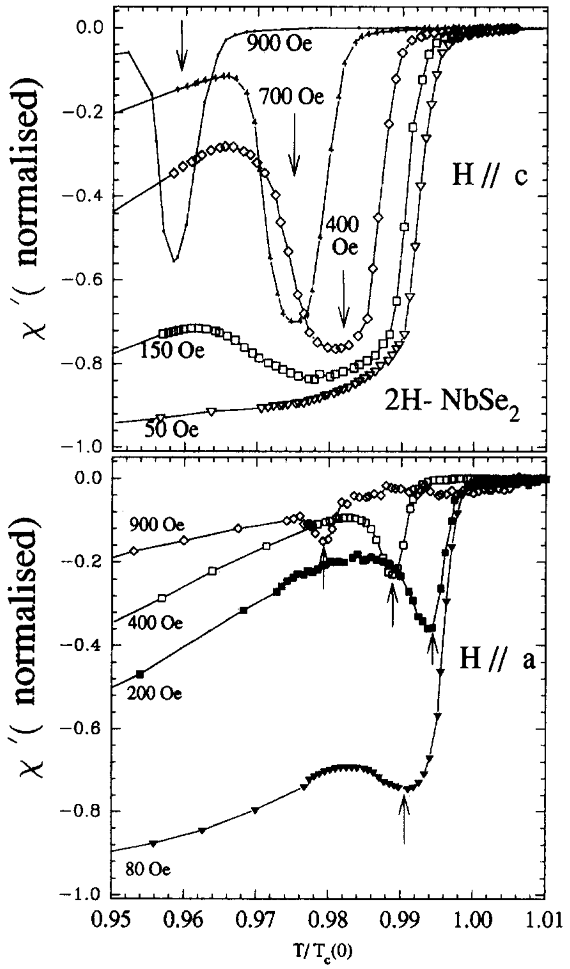

Fig. 2. $\chi'(T)$ curves of a frequency of 211 Hz showing peak effect phenomenon for $H \| c$ and $H \| a$ in 2H-NbSe$_2$.

turn around field of around 150 Oe is 4000 Å, which compares favourably with λ values listed in Table 1. The observed broadening of negative peak in χ' and its eventual disappearance at low $H(<50\,\mathrm{Oe})$ is believed to be a consequence of the crossover from interaction-dominated regime to disorder-dominated regime as a_0 exceeds λ values [4]. This speculation stands confirmed [7] from new data in an impure crystal of 2H-$NbSe_2$, where broadening of peak in χ' sets in below about 400 Oe and the reentrant characteristic in PE curve becomes elusive.

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