Disordered superconductivity in boron-doped nanocrystalline diamond

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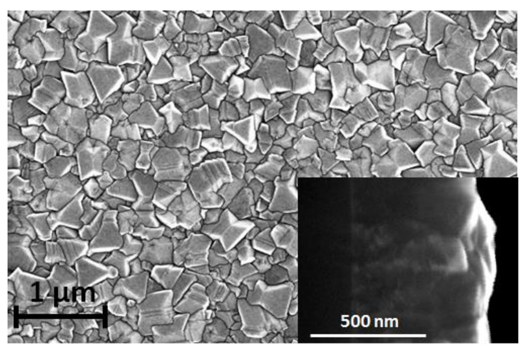
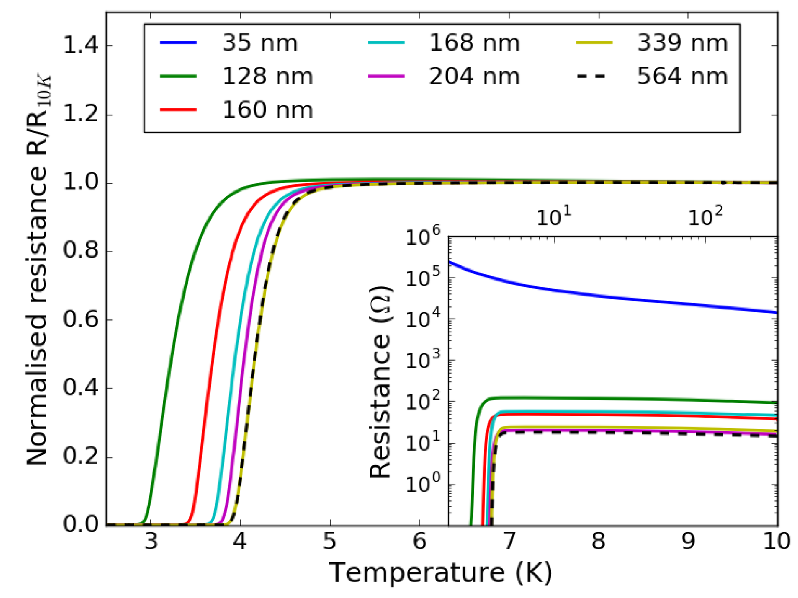
Boron-doped nanocrystalline diamond is a disordered superconductor linking fluctuation conductivity, glassy superconductivity, and phase slip-like transport.

n_B	T_c	H_{c2}	ξ	λ_L	$L_{k,\square}$
~10^{21} cm^{-3}	3 - 5 K	Up to ~8 T	~10 nm	~3.8 μm	680 pH/□

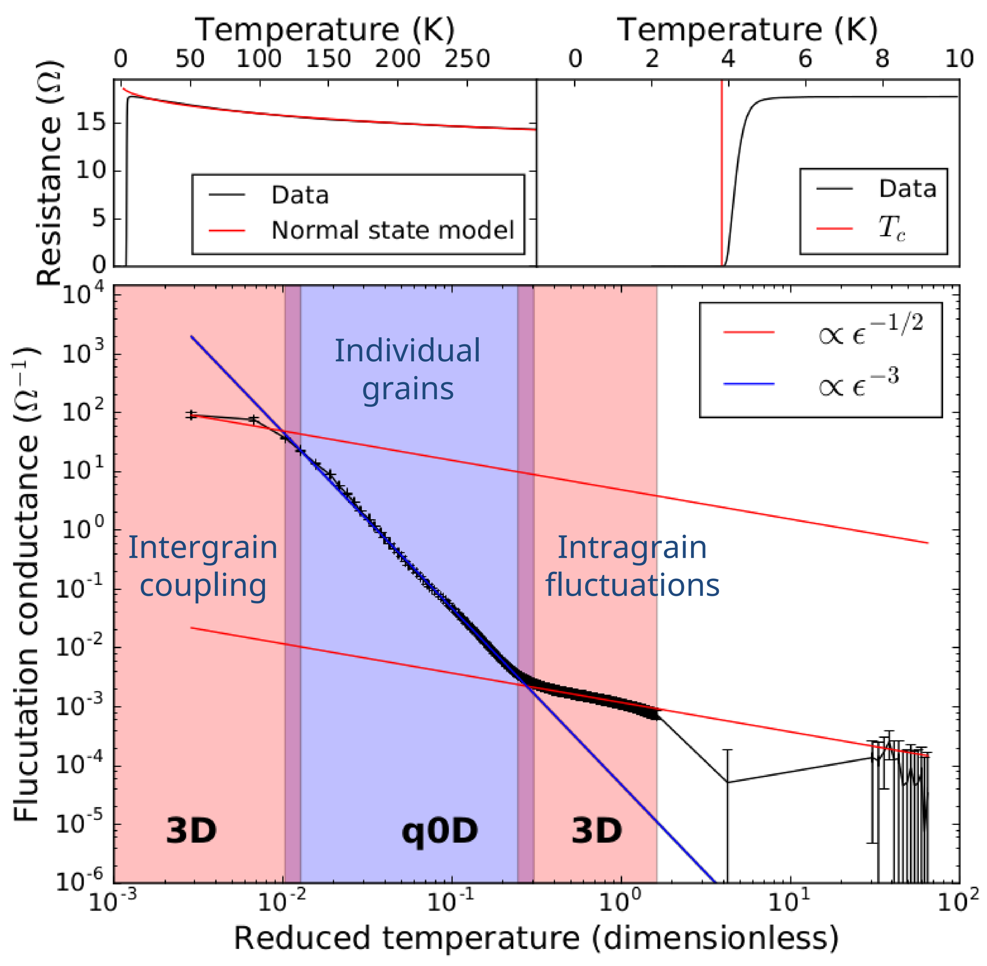


Fluctuation spectroscopy of BNCD



Thickness-varied BNCD films with fixed boron doping show systematic shifts in T_c, consistent with changes in nanocrystalline grain size.

Above T_c, the fluctuation conductivity follows the dimensional crossover predicted for granular superconductors [1,2].



$$G_{fl} = G - G_{ns}$$
$$G_{ns} = a + b\sqrt{T}$$
$$T_c: G_{fl} \to \infty$$

LVV prediction for granular superconductors [1]:

$$\frac{d\ln\sigma_{fl}}{d\ln\epsilon} = \begin{cases} -\frac{1}{2} \ (3D) & \epsilon \lesssim \epsilon_t \\ -3 \ (q0D) & \epsilon_t \lesssim \epsilon \lesssim \epsilon_g \\ -\frac{1}{2} \ (3D) & \epsilon_g \lesssim \epsilon \lesssim 1 \end{cases}$$

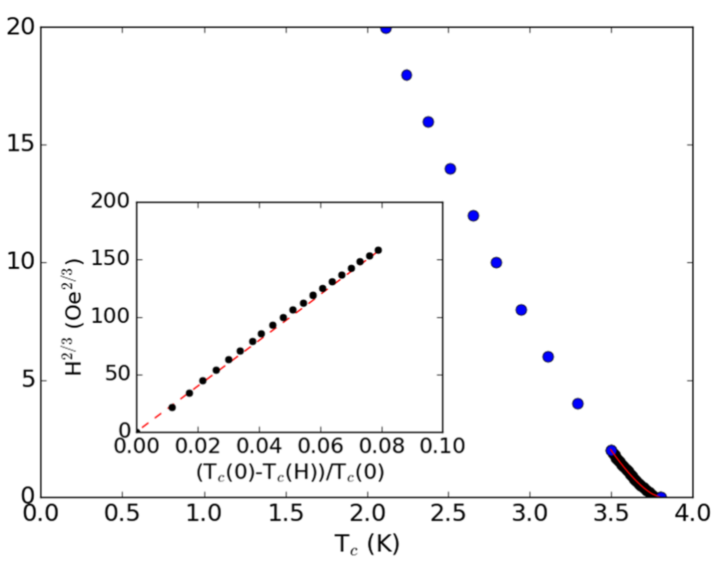
where

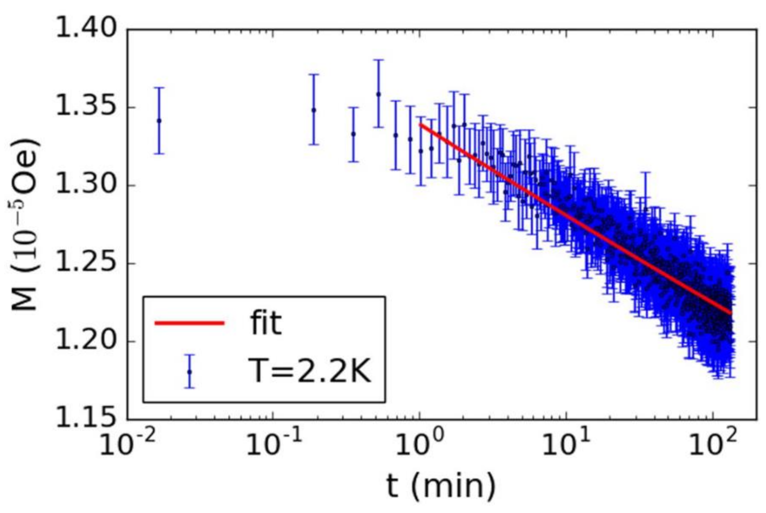
$$\epsilon = (T - T_c)/T_c$$
$$\epsilon_g = E_{Th}/(k_B T_c), \epsilon_t = \Gamma/(k_B T_c)$$

The crossover positions can be tracked across the film series to estimate the Thouless and tunnelling energy scales, giving spectroscopic access to intra- and intergrain transport parameters.

Glassy superconductivity

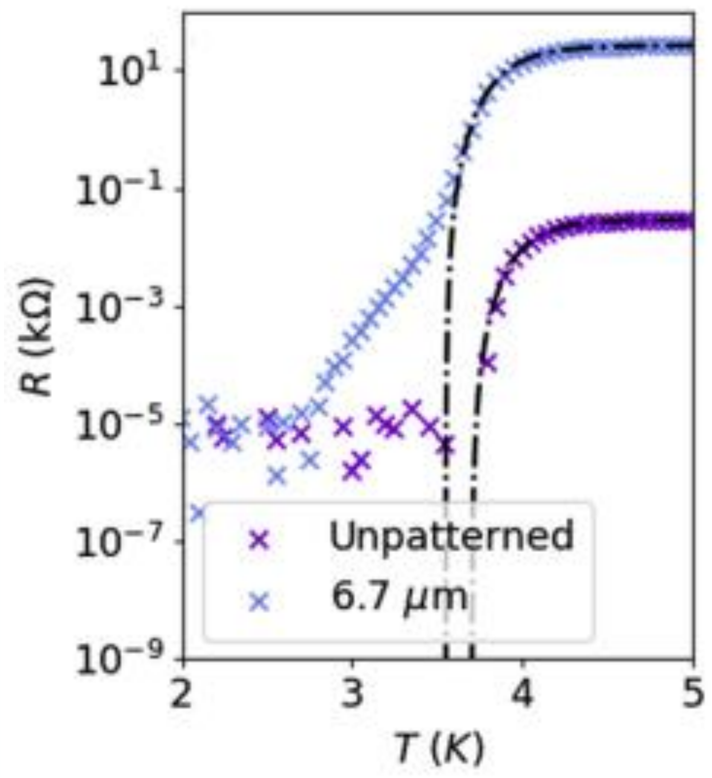
Fluctuation analysis of magnetoresistance curves gives a precise $T_c(H)$, allowing the $H - T$ phase boundary to be mapped without relying on onset/midpoint/offset criteria [3].

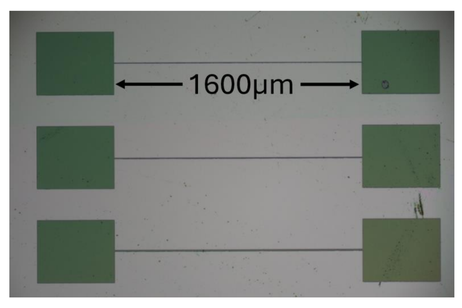




The H–T boundary follows a quasi de Almeida–Thouless form, and magnetisation measurements show logarithmic relaxation, consistent with superconducting glass behaviour in BNCD.

Phase slip-like transport in wide BNCD microbridges



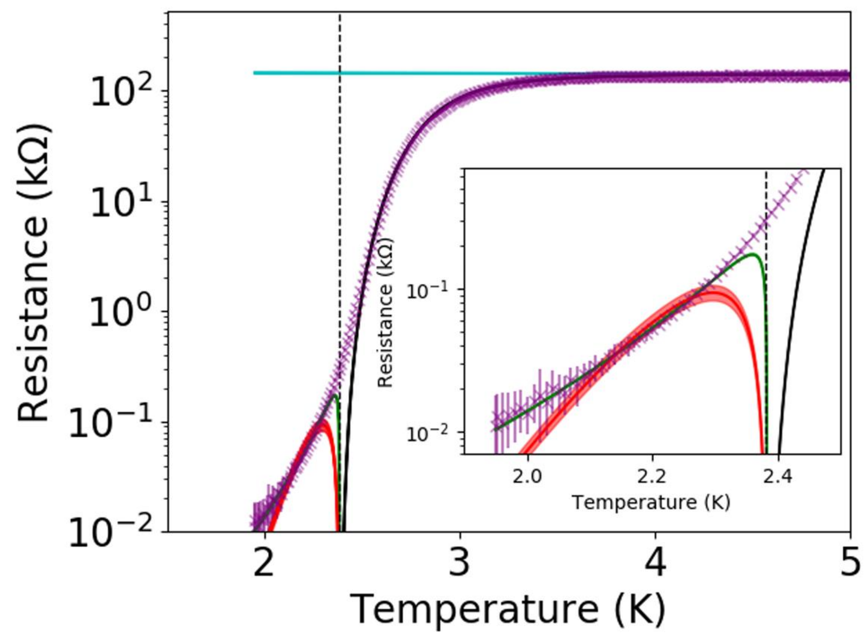


w = 4.6-6.7μm ≫ ξ~10nm

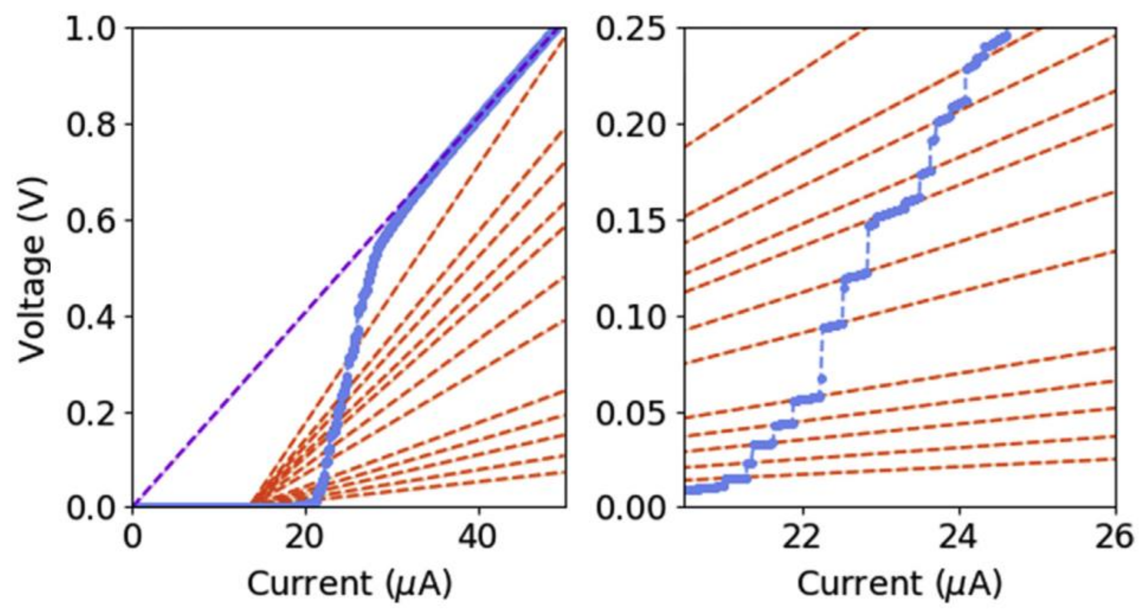
Micron-wide BNCD bridges show a residual resistance below T_c [4]. These devices are hundreds of times wider than the conventional 1D phase slip limit.

Residual resistance is QPS-like

The residual resistance is better described by a QPS-like phenomenological model than by thermally activated phase slips [5]. This is an effective description of phase slip-like dissipation, not conventional 1D nanowire QPS.

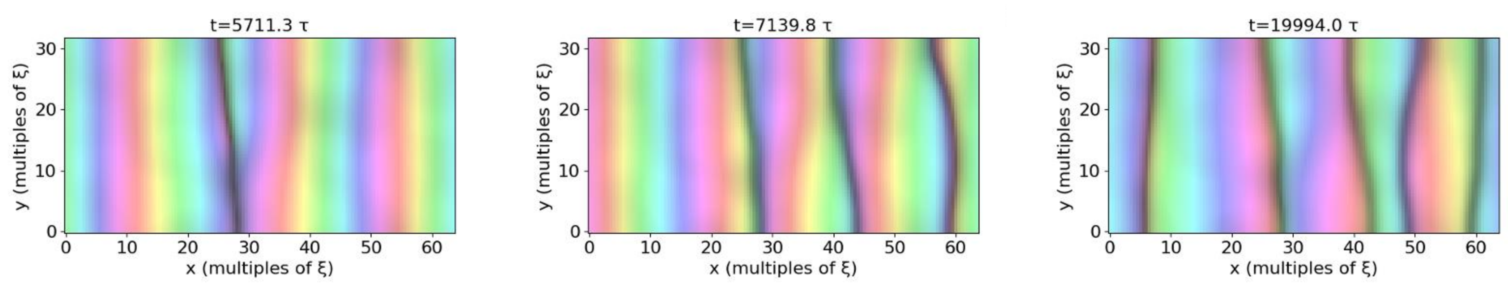


Discrete finite-voltage branches



The finite-voltage branch breaks into discrete steps. Linear fits extrapolate towards common current-axis intercepts, consistent with phase slip-like dissipative regions forming within the bridge [4].

Phase slip line interpretation



TDGL simulations support voltage-carrying states formed by phase slip lines spanning the bridge width. Higher-voltage states correspond to additional phase-slip lines [6].

BNCD links fluctuation spectroscopy, superconducting-glass behaviour and phase-slip-like transport in a single disordered superconducting material system. Patterned wide microbridges show dissipative states consistent with phase slip line transport outside the conventional 1D nanowire limit.

References

[1] I. V. Lerner, A. A. Varlamov and V. M. Vinokur, *Phys. Rev. Lett.* **100**, 117003 (2008).
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[4] G. M. Klemencic et al., *Carbon* 175, 43–49 (2021).
[5] J. J. Bennett et al., manuscript under review (2026).
[6] G. M. Klemencic et al., manuscript in preparation (2026).