One-dimensional superconductivity in 0.4 nm single-walled carbon nanotubes

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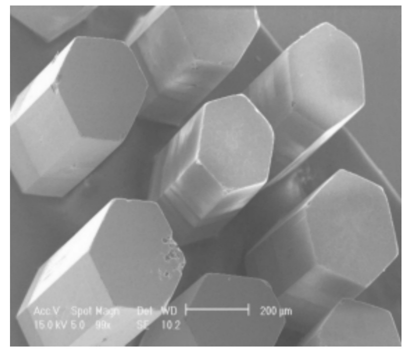
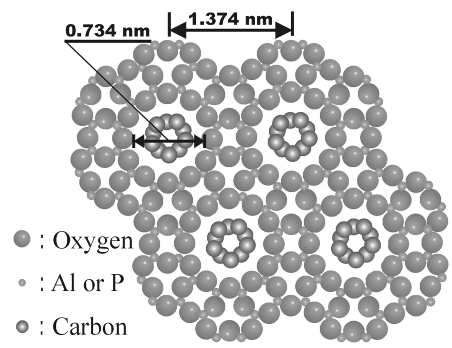
We report the observation of superconductivity in mono-sized ultra-small (0.4 nm in diameter) single-walled carbon nanotubes (SWNTs) [1]. These SWNTs were prepared by pyrolysis of tripropylamine molecules in the channels of porous zeolite $AlPO_4$-5 (AFI) single crystals [2]. Fig. 1 (a) shows the SEM image of the nanotube-contained AFI single crystals. The framework structure of the AFI single crystal viewed along (001) direction, in shown in Fig. 1 (b). The carbon nanotubes structure is also schematically shown in the channels. Because these SWNTs are highly aligned and uniform in size, they show interesting electrical transport properties. Local density functional calculations indicate that when the diameter of the SWNT is smaller than 0.5 nm, strong curvature effects induce strong σ-π mixing of the unoccupied orbitals, which leads to novel electronic properties departing from the prediction of the band-folding theory for large-sized SWNTs [3]. The induced curvature opens new electron-phonon scattering channels that increases the electron-phonon coupling and makes the small tubes superconducting. Investigation of the magnetic and electric transport properties of the 0.4 nm SWNTs revealed that at temperatures below 20 kelvin, the ultra-small tubes exhibit superconducting behavior manifest as an anisotropic Meissner effect, with a superconducting gap and fluctuation supercurrent. Fig. 2 is the normalized magnetic susceptibility of the SWNTs plotted as a function of temperature for five values of the magnetic field (experimental: filled circles, theoretical: open circles). The measured superconductivity exhibits one-dimensional (1D) fluctuations, and displays smooth temperature variations with a mean-field super-conducting transition temperature of 15 K. The data are consistent with the manifestations of a 1D BCS (phonon-mediated) superconductor. Statistical mechanic calculations based on the Ginzburg-Landau free energy functional yield predictions that are in excellent agreement with the experiments.



(a)



(b)

Fig. 1 (a) The SEM image of the nanotube-contained AFI single crystals, (b) the framework structure of the AFI single crystal viewed along (001) direction, carbon nanotubes structure is also schematically shown in the channels.

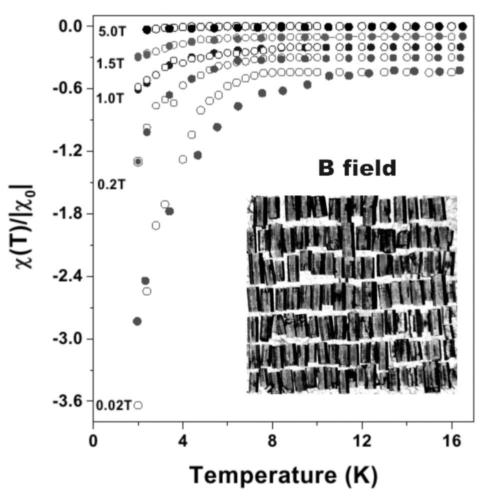


Fig. 2. Normalized magnetic susceptibility of the SWNTs plotted as a function of temperature for five values of the magnetic field. Experimental values (filled circles) and theoretical predictions for the fluctuation super-current (open circles) are shown. The inset shows the aligned nanotube samples and the direction of applied magnetic field.

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[2]. N. Wang, Z. K. Tang, G. D. Li, J. S. Chen, *Nature* **408**, 50 (2000).
[3]. Z. M. Li, Z. K. Tang, H. J. Liu, N. Wang, and C. T. Chan, R. Saito, S. Okada, G. D. Li, J. S. Chen, *Phys. Rev. Lett.* **87**, 127401 (2001).