The design of high-T_c superconductors: universal behavior from thermodynamics to applied properties

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Cuprate and iron pnictide high-T_c superconductors exhibit a rich and subtle phase behavior which complicates both their understanding and their application. We would like to understand them not just for fundamental reasons but to optimise and improve their applied properties. Despite the continuing challenge to achieving a full microscopic understanding of these materials the application of principles of thermodynamics allows us to make generic statements about their behaviour. Working from electronic specific heat data we show that these are near weak-coupling BCS-like superconductors (with the pairing boson yet to be fully established) but subject to strong fluctuations which depress both T_c and the critical current density J_c. Thermodynamics also accounts fully for the effects of impurity scattering. We then focus on the superfluid density and show that this is the key parameter that governs fluctuation effects, critical currents and irreversibility fields. From these relations there emerge several universal scaling relations which allow us to understand in detail the scope and limits to practical performance of these remarkable materials. Some of the results are surprising e.g. the critical current density in the superconducting state scales with the conductivity or electronic entropy in the normal state. These results, in turn, provide a set of design principles to improve on current conductors. This talk traverses both fundamental and applied properties and finishes with a number of current applications and implementations of high-T_c superconductors.

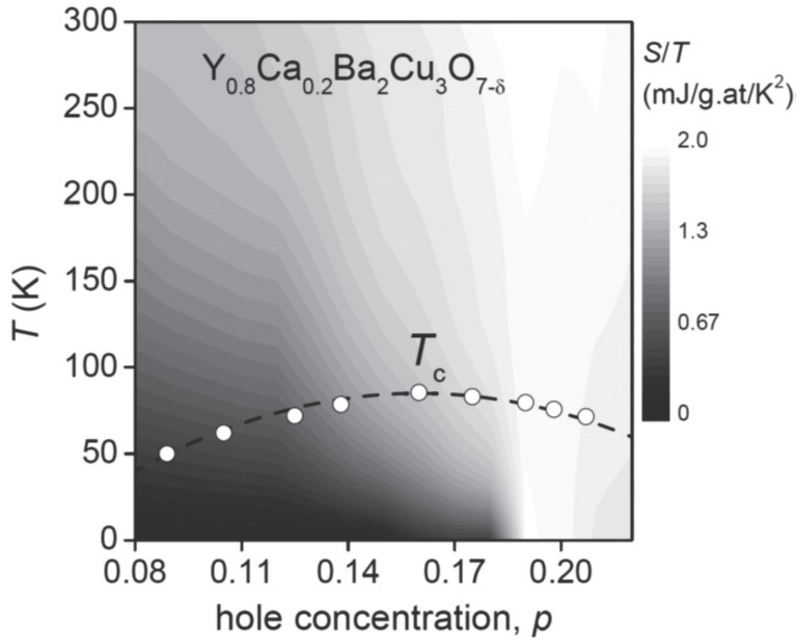

Fig. 1. False-shade plot of the normal-state electronic entropy, S, for $Y_{1-x}Ca_xBa_2Cu_3O_y$. This property, with its sharply peaked behavior a little off to one side of the phase diagram, plays a key role in determining many important properties in high-T_c superconductors including the critical current density.