Doping of high-T_c superconductors by carrier injection

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The generic structure of high-T_c superconductors is a stacking sequence of superconducting planes separated by so-called charge reservoir layers. It is well known that carrier doping of these materials is achieved either by substitution of atoms or by nonstoichiomety in the charge reservoir layer. However, the alternating type of stacking causes yet another two important consequences. First, the transport anisotropy of these materials is so high, that in the superconducting state the c-axis transport is governed by the intrinsic Josephson effect, and second, as the transport across the doping layers is accomplished by tunneling, the kinetic energy of carriers can exceed by far the drift velocity of thermalized transport, and can even overcome the threshold energy of charge trapping in the charge reservoir layers. Therefore, a substantial amount of charge can be deposited only by injecting large c-axis currents.

In hole-doped materials, by charge compensation, this increases the concentration of (mobile) holes in the conducting layers of the crystal. In this sense, doping appears as intrinsic field effect. It is interesting to test this interpretation by carrier injection into electron-doped materials. Here, the deposition of negative charge should lead to a decrease of the concentration of mobile electrons. We were able to confirm this idea by our recent experiments of carrier injection into 1111 pnictides, like fluorine-doped LaOFeAs, and into 1048 pnictides, like pure and Pt-doped $(CaFeAs)_{10}Pt_4As_8$.

Carrier injection is a fully electronic type of doping. It can be nicely characterized by normal resistance, superconducting critical temperature, interlayer critical current, and, especially, by the quantities characteristic for the Josephson effect, including the parameters from macroscopic quantum tunneling, like bare Josephson plasma frequency, and thermal-to-quantum crossover temperature. Our most spectacular results include the creation of high-T_c superconductivity in oxygen-depleted, non-superconducting $Bi_2CaSr_2Cu_2O_{8+\delta}$ and the spectacular increase of critical temperature by carrier injection into overdoped 1111 as well as 1048 pnictide superconductors. In hole-doped materials, our systematic doping experiments revealed a drastic increase of the interlayer capacitance. Apparently, carrier doping significantly increases the effective thickness of the superconducting layer while the thickness of the insulating region is decreased.