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Influence of transition metal substitutions on the normal and superconducting state properties of high temperature superconductors

The substitution of transition metal ions into host material is often used to probe the properties of superconductors. Dopants may introduce localized magnetic moment and may influence the magnetic properties of materials, they may modify the band structure and the density of states, or may increase the scattering of carriers. In the case of multiband materials the scattering may affect the type of order parameter due to the coupling of quasiparticles excitations to different pockets of the Fermi surface.

In this work the properties of two types of high temperature superconductors doped with transition metal ions are investigated. The polycrystalline samples of cuprate superconductor, $La_{1.85}Sr_{0.15}Cu_{1-y}Ni_yO_4$ ($0 \leq y \leq 1$), are prepared by the standard solid-state reaction method. These samples are used both as the objects of measurements, and as the targets for pulsed laser deposition of thin films, with y content in the range $0 \leq y \leq 0.09$. The samples of iron chalcogenide have a form of single crystals, grown by Bridgman's method, with composition $Fe_{1-y}M_yTe_{0.65}Se_{0.35}$ (M = Co, Ni, Cu), and y content in the range $0 \leq y \leq 0.21$. In addition, in the case of Co and Ni impurities, two types of crystals with different crystalline quality, prepared using different cooling rates, are examined. The broad impurity doping and large pool of samples provides reliable assessment of the influence of impurities on the properties of these superconductors.

The study of the doped cuprate reveals that Ni substitution into Cu-site induces a magnetic moment, which remains constant and equal to 0.7 μ_B per Ni ion up to $y \sim 0.07$, while for larger y it increases abruptly and reaches the value of about 1.6 μ_B per Ni ion. The substitution suppresses superconductivity at $y \sim 0.038$, and leads to a metal-insulator transition at $y \sim 0.07$. It also affects the temperature of the pseudogap opening, which begins to decreases for $y > 0.05$ and disappears close to metal-insulator transition at about $y \approx 0.07$. These observations suggest that both the suppression of the pseudogap, and the metal-insulator transition, may be caused by spin scattering induced by increasing concentration of the Ni^{2+} ions in the high-spin ($S = 1$) state. On the other hand, the superconductivity dissapears at significantly smaller y than the pseudogap, so either these two effects are unrelated, or superconductivity is more strongly affected by impurity-induced scattering than the pseudogap.

In the case of iron chalcogenides impurities do not introduce any magnetic moment but affect the concentration and mobility of the carriers. The differences between the transport properties of slow and fast-cooled crystals are observed, most likely caused by non-superconducting inclusions in the slow-cooled crystals. The evaluation of the fast-cooled crystals indicates that the low-temperature Hall coefficient R_H changes sign to negative for crystals with y exceeding 0.135 (Co) and 0.06 (Ni), consistent with the electron doping induced by these impurities. Superconducting transition temperature T_c approaches zero for $y \approx 0.14$ (Co) and 0.03 (Ni), while the resistivity at the T_c onset is only weakly affected by Co doping, but it increases strongly for the Ni. The analysis based on a two-band model suggests that at high T residual hole pockets survive the doping, but holes get localized upon the lowering of temperature, so that the effect of the electron doping on the transport becomes evident. The suppression of the T_c by Co impurity is related to electron doping, while in the case of the Ni impurity strong electron localization most likely contributes to fast decrease of the T_c.