Discovery of Quantum Phase Transition in Pressurized Cuprate Superconductors

The discovery of cuprate high-temperature superconductors in 1986 impacted science and technology considerably and continues to fascinate the communities of condensed matter physics and material sciences because they host the highest ambient-pressure superconducting transition temperature and unconventional electronic behavior. However, the underlying mechanism of the superconductivity is yet an unsolved mystery. Searching for the universal links between the superconducting state and its neighboring quantum states is believed to be an effective approach to elucidate the high-temperature superconducting mechanism.

Recently, Prof. SUN Liling's team from the Institute of Physics (IOP), Chinese Academy of Sciences, in collaboration with Profs. XIANG Tao, ZHOU Xingjiang and HU Jiangping from IOP, Prof. GU Genda from Brookhaven National Laboratory and Prof. LIN Cheng-Tian from the Max Planck Institute for Solid State Research, found the pressure-induced quantum transition from superconducting state to insulating-like state in bismuth-based cuprate superconductors, through their precise *in-situ* high-pressure measurements. These experimental results reveal that the observed quantum phase transition is universal in the bismuth-bearing cuprate superconductors, regardless of the doping level and the number of CuO_2 planes in a unit cell.

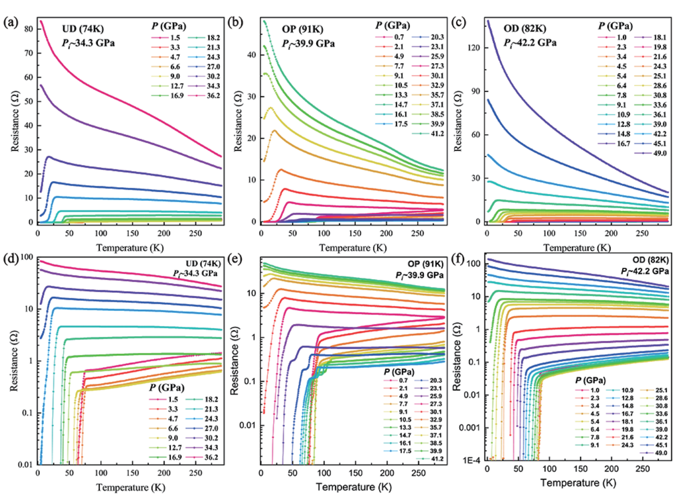

Figure 1: Temperature dependence of in-plane resistance for $Bi_2Sr_2CaCu_2O_{8+\delta}$ at different pressures. (a) and (d) are the plots of temperature versus resistance with linear and log scales for the under-doped (UD) superconductor; (b) and (e) for the optimally-doped (OP) sample, the two-step superconducting transition demonstrates a crossover from two-dimensional to three-dimensional superconducting phases in the pressure range of 4.9–23.1 GPa, in good agreement with our previous studies [*Nature* Physics 16(2020)295]; (c) and (f) for the over-doped (OD) sample.

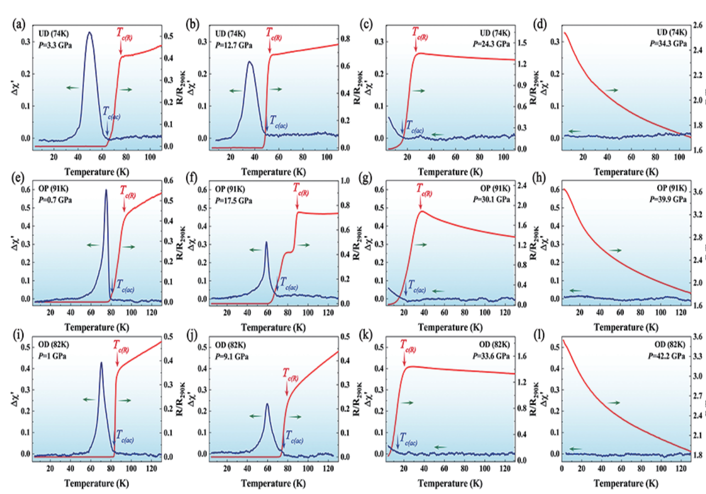

Figure 2: In-plane resistance (R) and ac susceptibility ($\Delta\chi'$) as a function of temperature (T) for the $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductors at different pressures: (a)-(d) for the under-doped (UD) superconductor; (e)-(h) for the optimally-doped (OP) superconductor; (i)-(l) for the over-doped (OD) superconductor. The blue lines in the figures are the data of $\Delta\chi'$(T), while the red lines are the data of R(T). The red and blue arrows indicate the temperatures of the onset superconducting transition detected by resistance and ac susceptibility measurements, respectively.

It is a grand surprise that the system even enters into an insulating-like state after the superconductivity is fully suppressed, given the well-known fact that the ground state of the over-hole-doped non-superconducting cuprate is a metallic state, and generally one would expect increased bandwidth induced by rises in pressure. In other words, the system should become more metallic-, instead of insulating-like. The anti-intuitive discovery of the universal quantum transition provides a fresh challenge and a new opportunity for better understanding the mechanism of superconductivity in these materials.

This study, entitled "Quantum phase transition from superconducting to insulating-like states in a pressurized cuprate superconductor," has been published in *Nature Physics* [18(2022)406] (https://doi.org/10.1038/s41567-022-01513-2).

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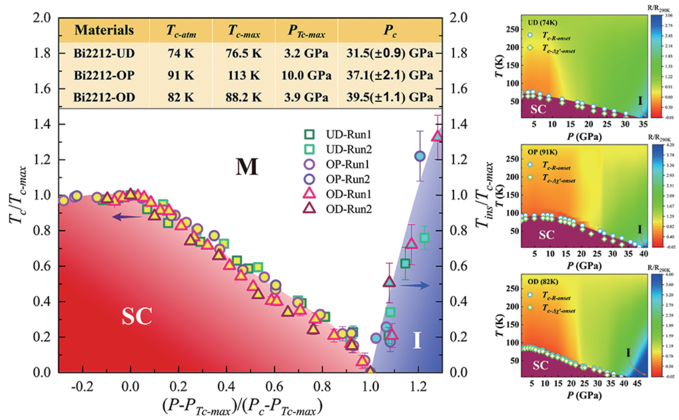

Figure 3: Pressure-T_c phase diagrams for $Bi_2Sr_2CaCu_2O_{8+\delta}$ superconductors. The Right panels are the phase diagrams established by the experimental results from the under-doped (UD), optimally-doped (OP) and over-doped (OD) samples, together with the mapping information of temperature and pressure dependent R (shown in color scale). The left panel is a normalized phase diagram that is built on the basis of the experimental phase diagrams (the right panels).

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