Hydrostatic pressure effect on the pseudogap in slightly doped $Y_{0.77}Pr_{0.23}Ba_2Cu_3O_{7-\delta}$ single crystals

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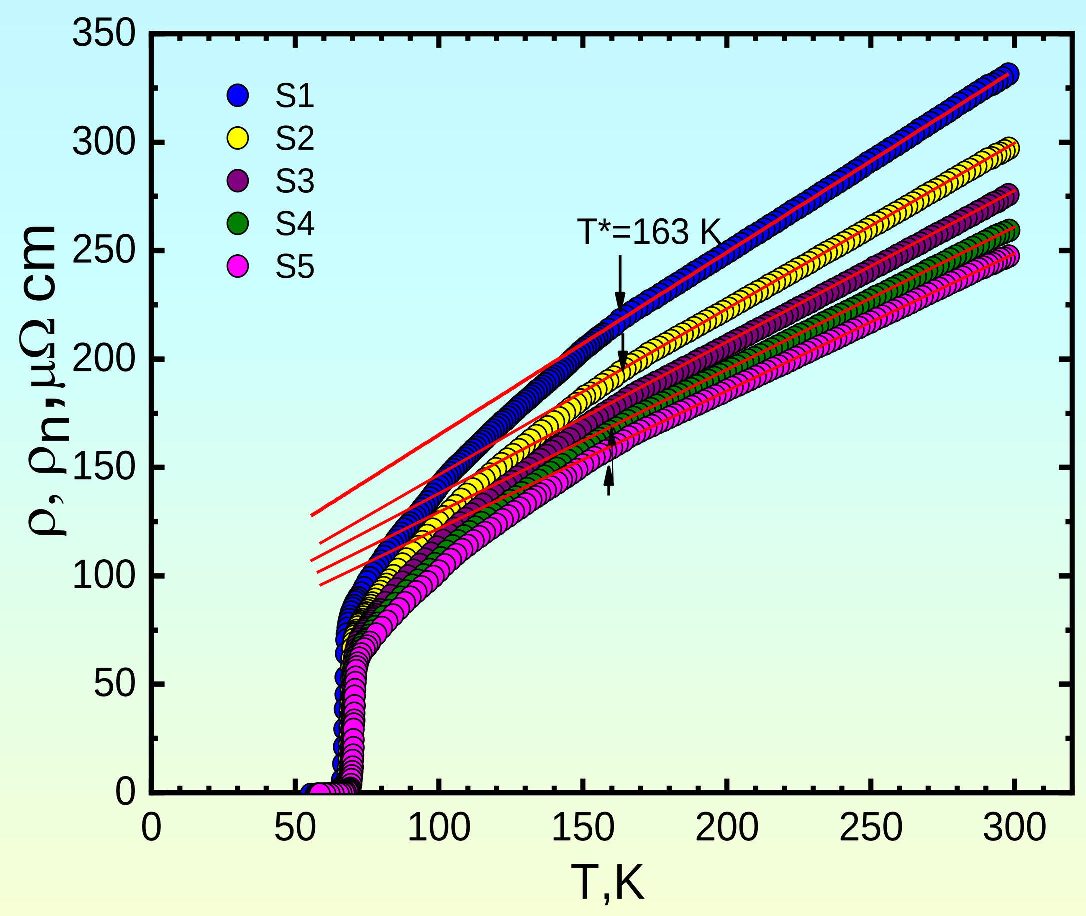
Introduction and motivation

The discovery of high-temperature superconductors (HTSCs) is undoubtedly one of the landmark events in modern solid state physics. However, despite the efforts of numerous scientific groups and an extraordinary number of publications on HTSCs, the mechanism of superconducting (SC) pairing, which makes it possible to obtain Cooper pairs at T >> 100 K, is still not clear. The pseudogap (PG) state, which is opened in cuprate HTSCs below the characteristic temperature $T^* >> T_c$, is one of the most mysterious and simultaneously interesting phenomena in modern solid state physics. It is well established that in HTSCs, the PG is observed when the charge carrier concentration varies between slightly doped (SD) and optimally doped levels. Understanding the PG physics would definitely shed more light on the mechanism of superconducting pairing in HTSCs, which is also not fully clarified yet. The $YBa_2Cu_3O_{7-\delta}$ cuprate is believed to be the most reliable material for studying the PG, especially when high pressures is applied.

Temperature dependences of the resistivity of slighly doped $Y_{0.77}Pr_{0.23}Ba_2Cu_3O_{7-\delta}$ single crystals ($T_c \approx 66.4$ K) at different pressure. The arrows designate T^*.



$$\rho_N(T) = \alpha T + \beta$$

α, β - const

$$\sigma'(T) = \frac{1}{\rho(T)} - \frac{1}{\rho_N(T)}$$

S1 = 0; S2 = 0.41 GPa; S3 = 0.64 GPa; S4 = 0.87 GPa; S5 = 1.1 GPa

***Table.** Resistive and fluctuation conductivity parameters (FLC) parameters of $YPrBa_2Cu_3O_{7-\delta}$ single crystal at different presure.*

GPa	ρ(300K) μΩ(cm)	ρ(100K) μΩ(cm)	T_c (K)	T_c^{mf} (K)	T_o (K)	T_{01} (K)	T_G (K)	d_{01} (A)	$\xi_c(0)$ (A)	Gi
0	331.24	141.16	66.4	67.55	68.0	74	67.6	3.18	1.00	0.0007
0.41	296.9	124.6	68.25	69.18	70.0	76.4	69.3	3.88	1.2	0.0017
0.64	275.6	113.2	68.91	69.85	70.2	75.4	69.9	3.18	0.90	0.0007
0.87	259.3	108.3	69.07	70.18	70.6	75.7	70.3	3.3	0.89	0.0017
1.1	247.36	102.14	69.7	70.55	70.9	76.1	70.7	3.41	0.884	0.0021

Dependences of excess conductivity $\sigma'(T)$ versus the reduced temperature ε in double logarithmic scale for S1 and S5 in the range of SC fluctuations near T_c in comparison with fluctuation theories:

3D Aslamazov-Larkin (AL) (red straight lines)

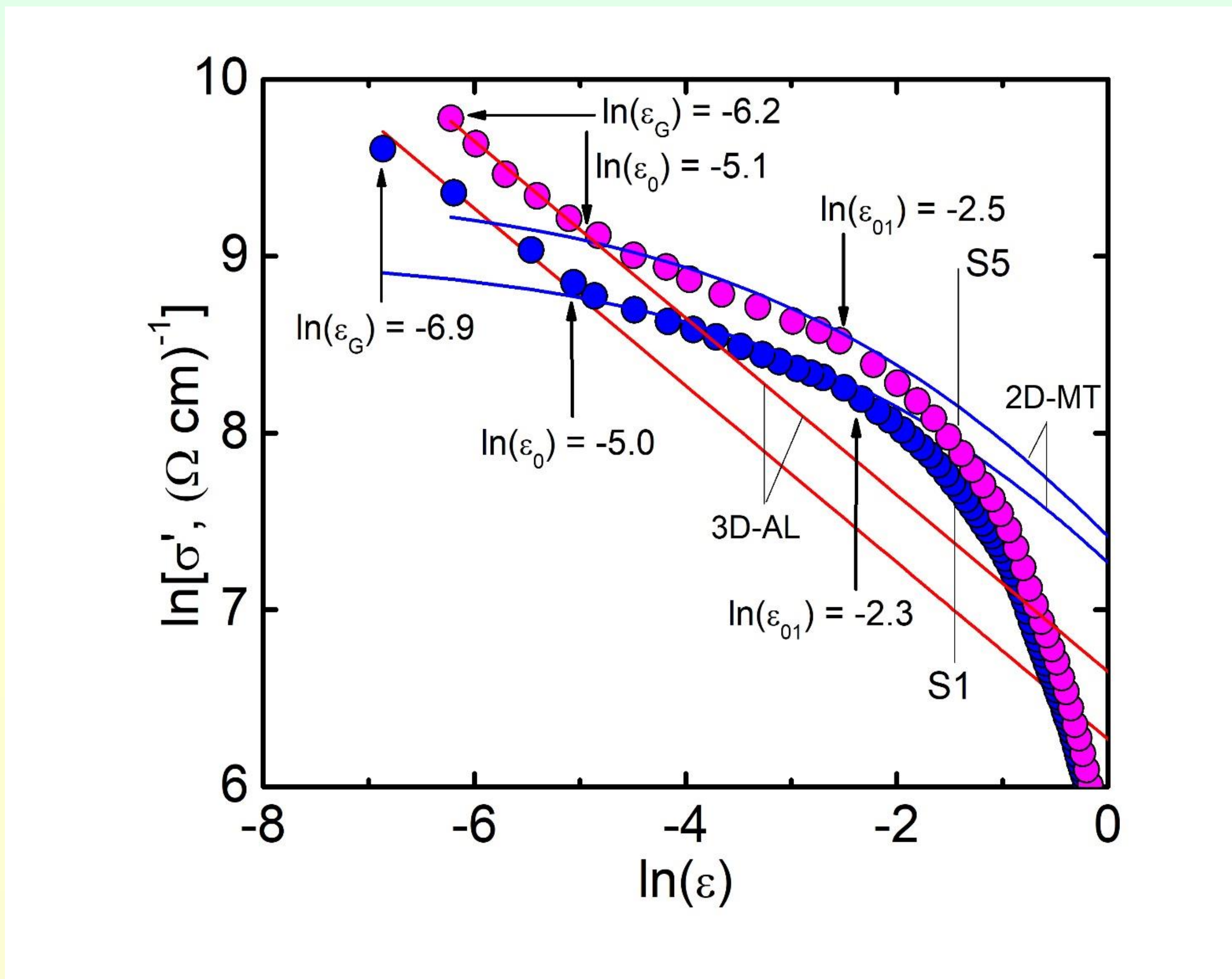
$$\sigma'_{AL} = \frac{e^2}{32\hbar\xi_c}\varepsilon^{-1/2}$$

2D Maki-Thompson (MT) (blue curves)

$$\sigma'_{MT} = \frac{e^2}{8d\hbar}\cdot\frac{1}{1-\alpha/\delta}\cdot \ln\left((\delta/\alpha)\cdot\frac{1+\alpha+\sqrt{1+2\alpha}}{1+\delta+\sqrt{1+2\delta}}\right)\cdot\varepsilon^{-1}$$

L. G. Aslamazov and A. L. Larkin, Phys. Lett., 26A, 238 (1968).

All characteristic temperatures T_G, T_0 and T_{01} are marked with arrows.



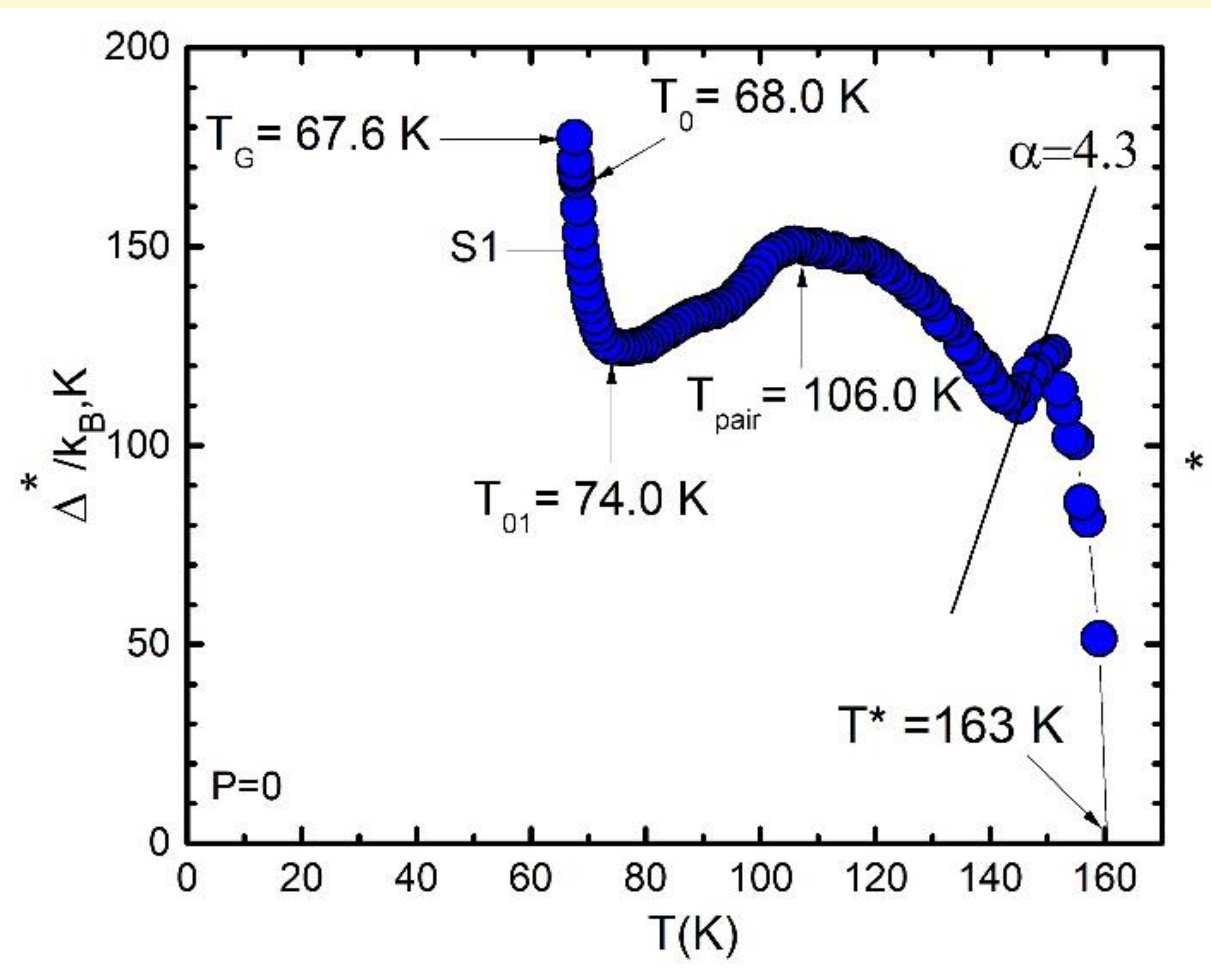
Main results

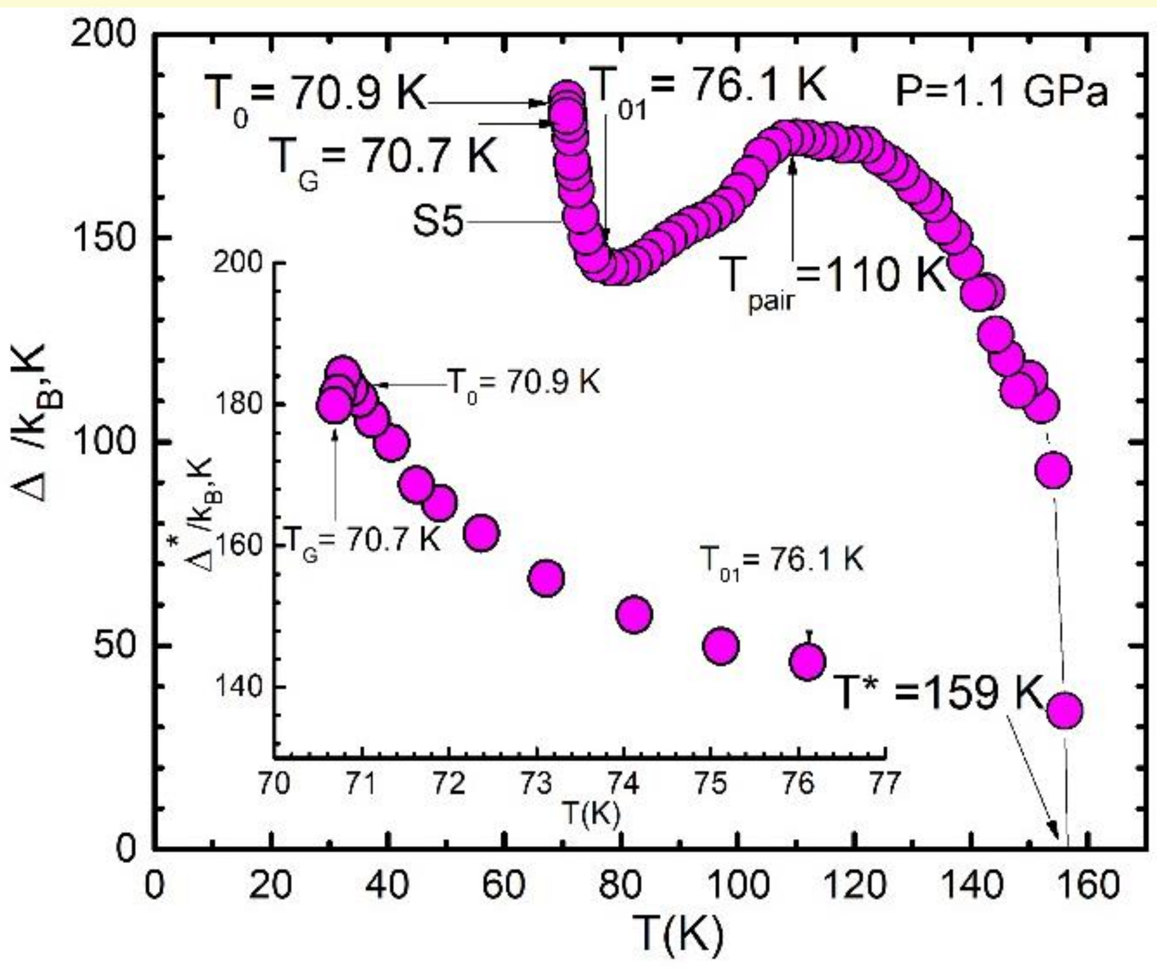
Temperature dependences of the pseudogap $\Delta^*(T)$

$$\Delta^*(T) = T\ln\frac{e^2 A_4\left(1-\frac{T}{T^*}\right)}{\sigma'(T)16\hbar\xi_c(0)\sqrt{2\varepsilon^*_{c0}}\sinh(2\varepsilon/\varepsilon^*_{c0})}$$

Solovjov A.L. Superconductors – Materials, Properties and Applications. Chapter 7: Pseudogap and local pairs in high-Tc superconductors, Ed. A.M. Gabovich / A. L. Solovjov // Rijeka. – 2012. – P. 137-170

for the as-grown SD $Y_{0.77}Pr_{0.23}Ba_2Cu_3O_{7-\delta}$ single crystals (0 and 1.1 GPa).
Inset shows $\Delta^*(T)$ in the range from T_G down to T_{01}. The arrows indicate the corresponding characteristic temperatures.





Conclusions

In our work, for the first time, we carried out the analysis of the influence of hydrostatic pressure up to 1.1 GPa on the temperature dependence of pseudogap $\Delta^*(T)$ of the SD $Y_{0.77}Pr_{0.23}Ba_2Cu_3O_{7-\delta}$ single crystals.

It is shown that the pressure effect on T_c and resistivity $\rho(T)$ is different. Under pressure, $\rho(T)$ decreases, while T_c increases, which is associated with the redistribution of charge carriers in the CuO_2 planes.

It is demonstrated that under pressure, the $\Delta^*(T)$ increases with a rate $d\ln\Delta^*/dP$ = 0.9 GPa^{-1}, which is most likely due to a decrease in the frequencies of the phonon spectrum of the superconductor when pressure is applied.

It is revealed that without pressure, a “magnetic” maximum occurs on the $\Delta^*(T)$ at high temperatures, followed by a linear section with a positive slope, limited by the temperatures of structural transition T_S and spin density wave ordering T_{SDW}. At 1.1 GPa, the maximum disappears.