STUDY OF THE PSEUDOGAP TEMPERATURE DEPENDENCE IN YBCO FILMS IN MAGNETIC FIELDS UP TO 8 T

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INTRODUCTION

It is believed that understanding the mechanism of electron pairing in high-temperature superconductors (HTSCs) will indicate the direction of synthesis of superconductors with a desired high T_c. For this, it is necessary to study the properties of HTSCs, especially cuprates, in the normal state, where the pseudogap (PG) is opened at $T^{*} >> T_c$ [1, 2]. It is worth noting that the PG state refers to a range of temperatures and energies where the density of states in a superconductor is reduced, but superconductivity is not yet fully developed. This state near T_c is sensitive to the influence of a magnetic field, which can further modify the transport properties of a HTSC. Obviously, applying of an external magnetic field is one of the promising methods to study superconducting properties of cuprate HTSCs.

In our work, we studied a high quality 100 nm-thick YBCO film with T_c = 88.7 K in zero magnetic field (Fig. 1). Resistive measurements were carried out in a magnetic field up to 8 T in B||ab configuration (Fig. 2).

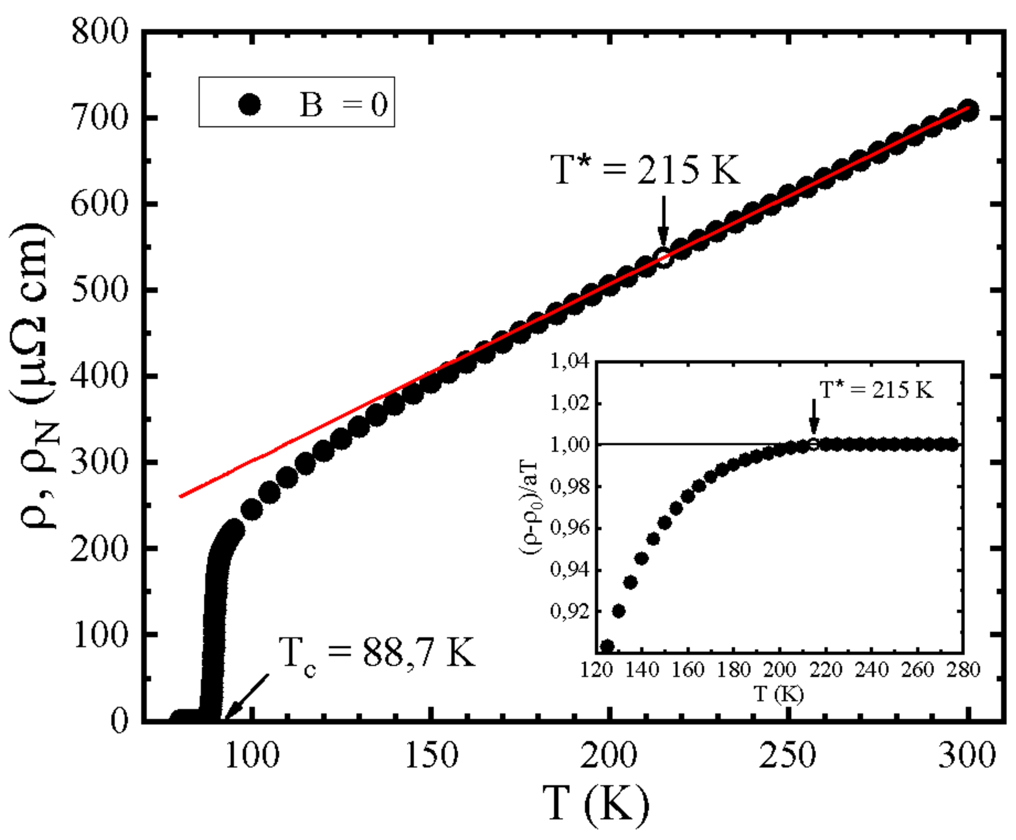

Fig.1. Temperature dependence of ρ for $YBa_2Cu_3O_{7-\delta}$ film in the absence of external magnetic field (B = 0, dots). The solid red line defines $\rho_N(T)$ extrapolated to the low-temperature region. The open circle corresponds to temperature T^*. Inset: method for determining T^* using the criterion $[\rho(T) - \rho_0]/aT = 1$.

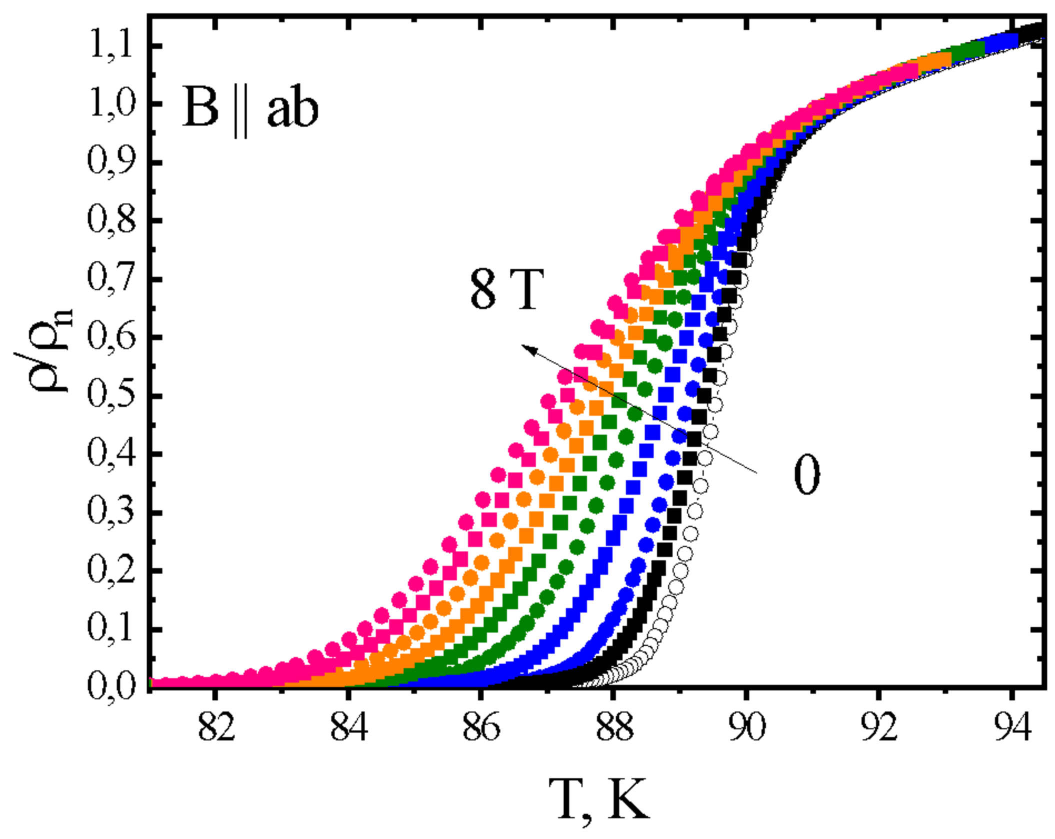

Fig.2. Temperature dependences of ρ in units of (ρ/ρ_N) of the $YBa_2Cu_3O_{7-\delta}$ film, obtained for the field oriented parallel to the *ab*-plane ($B \parallel ab$, B = 0, 0.5, 1, 2, 3, 4, 5, 6, 7 and 8 T). ρ_n =203 μΩ·cm at T = 92.3 K is a normal state resistivity in the vicinity of the SC transition..

PSEUDOGAP ANALYSIS

It is well-known that the normal state of HTSCs above T^* is characterized by the linear temperature dependence of the resistivity $\rho(T) = \rho_{ab}(T)$ (red straight line in Fig. 1). In resistive measurements, excess conductivity $\sigma'(T)$ arises as a result of the PG opening leading to the deviation of $\rho(T)$ at $T \le T^*$ from the linearity towards lower values (see Fig. 1), which allows us to determine T^*. Accordingly, the excess conductivity is given by the equation:

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

where $\rho_N(T) = aT + \rho_0$ is the resistivity of the sample in the normal state, extrapolated to the low temperature range. Accordingly, a determines the slope of the linear dependence $\rho_N(T)$, and ρ_0 is the residual resistance cut off by this line along the Y axis at T = 0.

In our approach, in order to explicitly describe the PG temperature dependence $\Delta^*(T)$ under the influence of external magnetic fields, we use an equation proposed within the framework of the local pair (LP) model [1, 2], to describe the experimentally measured $\sigma'(T)$:

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

In this case, the dynamics of pair formation (1 – T/T) and pair breaking (exp[–Δ*(T)/T]) above T_c are taken into account. Here, T is a current temperature, T* is a PG opening temperature, A_4 is a numerical factor, $\xi_c(0)$ is a coherence length along the c-axis, ε is a reduced temperature, ε^*_{c0} is a theoretical parameter, $\Delta^*(T) = \Delta^*(T_G)$. All this parameters can be determine from the experiment.*

Using 3D Aslamasov-Larkin and 2D Maki-Thompson conventional fluctuation theories, we know how to determine mean-field critical temperatures T_c^{mf}, responsible for ε, and $\xi_c(0)$ [3]. Therefore, here the problem was reduced to finding the appropriate values of A_4, ε^*_{c0} and $\Delta^*(T_G)$. Fig.3 shows some of the corresponding sets of σ'(T) calculated for different H. *Having obtained reliable data of the fitting parameters, we plotted series of Δ*(T,B) (Fig. 4), using corresponding equation for Δ*(T) [1-3].*

To determine the density of local pars at different B, we compared the results in the vicinity of T_c with the Peters-Bauer (PB) theory [4] (Fig. 5).

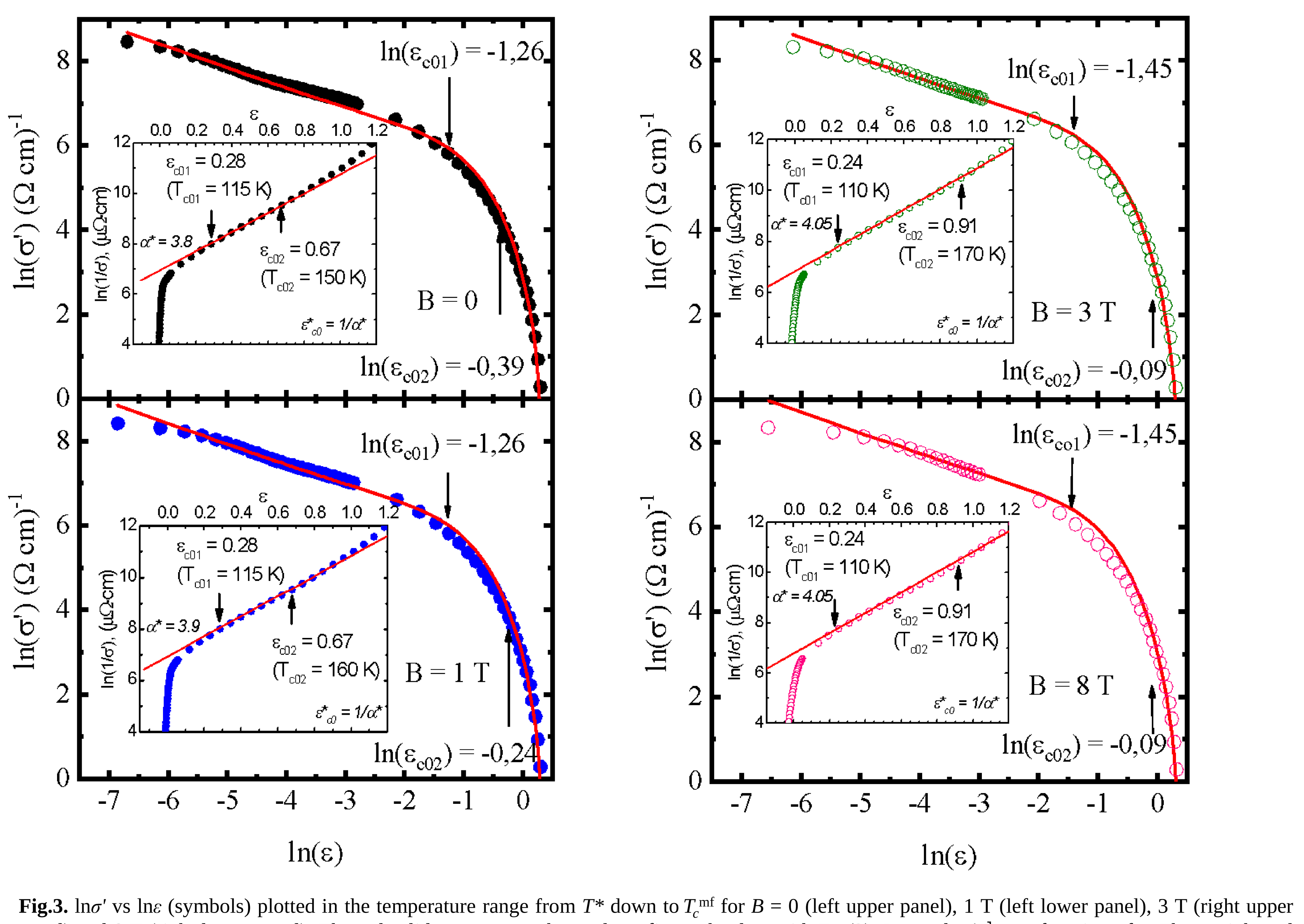

Fig.3. lnσ′ vs lnε (symbols) plotted in the temperature range from T^* down to T_c^{mf} for B = 0 (left upper panel), 1 T (left lower panel), 3 T (right upper panel) and 8 T (right lower panel). The red solid curves at each panel are fits to the data with Eq.(2). Insets: $\ln\sigma'^{-1}$ as a function of ε. The straight red lines denote the linear parts of the curves between ε_{c01} and ε_{c02}. The slope α* determines the parameter $\varepsilon^*_{c0} = 1/\alpha^*$

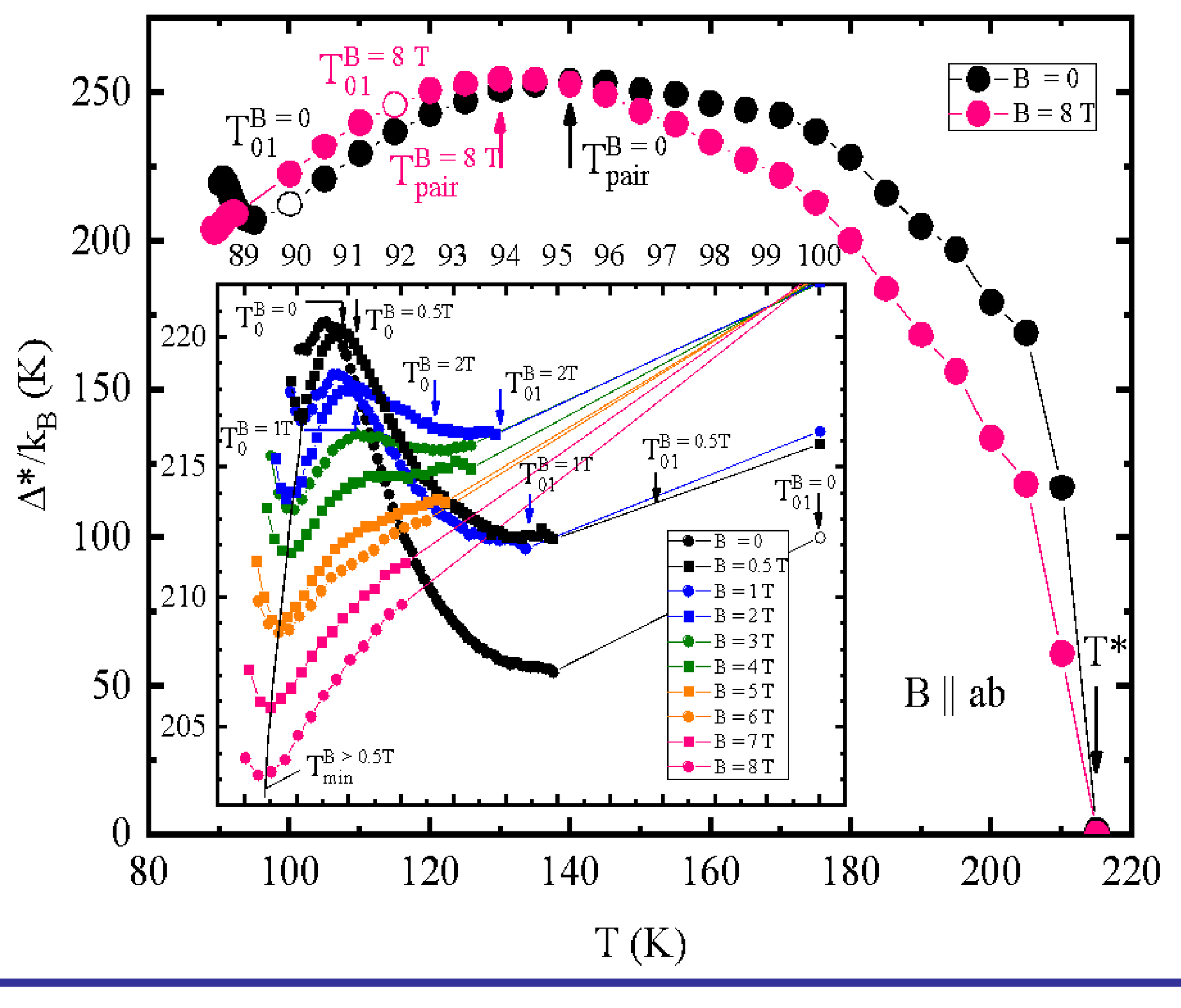

Fig.4. Pseudogap Δ^* as a function of T of the $YBa_2Cu_3O_{7-\delta}$ film, calculated by Eq. (3) for B = 0 (black dots) and 8 T (pink dots). Empty circles indicate the characteristic temperature T_{01}, which limits the range of SC fluctuations from above (also in the inset for B = 0). Inset: The same dependences for the temperature interval $T_G < T < T_{01}$ for B = 0, 0.5, 1, 2, 3, 4, 5, 6, 7 and 8 T. The scales in the inset have the same dimensions as the main figure. All characteristic temperatures, both on the main panel and in the insert, are indicated by arrows. The leftmost symbol of each curve is T_G which limits SC fluctuations from below. The auxiliary black curve in the inset helps to trace the field evolution of the low temperature minimum T_{min} that appears at B > 0.5 T. The other solid curves are drawn to guide the eyes.

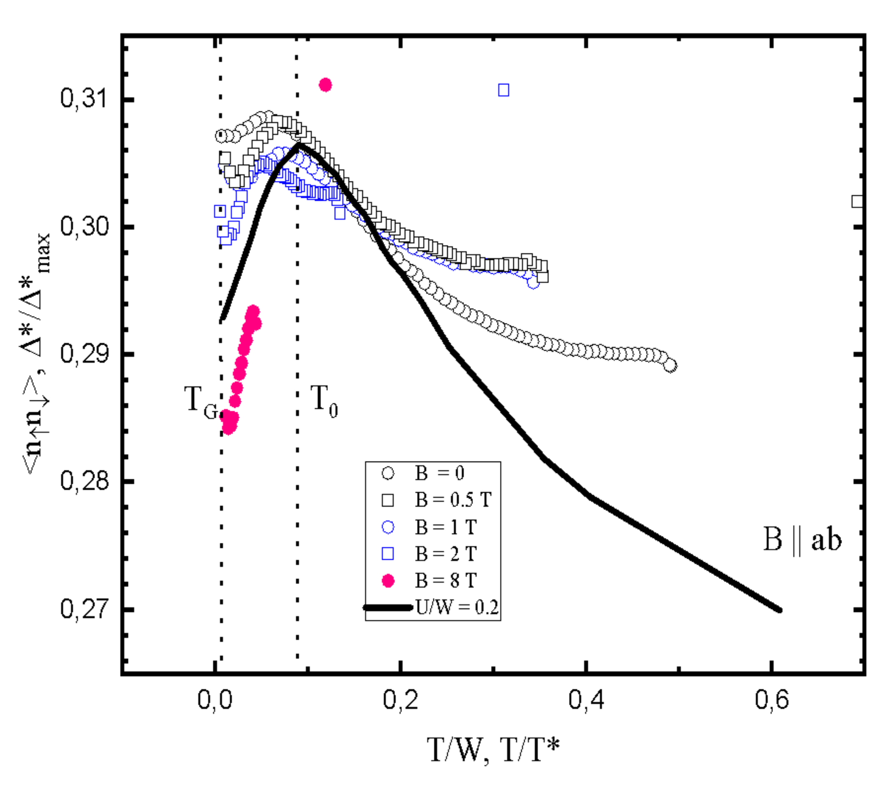

Fig.5. Δ^*/Δ^*_{max} as functions of T/T^* near T_c for the magnetic fields B = 0 (black circles), 0.5 (black squares), 1 (blue circles), 2 (blue squares) and 8 T (pink dots) compared with the theoretical dependence of $<n_\uparrow n_\downarrow>$ on T/W at U/W = 0.2 (black curve). The dashed lines indicate the temperatures T_0/T^* and T_G/T^*.

Conclusion

In the region of SC fluctuations near T_c, the magnetic field begins to reduce values and change the behavior of $\Delta^*(T)$. The decrease in $\Delta^*(T_G)$ with increasing field turns out to be also unusual. Indeed, the $\Delta^*(T_G)$ field dependence consists of two linear sections with the same slope but shifted by ~ 1 T at B > 2 T. The revealed behavior correlates with changes in several other sample parameters at B > 2 T, suggesting that pair breaking is not the only factor in the influence of the magnetic field.

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