INFLUENCE OF STRONG MAGNETIC FIELDS ON THE TEMPERATURE DEPENDENCE OF PSEUDOGAP IN YBCO FILMS

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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 H||ab configuration (Fig. 1 and 2).

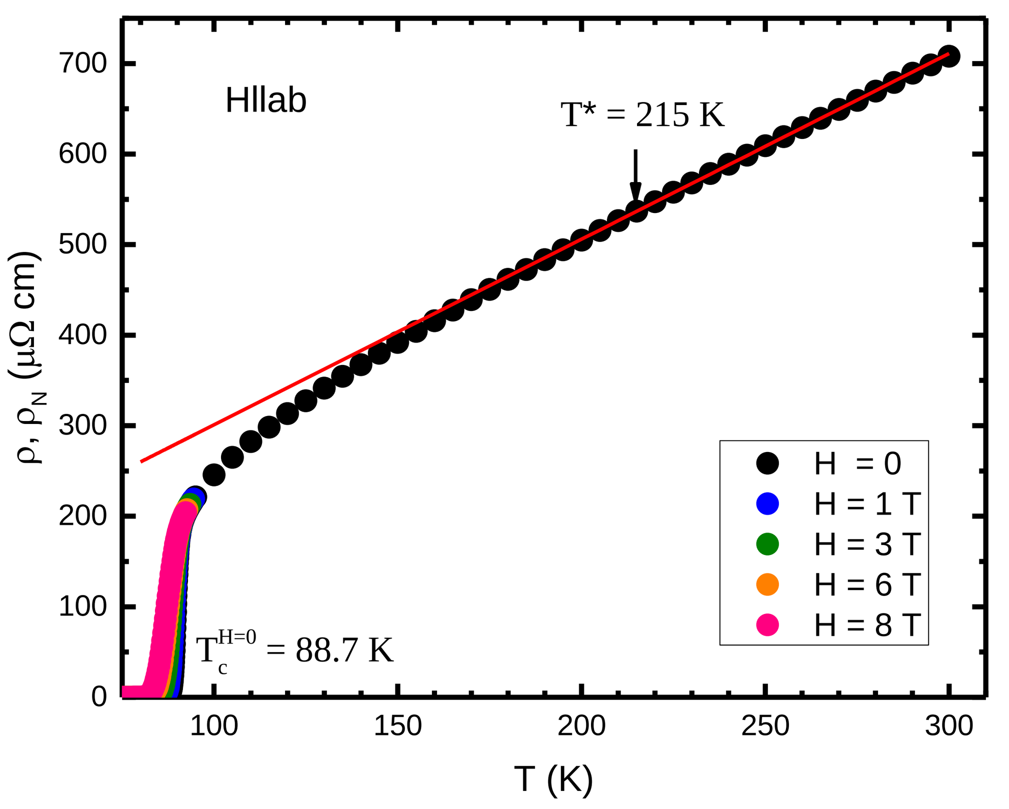

Fig.1. In-plane resistivity $\rho(T)$ of the 100 nm-thick YBCO film as a function of T for different values of an applied magnetic field up to 8 T. The red line designates extrapolated normal-state resistivity $\rho_N(T)$. The arrow defines T^* for the sample.

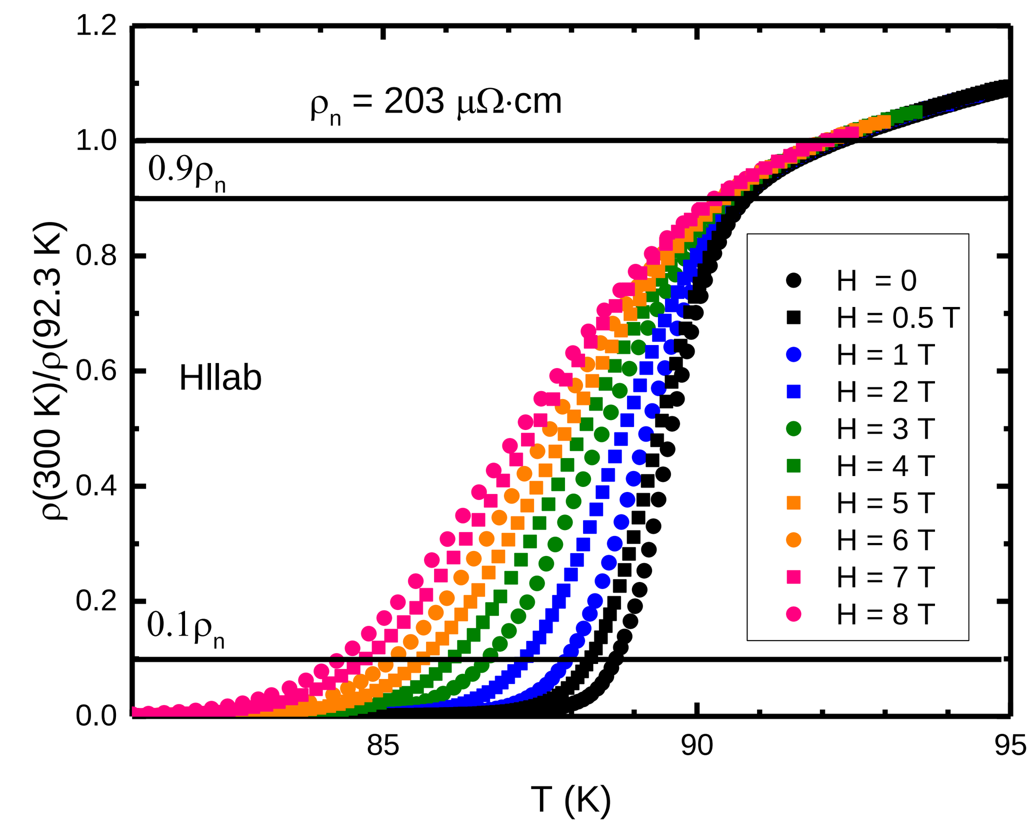

Fig.2. Normalized resistivity of the studied sample in the range of superconducting transition for different values of an applied magnetic field up to 8 T. The horizontal lines (0.9 ρ_n) and (0.1 ρ_n) help to determine onset and offset values of T_c, respectively, where ρ_n is the resistivity, below which the superconducting transition debegins.

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 $\rho_N(T) = \underline{a}T + \rho_0$ is the resistivity of the sample in the normal state, extrapolated to the low temperature range. Accordingly, $\underline{a}$ 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 $\sigma'(T)$ calculated for different H. Having obtained reliable data of the fitting parameters, we plotted series of $\Delta^*(T,H)$ (Fig. 4), using corresponding equation for $\Delta^*(T)$ [1-3].

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

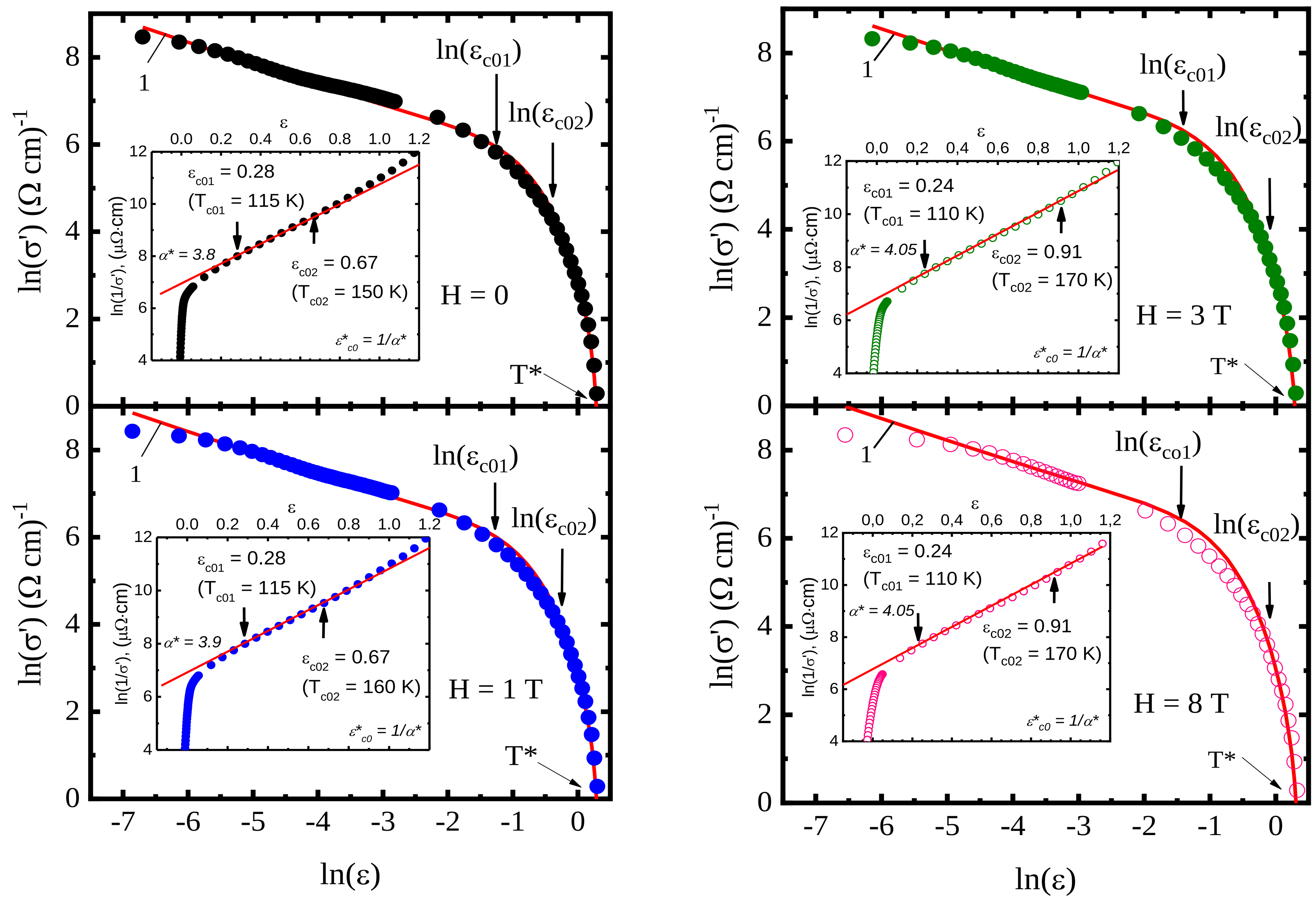

Fig.3. Dependences of lnσ′ vs lnε of the studied 100 nm-thick YBCO film plotted in the whole temperature range from T^* down to Ginzburg temperature T_G at different magnetic fields (0, 1, 3 and 8 T) in comparison with Eq.(2) (solid red curves 1). Down to T_G, *designated as ln(ε$_G$) in the figure*, the mean-field theory operate with decreasing T. Insert: $ln\sigma^{-1}$ as a function of ε. Solid line indicates the linear part of the curve between ε_{c01} and ε_{c02}. Corresponding $ln\varepsilon_{c01}$ and $ln\varepsilon_{c02}$ are marked by arrows in the main panel. The slope α^* determines the parameter $\varepsilon^*_{c0} = 1/\alpha^*$.

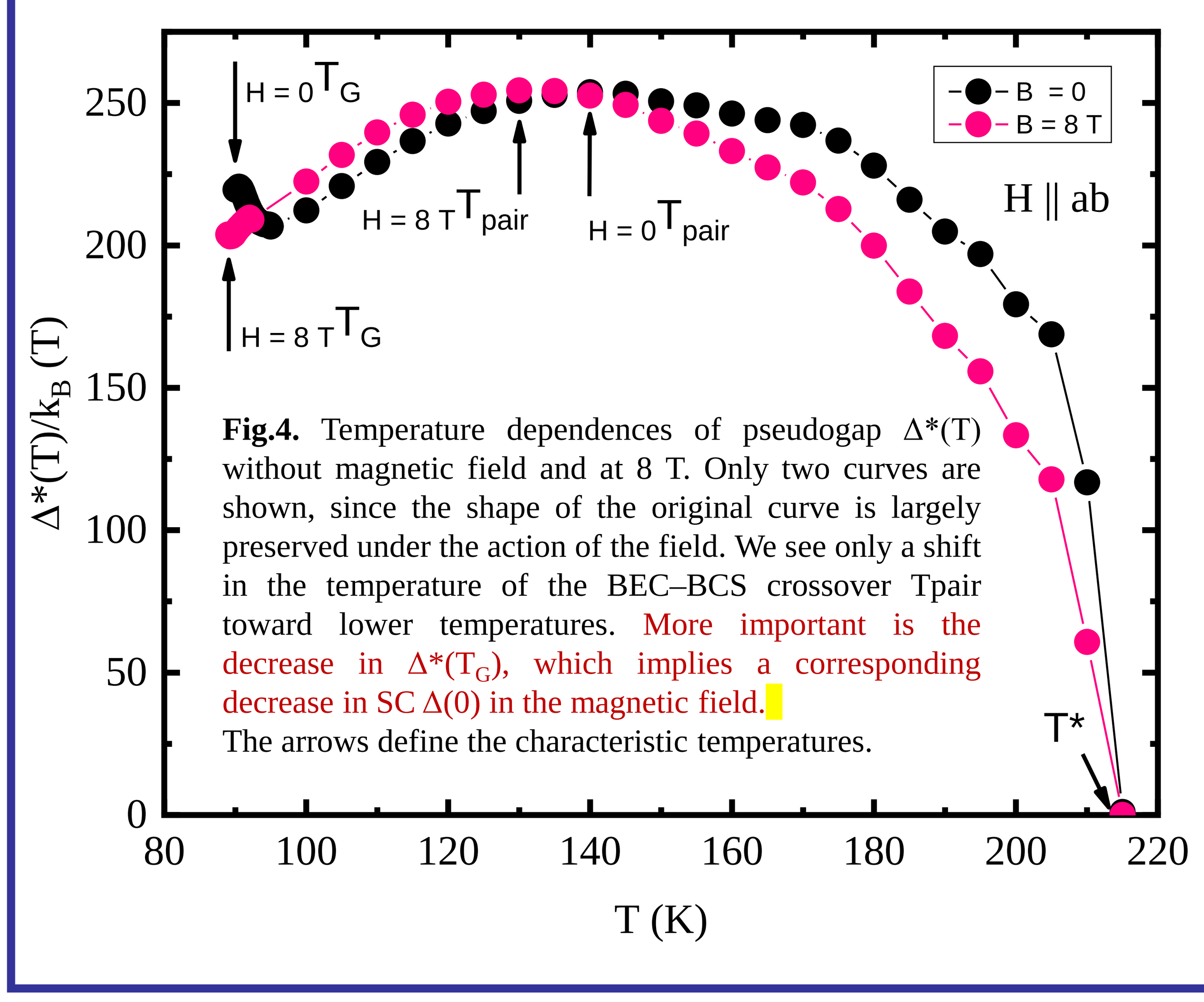

Fig.4. Temperature dependences of pseudogap Δ*(T) without magnetic field and at 8 T. Only two curves are shown, since the shape of the original curve is largely preserved under the action of the field. We see only a shift in the temperature of the BEC–BCS crossover Tpair toward lower temperatures. More important is the decrease in $\Delta^*(T_G)$, which implies a corresponding decrease in SC Δ(0) in the magnetic field.
The arrows define the characteristic temperatures.

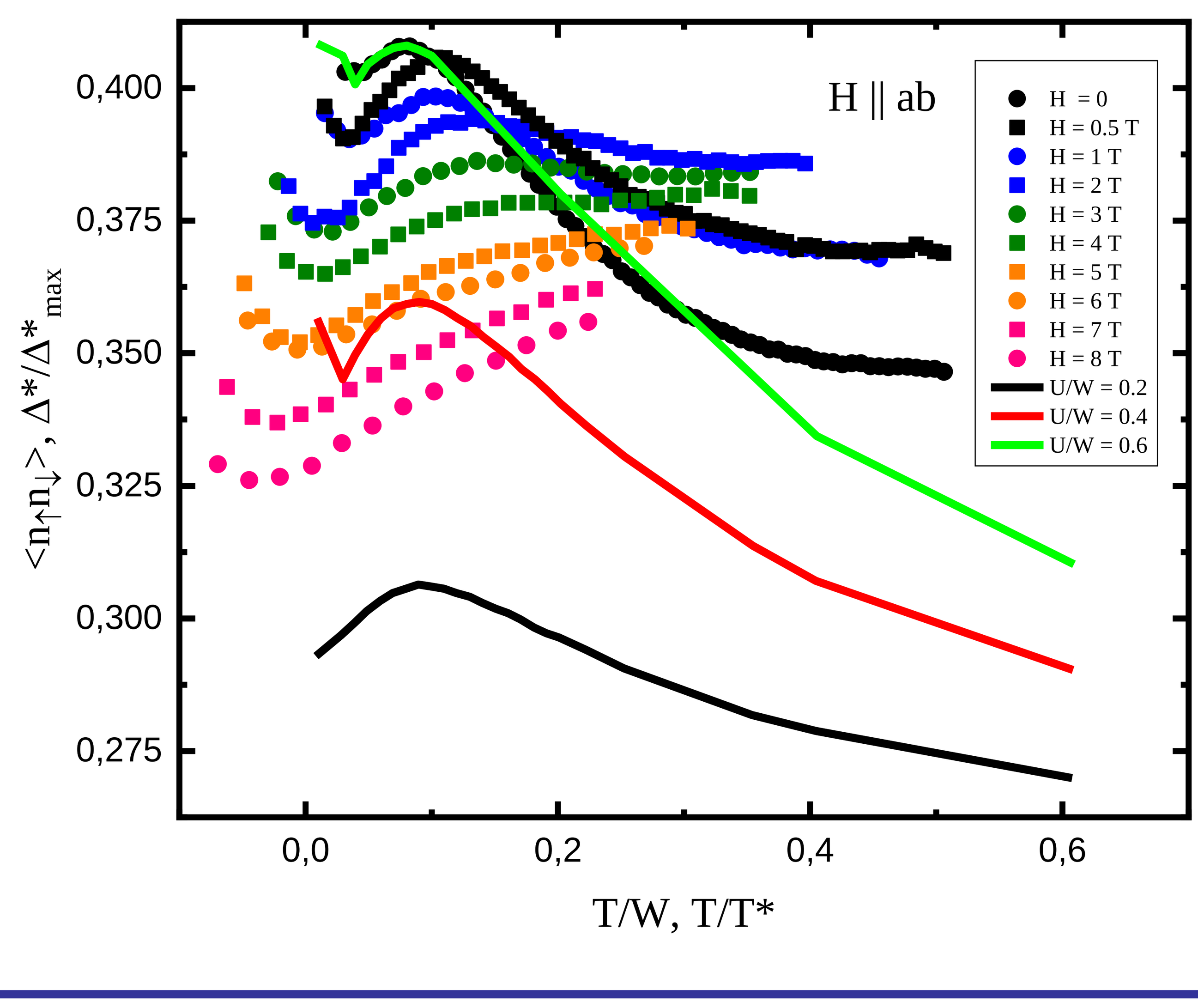

Fig.5. Curves of Δ^*/Δ^*_{max} (symbols) as functions of T/T* in comparison with the theoretical curves of local pairs density $\langle n_\uparrow n_\downarrow \rangle$ as functions of T/W [4], at corresponding U/W interaction values: 0.2 (black curve), 0.4 (red curve), 0.6 (green curve). All Δ^*/Δ^*_{max} curves have intentionally the same shift and scaling factors to show the evolution of Δ* more clearly. Note that the shape and magnitude of Δ^*/Δ^*_{max} (H = 0) and U/W = 0.6 tends to coincide. But the local pair density noticeably decreases with increasing field, which can explain the observed increase in R under the action of the field (Figs. 1-2). In this case, the shape of the Δ^*/Δ^*_{max} curves strongly deviates from the theory, suggesting the noticeable change in the interaction of the local pairs with increasing magnetic field.

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