# Two-dimensional superconducting fluctuations in MgB2 films

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# Two-Dimensional Superconducting Fluctuations in $MgB_2$ Films

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The origin of the resistive transition broadening for superconducting $MgB_2$ films is investigated experimentally. The crucial role of two-dimensional weak and critical fluctuations is demonstrated.

**KEY WORDS:** fluctuations; dimensionality; magnesium diboride.

## 1. INTRODUCTION

The discovery of superconductivity in $MgB_2$ [1], a material with hexagonal layered crystal structure, raised several questions about its transport properties. The crystal structure of $MgB_2$ and band structure calculations suggest that the quasi-two-dimensional boron planes are mainly responsible for the electrical transport. Therefore, the superconducting properties of magnesium diboride are expected to reflect a two-dimensional 2D character.

There exists a fundamental reason for the broadening of the resistive transition of a superconductor because of an intrinsic transition width associated with thermodynamic fluctuations of the order parameter. This minimal width, $\Delta T_c$ is given by the Ginzburg criterion [2], $\Delta T_c = Gi T_c$, where

$$Gi = \left[2\mu_0 k_B T_c / B_c^2(0)\xi_0^3\right]^2 \qquad (1)$$

is the Ginzburg parameter, with $B_c(0)$ the critical flux density at $T = 0$ K, $\xi_0 = \hbar v_F / 2\pi k_B T_c$, $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am, and $v_F$ the Fermy velocity. The value of $Gi$ is extremely small for pure 3D conventional superconductors like bulk Pb and Al ($Gi \sim 10^{-13}$), rising many orders of magnitude for dirty and low dimensional systems making the fluctuation effects observable experimentally [3]. For layered superconductors with a small coherence length $\xi_0$, the intrinsic width $\Delta T_c$ may be much larger, up to $Gi \sim 10^{-2}$ for high-$T_c$ superconductors like $YBa_2Cu_3O_{7-x}$ [4].

The layered character of the new superconductor $MgB_2$ with its small coherence length lets one expect the possibility of a detection of fluctuation effects. Therefore, in this work we report about an experimental study of the origin of the resistive transition broadening in $MgB_2$ thin films.

We performed critical field and resistance measurements of $MgB_2$ films grown on MgO single crystalline substrate by dc-magnetron sputtering. The linear temperature dependence of the upper critical field demonstrates a 3D character of superconductivity in our samples below $T_c$ as discussed in [5]. In contrast, resistivity measurements yield a temperature dependence of the fluctuation conductivity above $T_c$ which agrees with the Aslamazov–Larkin (AL) theory [6] for a 2D superconductor in the weak fluctuations region, $T > T_c$ and with the theory of critical fluctuations [7] in the vicinity of the superconducting transition, $T \sim T_c$ as shown in the present paper. Our experimental results indicate a quasi 2D origin of the nucleation of superconductivity in $MgB_2$.

## 2. SAMPLES

The $MgB_2$ films were prepared by dc-magnetron sputtering from Mg-$MgB_2$ composite targets on single

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crystalline MgO substrate using a two-step process. The substrate temperature was kept at 200°C during the process of sputtering and then raised up to 600°C, followed by an *ex situ* annealing. Details of the sample preparation are given in [5]. The X-ray diffraction study yields a (101)-textured structure of the films, SEM-characterization of the samples demonstrated a polycrystalline very smooth morphology of the films with ~100 nm crystallites size. The resistive transitions $R(T)$ in constant external magnetic fields were measured by a conventional four-terminal resistive method. The special procedure used for determination of the residual resistance, $R_n$, is described in detail in [5].

## 3. RESULTS AND DISCUSSION

Figure 1 shows the resistive transition $R(T)$ at zero magnetic field of $MgB_2$ for one of the investigated samples. The transition width $\Delta T_c$ is about 0.7 K ($0.1R_n$–$0.9R_n$ criteron), demonstrating a high homogeneity of the film. In many works the broadening of the resistive transition of thin films and layered superconductors in zero magnetic field was interpreted in terms of superconducting fluctuations, rising in the vicinity of the critical temperature, $T_c$. The fluctuation or excess conductivity, $\sigma' \equiv 1/R(T) - 1/R_n$ strongly depends on the superconductor dimensionality, $D$.

For a 2D superconductor ($D = 2$) in the weak fluctuation region the excess conductivity $\sigma' \sim (T/T_c^{AL} - 1)^{(D-4)/2}$ is reverse proportional to the temperature

$$[\sigma'(T)]^{-1} = (R_n/\tau_{AL})\left(T - T_c^{AL}\right)/T_c^{AL} \qquad (2)$$

where $\tau_{AL} = (R_n^{\square}e^2)/16\hbar$ and $R_n^{\square}$ is the sheet resistance of the film [6].

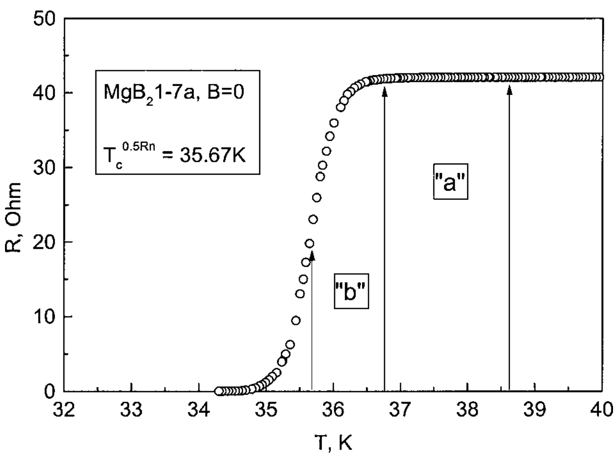


**Fig. 1.** Resistive transition for a $MgB_2$ film (thickness $d = 5.6\ \mu$m). Weak- and strong fluctuation regions are marked as "a" and "b," respectively.

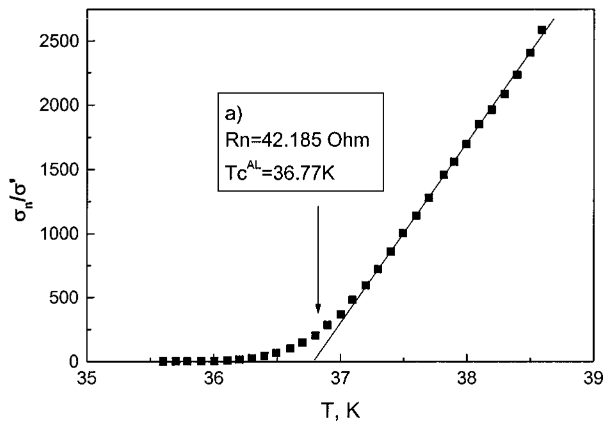


**Fig. 2.** Linear behavior of the fluctuation conductivity on 1/T in the weak fluctuation region, i.e. the upper part of the resistive transition, marked as "a" in Fig. 1. The solid line corresponds to the AL-theory for a 2D-superconductor, crossing the T-axis at $T_c^{AL}$ (pointed by the arrow.)

Figure 2 presents the results of Fig. 1 in the $(\sigma_n/\sigma')$ on $T$ plot, indicating that the resistive behavior of the $MgB_2$ film is caused by superconducting fluctuations according to Eq. (2). The fit of the experimental results in Fig. 2 by Eq. (2) gave us the values of $R_n^{\square}$ and $T_c^{AL}$. The intersection of the linear fit, according to Eq. (2), with the $T$-axis gives the critical temperature $T_c^{AL} = 36.77$ K, higher than the middle-point value of $T_c^{0.5R_n} = 35.67$ K as a result of the critical temperature shift due to fluctuations.

Figure 3 shows the results of Fig. 1 in the $ln(\sigma_n/\sigma')$ on $T$ plot. According to the theory of critical fluctuations [7] in the vicinity of $T_c$ for a 2D superconductor an exponential behavior of the fluctuation conductivity is expected, with

$$[\sigma'(T)]^{-1} \sim R_n \exp[-(1 - T/T_c)/Gi] \qquad (3)$$

The solid line in Fig. 3 is the best fit of the experimental data to Eq. (3). From the inset of Fig. 3, we get the slope $B = 1/Gi = 76.3774$ yielding the value $Gi = 0.013$ for the Ginzburg parameter. This value results in the resistive transition width $\Delta T_c = GiT_c = 0.47$ K which is in a good agreement with the experimental value of $\Delta T_c = 0.7$ K, mentioned above.

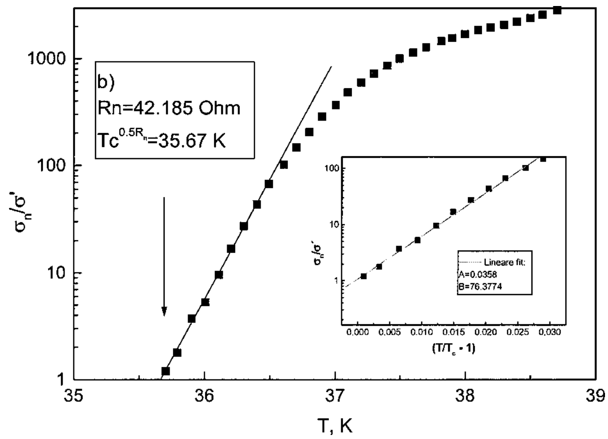


**Fig. 3.** Linear behavior of the fluctuation conductivity in a semilogarithmic scale on temperature in the strong fluctuation region, marked as "b" in Fig. 1.

## 4. CONCLUSIONS

From our experimental results follows a strong influence of superconducting fluctuations on the broadening of the resistive transition of superconducting $MgB_2$. The 2D character of the fluctuations as well in the weak fluctuation region (Aslamazov–Larkin case) as also in the critical fluctuation region demonstrates the two-dimensional nucleation of superconductivity in this novel layered compound.

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