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Magnetic field dependence of the superconducting energy gap in $Bi_2Sr_2CaCu_2O_{8+\delta}$ probed using break-junction tunneling spectroscopy

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The magnetic-field-dependent in-plane tunneling conductance $dI/dV(V)$ on the $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystals has been investigated using break junctions. In contrast to previous tunneling measurements of Bi2212, where the position of the gap peak in $dI/dV(V)$ remained almost unchanged in the applied magnetic fields, our data present evidence that the magnetic field suppresses the superconducting gap in Bi2212. The behavior of a dip-hump structure in tunnel spectra indicates that the magnetic field acts differently on the gap and pseudogap and suggests that the pseudogap does not correlate with the existence of a superconducting gap.

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I. INTRODUCTION

It is well known that for a conventional (BCS) superconductor the application of a sufficiently large magnetic field induces a transition from the superconducting to the normal state. A magnetic field suppresses superconductivity through the orbital pair breaking of Cooper pairs in the superconducting state and also by lowering the relative energy of the normal state via the Pauli paramagnetism of the electron spins. Pair breaking effects in BCS superconductors have been extensively investigated and seem to be very well understood. In bulk systems, the orbital effect usually dominates, while in very thin films it is the Pauli limit which leads to a quenching of superconductivity. Since superconductivity is destroyed at a critical value of the magnetic field, one may expect that the superconducting energy gap 2Δ should decrease to zero for magnetic fields approaching the critical field H_{c2}. This suggestion follows both from Ginzburg-Landau and BCS theory which predict that the value of the gap decreases continuously with increasing magnetic field and vanishes at H_{c2}. This prediction has been confirmed using tunneling spectroscopy[1,2] which is one of the most efficient investigation techniques for superconductors because the conductance of a tunnel junction is directly proportional to the quasiparticle density of states.

Generally, BCS theory is described using a single parameter 2Δ which is at the same time the energy gap and the order parameter (a measure of the pair correlation). However, in uniform two-dimensional or one-dimensional structures, such as thin films or wires, the gap and the order parameter can be very different. For example, there are reports of a magnetic field-induced suppression of the superconducting energy gap together with the existence of gapless superconductivity close to the critical field. These experiments are in general agreement with the theory of dirty superconductors in magnetic fields or a superconductor with paramagnetic impurities (reviewed in Ref. 3).

In the case of high-temperature superconductors (HTSC), considerable evidence shows that their magnetic properties are very different from those of BCS superconductors. For this reason one might expect that the magnetic field behavior of the superconducting gap in HTSC should also be quite different. For example, it is widely accepted that HTSC have $d_{x^2-y^2}$ symmetry of the order parameter (see, e.g., Ref. 4). Among the HTSC, $Bi_2Sr_2CaCu_2O_{8+d}$ (Bi2212) has often been studied by the tunneling method. We have previously investigated in detail the quasiparticle density of states using high-quality break junctions fabricated on Bi2212 single crystals at temperatures 30–50 mK in magnetic fields up to 26 T.[5] We were unable to explain our data with either a pure *s*-wave pairing or pure *d*-wave pairing.

The layered high-T_c crystals behave like stacks of superconductor-insulator-superconductor (SIS) Josephson junctions. In particular, the critical current between the layers I_c in Bi2212 single crystals has been reported to decrease exponentially with magnetic field applied perpendicular to the conducting planes.[6–8] For BCS superconductors, in the resistively shunted junction model, the product of the critical current and the normal resistance of the junction is proportional to the superconducting energy gap ($I_cR_N \propto 2\Delta$).[9] The observed behavior of I_c in Bi2212 was consistent with the field dependence of the critical current calculated using Lawrence-Doniach theory by taking into account fluctuations of the vortices.[10] Since in BCS superconductors $I_c \propto 2\Delta$, it would appear reasonable that in HTSC the superconducting gap should decrease with increasing magnetic field.

Measurements of the superconducting gap in magnetic fields are relatively scarce because such experiments are technically demanding. Several research groups have investigated the magnetic field dependence of the energy gap in high-T_c cuprates with the magnetic field perpendicular and parallel to the CuO_2 planes at different temperatures. However, the obtained results remain controversial. The existence of a normal state pseudogap in the electronic density of states further complicates the interpretation of the experimental data. The reported behavior of the superconducting gap ranges from almost magnetic field independent[5,11–14] to a strong H dependence in electron-doped cuprates.[15] Moreover, in Bi2212 single crystals, interlayer tunneling spectroscopy at fixed temperatures shows that the tunneling conductance peak associated with the superconducting gap broadens and shifts toward higher voltages with increasing magnetic field.[13,14] Such a behavior of the tunnel spectra has never been observed in BCS superconductors and is contrary to theoretical predictions based on BCS theory. Krasnov *et al.*[14] suggested that they observed the superconducting gap and the pseudogap at one time. The broad pseudogap peak in the tunneling conductance is located slightly above the superconducting gap energy and the two peaks are superimposed in the spectra. A magnetic field reduces the amplitude of the superconducting peak so that the combined peak shifts toward higher energies. Anagawa *et al.*[13] explained such behavior of the tunnel spectra by an unconventional pairing interaction or a field-induced ordered state that competes with superconductivity.

On the other hand, Krasnov *et al.*[14] found that in zero magnetic field, the sharp peak in the tunneling conductance, which they associated with the superconducting gap, decreases in magnitude and shifts to lower voltages with increasing temperature for $T=40$, 60, 72, and 80 K. This peak is suppressed by a magnetic field of only 14 T at these temperatures, while the background associated with the pseudogap does not change (see Fig. 1 in Ref. 14). However, in our opinion, the reported shift of the sharp conductance peak to lower voltages is due to the increase in the temperature rather than the applied magnetic field. The mean-field upper critical field H_{c2} for the Bi2212 system is estimated to be nearly 90 T.[16] Using the Werthamer-Helfand-Hohenberg theory[17] it is easy to verify that H_{c2} of a Bi2212 sample with $T_c=92$ K (Ref. 14) should be 65, 42, 27, and 16.5 T at temperatures 40, 60, 72, and 80 K, respectively. A magnetic field of 14 T is largely insufficient to suppress superconductivity by orbital pair breaking of Cooper pairs at these temperatures. It must be mentioned that sometimes we have also observed almost identical double peaks in the conductance at voltages of nearly $2\Delta/e$. In our case these "superconducting" peaks did not shift with increasing field at a constant temperature but instead disappeared even at ultralow temperatures (30–50 mK) in moderate magnetic fields of 15–20 T, far below H_{c2} (see Fig. 5 in Ref. 5). We attributed these double peaks to nanoscale inhomogeneity in a region of the junction, although we cannot exclude that they are due to critical current effects in parasitic weak links of a Bi2212 single crystal.

The superconducting gap in optimally doped and overdoped Bi2212 is close in size to the pseudogap (see, e.g., Ref. 18) questioning if the gap of the superconducting state is detected at all in the tunneling measurement. Such a question is indeed relevant because the weak temperature dependence of 2Δ observed in Bi2212 may also be related to the pseudogap. Moreover, as is shown in Ref. 19, the pseudogap observed in underdoped cuprates corresponds to a real gap in the one-particle excitation spectrum. It is "pseudo" in the experiment only because of the extreme sensitivity to sample imperfections caused by the close proximity to the phase transition. Thus, the relationship between the superconducting gap and the pseudogap remains an open issue for high-T_c cuprates.

Recent angle-resolved photoemission spectroscopy (ARPES) studies of Bi2212 showed that the spectral gap in the nodal and antinodal regions of momentum space has a distinctly different temperature dependence. In the vicinity of the nodal region the gap opens at T_c and has a BCS-like temperature dependence, while in the antinodal direction the gap scales with the pseudogap temperature and is much less sensitive to T_c.[20,21] The observed dramatic variation in the temperature dependence of the ARPES spectral gap as one moves along the Fermi surface suggests that the magnetic field dependence of the energy gap at different points of the Fermi surface should also be very different. Our aim is to find in Bi2212 the gap near the nodal region of the momentum space, with a BCS-like temperature dependence as seen in the ARPES measurements, and to study the effect of the magnetic field on this gap using the tunneling method. The observation of a strong suppression of the gap with increasing magnetic field would be an important confirmation of its relation to superconductivity. Since the observed gap anisotropy is sensitive to sample quality,[22] we have used here only our high-quality Bi2212 single crystals.

Most experiments (scanning tunneling microscopy, planar, break, and point-contact tunnel junctions) are carried out in the c-axis tunneling configuration where the tunneling samples an angular average over the ab-plane density of states.[18] However, in the case of ab-plane tunneling, the tunneling occurs along the CuO_2 planes and the shape of spectra can be quite different depending on the tunneling direction (see, e.g., Refs. 23–25). In this work, we have performed tunneling experiments on Bi2212 single crystals using break junctions in high magnetic fields up $H=20$ T. Our measurements confirm that the superconducting gap in Bi2212 is suppressed by the magnetic field. Intriguingly, if the hump structure, observed at higher voltages than the superconducting gap peak, is associated with the pseudogap which exists over a wide region of the momentum space, then the pseudogap feature shifts more rapidly than the superconducting gap suggesting that the pseudogap and the superconducting gap are not linked.

II. EXPERIMENT

In this work we have used three slightly underdoped *as-grown* single crystals $Bi_{2.22}Sr_{1.55}Ca_{1.17}Cu_{2.01}O_{8+\delta}$ with $T_c=84$ K and transition width $\Delta T_c=1.5$ K.[5] The dimensions of the investigated crystals were $\simeq 1\ \mathrm{mm}\times(0.5-1)\ \mathrm{mm}\times(1-3)\ \mu\mathrm{m}$. The sample with a four-probe contact configuration, with symmetrical positions of the low-resistance contacts ($<1\ \Omega$) on both ab surfaces, is fixed on a flexible substrate. In liquid helium, with a differential screw mechanism the flexible substrate is bent and the single crystal is broken along an incision made earlier resulting in a symmetric SIS tunnel junction. In our break junctions fabricated on Bi2212 single crystals using a precision setup, the tunneling can occur along CuO_2 planes because many plane edges are created. In our opinion, this is the better way to measure tunnel spectra in the ab plane for different tunneling angles. The validity of this, the details of our break-junction setup, and preparation of the Bi2212 single crystals are described elsewhere (see Ref. 5, and references cited therein). The current-voltage $I(V)$ characteristics of the junction were measured simultaneously with the differential conductances dI/dV and the second derivative d^2I/dV^2 characteristics by applying a small ac modulation current at $f \simeq 670$ Hz together with the dc bias. dI/dV and the second derivative d^2I/dV^2 were measured using phase-sensitive detection at f and $2f$. Sensitivity for the detection at $2f$ was improved by using a notch filter to remove the unwanted component at f. Each junction was stable with reproducible characteristics at different magnetic fields.

Mechanically retuning the break junction repeatedly, we were able to fabricate a large number of tunnel junctions at different places along the initial break of the crystal where tunneling occurs in the *ab* plane. At the same time, we cannot say anything about the exact tunneling direction in the *ab* plane itself. Nevertheless, we succeeded in finding the direction with a considerable magnetic field dependence of the energy gap.

III. RESULTS AND DISCUSSION

A. Critical current of break junction in parallel fields

We start by presenting the current-voltage characteristics in order to determine the critical current I_c over a wide range of fields to confirm that investigated break junctions are indeed *ab*-plane Josephson junctions. In addition, the measured $I_c(H)$, assuming that the critical current multiplied by the normal resistance R_N is proportional to the superconducting energy gap,[9] gives some information concerning the dependence of the superconducting gap on magnetic field. Both hysteretic and nonhysteretic junctions have been fabricated, with the critical current I_c and normal state resistance R_N varying over three orders of magnitude while the I_cR_N product remained approximately constant.

Figure 1(a) displays a set of nonhysteretic current-voltage characteristics for the low-resistance break junction in the subgap region at $T=4.2$ K for different magnetic fields between 0 and 9.3 T applied along the *ab* plane for one of the Bi2212 crystals (sample 1). The arrows indicate the direction of the bias current sweep during the measurements. The $I(V)$ characteristics exhibit features typical for superconducting Josephson tunnel junctions. It is known that a nonhysteretic $I(V)$ characteristic points to the small size of the tunnel junction, and importantly, the absence of any self-heating effect. The linearity of the zero-field $I(V)$ characteristic at high bias voltages shown in Fig. 1(b) indicates that the junction has a good tunnel barrier without current leakage.[26] The value of the zero-field critical current I_c and the normal state resistance R_N of this junction were 135 μA and 30 Ω, respectively, giving an I_cR_N product of about 4 mV.

In Fig. 1(c), we plot I_c versus magnetic field (circles) determined from the $I(V)$ characteristics shown in Fig. 1(a). One can see that the critical current decreases monotonically with increasing magnetic field. It decreases to about 25% of its zero-field value for a magnetic field of 9.3 T. The experimental data are well fitted using a logarithmic dependence $I_c \propto -\ln(H)$ (dashed line) although, due to the limited variation of $I_c(H)$, we cannot exclude an exponential dependence which also provides a reasonable approximation to the data (not shown). Indeed, an exponential behavior of $I_c(H)$ has been previously reported for the *c*-axis critical current as a function of magnetic field in Bi2212 crystals (see, e.g., Refs. 6–8 and 27). Although the current in our break junction flows mainly along the *ab* planes, the net supercurrent in the junction, according to a model developed by Bulaevskii *et al.*,[28] essentially depends on the Josephson critical current along the *c* axis of the single crystal. In such a model, the field dependence of the Josephson critical current and I_c are the same. For this reason, it is not surprising that the magnetic field dependence of I_c in Fig. 1 is in agreement with previous measurements on Bi2212 crystals.[6–8,27]

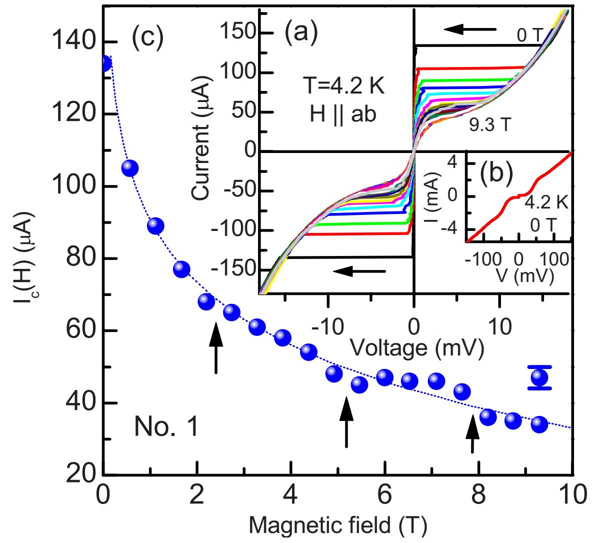

FIG. 1. (Color online) (a) Current-voltage characteristics for a low-resistance break junction in the subgap region at $T=4.2$ K for magnetic fields between 0 and 9.3 T applied along the *ab* plane for Bi2212 crystal No. 1. The arrows indicate the direction of the bias current sweep during the measurements. (b) Zero magnetic field $I(V)$ characteristic over extended voltage range showing the high quality of the break junction. (c) Critical current I_c versus magnetic field determined from the $I(V)$ characteristics in (a). Current minima are indicated by arrows. The dashed line is a fit to the data using $I_c \propto -\ln(H)$.

In addition, as can be seen from Fig. 1(c), the critical current of this junction was weakly modulated by the magnetic field with a period of about 2.8 T (the current minima marked by arrows). One is inclined to think that these oscillations may be connected with interlayer Josephson current in the single crystal itself. In the case of Bi2212 mesa structures in a parallel magnetic field, the period of the *c* oscillations is $\Delta H = \Phi_0 / Ws$, where Φ_0 is the flux quanta, W is the junction size perpendicular to the field, and $s=15$ Å is the interlayer spacing,[29] so that W should be $\simeq 0.5$ μm. All of the dimensions of the investigated crystal are significantly larger than the obtained W and therefore the periodic oscillations of the critical current in Fig. 1 are linked to the tunnel break junction where tunneling occurs in the *ab* plane.

B. Gap structure in magnetic fields oriented perpendicular to the CuO$_2$ planes

In order to investigate the magnetic field dependence of the superconducting energy gap, we use a high-resistance break junction in order to rule out the influence of the Jo-

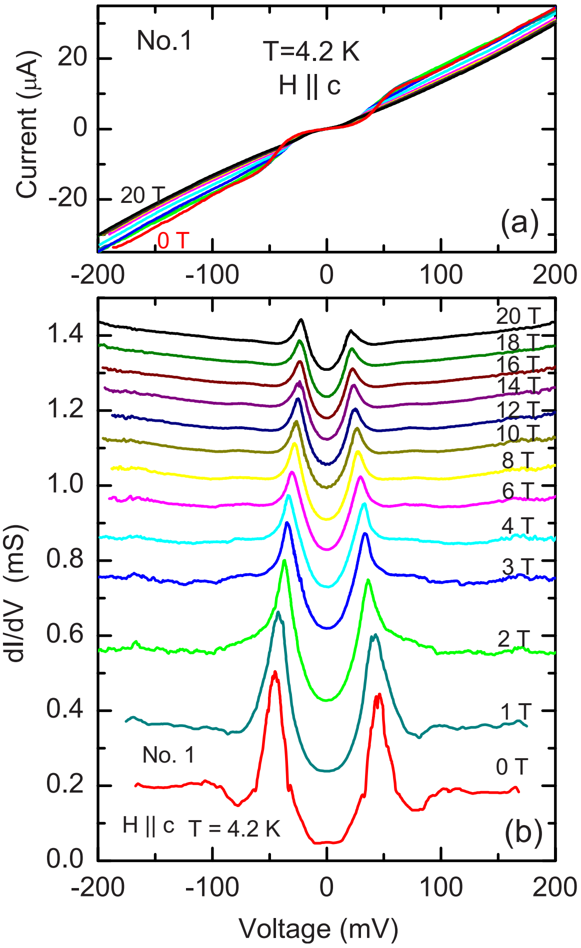

FIG. 2. (Color online) (a) $I(V)$ characteristics and (b) simultaneously measured tunneling conductances dI/dV as a function of the bias voltage V for a 5.8 kΩ tunnel break junction at T=4.2 K measured at various magnetic fields up to H=20 T applied parallel to the c axis of the crystal (sample 1). All dI/dV curves except the lowest one are offset vertically for clarity.

sephson current in the subgap regions of the differential conductance $dI/dV(V)$ and to study the magnetic field dependence of the zero bias conductance. Figure 2(a) shows $I(V)$ characteristics for a 5.8 kΩ tunnel break junction at T=4.2 K measured at various magnetic fields up to H=20 T applied parallel to the c axis of the crystal (sample 1). The zero-field $I(V)$ curve exhibits a characteristic feature typical for a superconducting tunnel junction with a sharp increase in the tunneling current around $V=\pm 2\Delta/e$, where 2Δ is the superconducting energy gap.[26] All of the $I(V)$ characteristics at high bias voltages are parallel and sufficiently approach a straight line that crosses the origin for any magnetic field. This reflects the high quality of the tunnel junction and the independence of its resistance and intrinsic properties on the magnetic field.

Figure 2(b) displays the tunneling conductances dI/dV as a function of the bias voltage V measured simultaneously with the $I(V)$ characteristics shown in Fig. 2(a). All curves except the lowest one are offset vertically for clarity. They have a shape typical for SIS tunnel junctions with sharp peaks in the conductance at the voltage $\pm V=2\Delta/e$. The superconducting gap, defined as half the peak separation, is 45 meV at 4.2 K. The reduced gap, $2\Delta/k_BT_c \simeq 6.2$, is reasonable when compared with our previous results.[5]

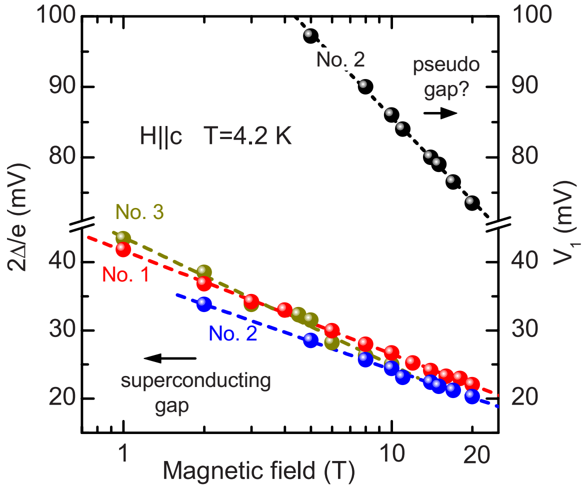

FIG. 3. (Color online) The magnetic field dependence of the gap 2Δ plotted using a semilog scale for the three break junctions formed on each of the three Bi2212 single crystals. The apparently logarithmic decrease with magnetic field, $2\Delta \propto -\ln(H)$, can be seen (dashed lines) although due to the limited data range and exponential behavior cannot be excluded. On the right axis the voltage position V_1 of the hump feature which we believe to be related to the pseudogap in Fig. 4(b) is plotted. The "pseudogap" feature shows a similar logarithmic decrease with magnetic field (dotted line) but at a much faster rate than the superconducting gap.

In contrast to previous measurements on Bi2212, where the position of the gap peak remained almost unchanged in an applied magnetic field, the superconducting conductance peaks in Fig. 2(b) decrease in magnitude and shifts to *lower voltages* with increasing magnetic field. The only possible interpretation of such a behavior of the tunnel spectra is the suppression of the superconducting gap in Bi2212 by magnetic field. This is an unambiguous observation of the suppression of the superconducting gap by magnetic field in tunneling investigations of the Bi2212 system and this is the central observation of this paper.

We note that Krasnov *et al.*[14] observed a relatively insignificant (8%) decrease in the superconducting gap in a magnetic field of only 14 T at 4.2 K, not for a pure Bi2212, but for an intercalated overdoped HgBr2-Bi2212 mesa in which a $HgBr_2$ monolayer is intercalated between Bi-O double layers of the Bi2212 host crystal. In our break junctions fabricated on the high-quality Bi2212 single crystals, the superconducting gap decreases by around 50% at the same field and temperature.

In Fig. 3 we present the magnetic field dependence of the gap 2Δ using a semilog scale for sample 1 extracted from the gap spacing in the dI/dV curves in Fig. 2(b). Data for break junctions 2 and 3 formed on two other Bi2212 single crystals are also included to demonstrate the reproducibility of the field dependence of 2Δ. This figure suggests that 2Δ shows a logarithmic decrease with magnetic field (dashed lines), although, as for $I_c(H)$, we cannot exclude an exponential dependence which also reproduces the data reasonably well (not shown). More importantly, the observed field dependence of the gap is out of all proportion to the expectations of Ginzburg-Landau theory, which predicts $\Delta(H)=\Delta(0)[1-(H/H_{c2})^2]^{1/2}$, so that the gap should be almost independent of the magnetic field for $H \ll H_{c2}$.

In tunneling spectroscopy, the difference between *d*-wave and conventional *s*-wave pairings is more pronounced in the magnetic field dependence of the zero-energy density of states. Volovik[30] showed that the zero-energy density of states varies as $H^{1/2}$ for *d*-wave pairing or as H for *s*-wave pairing. Anagawa *et al.*[13] and Heim *et al.*[31] measured the magnetic field dependence of the quasiparticle density of states in fields up to 9 T and 14.6 T, respectively, in Bi2212 mesas and did not find any change in the tunneling conductance below the gap voltage, in particular, near $V=0$. Our measurements here confirm that the tunneling conductance at zero voltage remains almost unchanged in an applied magnetic field so that either pure *s*-wave or pure *d*-wave pairing cannot explain our data. These results are consistent with earlier work reviewed in Ref. 32 which suggest that the superconducting state of optimally doped Bi2212 can be described by BCS theory with a *d*-wave gap together with small-angle scattering from out-of-plane defects or the anisotropic *s*-wave pairing within a one-band BCS framework.[22]

The observed behavior of the superconducting gap is consistent with magneto-Raman spectroscopy results on a different cuprate $Tl_2Ba_2CuO_{6+\delta}$ where the superconducting gap (2Δ peak in Raman spectra) exhibited strong nonlinear decrease in magnetic fields.[33] The authors interpreted the nonlinear intensity drop as a result of the quasiparticle density renormalization in the vicinity of the Abrikosov vortex lines. An alternative explanation may be the trapping of Abrikosov vortices by the junction electrodes, the vortices being normal to the plane of the electrodes.

Since the mean-field upper critical field H_{c2} for the Bi2212 system is estimated to be nearly 90 T,[16] a magnetic field of 20 T is largely insufficient to suppress superconductivity by orbital pair breaking of Cooper pairs at 4.2 K. This explains why we observe only a twofold decrease in the superconducting gap. In order to verify that behavior is logarithmic and persists up to H_{c2}, experiments at higher fields need to be performed, especially since a linear extrapolation of the data in Fig. 3 gives an unreasonably large value for H_{c2} (of the order of a few hundred tesla).

C. Dip-hump structure in magnetic fields applied perpendicular to the CuO_2 planes

We turn now our attention to Fig. 2(b) and discuss the field dependence of the remarkable additional structure at higher energy beyond the superconducting gap peaks. A dip-and-hump structure just beyond the gap peaks has been the subject of much controversy because it is not yet clear whether that is associated with the *c*-axis pseudogap[14] or related to a strong-coupling effect.[34] It can be seen that the dip and the hump are correlated with each other and both broaden, diminish in amplitude rapidly, and shift to lower voltages simultaneously with increasing magnetic field following the gap peak. Our data in Fig. 2(b) are consistent with the temperature dependence of the dip-and-hump structure in underdoped Bi2212 samples, which has been observed using intrinsic tunneling spectroscopy. Below T_c, the hump and the superconducting gap peak shifted simultaneously to lower voltages with increasing temperature while keeping the difference in their voltage positions constant.[35] At the same time, our results are in striking contrast with those observed in Ref. 14 where the hump associated with the pseudogap did not change either in shape or in the voltage position with magnetic field.

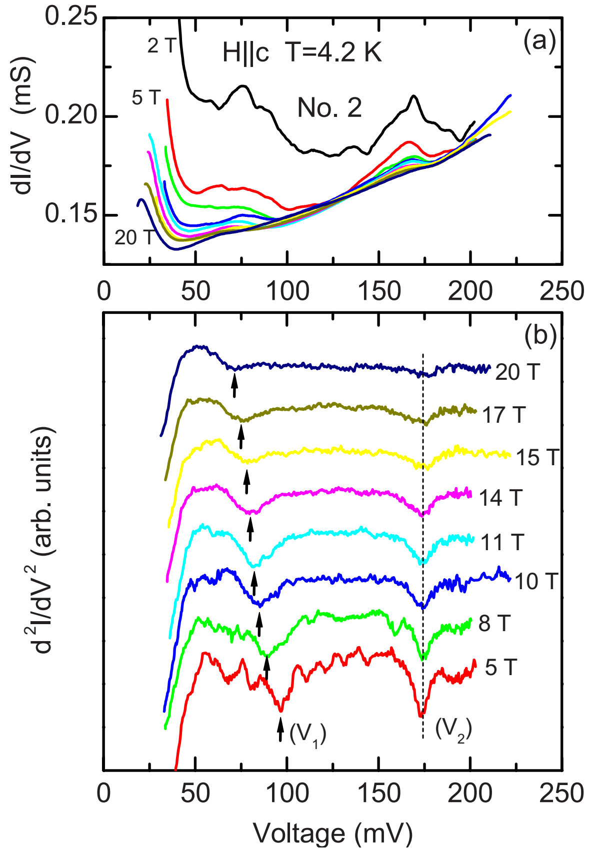

FIG. 4. (Color online) (a) Tunnel conductance $dI/dV(V)$ together with (b) the second derivative $d^2I/dV^2(V)$ at positive sample bias at voltages above the superconducting gap for the break junction formed on crystal 2 measured at 4.2 K in different magnetic fields oriented perpendicular to the *ab* plane. The curves $d^2I/dV^2(V)$ have dip related to the hump (marked by arrows) and the second feature (dashed straight line), respectively. For clarity, the $d^2I/dV^2(V)$ curves have been shifted vertically.

In addition, as can be seen from Fig. 2(b), we have observed a second pronounced feature in the tunneling conductance $dI/dV(V)$ at higher voltages beyond the hump. The behavior of this feature and also the dip-and-hump structure can be more clearly seen in Fig. 4(a), where we plot the $dI/dV(V)$ curves at positive sample bias at voltages above the superconducting gap for the break junction formed on crystal 2 measured at 4.2 K in different magnetic fields oriented perpendicular to the *ab* plane. As for the dip-and-hump structure, the additional feature at higher voltages also gradually decreases in amplitude with increasing field and broadens before practically disappearing at 20 T.

This behavior has been studied in more detail by measuring the second derivative $d^2I/dV^2(V)$ of the junction characteristic. Figure 4(b) shows the measured second derivative which has dip related to the hump and the second feature for different magnetic fields. It is seen that both features decrease in amplitude simultaneously with increasing field. However, the first dip shows a clear shift to lower voltages with increasing magnetic field (marked by arrows), whereas the voltage position of the second dip remains unchanged (dashed vertical line). Significantly, the voltage position of the first dip, associated with the hump, shifts to lower voltages with the increasing field at a faster rate than the superconducting gap peak (see Fig. 3 where the voltage position of the hump feature, V_1, is plotted versus magnetic field). For this reason it seems impossible to explain the dip-and-hump structure just beyond the gap peak by the strong-coupling effect[34] because in this case the hump-dip and the superconducting gap peak must shift simultaneously to lower voltages with increasing field keeping the difference in their voltage positions constant. As can be seen from Fig. 3, this is not the case. It seems more reasonable to assume that the hump-dip structure is associated with the pseudogap which exists over a wide region of the momentum space. The different slope in the gap and the hump indicates that the magnetic field acts differently on the gap and pseudogap (Fig. 3) and suggest, as before,[36] that the pseudogap does not correlate with the existence of the superconducting gap. Concerning the nature of the second magnetic field independent dip V_2 in Fig. 4, we believe that it may be a consequence of inelastic processes in the tunneling barrier.[37]

IV. CONCLUSION

We have studied the magnetic-field-dependent in-plane current-voltage and tunneling conductance in Bi2212 single crystals using high-quality break junctions. In contrast to previous tunneling measurements on Bi2212, where the position of the gap peak in $dI/dV(V)$ remained almost unchanged in the applied magnetic fields, our data present evidence that the magnetic field suppresses the superconducting gap in Bi2212. The behavior of the dip-hump structure in tunnel spectra, if associated with the pseudogap, indicates that the magnetic field acts differently on the superconducting gap and the pseudogap which suggests that the pseudogap does not correlate with the existence of a superconducting gap.

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