Observation of superconductivity in bilayer graphene/hexagonal boron nitride superlattices

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Abstract:

A class of low-dimensional superconductivity (SC), such as most of “atomic-layer” SCs, has only survived under certain circumstances, implying a role of the substrate. Moreover, in some recent discoveries of SC at heterogeneous interfaces, SC was buried in bulk solids and ex-situ. Genuine atomic-layer SC is difficult to access. Here, we report a novel route to atomic-layer SC in graphene superlattices. Our device comprises stacked non-twisted bilayer graphene (BLG) and hexagonal boron nitride (hBN), i.e., hBN/BLG/hBN Moiré superlattices. Upon in-situ electrostatic doping, we observe an SC dome with characteristic temperatures up to $T_{\text{onset}} \sim 50$ K, $T^* \sim 30$ K, $T_{\text{BKT}} = 14$ K, which correspond to the onset of SC, the crossover to SC and the confinement of vortices respectively. Our device belongs to the SC class with the highest transition temperatures where the onset of SC is above 50 K. We believe that SC via doping Dirac materials is ubiquitous in condensed matter and that this study paves a way toward the design of a new SC family.
Main Text:

Superconductivity (SC) has been one of the central topics in condensed matter physics since the discovery of SC phenomena and theory (1, 2). In particular, the discovery of atomic-layer superconductors will have consequences for both fundamental physics and applications and implies a novel route to high critical temperature ($T_c$) SC, such as in cuprates (3) and quantum information devices. The emergence of Dirac fermions in solids (“Dirac materials”) has been well established since the discovery of the “1st generation” in graphene (4, 5). Very recently, superconductivity due to doping a “Mott” insulator has been reported in magic-angle twisted bilayer graphene superlattices (6).

The field of SC in graphite intercalations has a long history (7, 8), and SC in carbon materials has long been sought after with a promise of high yields from both fundamental and applied points of view. In this context, carbon-based superlattices are a novel class of quantum metamaterials. In particular, graphene superlattices are composed of vertically stacked ultra-thin/atomic-layer quasi-two-dimensional materials, which differ distinctly from conventional molecular beam epitaxy/pulse laser deposition (MBE/PLD)-grown superlattices (9).

Here, we report a novel route to atomic-layer superconductivity in graphene superlattices via in-situ electrostatic on/off switching. We note that fine-tuning to a magic angle is not necessary in our device. Moreover, the ability to switch between a superconducting state and a “parent state” (10, 11) opens a door to state-of-art engineering in atomic-layer quantum devices. Further, small carrier concentration/Fermi pockets should lead to SC with enhanced critical fluctuations (12–14) and intriguing phenomena.

Our device is fabricated by stacking bilayer graphene (BLG) and hexagonal boron nitride (hBN) (hBN/BLG/hBN stacks) with a small angle near zero between one of the two hBN sheets and the BLG (BLG itself is non-twisted); this is called a Moiré superlattice. This Moiré superlattice serves as a stage for our demonstration. Via in situ doping, we observe tunable zero resistance states.

In this study, we employed hBN/BLG/hBN Moiré superlattices. Fig. 1(A) shows a schematic of the typical structure of our device. In the optical microscope image, two devices are shown. In this paper, we employed the larger one. The resistance is defined through the four-terminal resistance $R_{ij,kl}$, which is defined by the voltage drop between terminals $k$ and $l$ divided by the electrical current injected between $i$ and $j$ in Fig. 1(A) (see also the Supplementary Information for more details). Fig. 1(B) shows an intensity
map of the longitudinal resistance, $R_{xx}$, as a function of the back-gate voltage, $V_g$, and the magnetic field, $B$ (applied perpendicular to the substrate), at 6 K. In Fig. 1(B), the correspondence between $V_g$ and the density $n$ is also shown. We estimated $n$ through our device structure/electrostatic capacitances (see also the Supplementary Information for the definition of $n$). In these superlattices, a long wavelength Moiré pattern occurs and leads to a Hofstadter butterfly under a magnetic field (15, 16). Graphene Moiré superlattices have recently been intensively studied, in particular, Moiré bands/butterflies in BLG (16–18). A Moiré superlattice leads to an energy gap at the charge neutral point (CNP), at which $n = 0$ cm$^{-2}$, and the emergence of satellites of the CNP. When subject to a magnetic field, the resistance peaks lead to 1$^{st}$ and 2$^{nd}$ generation Landau fans. The 1$^{st}$ generation corresponds to the CNP. The 2$^{nd}$ generation is due to inversion-symmetry breaking by hBN and corresponds to the satellites of the CNP. Fig. 1(B) also shows the Landau fans. The longitudinal and Hall resistivities exhibit basically the same pattern as seen in previous reports (16); the pronounced peak in the longitudinal resistance at the CNP occurs at a gate voltage, $V_g \sim 0$ V, and the satellite resistance peak occurs at $V_g \sim -30$ V, which we just call “satellite” for simplicity. When subject to a magnetic field, these resistance peaks lead to the 1$^{st}$ and 2$^{nd}$ generation Landau fans, respectively (Fig. 1(B)). The alignment angle between the graphene and hBN is estimated to be $\theta \sim 0^\circ$ (11). Further, the measurement shows a Landau level formation with Hall conductance ($\sigma_{xy}$) steps of $4e^2/h$, where some degeneracies are lifted and additional plateaus also occur (Fig. 1(C)). This QHE results are the characteristics of BLG. Fig. 1(D) shows $R_{xx}$ as a function of $n$ at various temperatures without a magnetic field ($B = 0$ T). Sudden drop of the $R_{xx}$ is shown around $n \sim -3.5 \times 10^{12}$ cm$^{-2}$, which indicates precursor to zero resistances of SC. The inset of Fig. 1(D) provides $R_{xx}$ as a function of the temperature, $T$, at the satellite ($n = -1.93 \times 10^{12}$ cm$^{-2}$) and the optimal doping for SC ($n = -3.48 \times 10^{12}$ cm$^{-2}$). At the optimal doping, SC shows the highest transition temperatures as discussed below in Fig. 2. At the satellite, the resistance shows non-metallic behavior due to the hBN-induced band gap (16). The Fig. 1(E) shows the typical resistances, $R_{xx}$, as a function of the temperature, $T$, without a magnetic field. At the lowest temperature, data show low resistance below the noise floor, which corresponds to the regime with sudden resistance drop in Fig. 1(D). The $I$–$V$ characteristics are shown in Fig. 1(F) for various temperatures near the optimal doping ($n = -3.59 \times 10^{12}$ cm$^{-2}$), which shows SC critical current behavior at lower temperatures.

Fig. 2 shows the resistance, $R_{xx}$, as a function of both the density, $n$, and the temperature, $T$, without a magnetic field. A dome-shaped superconducting region, an
SC dome, appears in the phase diagram. Inside the dome, data show SC behavior as discussed in Fig. 1(E, F). The SC appears sharply at \( n \sim -3.2 \times 10^{12} \text{ cm}^{-2} \) and \(-3.6 \times 10^{12} \text{ cm}^{-2} \). The SC critical temperature saturates near the optimal doping \( n \sim -3.48 \times 10^{12} \text{ cm}^{-2} \), which leads to the dome-shaped SC phase referred to as an SC dome. We observe no (correlated) insulator behaviour between the satellite and the SC dome. Upon \textit{in-situ} electrostatic doping, we observe an SC dome with characteristic temperatures up to \( T_{\text{onset}} \sim 50 \text{ K}, T^* \sim 30 \text{ K}, T_{\text{BKT}} = 14 \text{ K} \) (see the Supplementary Information for details on the critical temperature analysis). Our device belongs to the SC class with the highest transition temperatures above 50 K.

Fig. 3(A) shows the magnetoresistance, \( R_{xx}(B) \), with focus on the regime near \( n \sim -3.5 \times 10^{12} \text{ cm}^{-2} \), which includes a close-up of Fig. 1(B) at 10 K. A pronounced suppression of the resistance is shown around there. Fig. 3(B) shows the magnetoresistance, \( R_{xx}(B) \), at 10 K with \( n = -3.48 \times 10^{12} \text{ cm}^{-2} \). The data indicate that the SC dome exhibits rigidity under a magnetic field applied perpendicular to the substrate.

In conclusion, novel atomic-layer superconductivity is discovered in graphene superlattices. Superconductivity via doping Dirac materials, in particular graphene superlattices, can be ubiquitous in condensed matter. Full details including more examples with high-\( T_c \) are left to be studied beyond carbon-based materials.

\textbf{Methods Summary:}

The device fabrication with a modified dry-transfer technique is detailed in ref. (10, 11) for hBN/BLG/hBN superlattices. Fig. 1(A) shows the schematics of our devices, wherein BLG is encapsulated between two hBN layers. The thickness of the top- and bottom-layer hBN is both 30 nm. We fabricated the device by transferring BLG and hBN flakes onto an hBN substrate supported on a SiO\(_2\)/Si wafer. The sample was then etched into the H-bar geometry. The one-dimensional Cr/Au (= 5/55 \( \mu \text{m} \), 0.5\( \mu \text{m} \times 0.5\( \mu \text{m} \)) contacts were then deposited by electron beam (EB) evaporation followed by EB lithography. Note that the contact itself is non-superconducting without proximity effects. The sample quality of this device was estimated in ref. (11). Here we show an example. The quality of the graphene-related device is closely related to \( \delta n \), which indicate the sharpness of the resistance peak at CNP/DP. In our device, \( \delta n \) is less than \( 5 \times 10^{10} \text{ cm}^{-2} \), which is comparable to that in ref. (19). For hBN/SLG/hBN superlattices in the Supplementary Information, see ref. (10) for details and Fig. S2(A) for schematics. The thickness of the top- and bottom-layer hBN is 16 nm and 20 nm, respectively. Note that Hall-bar geometry is employed in this case.
Measurement setup is as follows. For hBN/BLG/hBN superlattices, the resistance is defined through the four-terminal resistance $R_{ij,kl}$, which is defined by the voltage drop between terminals $k$ and $l$ divided by the electrical current injected between $i$ and $j$ (see also Fig. 1(A)). The measurement was performed at 1.5 K–80 K using both DC and a low-frequency (17 Hz) lock-in technique with an AC excitation current of 10–100 nA and in variable temperature cryostats (two types of cryostat were used: base temperature were 5 K and 1.5 K, respectively). $R_{12,43}$ defines the longitudinal resistance $R_{xx}$. $R_{xy}$ is defined by $R_{13,42}$. Our device shows four-terminal rectangular structures, wherein the mean free path is within the device dimensions (the order of 1 μm) (11) and the I-V characteristics reveal an Ohmic behavior in the normal phase (20). $R_{13,42}$ leads to the Hall coefficient after a symmetrization as a function of magnetic field $B$ (21,22). The Hall conductance $\sigma_{xy}$ is defined by $R_{xy}/((R_{xx} W/L)^2 + R_{xy}^2)$. For the measurement setup the hBN/SLG/hBN superlattice in the Supplementary Information, see ref. (10) for details. Note that Hall-bar geometry is employed in this case.

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**Acknowledgments:**

We thank K. Kobayashi of Osaka University for helpful discussions. The device fabrication and measurement were supported by the Japan Society for Promotion of Science (JSPS) KAKENHI 26630139; and the NIMS Nanofabrication Platform Project, the World Premier International Research Center Initiative on Materials Nanoarchitectonics, sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan. S.M. acknowledges financial support from a Murata Science Foundation. Growth of hexagonal boron nitride crystal was supported by the Elemental Strategy Initiative conducted by the MEXT, Japan and the CREST (JPMJCR15F3), JST.
Fig. 1. Characterization of our devices. (A) Schematic of our hBN/BLG/hBN superlattice and the four-terminal measurement scheme. The one-dimensional Cr/Au (= 5/55 µm, 0.5µm×0.5µm) contacts were deposited. In situ tuning of the electron density was performed via a back gate beneath the bottom-hBN. An optical microscope image of the two devices is also shown. The larger one is employed in this paper, which corresponds to the schematic. (B) Intensity map of the longitudinal resistance, $R_{xx}$, as a function of the gate voltage $V_g$ and the magnetic field, $B$ (applied perpendicular to the substrate), at 6 K. The correspondence is also shown between the gate voltage $V_g$ and the density $n$. (C) Quantum Hall effect (QHE) in our device at $T = 1.6$ K and $B = 2.1$ T. The Hall conductance ($\sigma_{xy}$) steps of $4e^2/h$ are shown versus the density $n$, which are the characteristics of BLG. (D) The resistances, $R_{xx}$, as a function of $n$ at $B = 0$ T at various temperatures. The inset provides $R_{xx}$ as a function of $T$ at the satellite resistance peak ($n = -1.93\times10^{12}$ cm$^{-2}$) and the optimal doping for SC ($n = -3.48\times10^{12}$ cm$^{-2}$). (E) The resistances, $R_{xx}$, as a function of the temperature, $T$, at different densities $n$ with $B = 0$ T ($n = -3.24$, $-3.61\times10^{12}$ cm$^{-2}$). (F) The $I$–$V$ characteristics are shown at various temperatures with $B = 0$ T near the optimal doping ($n = -3.59\times10^{12}$ cm$^{-2}$).
Fig. 2. *In situ* electrostatic doping and the SC dome in our devices ($B = 0$ T). The resistance, $R_{xx}$, as a function of both the density, $n$, and the temperature, $T$. An SC dome is shown (blue-colored region).
Fig. 3. Magnetoresistance in our devices. (A) An intensity map of the longitudinal resistance, $R_{xx}$, as a function of the density, $n$, and the magnetic field, $B$ (applied perpendicular to the substrate). This includes a close-up of Fig. 1(B) with a focus on the regime near $n \sim -3.5 \times 10^{12}$ cm$^{-2}$ at $T = 10$ K. (B) The magnetoresistance, $R_{xx}(B)$, at $T = 10$ K with $n = -3.48 \times 10^{12}$ cm$^{-2}$. 
Supplementary Information for

Observation of superconductivity in bilayer graphene/hexagonal boron nitride superlattices

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Supplementary Text

#1 More on the Superconductivity: Nonreciprocal Superconductivity

Nonreciprocal transport is ubiquitous in solids without inversion symmetry, which is our case due to hexagonal boron nitride (hBN). In such cases, the $I$–$V$ characteristics can depend on the direction of $I$, as in a p–n diode, which is referred to as a nonreciprocal response. Rikken formulated the non-linear response for nonreciprocal charge transport as $R_{xx} = R_0 (1 + \chi I B)$.

The $\chi$-value is generally suppressed in metals and is difficult to access. However, in a superconductor, a new energy scale applies, i.e., the superconducting gap, which can enhance the nonreciprocal charge transport. This type of effect has been studied theoretically only in the weak-coupling regime. Conversely, our case is in the vicinity of quantum-limited superconductivity (SC) ($k_F \xi \approx 1$) combined with an extremely clean (xC) limit, where $k_F$ is the Fermi wavelength and $\xi$ is the superconducting coherence length. Further, this case should give a clue to identifying a pairing symmetry with a possible broken time-reversal symmetry, e.g., chiral SC (ChSC).

There are two characteristic regimes in two-dimensional SC. One is the fluctuation regime near $T^*$ at which the amplitude of the order parameter develops but the fluctuation of the superconducting “phase” suppresses the “rigidity” which implies finite superfluid density. The other is the SC regime, where the rigidity develops at the Berezinskii–Kosterlitz–Thouless (BKT) transition temperature, $T_{\text{BKT}}$.
Around the fluctuation regime of SC, the thermally fluctuating order parameter leads to additional conductivity (12–14). In the SC regime, where the rigidity develops at $T_{\text{BKT}}$, a vortex state can emerge under a magnetic field, which can be “creepy” due to thermal and/or quantum fluctuations. Here, the vortex motion is a relevant origin for the voltage drop due to the Josephson relation. Note that vortex motion in quantum-limited SC combined with the xC limit has not been investigated in detail where extrinsic effects, e.g., disorder and/or random pinning, are suppressed. Further, in SC with broken inversion symmetry, vortices moving via an external electric current can feel an effectively asymmetric potential, i.e., a “ratchet” effect. Even though the vortex phase diagram and its details remain to be examined for our device, we show the nonreciprocal charge transport state in the SC regime in Fig. S1.

#2 A comparative study: Single-layer graphene superlattices

In the main text, our focus is on in situ electrostatic doping in BLG. For a comparative study, here we study single-layer graphene (SLG) superlattices.

The emergence of Dirac fermions in solids (“Dirac materials”) has been well established since the discovery of “1st generation” in graphene (4, 5). Here, we focus more on emergent Dirac fermions in solids, i.e., we search for “higher generations”.

Our focus is on hBN/SLG/hBN structures, which harbor higher-generation Dirac fermion points with a narrow bandwidth, i.e., with a relatively strong correlation.

Our device was fabricated by stacking SLG and two thin sheets of hBN in an hBN/SLG/hBN stack with a small angle between one of the two sheets of hBN and the graphene (Fig. S2(A)). This superlattice provides a stage for our demonstration. In monolayer graphene with Dirac-type relativistic energy dispersion, the inversion symmetry can be broken by stacking graphene on an hBN substrate with an angle near zero degrees, which leads to a long-length Moiré pattern due to the 1.8% lattice mismatch between the graphene and the hBN. We fabricated hBN/SLG/hBN heterostructures with one-dimensional Cr/Au contacts. Fig. S2(A) shows a schematic of the typical structure of our device. $R_{\text{xx}}$, $R_{\text{xy}}$ defines the longitudinal resistance $R_{\text{xx}}$. $R_{\text{xx}}$, $R_{\text{xy}}$ defines a Hall resistance. Fig. S2(B) shows an intensity map of the longitudinal resistance $R_{\text{xx}}$ as a function of the back-gate voltage, $V_g$, and the magnetic field, $B$ (applied perpendicular to the substrate), at 1.5 K. Sharp increases in the longitudinal resistance ($R_{\text{xx}}$) at $V_g$ values of 0 V and −21 V correspond to the 1st (DP) and 2nd (SDP) generation Dirac points, respectively. The emergence of the SDP is a consequence of energy band engineering due to the misalignment of the graphene and hBN crystals,
which leads to energy gaps at DP and SDP. The QHE of single-layer graphene is observed near the DP, and a Landau-fan diagram is observed (15).

Upon in situ electrostatic doping away from the SDP, we observed “signatures” of SC. Fig. S3(A) is a zoom-in of Fig. S2(B) with a focus on the regime near $V_g \sim -26.5$ V. Pronounced suppression of the resistance is shown around there, which resides near the van Hove singularity (vHs), and the sign of the carrier charge changes (but it is not DP/SDP), as discussed below. Fig. S3(B) shows the magnetoresistance at $T = 1.5$ K with $V_g = -26.55$ V near the vHs. We confirmed that this device does not show an SC dome in the dilution refrigerator measurement of the mixing chamber temperature $T_{mix} = 40$ mK and that it is weakly SC at best.

#3 Estimation of the carrier density via the low-field Hall effect

In Fig. S4, the carrier density, $n_H$, is shown as a function of the gate voltage, $V_g$. The carrier density, $n_H$, is estimated via the low-field Hall effect. In the low-temperature limit, we estimated $n$ by extrapolating a linear relation ($n_H$ versus $V_g$) from CNP/DP, which is consistent with the estimation through our device structure/electrostatic capacitances.

Note that, in the beginning, the sign of the carrier changes at higher-generation Landau fans due to switching from electrons to holes. In the following, we focus on the sign change of the carrier away from such points.

In the case of SLG (Fig. S4(A)), the longitudinal resistivity $\rho_{xx}$ shows a dip structure (some “signature”) in the vicinity of the point where the sign of the carrier changes (however, it does not belong to the 1st or 2nd generations of the Landau fans), i.e., near vHs. The dip locates at $V_g = -26.55$ V with $\rho_{xx} = 1.6$ Ohm.

In the case of BLG (Fig. S4(B)), as $V_g$ is swept at temperatures above $T_c$ (40 K), the sign of the carrier changes as implied by the low-field Hall effect. The SC dome resides near such sign-changing points, as discussed in the main text.

#4 Temperature dependence of the resistivity: Global picture

In the main text, our focus is on the SC dome and the low-temperature regime. Here, as a compliment to the main text, we discuss the temperature dependence of the resistivity from a more global point of view.

In Fig. S5, the longitudinal resistances are shown as a function of the temperature, $T$, for the case of both SLG (Fig. S5(A,B)) and BLG (Fig. S5(C,D)). Here, we comment on several scenarios for the exponent, $\alpha$, i.e., $\Delta R(T) \sim T^\alpha$, which is a temperature-dependent part of the resistance with the residual resistance subtracted. $\alpha = 2$ is a result
of the celebrated Fermi-liquid exponent, which was recently assigned to the Umklapp process in graphene superlattices (29). $\alpha = 1$ is reminiscent of “strange metal” in cuprates (30) but is also consistent with scattering by acoustic phonons (31, 32). Further, we assume a two-fluid model due to nodal and antinodal components. This is reasonable in some graphene superlattices (and some materials with unconventional density waves). This two fluid model leads to a crossover between $\alpha = 1$ and $2$ due to the Umklapp process (33). A more careful assignment of the scattering mechanism will be discussed in a separate paper.

More comments are in order on the temperature dependence. Triggered by the recent discovery of magic-angle SC (6), new players (SC and magnetism) have entered the stage for graphene superlattices. We believe that this is more ubiquitous than expected. Actually, we have encountered many “signatures” in more general settings without “magic”. Here, we show an example. In Fig. S5(C, D), the temperature dependences of the longitudinal resistance between CNP and the satellite is also shown for BLG ($V_g = -17.4, -28.0$ V). This indicates non-metallic behavior between CNP and the satellite, which is not naively expected and has never been observed (16). In our device, however, we confirmed that this does not lead to the “Mott” insulator or SC even at $T_{\text{mix}} = 40$ mK.

#5 Critical temperature analysis

For the analysis of the critical temperature, we applied a BKT-type analysis (26–28). In the BKT-type analysis, $\ln(R_{xx}(T)/R_0) = -b(T/T_{\text{BKT}} - 1)^{-1/2}$ is assumed, where $R_0$ and $b$ are non-universal, material-dependent parameters. In Fig. S6, an example of the measured resistance, $R_{xx}(T)$, is plotted, which is consistent with the BKT-type analysis and leads to an estimation of the critical temperature, $T_{\text{BKT}}$. In this example, $T_{\text{BKT}} = 14$ K.

Here let us define the temperature $T_{\text{onset}}$ at which SC onsets i.e. a 90% of the total transition/normal resistance. In our case, the normal resistance shows a linear behavior of $T$. We define the normal resistance for $T_{\text{onset}}$ (and $T^*$ in the next) by the value where the resistance deviates from the linear form. We define $T^*$ by the temperature at which the resistance becomes 50% of the normal resistance. This corresponds to the mean-field transition temperature and a crossover to SC. In our device in the main text, these characteristic temperatures are up to $T_{\text{onset}} \sim 50$ K, $T^* \sim 30$ K.
Another device

We also studied another H-bar device to check/exclude the role of artificial geometrical effects. In Fig. 1(A), the optical microscope image of two devices is shown. In the main text, we employed the larger one. Here we show a typical data for the smaller one in Fig.S7, where the onset of SC is reconfirmed with an approximate particle-hole symmetry of CNP.
Fig. S1. Nonreciprocal charge transport in our BLG superlattices. In the SC regime at 9 K and 26 mT, the $I-V$ characteristic is shown with $n = -3.41 \times 10^{12} \text{ cm}^{-2}$. 
Fig. S2. Characterization of our SLG superlattices. (A) Schematic of our hBN/SLG/hBN superlattice with one-dimensional Cr/Au contacts and the four-terminal measurement scheme. (B) Intensity map of the longitudinal resistance, $R_{xx}$, as a function of the gate voltage $V_g$ and the magnetic field, $B$ (applied perpendicular to the substrate), at 1.5 K.
Fig. S3. Magnetoresistance in our SLG superlattices. (A) Close-up of Fig. S2(B) with a focus on the regime near $V_g \sim -26.5$V, which resides near a van Hove singularity (vHs). (B) The magnetoresistance, $R_{xx}(B)$, at 1.5 K with $V_g = -26.55$ V near the vHs.
Fig. S4. Carrier density estimated via the low-field Hall effect for our SLG/BLG superlattices. The carrier density, $n_H$, is shown as a function of the gate voltage, $V_g$, for (A) SLG at 1.5 K (with the resistivity $\rho_{xx}$) and (B) BLG at 40 K (with the resistance $R_{xx}$).
Fig. S5. Temperature dependence of the resistance for our SLG/BLG superlattices. The resistance as a function of the temperature, \( T \), for some values of the gate voltage, \( V_g \), for (B) SLG and (D) BLG. The mapping of the resistance is also shown as a function of \( T \) and \( V_g \) for (A) SLG and (C) BLG.
**Fig. S6. Critical temperature analysis.** An example ($n = -3.48 \times 10^{12}$ cm$^{-2}$ for our BLG superlattices) of the measured resistance, $R_{xx}(T)$, is shown (red points), which is consistent with the BKT-type analysis (blue line) and leads to an estimation of the $T_{\text{BKT}}$. In this case, $T_{\text{BKT}} = 14.3 \pm 0.9$ K and it is recorded as $T_{\text{BKT}} = 14$ K. Broad character of the transition causes uncertainty in the fitting procedure and an error bar in fixing the $T_{\text{BKT}}$. 
Fig. S7. Another H-bar device. We also studied another H-bar device to check/exclude the role of artificial geometrical effects. Typical data are shown, where the onset of SC is reconfirmed. The resistances, $R_{xx}$, are shown as a function of $V_g$ at $B = 0$ T at 3 K.
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