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Electrical tuning of cyclotron resonance magnetic field in a dual-gated trilayer graphene/h-BN vdW heterostructrue

ABA-stacked trilayer graphene (TLG) possesses both monolayer graphene (MLG)-like and bilayer graphene (BLG)-like bands. In a high perpendicular magnetic field $B_\perp$, the energy interval of Landau levels (LLs) in TLG is in a wavelength range from mid-infrared to near-infrared, which is technologically important for optoelectronics application. By applying perpendicular electric displacement field D, a band gap is induced and D hybridizes MLG-like and BLG-like bands in TLG, which appears as anti-crossings of LLs [Figs. 1(a)(b)]. Thus, ABA-stacked TLG has a tunability of LLs in a large extent, which enables electrical tuning of cyclotron resonance (CR) magnetic field in TLG.

To demonstrate electrical tunability of CR signals in TLG, we fabricate a dual-gated TLG device in which we can control D by applying bias voltage to the top and bottom gate electrodes. Figs. 2(a)(b) show the optical image and schematic illustration, respectively, of our TLG device. After exfoliation of h-BN flakes onto a 290-nm-thick SiO_2/p-doped Si substrate, TLG was transferred onto h-BN using a method based on polypropylene carbonate (PPC) [1]. Before capping it with another h-BN flake, we put electrodes on TLG by metal deposition of Pd 15 nm. Then the top h-BN layer was transferred onto the stack and a graphite (6~8 layers) was put on the top of it as a transparent top gate. Figs. 3(a)-(d) show color maps of the photo-induced voltage V_{ind} at the charge neutrality point $\nu = 0$ irradiated by laser light of different wavelengths of $\lambda = 9.250$, 9.552, 10.247, and 10.611 μm, respectively, as a function of D and $B_\perp$. We set $\nu = 0$ by sweeping V_{BG} and V_{SD} along the line of R_{xx} peak in V_{SD}-V_{BG} plot [Fig. 2 (c)]. In these maps, the peak position of V_{ind} depends on D, drawing a curve which is symmetric to $D = 0$. These curves of V_{ind} evidently shows that CR signals in TLG is distinctly modified by D.

To give an account for D dependence of CR signals, we first calculated LL diagram by tight-binding approximation with different Δ_1 ranging from 0 to 40 meV, where Δ_1 is proportional to D. Using the calculated LLs, we plotted a position of $B_\perp$ for each Δ_1 where the LL interval is equal to the energy of irradiated laser, where CR transition between LLs is allowed. Hopping parameters are selected mostly based on the values reported in our earlier work [2], and adjusted to fit the experimental data. Figs. 3(e)-(h) show numerical plots of the calculated position of the CR transitions as a function of Δ_1 and $B_\perp$ with the wavelengths of irradiated light $\lambda = 9.250$, 9.552, 10.247, and 10.611 μm, respectively. The numerical plot reproduces the experimental results quite well. These agreement of calculation and experiment demonstrate that LLs in TLG is successfully tuned in our dual-gated TLG device. At the same time, CR signals directly reflects the energy interval of LLs, thus it can be utilized as a powerful probe to study LLs in TLG quantum Hall systems.

References

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[2] Y. Asakawa, S. Masubuchi, N. Inoue, S. Morikawa, K. Watanabe, T. Taniguchi, and T. Machida, Phys. Rev. Lett. **119**, 186802 (2017).

Figures

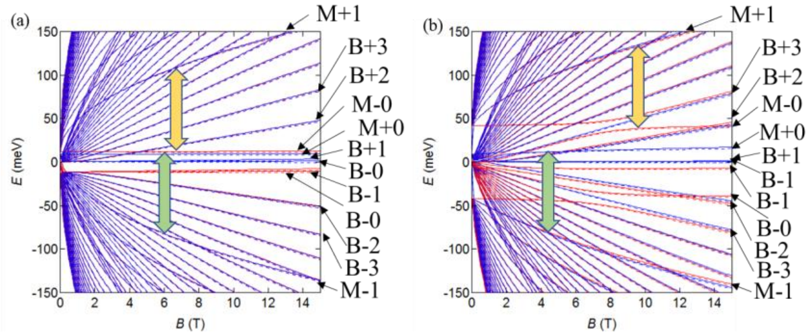

Figure 1: Landau level (LL) diagram with (a) Δ_1 = 0 meV (a) and (b) Δ_1 = 40 meV. The LL index is labeled near corresponding LL. (ex. Index of M-0(B-0) refers to minus-zeroth MLG(BLG)-like LL). Yellow arrow indicates CR transition from LL(M-0) to LL(M+1). Green arrow indicates CR transition from LL(M-1) to LL(M-0).

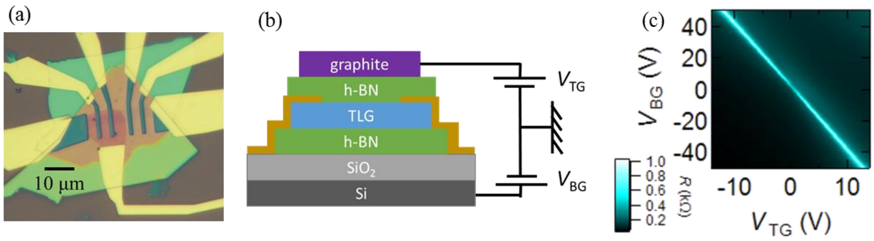

Figure 2: (a) Optical image of the TLG device on a 290-nm-thick SiO_2/p-doped Si substrate. (b) A schematic of the h-BN/TLG/h-BN device with graphite top gate. (c) R_{xx} as a function of V_{SD} and V_{BG}.

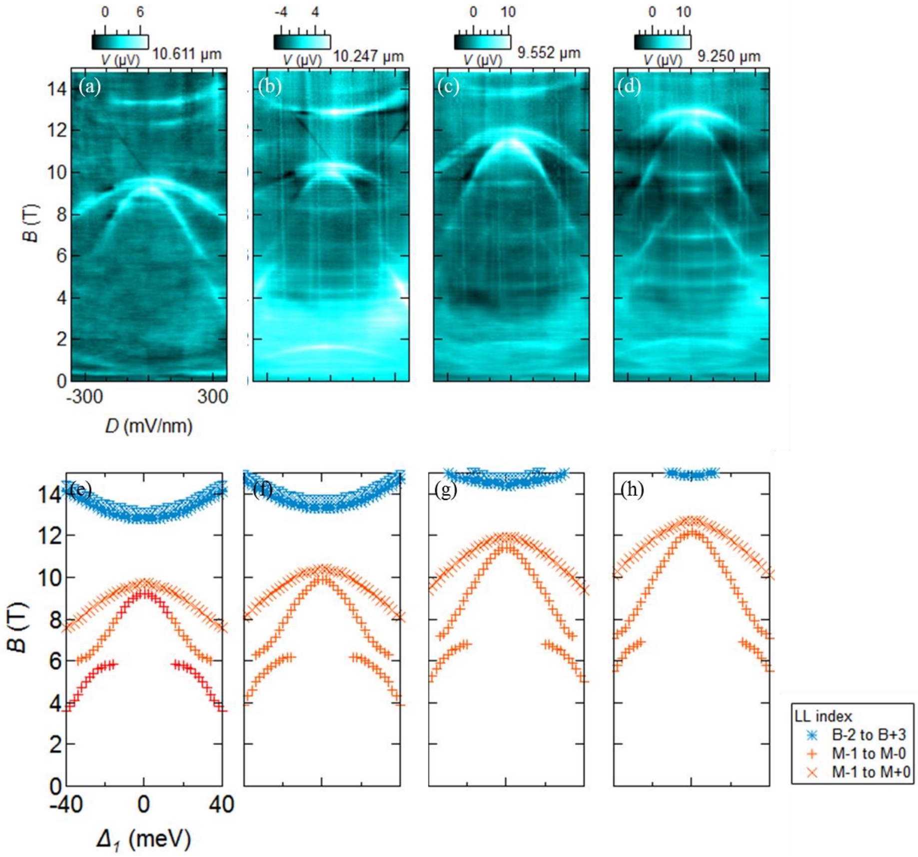

Figure 3: (a)-(d) Measured photovoltage V_{ind} as a function of D and B at ν = 0 with irradiated laser light of different wavelengths. (e)-(h) Numerical plot of resonance magnetic field of CR signals for different wavelengths.