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Cyclotron Resonance and Landau Level Spectroscopy in Graphene/MoS_2 heterostructure

A van der Waals heterostructure between graphene and MoS_2 have exhibited various exotic phenomena due to the strong interaction between these materials at the interface. Nevertheless, detail understanding of the interaction at graphene/MoS_2 interface is still on-going study. Here we focus on the interaction between Landau-quantized graphene and MoS_2 layer in *h*-BN encapsulated high quality *h*-BN/graphene/MoS_2/*h*-BN and *h*-BN/graphene/few-layer MoS_2/bilayer graphene/*h*-BN tunneling devices. Both devices are fabricated by vdW pick-up method and electrical contacts are fabricated by edge contact using Au/Cr metal stack [2]. Two different type of measurements as shown below are performed in this study.

(1) Electrical detection of cyclotron resonance in *h*-BN/graphene/MoS_2/*h*-BN structure

As shown in Fig. 1(a), cyclotron resonance of the graphene in *h*-BN/graphene/MoS_2/*h*-BN was detected from a photo-voltage generated under the irradiation of far-infrared light (λ=10.611 μm). A generated photo-voltage is measured as a function of back gate voltage V_{BG} and magnetic field B applied perpendicular to the plane. Result is plotted in Fig. 1(c). We clearly see the enhancement of photovoltage in particular B values (8 ~ 9 T); this is due to the cyclotron resonance absorption of graphene. Comparing Landau level energy of graphene (inset figure), we attribute this cyclotron resonance corresponds to the transition between N = 0 and N = ±1. Comparing between *h*-BN/graphene/MoS_2/*h*-BN [Figs. 1(a) and 1(b)] and *h*-BN/graphene/*h*-BN [Figs. 1(c) and 1(d)], we observed significant increase in resonance field for graphene/MoS_2 structure. We think this is attributed to the change of Fermi velocity of graphene due to the proximity effect of MoS_2.

(2) Landau level spectroscopy in *h*-BN/graphene/few-layer MoS_2/bilayer graphene/*h*-BN structure

Secondly, we demonstrate the vertical transport in graphene/few-layer MoS_2/bilayer graphene junction as shown in Fig. 2(a). Under the application of magnetic field both monolayer-(Mono-Gr) and bilayer-graphene (Bi-Gr) experience Landau quantization. We measured differential conductance dI/dV_{SD} of the junction as function of inter-layer bias V_{SD} and back-gate voltage V_{BG} as shown in Fig. 2(b-d); here different value of perpendicular magnetic field is applied. In these figures, we see the development of Landau levels in negative V_{BG} when we increase magnetic field value. These are the signature of resonant tunneling between the Landau levels of Mono-Gr and Bi-Gr through MoS_2 tunnel barrier. Finally, a photo-induced voltage at the junction under the irradiation of far-infrared light (λ=10.675 μm) is investigated on the same device. As shown in Fig. 2(e), we see resonant enhancement of junction photovoltage in high magnetic field region. Comparing different measurement geometry (not shown), we found that this photovoltage is generated at the junction not Mono-Gr or Bi-Gr electrode. This is a piece of evidence for photon assisted resonant tunneling in vdW heterostructure.

References

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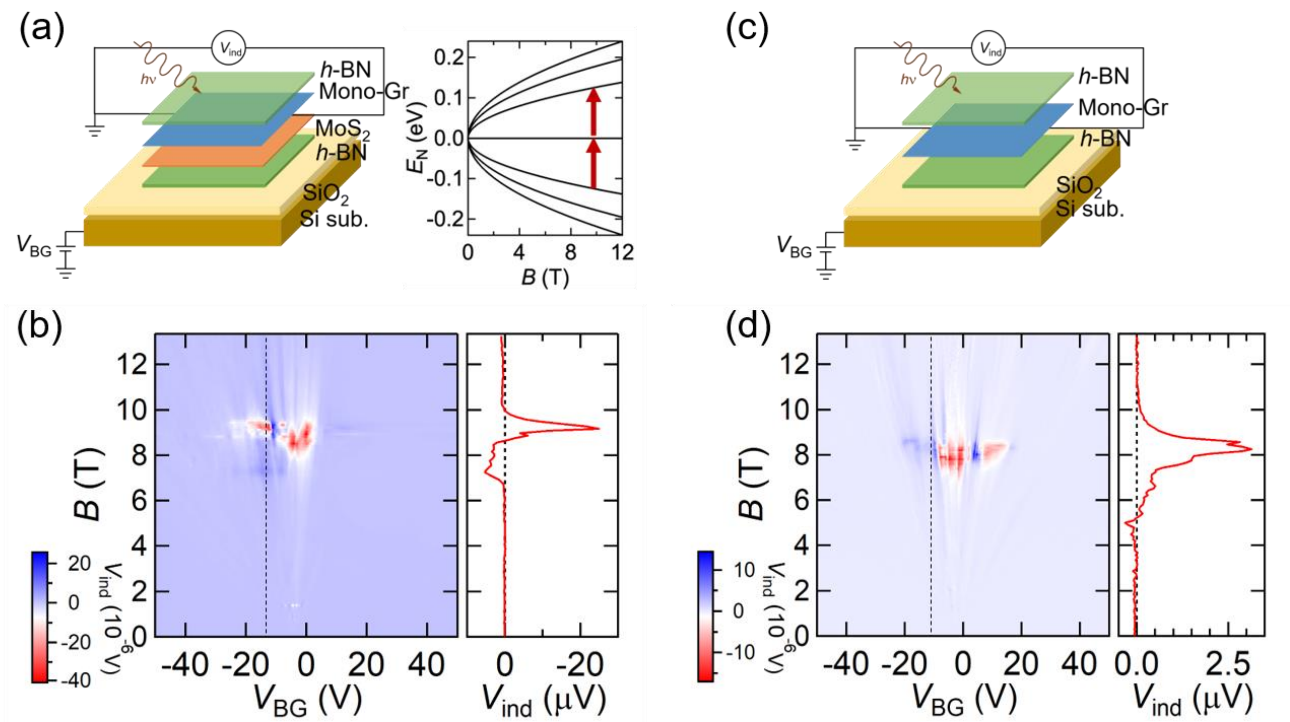

Figure 1: Cyclotron resonance data obtained from (a, b) *h*-BN/Mono-Gr/MoS_2/*h*-BN devices and (c, d) *h*-BN/Mono-Gr/*h*-BN devices. (a, c) Schematic illustrations of the devices. (b, d) Magnetic-field and V_{BG} dependence of the photo-induced voltage V_{ind} detected from zero magnetic field to a high magnetic field. Right side of each panel shows cross sections along the magnetic-field direction at fixed back gate voltages about -15V.

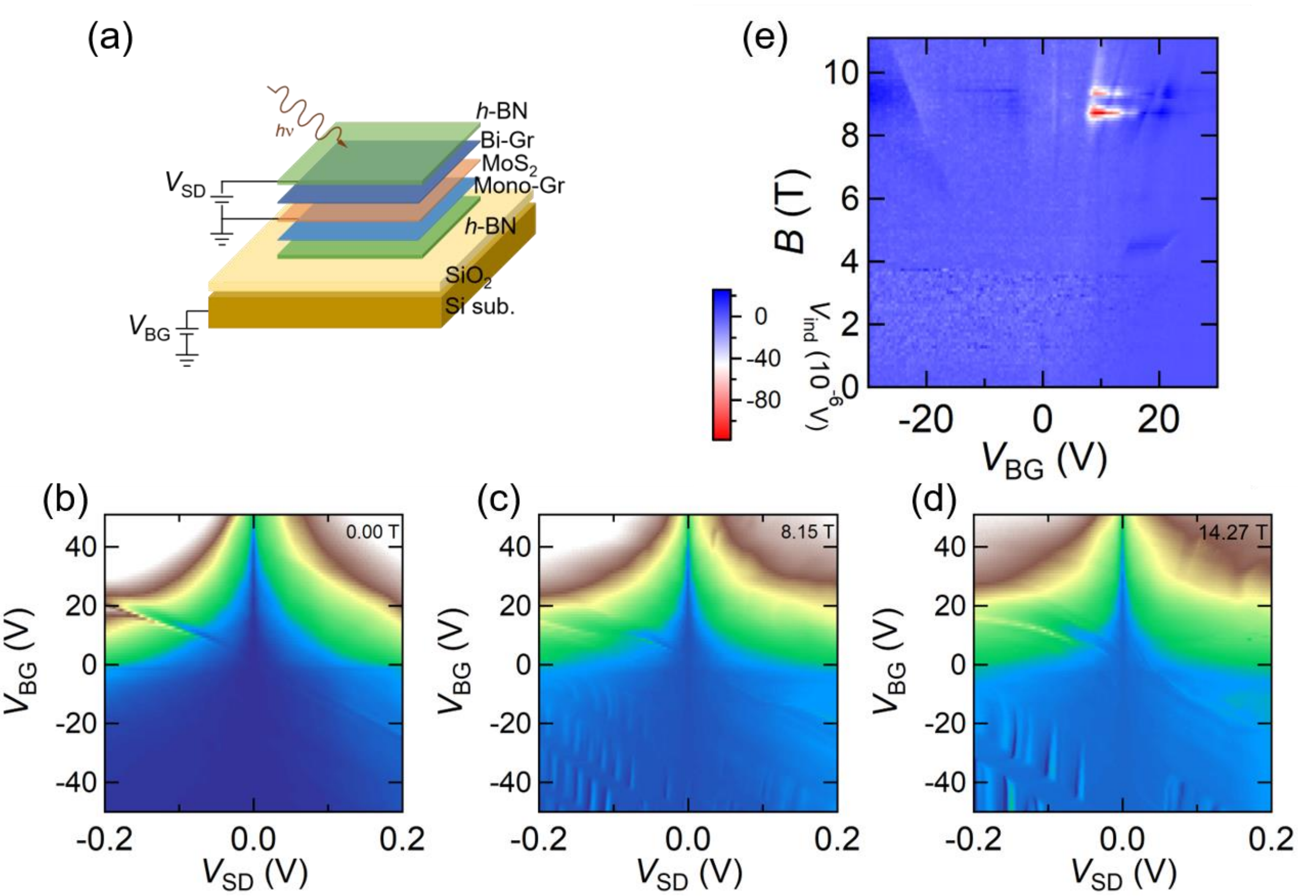

Figure 2: (a) Schematic illustrations of the device. V_{BG} and V_{SD} dependence of dI/dV_{SD} measured at (b) 0 T, (c) 8.15T , (d) 14.27 T. (e) Magnetic-field and V_{BG} dependence of the photo-induced voltage V_{ind} at the junction detected from zero magnetic field to a high magnetic field.