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Influence of C-rich domain in h-BN on the carrier transport in graphene/h-BN van der Waals heterostructures

Hexagonal boron nitride (h-BN) is the only insulating 2D material in van der Waals heterostructures, and has been widely used as an atomically flat substrate for various 2D materials. The h-BN crystal grown under high temperature and high pressure has very high crystal quality and it has been used in all over the world. However, it has been found that the carbon-impurity-rich domain is created in a central region of the crystal. This C-rich domain is unable to be distinguished with optical microscope or AFM, but can be recognized by measuring emission spectrums. The domain area emits light of 320 nm wavelength corresponding to carbon impurity in addition to the h-BN exciton emission at 210 nm. What is remarkable here is that these domains still exist even after exfoliation. It is very important for the development of 2D material science to determine the nature of C-rich domain, particularly when the number of stacking layers get larger.

In this work, we study the effect of C-rich domain on carrier transport properties of graphene by fabricating h-BN/graphene/h-BN van der Waals heterostructures with graphene across the border between the domain and non-domain regions of a h-BN flake [Fig. 1(a)]. This geometry enables the carrier transportation of graphene to be measured on both the domain and non-domain sides simultaneously. It provides us with a direct comparison of the two regions, excluding the effect of quality variation in different samples. It is easy to imagine that domain flakes can be incorporated into van der Waals heterostructures unnoticeably. The evaluation of the domain is crucial for the 2D materials research community.

First, we distinguished h-BN flakes with C-rich domain by the ultraviolet light photo luminescence (UV-PL) [Figs. 1(b-e)]. Monolayer graphene was transferred to stride the border of the C-rich domain and non-domain regions. After capping the graphene with another h-BN layer, we put electrodes on both the domain and non-domain regions, enabling us to compare the transport properties of graphene inside/outside of the C-rich domain [Fig. 1(f)]. The carrier mobility of graphene inside the C-rich domain at 1.5 K was 50,000 cm^2/Vs, whereas the carrier mobility exceeded 100,000 cm^2/Vs in graphene outside the C-rich domain region [Fig. 2(c)]. The carrier mobility in graphene on the C-rich domain was degraded. Under high magnetic fields, characteristic bendings of Landau-fan diagram were observed in graphene/C-rich domain at the electron-doped side, suggesting that carbon atoms in h-BN generate an impurity level in the graphene [Fig. 2(e)]. We fabricated a total of 3 devices with similar structure, and all devices showed the same trend. Thus, as a conclusion, h-BN domain has a distortive impact on the transport properties of graphene above.

Figures

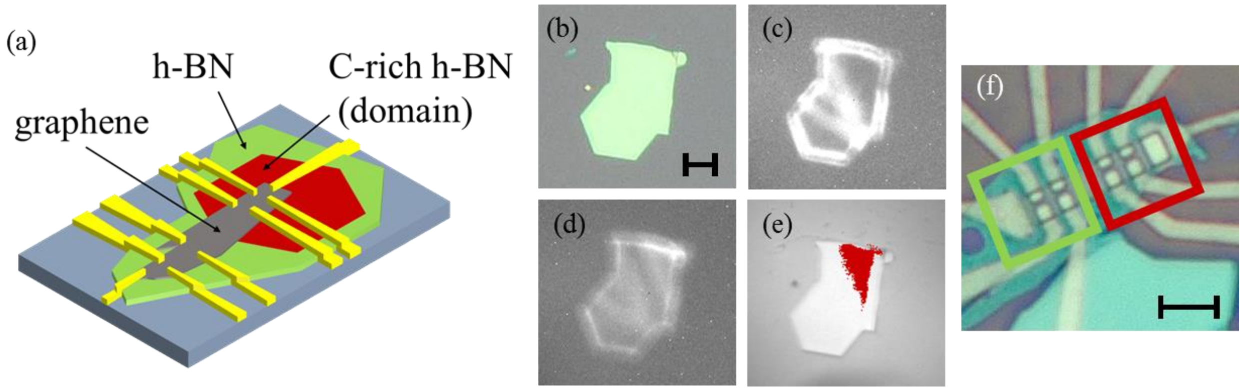

Figure 1: (a) Schematic of the sample structure. Graphene is positioned to accurately stride a border of the domain/non-domain region. (b) Optical micrograph of an exfoliated h-BN flake on SiO_2/Si substrate. The scale bar represents 10 μm. PL image of the flake at wavelengths of (c) 230 nm and (d) 340 nm. (e) Domain region determined by the PL spectrum (red). The ratio of the strength of 340 / 230 nm exceeds a threshold in the red area. (f) Optical micrograph of h-BN/graphene/h-BN samples on SiO_2/Si substrate. The scale bar represents 3 μm. The regions surrounded by a red square indicate graphene in the domain region, while those surrounded by a green square indicate graphene in the non-domain region.

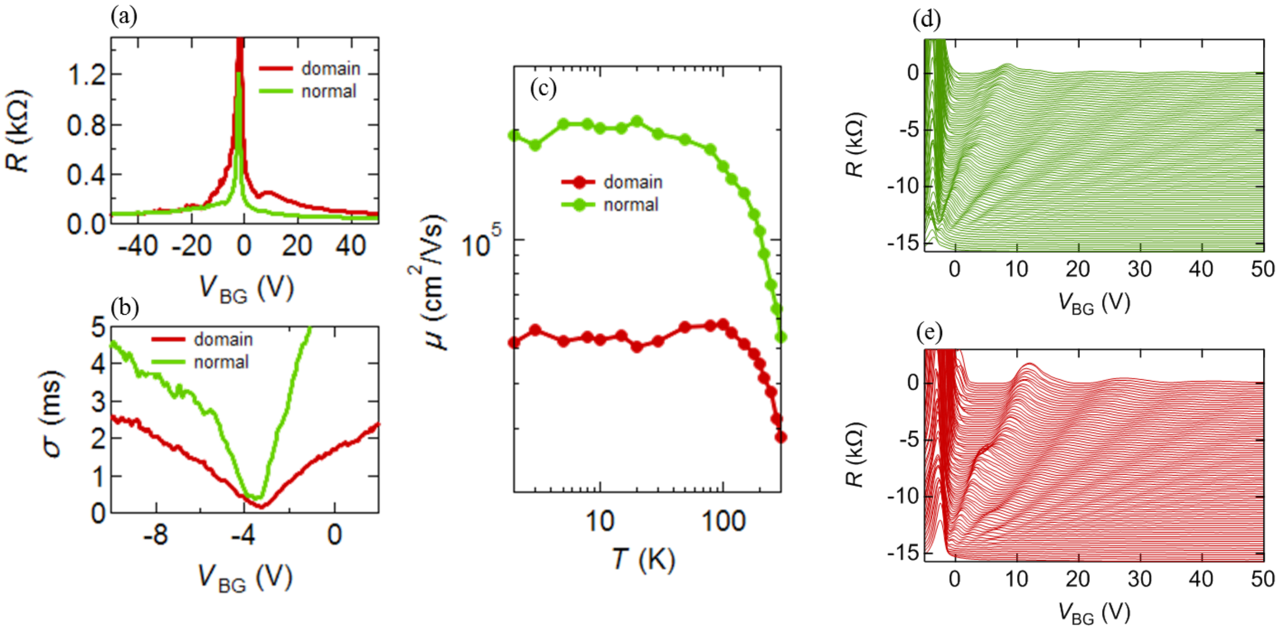

Figure 2: (a) R_{xx} – V_{BG} plot. The red line indicates data of graphene in domain, while green line indicates those of graphene in the non-domain. (b) σ – V_{BG} plot. (c) Temperature dependence of electron mobility. (d,e) R_{xx}–V_{BG} plot at B = 0-9 T outside (d) and inside (e) the domain region. Data are offset for clarity.