In recent years, hexagonal boron nitride (h-BN) has gained interest as a material for use in graphene based electronics due to its unique material properties. Its two-dimensional structure, insulating properties, and close lattice match to graphene have made it a natural candidate for dielectric integration. Initial work has shown great promise with enhancements of effective mobility and on-state currents of 2-3x compared to conventional dielectrics. In these works, increased mobility has been attributed to a reduction in surface roughness scattering, charged impurity scattering, and surface optical phonon scattering relative to thermally grown SiO_2 substrates and ALD deposited high-k gates to which the h-BN integrated devices were compared; however, no comprehensive study of scattering processes on h-BN supported graphene has yet been performed. Additionally, these results suggest that h-BN may be suitable as a top-gate dielectric in other graphene devices (one's not supported by SiO_2 substrates) in order to improve device performance by reducing these same scattering processes; yet, all work on h-BN integration has thus far focused on exfoliated or chemical vapor deposited (CVD) graphene, both of which are typically placed on SiO_2 supporting substrates. Alternatively, high-k dielectrics can lead to enhanced transport properties through dielectric screening, yet often lead to increased surface optical phonon scattering. In order to achieve the highest possible device performance, the effects of h-BN integration must be understood. Although initial experimental work has shown excellent promise for h-BN integration with certain graphene systems, more work is needed to model and understand the scattering physics of this system and to identify for what regimes and systems it is most applicable.

In this work, we examine the large-area integration of h-BN with quasi-free standing epitaxial graphene (QFEG) for the first time and compare it to the high-k dielectric, HfO_2. QFEG is a form of epitaxial graphene that utilizes a hydrogen passivation step to electrically isolate the graphene and SiC substrate, resulting in improved transport properties relative to conventional epitaxial graphene on SiC. Temperature dependent Hall effect measurements and modeling are used to discern the effects of top-gate dielectric on carrier transport and identify limiting factors of the QFEG system and indicate that remote charged impurity scattering is the dominant scattering mechanism for as-grown and dielectric coated QFEG, accounting for up to 90% of the scattering. Compared to HfO_2 dielectrics prepared by oxide seeded atomic layer deposition, h-BN dielectrics are found to introduce 33% less charged impurities into the dielectric-graphene system. The results confirm that integration of h-BN with QFEG is effective in reducing the density of charged impurity scatterers as well as surface optical scattering.

Although it is found that h-BN introduces significantly less charged impurity scatterers than HfO_2 and exhibits a higher energy surface optical phonon mode, the overall benefit of h-BN integration depends critically on the charged impurity density present in the as-grown material system. The large impurity density inherent to the as-grown QFEG system in this work places the samples in a regime of charged impurity limited transport where the ability of HfO_2 dielectrics to enhance transport through dielectric screening works to offset the additional scattering sources it introduces over h-BN dielectrics. Scattering models are utilized to show that h-BN dielectrics benefit charge carrier transport over HfO_2 dielectrics only for samples with as-grown impurity densities below a critical threshold of 4e12 cm^{-2} or at high temperatures.

Effect of Transferred Hexagonal Boron Nitride Dielectrics on Quasi-Freestanding Epitaxial Graphene

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In recent years, hexagonal boron nitride (h-BN) has gained interest as a material for use in graphene based electronics due to its unique material properties. Its two-dimensional structure, insulating properties, and close lattice match to graphene have made it a natural candidate for dielectric integration. Initial work has shown great promise, where increased mobility has been attributed to a reduction in surface roughness scattering, charged impurity scattering, and surface optical phonon scattering relative to conventional dielectrics; however, no comprehensive study of scattering processes on h-BN supported graphene has yet been performed. Alternatively, high-k dielectrics can lead to enhanced transport properties through dielectric screening, yet often lead to increased surface optical phonon scattering.

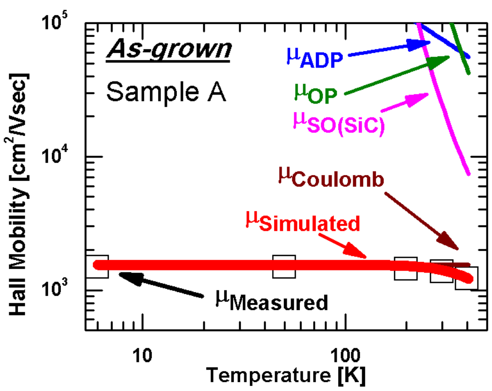

Figure 1: Experimental and simulated temperature dependent Hall mobility for an as-grown QFEG sample showing the dominance of impurity scattering.

In this work, we examine the large-area integration of h-BN with quasi-free standing epitaxial graphene (QFEG) for the first time and compare it to the high-k dielectric, HfO_2. QFEG is a form of epitaxial graphene that utilizes a hydrogen passivation step to electrically isolate the graphene and SiC substrate, resulting in improved transport properties relative to conventional epitaxial graphene on SiC. Temperature dependent Hall effect measurements and modeling (Fig. 1) are used to discern the effects of top-gate dielectric on carrier transport and identify limiting factors of the QFEG system and indicate that remote charged impurity scattering is the dominant scattering mechanism for as-grown and dielectric coated QFEG, accounting for up to 90% of the scattering (Fig. 1).

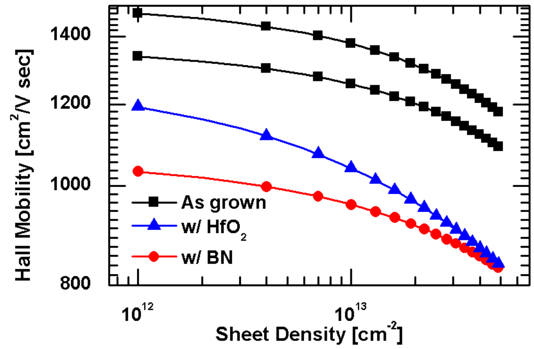

Figure 2: Carrier density dependency of Hall mobility for as-grown, HfO_2, and h-BN coated samples showing degradation of transport with dielectric integration.

Although it is found that h-BN introduces significantly less charged impurity scatterers than HfO_2 and exhibits a higher energy surface optical phonon mode, the overall effect of h-BN integration results in a slight degradation of Hall mobility relative to HfO_2 samples (Fig. 2). This is shown to depend critically on the charged impurity density present in the as-grown material system, where the large impurity density inherent to the as-grown QFEG system in this work places the samples in a regime of charged impurity limited transport where the ability of HfO_2 dielectrics to enhance transport through dielectric screening works to offset the additional scattering sources it introduces over h-BN dielectrics. Scattering models are utilized to show that h-BN dielectrics outpreform HfO_2 dielectrics only for samples with as-grown impurity densities below a critical threshold of 4e12 cm^{-2} (Fig. 3).

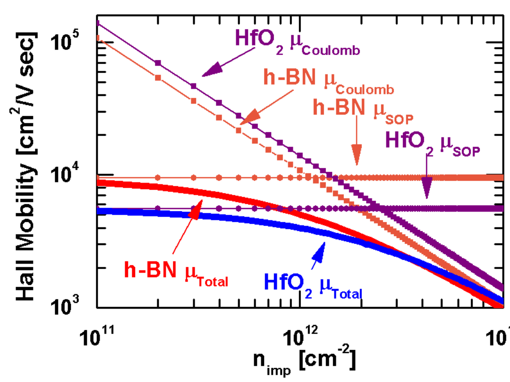

Figure 3: Dependency of Hall mobility on sample impurity density showing the impurity scattering limited regime (right) and phonon scattering limited regime (left) for dielectric coated graphene containing charged impurities.