

# Fabrication of Graphene Field Effect Transistors on Boron Nitride Substrates

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## Abstract:

Graphene is a two dimensional crystal of carbon atoms that has applications to new electronics and optoelectronics when fabricated as a field effect transistor (FET) [1]. The quality of these FETs is quantified partly by the carrier mobility of the device. The goal of this project is to determine a procedure for fabricating graphene FETs on hexagonal boron nitride (h-BN) substrates based on Dean et al. [2] in order to create devices with improved carrier mobility. A combination of chemical solvents and annealing procedures were used to clean the devices during fabrication. We found that only applying the chemical solvents yielded the devices with the highest carrier mobility ( $\sim 500 \text{ cm}^2/\text{Vs}$ ). However, this value is much less than that of typical graphene FETs, indicating our procedure can still be improved.

## Introduction:

Graphene is a monolayer of graphite composed of a single layer of carbon atoms arranged in a honeycomb lattice. Graphene has many remarkable mechanical, electronic, and optoelectronic properties stemming from its structure including its high carrier mobility and optical transparency in the visible to infrared wavelength range [1]. These properties make it an attractive material for use in high frequency electronics and devices requiring transparent conductive films [1].

A general measure for the quality of graphene FETs fabricated in the lab is the carrier mobility of the device. Despite graphene's high intrinsic carrier mobility, the carrier mobility of the devices fabricated on silicon dioxide ( $\text{SiO}_2$ ) substrates is limited by scattering caused by the surface roughness, charged impurities, and interactions with phonons of the  $\text{SiO}_2$  substrate [2]. Residues deposited during the fabrication process also limit carrier mobility [3]. Our goal was to improve the carrier mobility of our graphene FETs by fabricating them on h-BN substrates. Previous work by Dean et al. indicates that h-BN can act as a much better substrate for graphene devices than  $\text{SiO}_2$  because it has comparable dielectric properties to  $\text{SiO}_2$  while also having a smoother surface which should reduce carrier scattering within graphene.

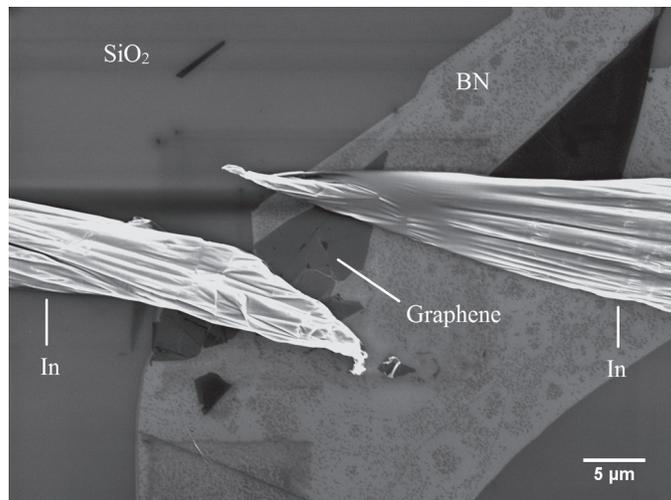


Figure 1: SEM of a graphene device on an h-BN substrate.

## Device Fabrication:

Standard graphene FETs are fabricated by first exfoliating graphene onto 300 nm of  $\text{SiO}_2$  on a doped silicon wafer, which acts as a back gate, and then writing gold electrical contacts with electron beam lithography (EBL) onto the graphene. The fabrication process we used for our h-BN devices was slightly more complex; graphene was first exfoliated onto a polymer stack and BN flakes were exfoliated onto 300 nm of  $\text{SiO}_2$  on doped silicon. Graphene was identified first based on contrast and then later confirmed with Raman spectroscopy. The h-BN flakes were selected using an atomic force microscope (AFM) to have a thickness of 10-30 nm and minimal changes in thickness over the surface. Using the procedure outlined by Dean et al. [2], the graphene was transferred onto the h-BN flake and the polymer stack was dissolved. We decided not to use EBL to write our contacts because it would deposit additional residue onto the device. Instead, we used a micromanipulator to write indium contacts onto the device. A scanning electron microscope (SEM) image of a device can be seen in Figure 1.

To remove residues deposited during the fabrication procedure, we used a combination of chemical solvents and annealing in argon gas (Ar) and molecular hydrogen gas (H<sub>2</sub>). Acetone (ACE) and isopropanol (IPA) were the primary solvents, and distilled water as used on select occasions. Annealing was done in a one-inch tube furnace at 350°C for 120 minutes. An AFM was used to identify the residues deposited during the fabrication process.

## Results:

Once the devices had been fabricated, the conductance (G) of each device was measured, using a sensitive preamplifier, by maintaining a constant source-drain voltage while sweeping the gate voltage. The carrier mobility ( $\mu$ ) was calculated according to the formula shown in Figure 2 [3]. In the formula,  $C = 115 \times 10^{-10}$  F/cm<sup>2</sup>,  $L$  is the length of the device parallel to the current path,  $W$  is the width of the device perpendicular to the current path, and the derivative of  $G$  with respect to gate

$$\mu = \frac{1}{C} \frac{L}{W} \frac{\partial G}{\partial V_{gate}}$$

Figure 2: Equation defining carrier mobility.

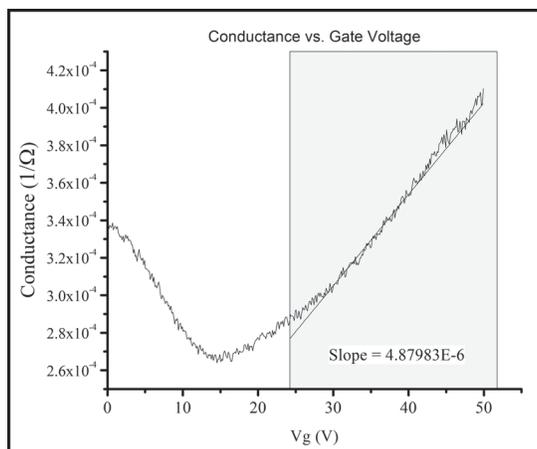


Figure 3: Example of conductance data from a device.

voltage is taken to be the slope of the highlighted region in Figure 3. In searching for the optimal fabrication procedure, we fabricated devices using different permutations on the basic fabrication procedure, altering the anneal parameters and the order in which we performed the annealing and graphene transfer.

## Conclusions:

As shown in Figure 3, we found that washing the h-BN flake in ACE and IPA prior to performing the transfer and then soaking in distilled water and rinsing with ACE and IPA after the graphene transfer and dissolving the polymer stack yields the highest carrier mobility (~ 500 cm<sup>2</sup>/Vs). Although other variations of the procedure were tried, the processes described in Figure 4 were the only ones that produced useable devices. In addition, the highest carrier mobility attained by the devices fabricated using our procedure was significantly smaller than that of devices fabricated using the standard process. This suggests that further research is required to develop our fabrication procedure.

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## References:

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Cleaning Processes Before Graphene Transfer	Cleaning Processes After Graphene Transfer and Polymer Dissolution	Carrier Mobility (cm <sup>2</sup> /Vs)
Soak/rinse in ACE and IPA	Soak in distilled water, rinse in ACE and IPA	497.4
Soak/rinse in ACE and IPA	Anneal in Ar /H <sub>2</sub>	322.2

Figure 4: A summary of the fabrication procedures that yielded useable devices.