Creating Controllable Strain in Graphene

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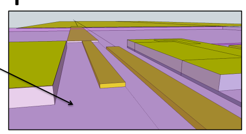
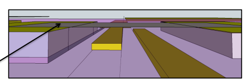
Introduction and Relevance:

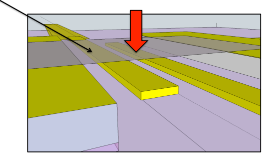
Graphene, a single atomic sheet of carbon, is expected to replace or supplant silicon in future electronic devices. However, it has recently been predicted that mechanical strain in graphene can perturb and modify its electrical properties. **Here, we develop approaches to create controllable strain of up to 1% in graphene.** First, we demonstrate that graphene can be strained by controllably pulling it onto a pre-patterned support. Second, we prove that strain can be induced in graphene as a result of thermal expansion of a polymer film attached to graphene. **We expect that the ability to create and control strain may potentially allow controlling graphene electrical properties, such as electron mobility and the size of a band gap.**

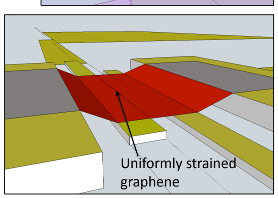
Approach I: Creating Strain by Collapsing Graphene

1. First, 2 gold supports are patterned and evaporated using Electron Beam Lithography with a 100nm SiO_2 layer sandwiched in between.
2. Graphene is laid across the surface and then patterned using Electron Beam Lithography.
3. The SiO_2 layer is etched away, collapsing and straining the graphene and completing the device.



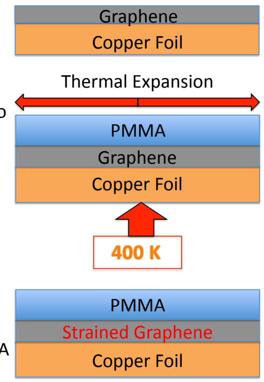




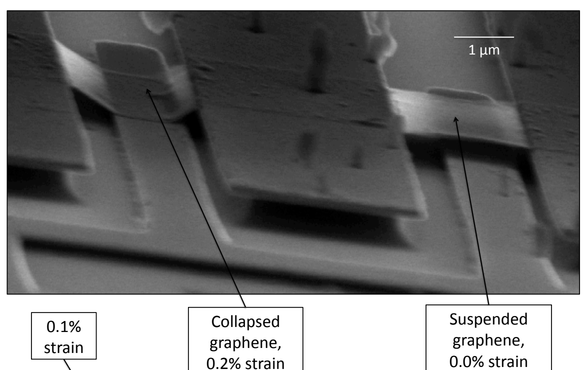


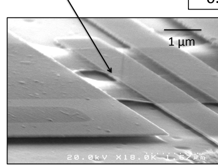
Approach II: Creating Strain by Controlled Thermal Expansion

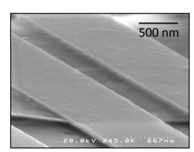
1. Chemical Vapor Deposition (CVD) graphene is grown on Copper.
2. Then 300 nm of PMMA is spun onto graphene. The PMMA is heated, and as it is heated it expands, pulling the graphene and causing strain. **Strain is induced at this step.**
3. PMMA's thermal expansion coefficient is smaller while cooling than during heating. Therefore the strain is not released. As the PMMA cools, it solidifies and keeps the graphene in this strained state.



Images of Controlled Strain Device: Scanning Electron Microscopy



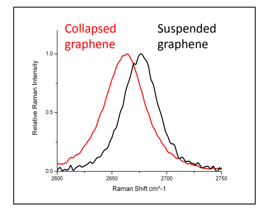




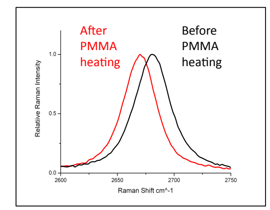
Analyzing Strain: Raman Spectroscopy

Raman spectroscopy is used as a quick and non-invasive way to detect strain in graphene. Strain is characterized by a wave shift in the 2D peak of graphene.[2,3] Results are shown for a representative device and for the polymer approach. **Maximum strain achieved via approach I: 0.3%. Maximum strain achieved using approach II: 0.25%.**

15 wavenumber shift: 0.25% strain



10 wavenumber shift: 0.17% strain



Future Goals and Outlook:

Our next goal is to measure electrical transport in devices with controllable strain and to observe the influence of strain on the carrier mobility of graphene. Computational models have determined that 0.1% strain should be enough to improve electrical transport.[1] We also hope to find ways to optimize device design for higher strain values. Currently we are limited in how much strain we can induce by what we believe to be frictional forces between graphene and the substrate. In this vein, we are looking into building thicker SiO_2 layers, clamping the graphene down from above so it does not slip during collapse, and making a device that uses both straining methodologies. We are modeling the polymer expansion method in COMSOL multiphysics in order to confirm the mechanism creating the strain.

References:

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3. A.C. Ferrari, et al., *Physical Review Letters* 97(2006), doi:10.1103/PhysRevLett.97.187401

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