Enabling Graphene Nanoelectronics

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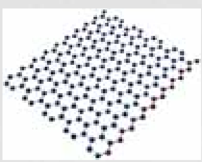
Problem

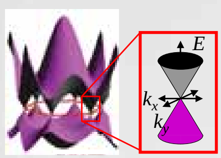
Develop a scientific understanding for improved growth of large area graphene (> 100 µm^2) that has high electronic quality.

Graphene is a new type of 2D electronic material formed from sp^2-bonded carbon atoms.

Our goals are to:

- develop a scientific basis for new synthesis and processing approaches suitable to graphene
- create proof-of-principle electronic devices exploiting graphene's unique electronic and mechanical properties





Linear electronic dispersion yields unique properties including relativistic Dirac fermions.

Why is graphene interesting?

Graphene is a gapless semimetal whose unique band structure enables phenomenal electronic and mechanical properties:

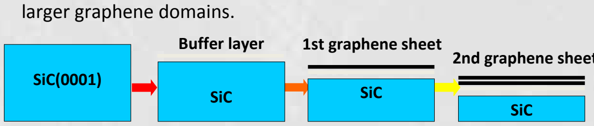
- High carrier mobility, ~200,000 cm^2/Vsec
- Long electron spin coherence length, > 1 µm
- Excellent thermal conductivity, ~5000 W/mK
- Large elastic modulus, ~ 1.0 TPa

Approaches

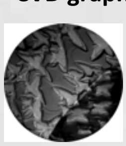
Graphene synthesis approaches

1. **Thermal decomposition of SiC in an argon atmosphere**

   An ~1100 °C anneal causes Si atoms to sublime, forming a buffer carbon layer at the SiC(0001) surface. Further sublimation at higher temperatures creates a high concentration of surface carbon atoms, which assemble into graphene layers. Annealing in an Ar atmosphere reduces Si sublimation and produces fewer nucleation sites, leading to larger graphene domains.



2. **CVD graphene nucleation on metals (Cu, Ni, Ir)**



Many graphene islands nucleate on the Cu(111) foil.

Each graphene island has four rotational domains.

Epitaxial graphene is transferred to glass substrates using an electrostatic exfoliation process

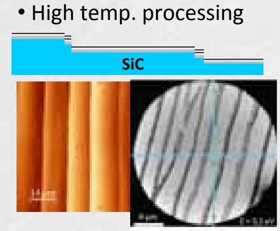
Characterization tools are used to improve synthesis and transfer

- Low Energy Electron Microcopy (LEEM) is used for structural characterization
- Raman Spectroscopy is used to measure quality and strain
- Electronic transport measurements

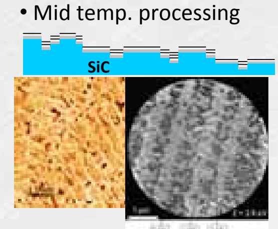
Results

Graphene formation by thermal decomposition of SiC in an Ar atmosphere

- Atmospheric pressure Ar
- High temp. processing

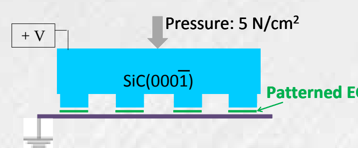


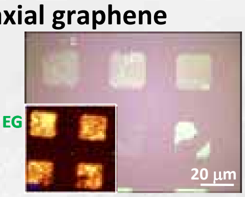
- Ultrahigh vacuum
- Mid temp. processing



Graphene synthesized using a high temperature Ar-mediated growth process produces larger higher quality domains than that synthesized in UHV.

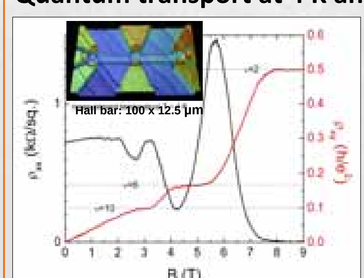
Electrostatic transfer of epitaxial graphene

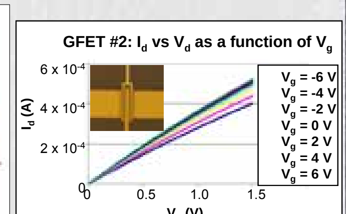




- Squares of graphene are transferred to glass from pre-patterned epitaxial graphene on SiC (inset: G-band Raman intensity map).
- The transferred graphene's sheet resistance is as low as 150 Ω/sq.

Quantum transport at 4 K and Graphene FETs





- Observed the integer quantum Hall effect (IQHE) in multiple devices
- Epitaxial graphene electron mobility: 14,000 cm^2/Vs
  - Highest measured for epitaxial graphene on SiC(0001)
- Electron density: 6 x 10^{11} cm^2
- Graphene sheet resistance: ~1600 Ω/sq (average of 12 devices)

Significance

- Producing large-area graphene films via Ar-assisted growth process (domain size ~ 100 µm^2)
- Observing IQHE with record carrier mobility (~ 14,000 cm^2/Vs) on epitaxial graphene
- Furthering the understanding of graphene growth mechanisms by real-time LEEM observations
- Developing a scheme to transfer epitaxial graphene to insulators, enabling a pathway for Si integration
- LDRD team has produced several "high-impact" publications

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SAND 2010-5503P

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