2-D Nanomaterials: Synthesis And Applications In Electronics and Optoelectronics

Jian Gao
Advisor: Nikhil Koratkar
Toh-Ming Lu
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• 1. 2-D materials intro.
• 2. h-BN as substrate of interconnects.
• 3. Transition Metal Dichalcogenides Synthesis.
• 4. MoS$_2$ grown on Graphene foam.
2-D materials

Graphene

Phosphorene

TMDs—MoS$_2$, WS$_2$, MoSe$_2$, etc

Hexagonal Boron Nitride

bandgap
2. h-BN as intermediate layer in interconnects

2.1 Background:

- No dangling bonds: Higher carrier mobility of graphene on h-BN than on SiO₂---great interests as intermediate dielectric layer in electronics.
- High thermal conductivity: 390 Wm⁻¹K⁻¹ (in plane) and 2 Wm⁻¹K⁻¹ (cross plane) vs. 1.5 Wm⁻¹K⁻¹ of SiO₂---A thin layer of h-BN would prevent Joule heating induced Cu interconnect failure during power overloading.

Left: transfer Graphene on h-BN. (James Hone, et. al., Nature Nanotechnology 5, 722 (2010))
Right: the Cu line deposited on h-BN can withstand ~1.9 times more power than on SiO₂.
2.2 deposition and electrical test.

- Cu lines are patterned by e-beam lithography, and deposited by e-beam deposition.
- 4-probe electrical measurements were carried out in ambient conditions and vacuum conditions.

Left: SEM images of Cu line on SiO$_2$, before (a) and after (c) electrical testing. (b, d) on h-BN.

Right: Resistivity of Cu line versus current density.
Summary:
- Theoretically, Cu line deposited on h-BN can withstand ~1.9 times more power than on SiO$_2$.
- Experimentally, Cu line failed at lower loading power.
- The lower failure power of Cu on h-BN may be caused by the wrinkles and steps-- Heavier scattering and thinner film.

Future works:
- 1. Directly growth of h-BN on dielectric layers.
- 2. Improve the transfer methods to prevent wrinkles.
3. WS₂ and MoS₂ CVD synthesis

Properties:
1. Monolayer MoSe₂, WSe₂, MoS₂, WS₂ has finite direct bandgap, 1.5eV-2.0eV.
2. Carrier mobility is 0.1-10 cm²V⁻²s⁻¹, not applicable in traditional electronics.
3. Less than 1nm thick monolayer MX₂ could absorb 5%-10% incident light, that’s one order magnitude higher than GaAs and Si.
3.1 WS$_2$ synthesis

Bigger than bigger

CVD setup

![CVD setup image]
3.2 TMDs heterojunctions

Synthesis:


3.3 Applications in Optoelectronics

- 1. MoS$_2$/graphene photodetector achieved the largest photoresponsivity at optical range.$^1$
- 2. 1nm MoS$_2$/graphene solar cell could achieve PCE=1%.

Nano Lett., 2013, 13 (8), pp 3664–3670
MoS$_2$-graphene foam: MoS$_2$ anchored with GF as anode in LIB. The discharge capacity of 1235.3 mAh g$^{-1}$ at a current density of 200 mA g$^{-1}$, retaining 85.8% of the initial reversible capacity after 60 cycles.

Published Papers

Since RPI:


D Shao, H Sun, J Gao, G Xin, MA Aguilar, T Yao, N Koratkar, J Lian,* S Sawyer,* Flexible, Thorn-like ZnO-Multiwalled Carbon Nanotube Hybrid Paper for Efficient Ultraviolet Sensing and Photocatalyst Applications, Nanoscale, 2014, DOI: 10.1039/C4NR03921A


Before RPI:


Thanks!