2D Layered Materials (beyond graphene) for photonic and sensing applications

- What lessons can we learn from CNTs and graphene that will help to speed up of the R&D of 2D materials and devices?

- What are the most promising advances in science and technology over the last few years, for different materials and devices? What lessons can we learn that will help the future R&D of 2D materials and devices.

- Two-dimensional materials and devices have potentials in electronics, photonics, sensing, energy, and other application areas. They also face competing technologies in each of these areas. Looking at 10 or 20 years from now, what will be the most likely commercial applications and what will be the commercial applications that would have the largest societal impacts? What are the key barriers that could prevent us reaching the desired goals?

- Functionalization, varying number of layers, etc.?

2D Materials for Sensors

- Challenges for Sensors in General:
  - Specificity
  - Signal to noise ratio; signal to information ratio!
  - Minimization of false positives, false negatives
  - Standoff/range vs. point
  - Power
  - Affordability, performance compared to existing tools
  - Portability/lightweight if required
  - Integration
  - Radiation hardness
- Advantages of 2D Materials
  - Vast chemistry provides platform for designing sensors for specific applications; many options
  - Purely surface and charge quantization
  - Variable electronic structure provides opportunity to integrate optical detection
  - Maybe advantages compared to top down approach of making 2D from 3D materials
  - Mechanical flexibility may provide opportunities for integration onto inexpensive platforms, with caveats: anything beyond cylindrical substrates is a practical challenge

Quantum Size Effects on the Chemical Sensing Performance of Two-Dimensional Semiconductors

Junghyo Nah,[†,‡,§,▽] S. Bala Kumar,[∥] Hui Fang,[†,‡,§] Yu-Ze Chen,[⊥] Elena Plis,[#] Yu-Lun Chueh,[⊥] Sanjay Krishna,[#] Jing Guo,[∥] and Ali Javey[†,‡,§,*]

[†]Electrical Engineering and Computer Sciences, University of California—Berkeley, Berkeley, California 94720, United States

[‡]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, United States

[§]Berkeley Sensor and Actuator Center, University of California—Berkeley, Berkeley, California 94720, United States

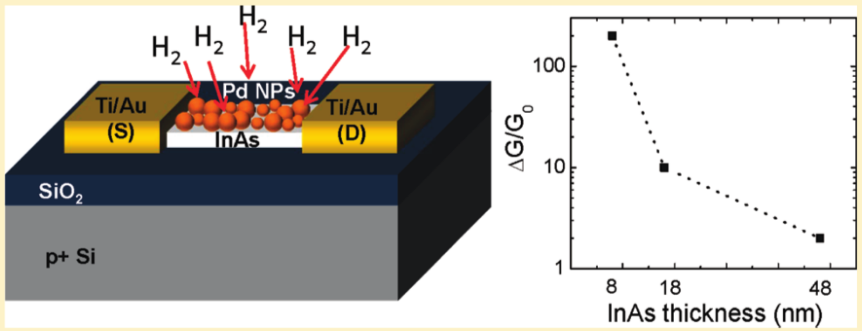
[∥]Electrical and Computer Engineering, University of Florida, Gainesville, Florida 32611, United States

[⊥]Materials Science and Engineering, National Tsing Hua University, Hsinchu 30013, Taiwan, Republic of China, 30013

[#]Electrical and Computer Engineering, University of New Mexico, Albuquerque, New Mexico 87106, United States

Supporting Information

ABSTRACT: We investigate the role of quantum confinement on the performance of gas sensors based on two-dimensional InAs membranes. Pd-decorated InAs membranes configured as H_2 sensors are shown to exhibit strong thickness dependence, with ~100× enhancement in the sensor response as the thickness is reduced from 48 to 8 nm. Through detailed experiments and modeling, the thickness scaling trend is attributed to the quantization of electrons which favorably alters both the position and the transport properties of charge carriers; thus making them more susceptible to surface phenomena.



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Sensor Recommendations

- Inexpensive chemical/solution based methods for producing optically and electrically active 2D materials for R&D should be explored. This is an enabling technology.
- A ubiquitous sensor that can detect everything is unrealistic
- The versatility of 2D materials are unique in providing a platform for tailored sensors
  - Concepts that exploit the rich chemistry of 2D materials without deteriorating the transport and optical properties
  - Control of transport properties (energy gap, carrier density) apparently possible in materials with a wide range of surface chemistry.
- 2D materials may be ideal for sensors exploiting optical (stand-off) means for detection: molecular adsorption can be successfully and efficiently interrogated optically due to magnified effects on electronic structure in a film already highly absorbent (see below).

Photonics with 2D Materials

- Graphene photonics have shown exciting properties
- Photonics with 2D materials remains largely unexplored
- New measurements show that the optical absorption in 2D materials is related to the fine structure constant times the number of allowed inter-band transitions (“quantum absorbance” Javey et al.)
- Observation of PL

Photonics recommendations

- *d*-orbital conductivity in metallic layered transition metal dichalcogenides (m-LMTDs) makes them rich for exploration of optical properties
  - Low band gap 2D materials for plasmonic and/or spintronics should be explored
  - Doping to modulate the carrier density
- Exploitation of excitonic effects in layered 2D materials
- Methods to increase the quantum yield of PL in LTMDs should be explored
- Synthesis of high quality materials over large area will be important
- Stacking layers