THE VOGEL GROUP: ELECTRONIC MATERIALS AND DEVICES

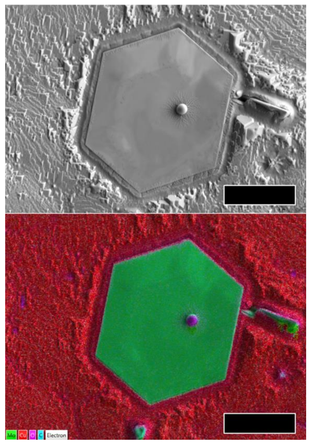
The Vogel Group pursues broad-based, cross-disciplinary research that spans the development and fundamental understanding of two-dimensional materials, electronic materials, devices, and circuits.

2D MATERIALS

Molecular Beam Epitaxy of Ferroelectric In_2Se_3

- In_2Se_3 is a van der Waals material that possesses a ferroelectric phase down to the monolayer limit
- This combination of properties allows for studying ferroelectricity and fabricating electronic devices at length scales where the depolarization field and other interfacial defects destabilize the ferroelectric phase in other materials systems
- Ferroelectric van der Waals materials are a relatively new class of materials and many studies have explored the properties of single crystalline flakes exfoliated from bulk crystals
- Synthesis of wafer-scale films of In_2Se_3 via molecular beam epitaxy (MBE) has begun
- We will characterize the defects in these films and in the heterostructures to understand how processing parameters ultimately influence electronic device behavior

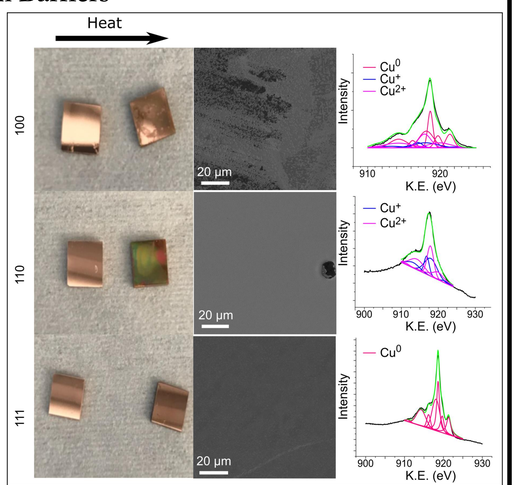
Ultrathin Mo_2C Synthesis by CVD



- **CVD Synthesis**
  - Mo atoms diffuse through liquid Cu substrate to react with CH_4
  - Necessary properties of substrate for ultrathin Mo_2C synthesis:
    - Low Mo solubility in liquid phase of substrate
    - CH_4 dehydrogenation
    - Alloy substrates must be soluble at low temperatures
- **Ultrathin Mo_2C as Gas Sensors**
  - Mo_2C nanomaterials have high sensitivity for gas sensing
  - High surface area to volume ratio, possibly enhancing sensitivity

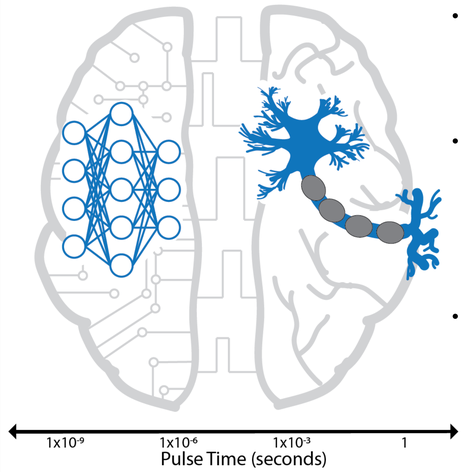
2D Materials as Permeation Barriers

- **Graphene Properties**
  - Atomically thin
  - Chemically inert
  - Extremely impermeable due to atomic structure
- **Graphene Corrosion Barrier**
  - Thermal oxidation barrier
  - Oxidizer diffusion through defects
  - Level of oxidation depends on interaction of graphene with underlying Cu grain orientation
- **Graphene Gas Permeation Barrier**
  - Reduces H_2 gas permeation through Cu

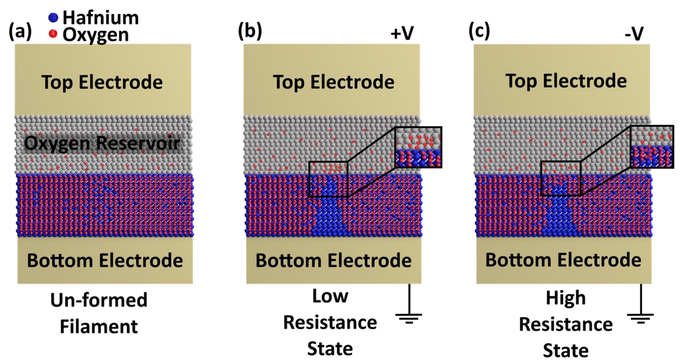


ELECTRONIC DEVICES

Resistive Random Access Memories (RRAMs)



- **Memristor Applications**
  - RRAMs
  - Replacing flash memory
  - Electrical synapse
- **Memristor Switching**
  - Metal-Insulator-Metal nanostructure
  - High resistance to low resistance state is caused by localized conductive path
    - Conducting filament
    - HfO_2 and $HfTiO_x$
- **Conducting Filament Mechanism**
  1. Applied voltage
  2. Oxygen vacancies/ions (in active layer)
  3. Local heating
  4. Metal-electrode interfaces

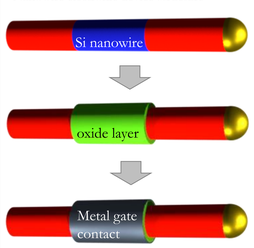


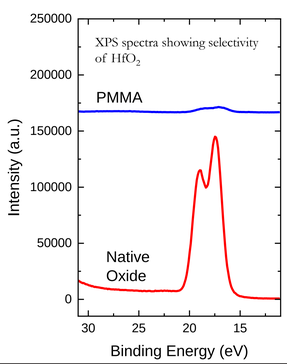
Nanowire Electronic Devices

Collaborative project with Prof. Filler's group to develop a bottom-up fabrication process to make electronic devices using semiconductor nanowires

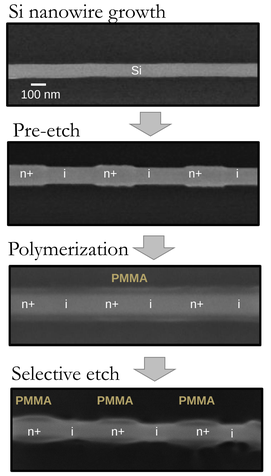
- Polymer film grown on semiconductor surface and selectively etched to pattern film
- Low temperature processes are required to prevent damage to the polymer mask
- Selective-area atomic layer deposition used to form high-quality oxide followed by metal deposition to form a full gate stack
- Studying and improving electronic properties of AS-ALD deposited material

Nanowire electronic device structure





Si nanowire growth

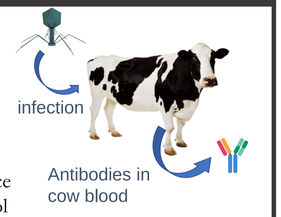


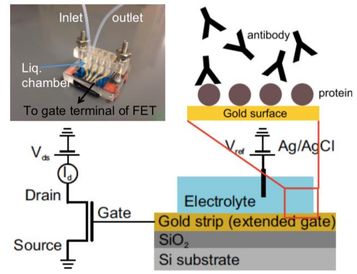
SEM images showing selective removal of PMMA polymer film on nanowire

BIOSENSORS

Bovine Animal Health Monitoring

- Collaboration with Tyndall National Institute and Queen's University Belfast
- Field deployable disease sensors will enable:
  - targeted disease treatment and informed herd health management
  - reduced therapeutic costs and increased animal performance
  - improved use of vaccination and eradication disease control strategies.



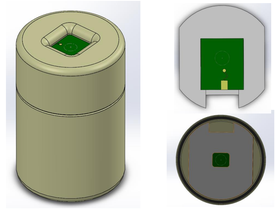


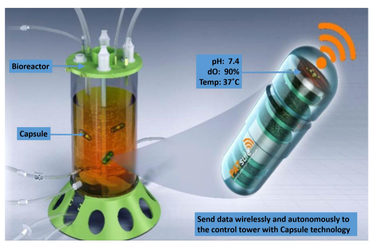
Project goals

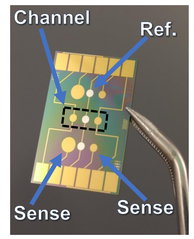
1. Use dual Impedimetric/ Potentiometric sensing platform to screen viral, bacterial and parasitic infections
2. Develop field deployable sensor format for on-farm testing.
3. Validate the developed diagnostic tests and sensor platform for on-farm testing using whole blood and milk as test matrices enabling rapid result reporting.

Real-time Bioreactor Sensor Capsules

- Aims to provide in-situ monitoring of cell and tissue growth
- Multiplexed sensors will enable continuous monitoring of cell metabolism and critical quality attributes
- Will improve efficacy of cancer cell therapies
- Wireless Bluetooth technology allows integration with smartphones

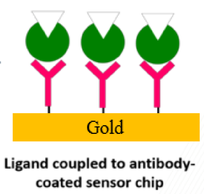


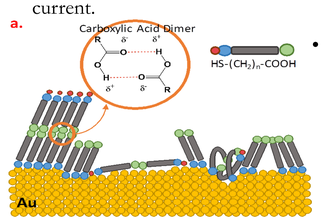




Clinical Applications of Potentiometric and Impedimetric sensing

- Collaboration with AVX to develop reliable, robust biosensors for clinical applications.
- Gold surface is used as an extended gate for a field-effect transistor.
- Thiol-based self-assembled monolayers (SAM) used to covalently attach a receptor protein to a gold surface.
- Utilize antibody-antigen interactions to detect infectious disease.
- The antibody-antigen binding is translated into a measured current.





- **Project Goal**
  - Improve the stability of the active layer on gold.
  - Study the chemical and electronic properties of three active layers:
    - Thiol based SAM
    - N-Heterocyclic Carbenes
    - Anthranilic Acid-polymer based active layer.
- Stable active layers on gold improves the sensitivity and repeatability of the biosensor-allowing for commercialization.