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Growth of hBN by High-Temperature Metal-organic Chemical Vapor Deposition

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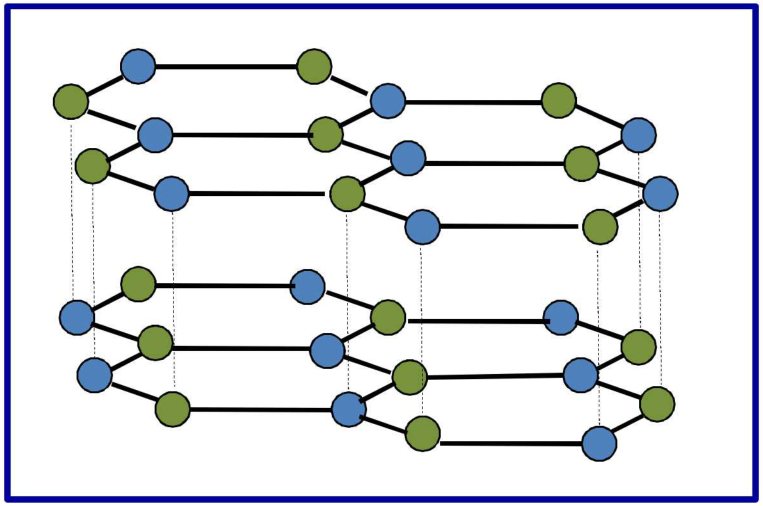

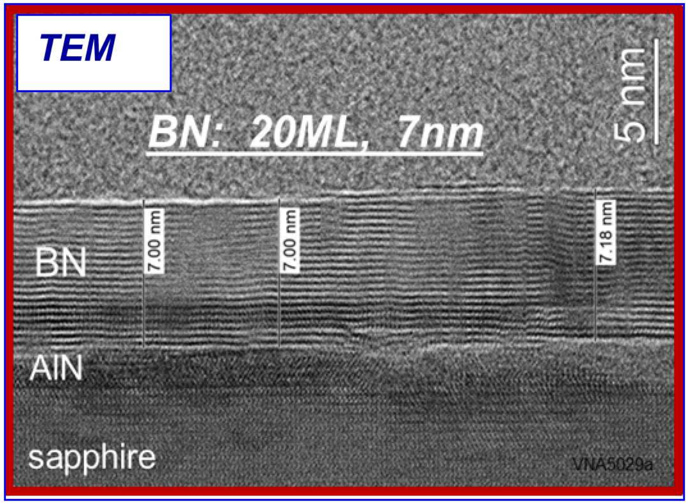

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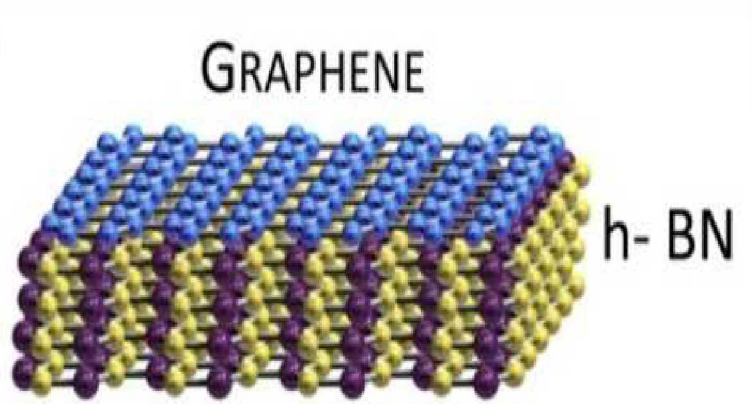
Background - Why hBN?

2D applications

- Dielectric substrate for high mobility graphene
- Stacked monolayers w/graphene a “circuit board” for TMDs
- Encapsulant for quantum Hall devices
- Single photon emitters, gas sensing, hyperbolic optics

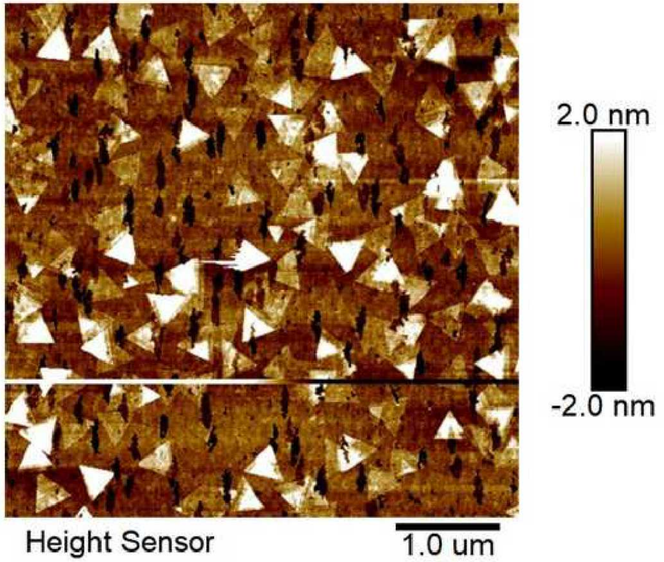
Bulk applications

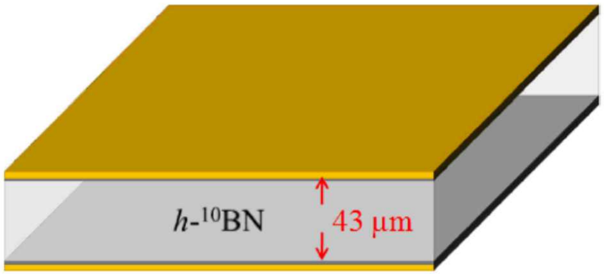
- Thermal neutron detection
- UV optoelectronics



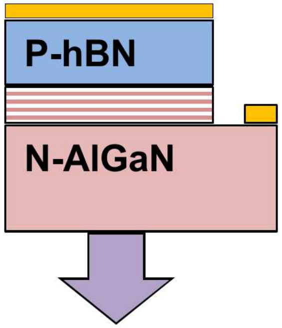
nanotechweb.org

Mono- and multi-layer WSe_2 grown on hBN





Maity et al., 2016



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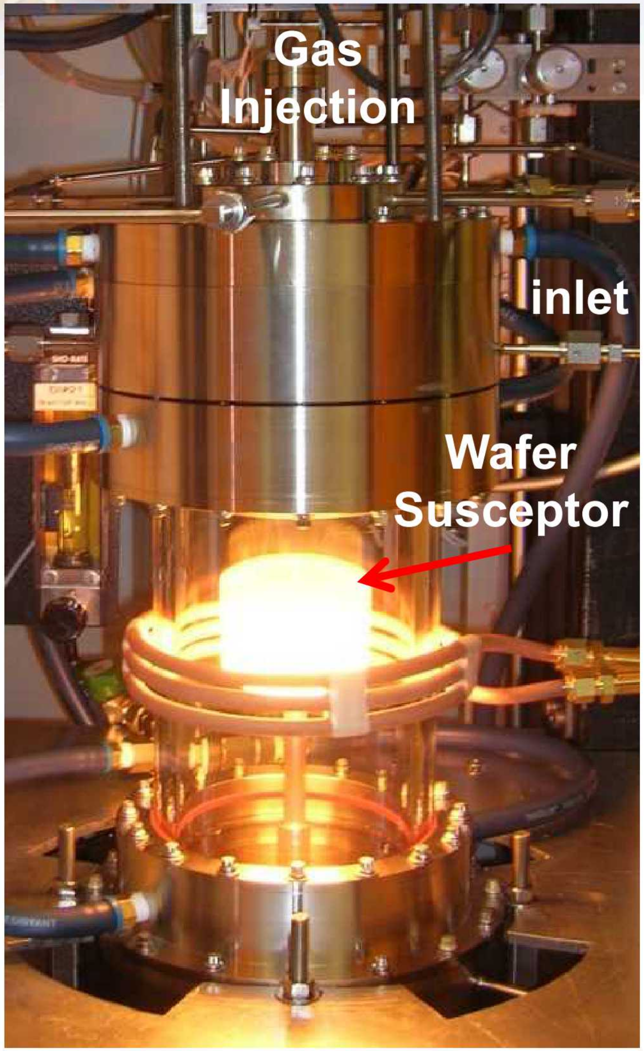
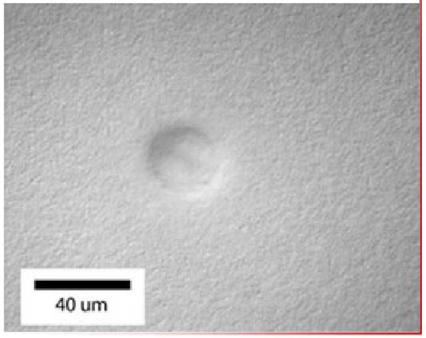
High Temperature MOCVD System



Reactor Design from Prof. Zlatko Sitar (NC State)

- **Advantages of HT growth**
  - Cold walled, RF heated up to 1900°C
  - Increased surface mobility of Group-III atoms
- **Continuous Growth (TEB + NH3)**
  - Temperature: 1200 – 1600 - 1800°C
  - Pressure: 50 torr
  - NH3: 0.1 – 2 - 5 slpm
  - TEB: 12 µmoles/min
  - Carrier gas: N_2 Diluent gas: H_2
- **Continuous Growth (Borazine)**
  - Temperature: 1300 – 1600 - 1700°C
  - Pressure: 50 torr
  - Borazine: 0.06 – 3.6 µmoles/min
  - Carrier & diluent gas: N_2
- **Substrates**
  - Sapphire & SiC

40 mm thick visibly transparent hBN film on SiC substrate w/defect



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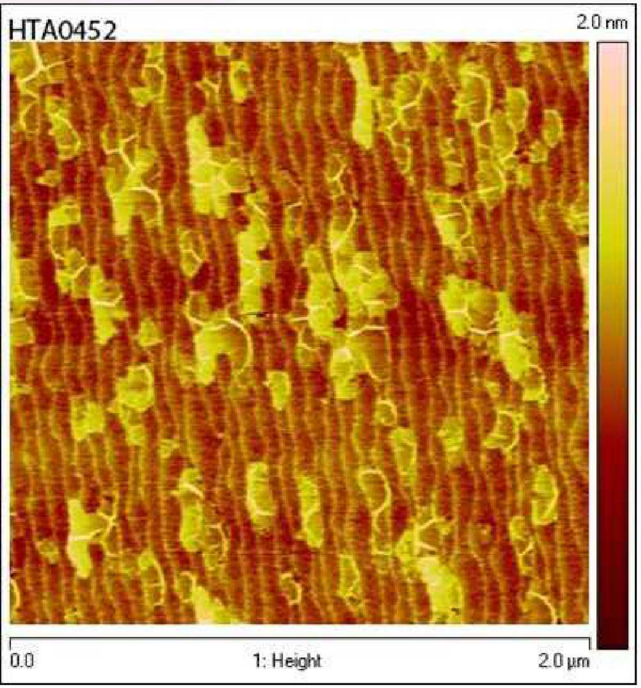
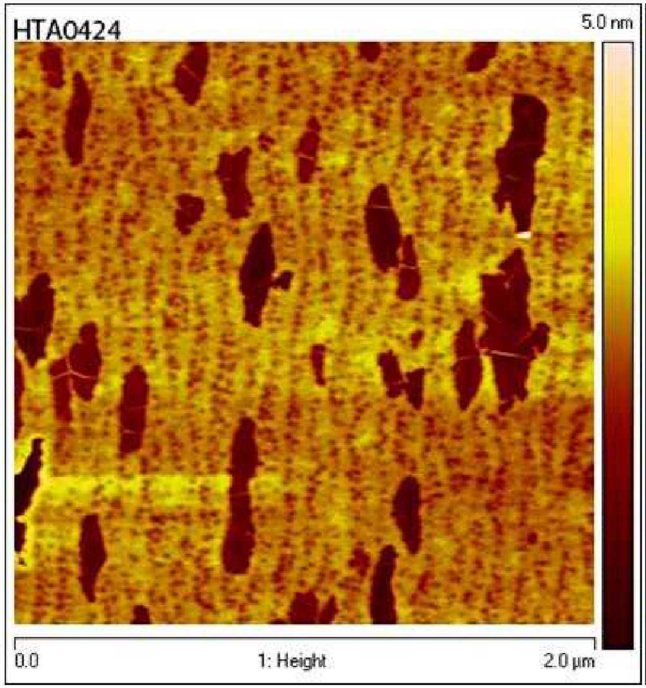
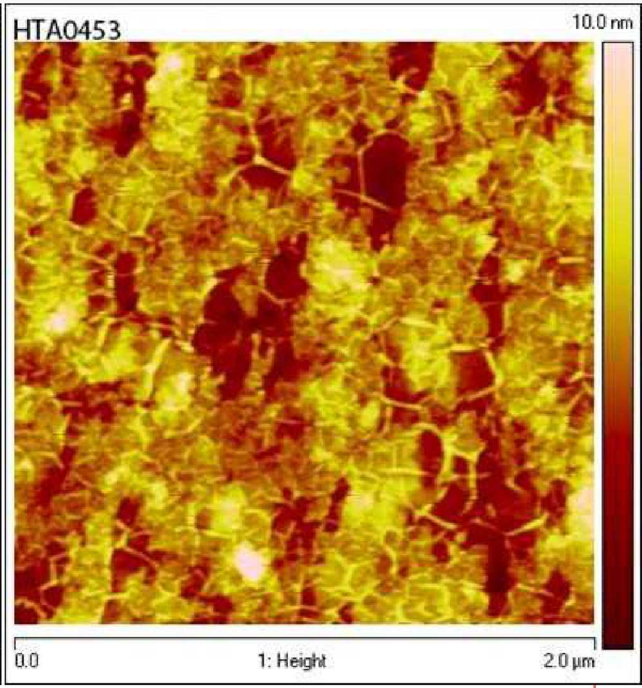
hBN Monolayer Growth







<1 monolayer
RMS roughness ~0.2 nm

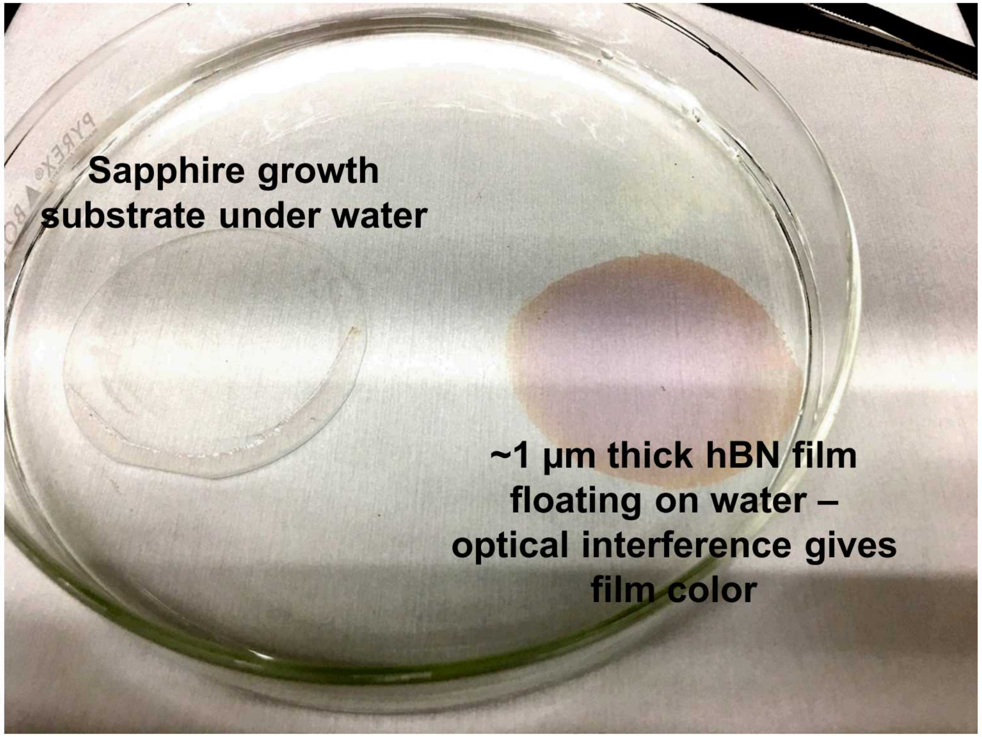
1 to 3 monolayers
RMS roughness ~0.5 nm

>3 monolayers
RMS roughness >1 nm

- **Have developed FTIR differential reflectance technique with better than 1 monolayer thickness resolution**

Separating hBN From Sapphire

- **Transfer hBN to other materials**
- **Allow for backside contacts**
- **Flatten surface, reduce strain**
- **Works with DI water, requires scribe at edge, "wrinkled" film, & near instantaneous lift of for 2" wafer**
- **Does not work with IPA – film tears apart, curls up, & stays submerged**



n Detector – Fabrication & Integration

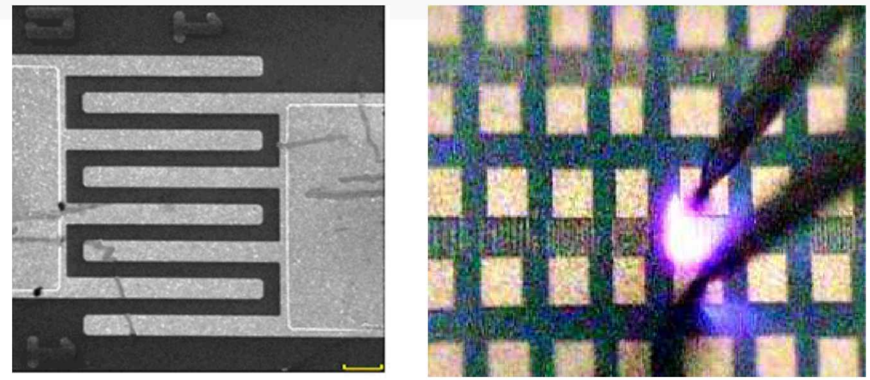
Initial test structures:

- MSM design with bulk samples and interdigitated front contacts with 2, 5, 10, 15 um gaps
- Characterized by photocurrent and ion beam induced current (IBIC) w/100 keV Li^+
- Difficult to extract $\mu\tau$ data due to non-uniform electric fields
- Analysis suggests surface leakage

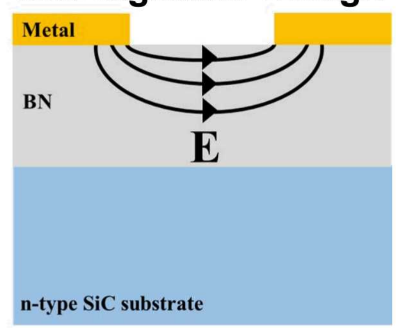
Revised design:

- Parallel plate, vertical structure to reduce $\mu\tau$ analysis complexity
- Probe volume of thicker films
- Side injected IBIC to probe thick film volumes

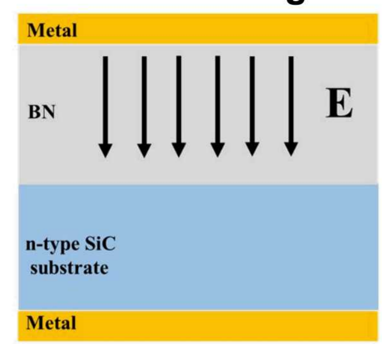
Interdigitated Design



E-field for Interdigitated Design



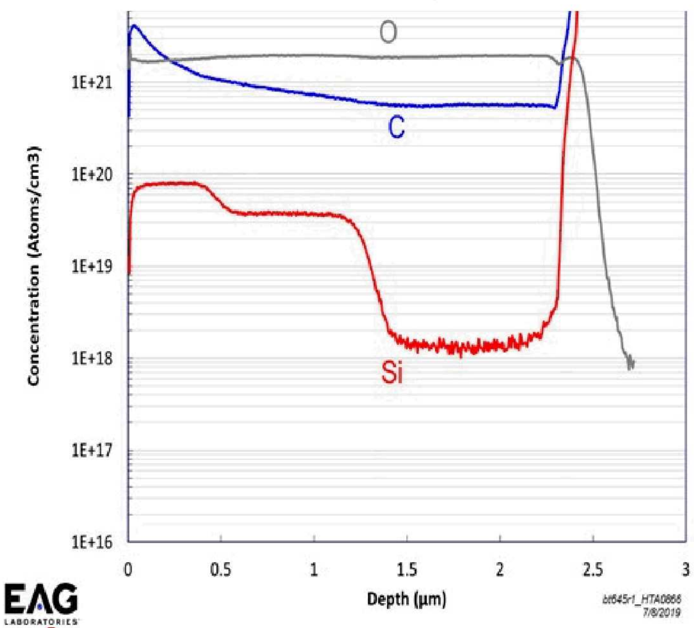
E-field for Vertical Design



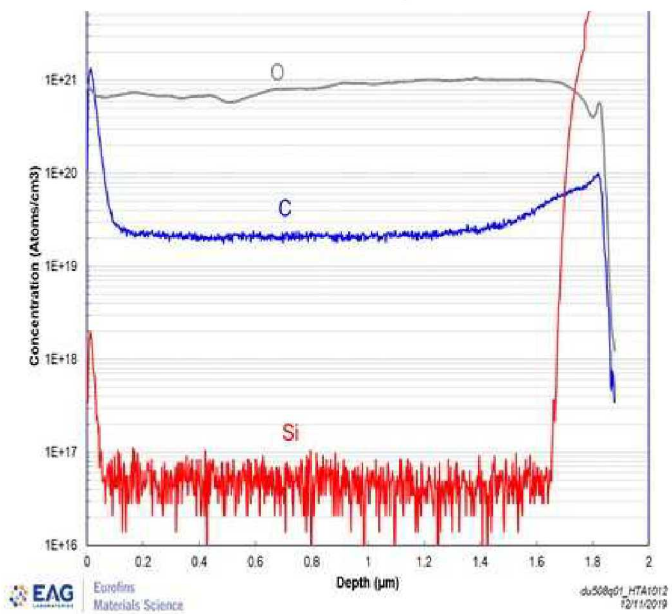
hBN Material Characterization

- SIMS analysis of hBN material indicates challenge
- Growth w/TEB & NH_3 (w/Si) has high C & O, consistent w/other results
- Borazine, w/no C, has reduced C but still too high
- Continuing to work for a reduction in C & O (e.g., higher purity precursors, alternate growth method)

Growth w/TEB [$(C_2H_5)_3B$] & NH_3, w/Si doping



Growth w/Borazine ($B_3H_6N_3$), no Si doping



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Summary

- Both monolayer and bulk hBN (40 μm) epitaxial layers demonstrated
- Demonstrated ability to remove hBN layers from sapphire
- Grown, fabricated, and tested bulk hBN for neutron testing
- Vertical, parallel plate structure preferred due to uniform E-field and avoidance of surface issues
- C and O challenges with either TEB/NH_3 and borazine precursors
- Continuing work to reduce impurities in the film growth

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