Probing 2D Materials using Quantum Capacitance Measurements

Akshay Patil , Chandni Usha , Satyarth Srivastav , Suvronil Dutta , Saisab Bhowmik , Radhika Soni , Pragya Prasad , Prabhat Mani
Nano-Scale and Device Fabrication Lab, Instrumentation and Applied Physics , Indian Institute of Science , Bengaluru , India.

Akshay Patil
akshaypatil@iisc.ac.in

Abstract & Summary

- 2D Materials can potentially help us realize the fascinating phenomenon such as Superconductivity at Room Temperature and Room Pressure, Quantum Computing of more than 70 Logical Qubits, Negative Quantum Capacitance, Quantum Memory Devices and many other applications based on the outstanding world of phenomenons such as Magnetism (orbital and Spin),Spin Orbit Coupling and Quantum Hall Effect, Quantum Anamolous Hall Effect, Quantum Spin Hall Effect, Co-related, Mott Insulators, Topological Insulators, Fractional Chern Insulators, Charge Density Wave Fluctuations, Nemacity , Pomeranchuk Effect etc. they show electrically! But to realize these epitomes practically we will have to probe these 2D materials and extract out the physical quantities that make us understand how these 2D materials behave electrically.
- We have successfully discussed the Probing of the 2D materials using various microscopy techniques and extracted out some dope quantities like Fermi Velocity , Fermi Energy , Phonon Velocity , Twist Angle , Thickness , Defect Characterization , etc. from Raman Spectroscopy and thickness of graphene and hBN from its optical contrast in Microscopy technique for our transfered hetero-structure .
- Moving on we have successfully extracted out Quantum Capacitance for our Dielectric-2D material-Dielectric hetero-structure on Si – SiO2 substrate by novel way and for graphene as 2D material's in plane resistivity measurement and from extracted quantum capacitance calculated close to 15 physical quantities and all of them successfully match the already available data for graphene both extracted theoretically from energy eigen values and experimentally via in plane measurement technique suggesting that this novel technique of extracting quantum capacitance is 100 percent accurate and a majority improvement over the already available complex techniques of ,

1. Constructing dielectric-2D material (whose quantum capacitance we want to measure)-dielectric-2D material (probes the top 2D material via its charge neutrality point)- dielectric using transfer technique and then carrying out in plane resistivity measurement of two Hall bar 2D material layers and ,
2. Making hardware changes in the capacitance measurement circuit using HEMT's to reduce its parasitic capacitance.

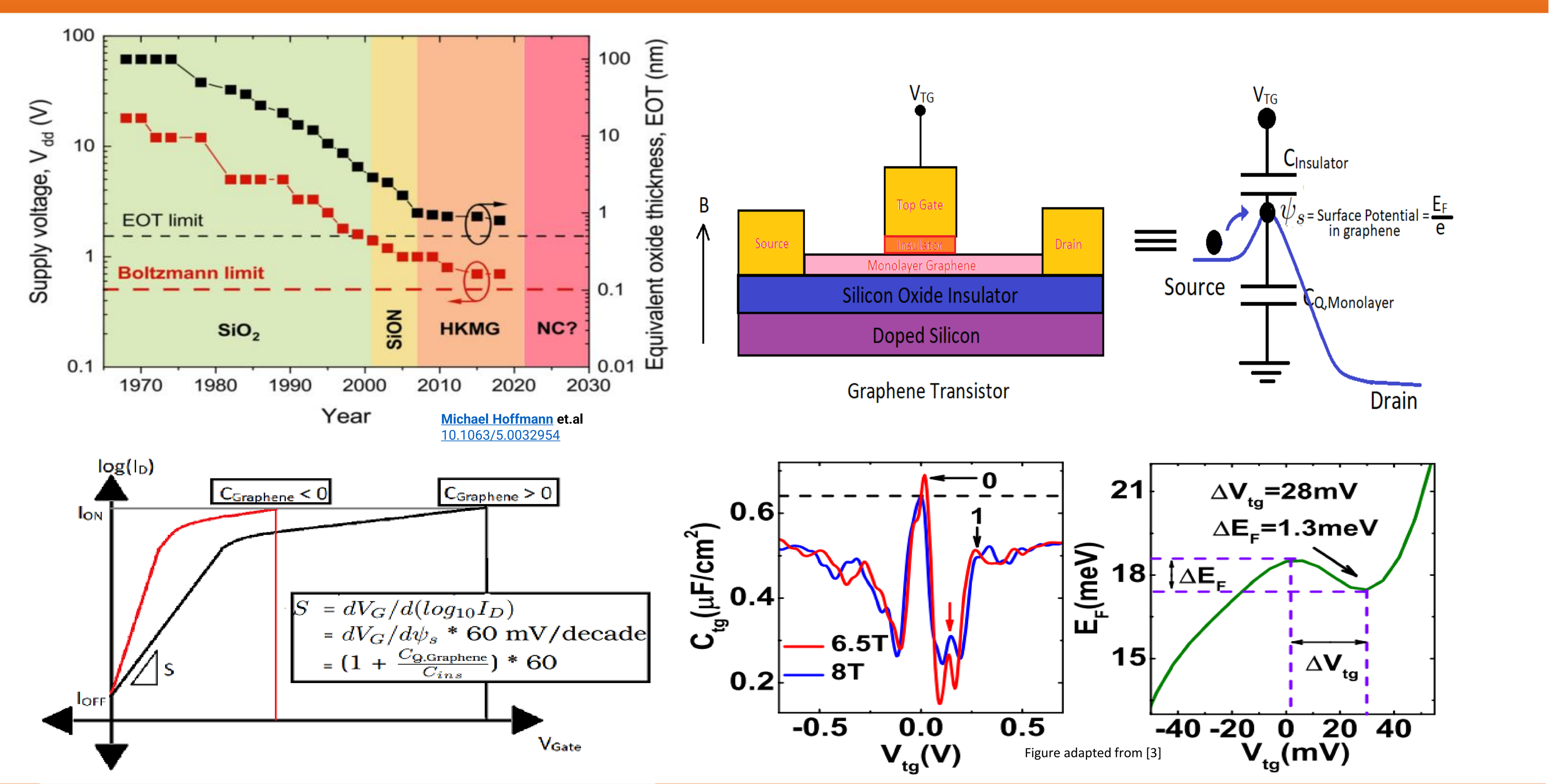
- This novel technique of extracting quantum capacitance can be applied for any 2D material and also the expressions discussed are general and not in any way specific to graphene and hence one can extract and completely characterize the electron transport of any 2D material using this technique and bring us one step closer to realizing these fascinating outlook.

Fascinating Outlooks/Impact of This Work

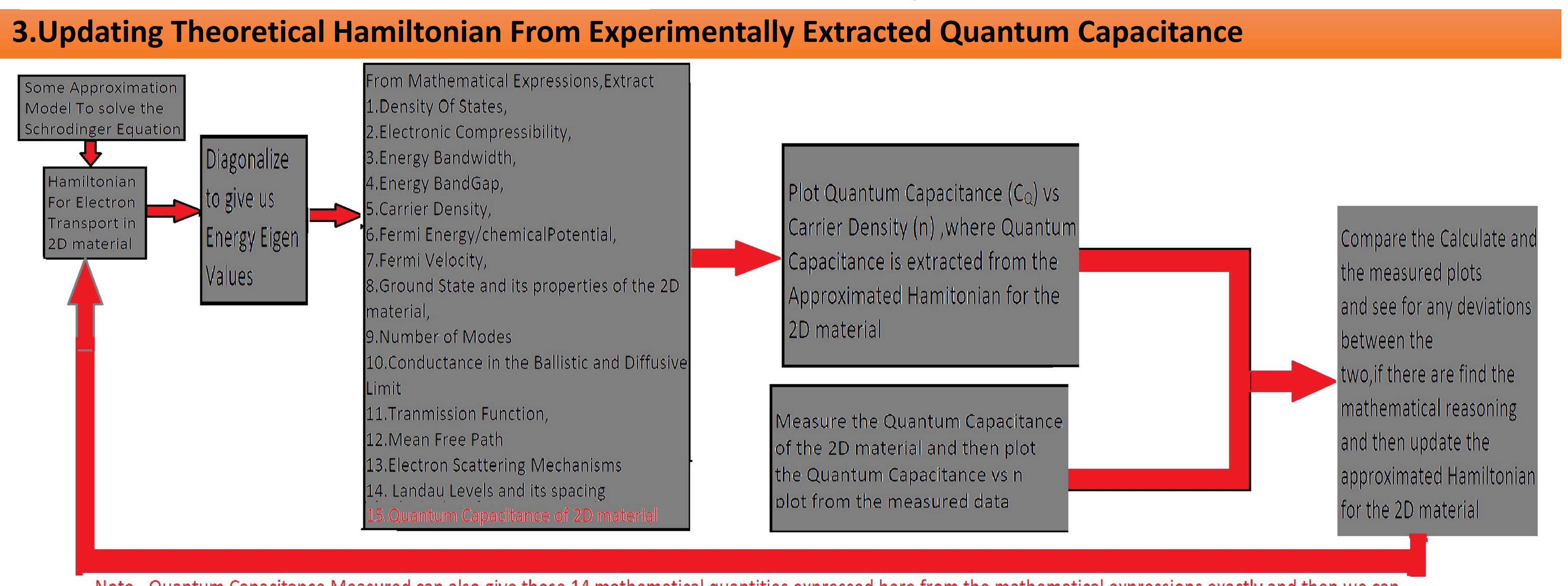
1. Fault Tolerant Quantum Computer Roadmap using Ballistic Transport Regime in Graphene -

- Graphene has mean free path i.e length of no scattering of electron of 10 micro-m at room temperature.
- Y channel monolayer graphene with width w allowing only propagation of one mode in one way of Y channel i.e |0⟩ or|1⟩ , later unify it to interference bridge of width W having two modes and length L decides the amplitude of the superposition of two states of electrons via interference pattern between two propagating electron waves.
- Set of universal gates construction possible
- Quantum Circuits having maximum of 500 Quantum Gates in one mean free path of graphene is possible.
- Coming to Y direction 200000 physical qubits owing to 200 logical qubits by error correction will just be hard fabricated in 12mm width chip.
- Just Apply potential difference between input and one of the output and measure current/transmission probabilities from other output.
- After 500 Quantum gates in direction we can use quantum repeators to reproduce the state at start of the next qubit line and start the coherence length afresh and realize required circuitry depth in x direction
- Road-Blocks – Fidelities of Circuits , Graphene has defects from fabrications which can lead to scattering and quasi-ballistic transport , Precision cutting of graphene to get graphene nano-ribbons and Fidelities of Quantum Repeators.
- Easy to Realize and measure with already available lock in amp's and sourcemeter.
- Refer D.Dragoman et.al doi: 10.1109/SMICND.2016.7783024 for more theoretical details on theory and construction of universal gates using Ballistic transport in graphene

2. Negative Quantum Capacitance in Graphene



3.Updating Theoretical Hamiltonian From Experimentally Extracted Quantum Capacitance

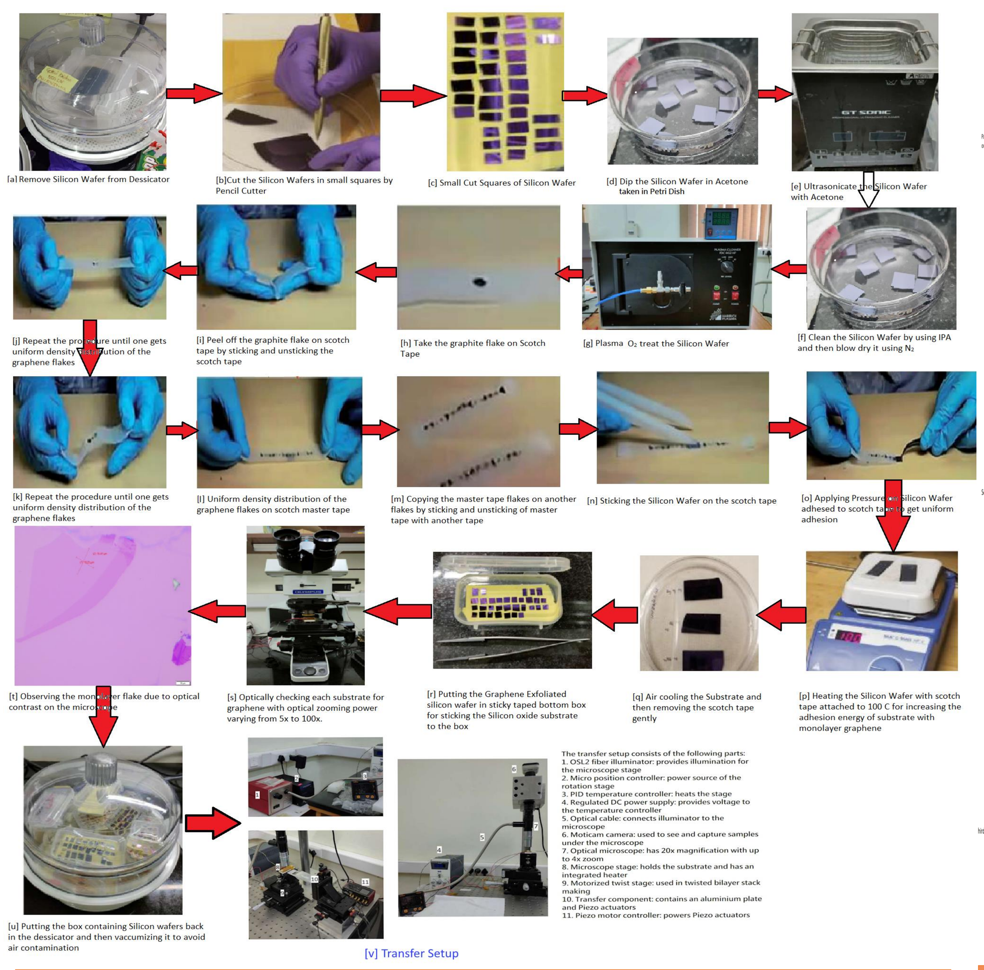


Note - Quantum Capacitance Measured can also give these 14 mathematical quantities expressed here from the mathematical expressions exactly and then we can compare those calculated values from measured data with the calculated values from approximated Hamiltonian Mathematical Expression and then update the Hamiltonian so that we can get an exact mathematical Hamiltonian and can exactly quantify it for the 2D material

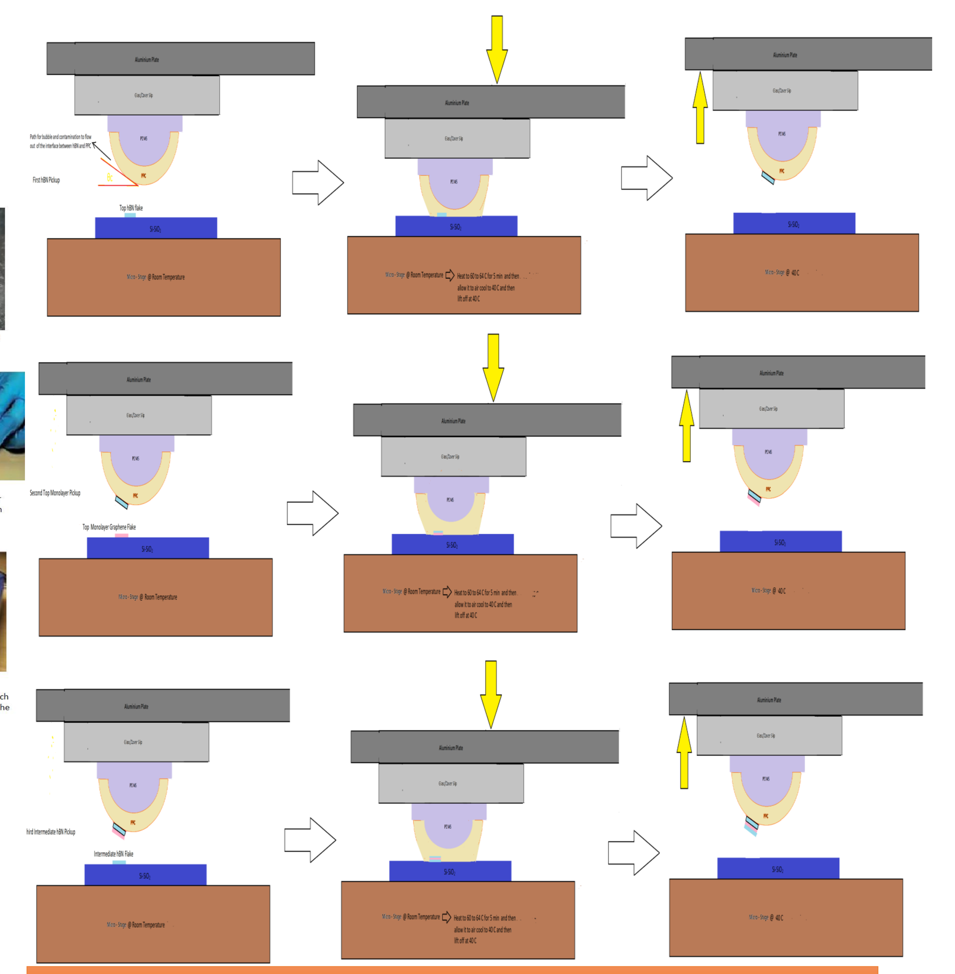
4. Industrially Synthesizing the Large Sheets of Monolayers of Graphene by Lap Joint/Butt Joint

5. Quantum Memory/Repeater Devices. 6.Superconductivity at Room Temperature and Pressure

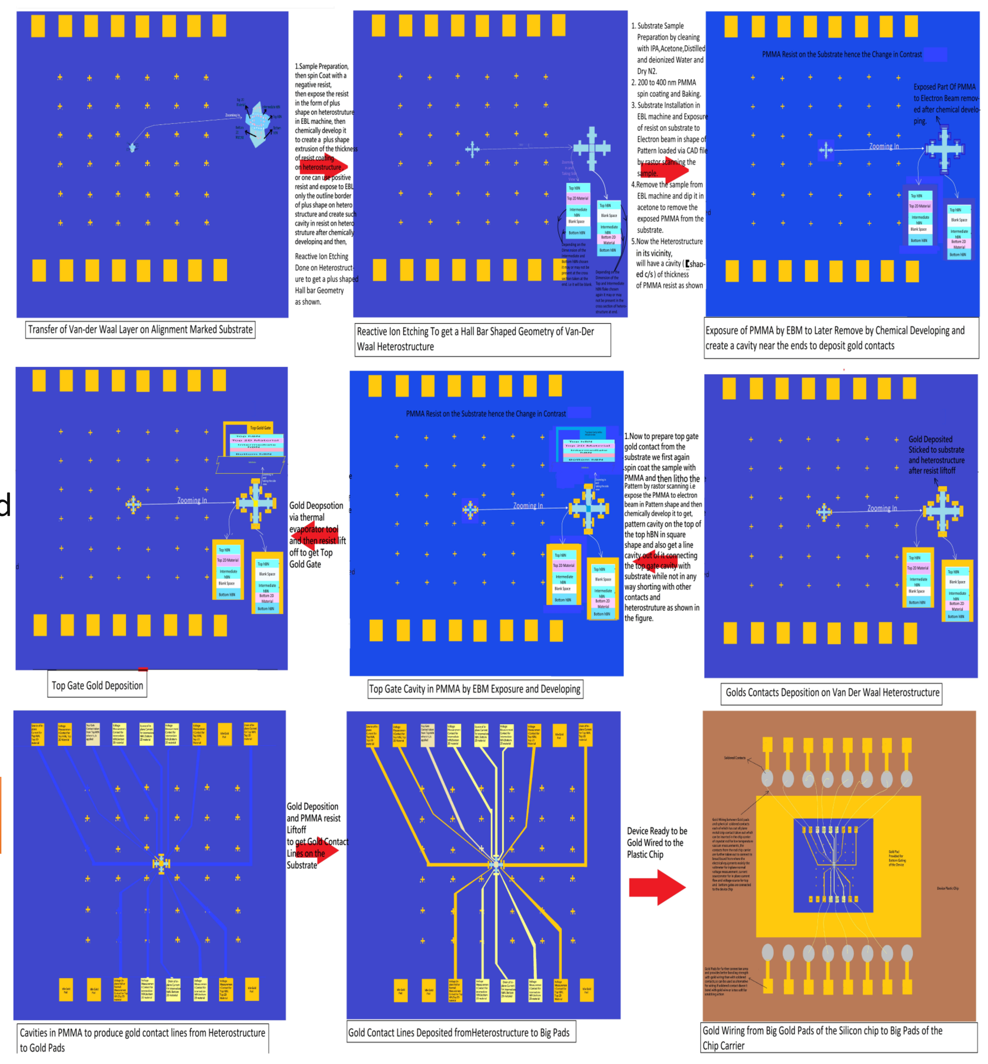
Van – Der Waal Heterostructure Making , Device Fabrication , Measurement Setup



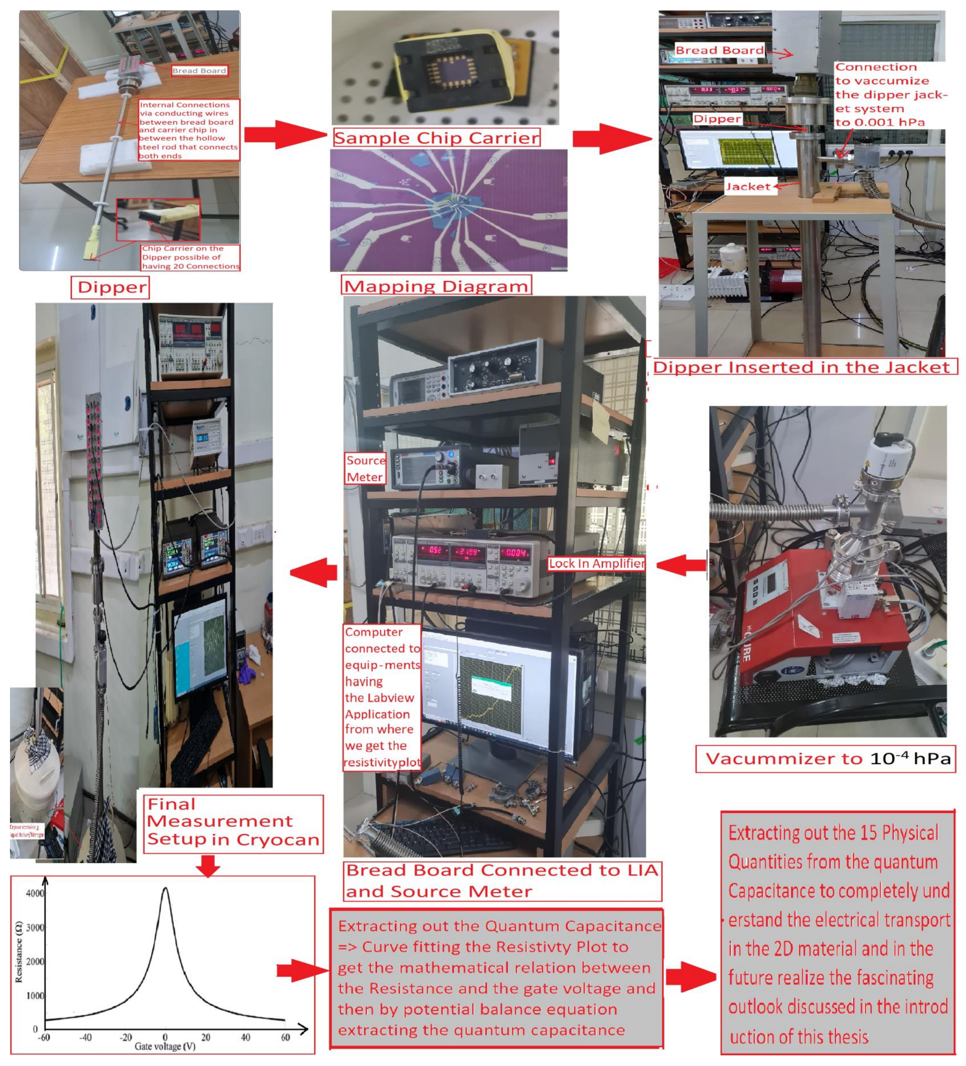
[a] Exfoliation Process of Graphene and hBN



[b] Transfer Schematic Process of Stack Making

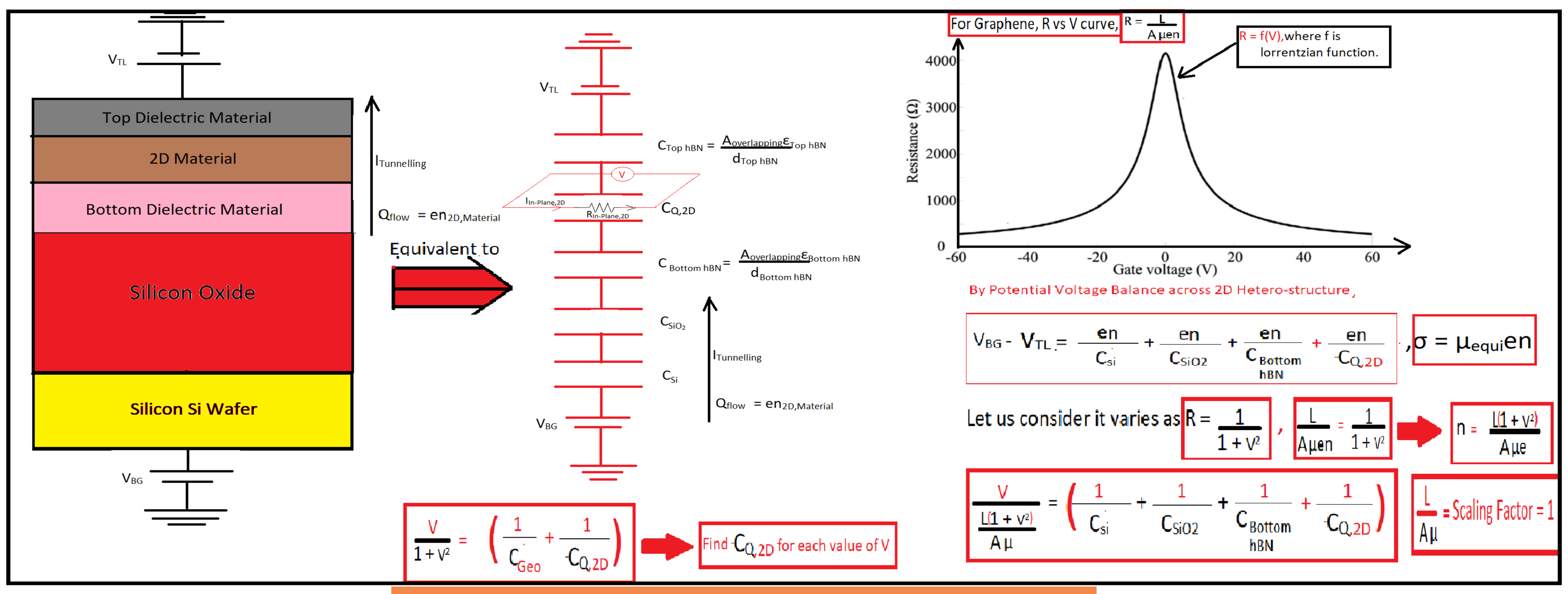


[c] Pre – Device Fabrication , Device Fabrication, Post – Device Fabrication

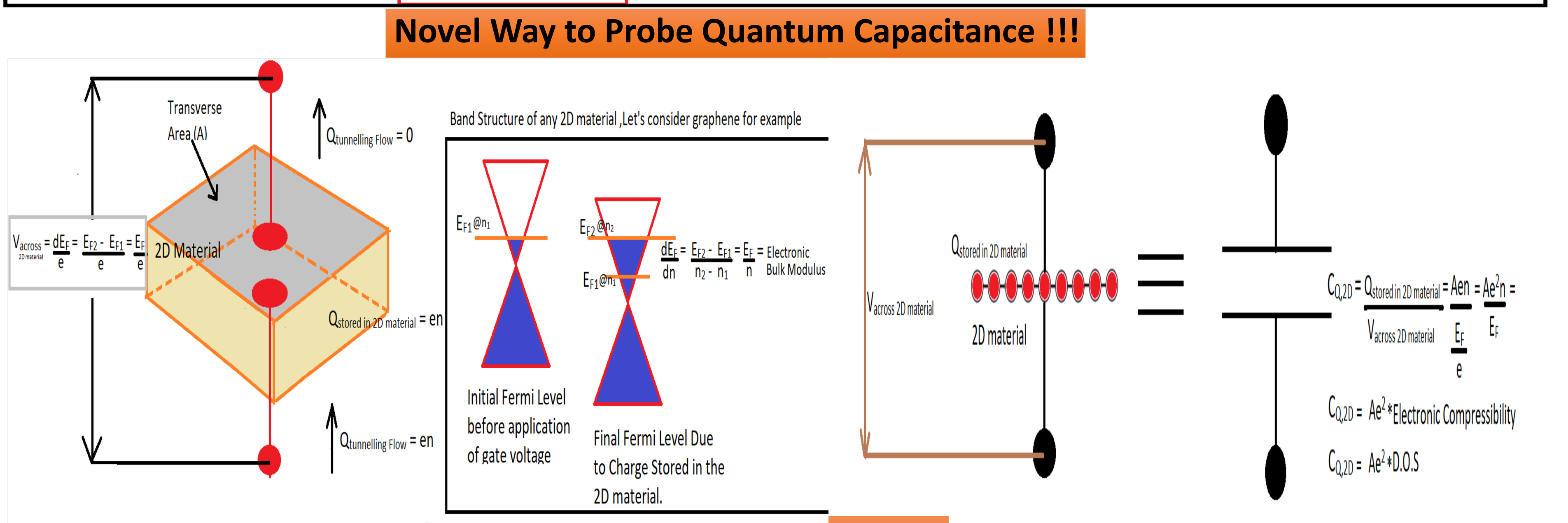


[d] Measurement Process of In Plane Resistivity of 2D materials

Novel Technique For Probing Quantum Capacitance of 2D materials



Novel Way to Probe Quantum Capacitance !!!

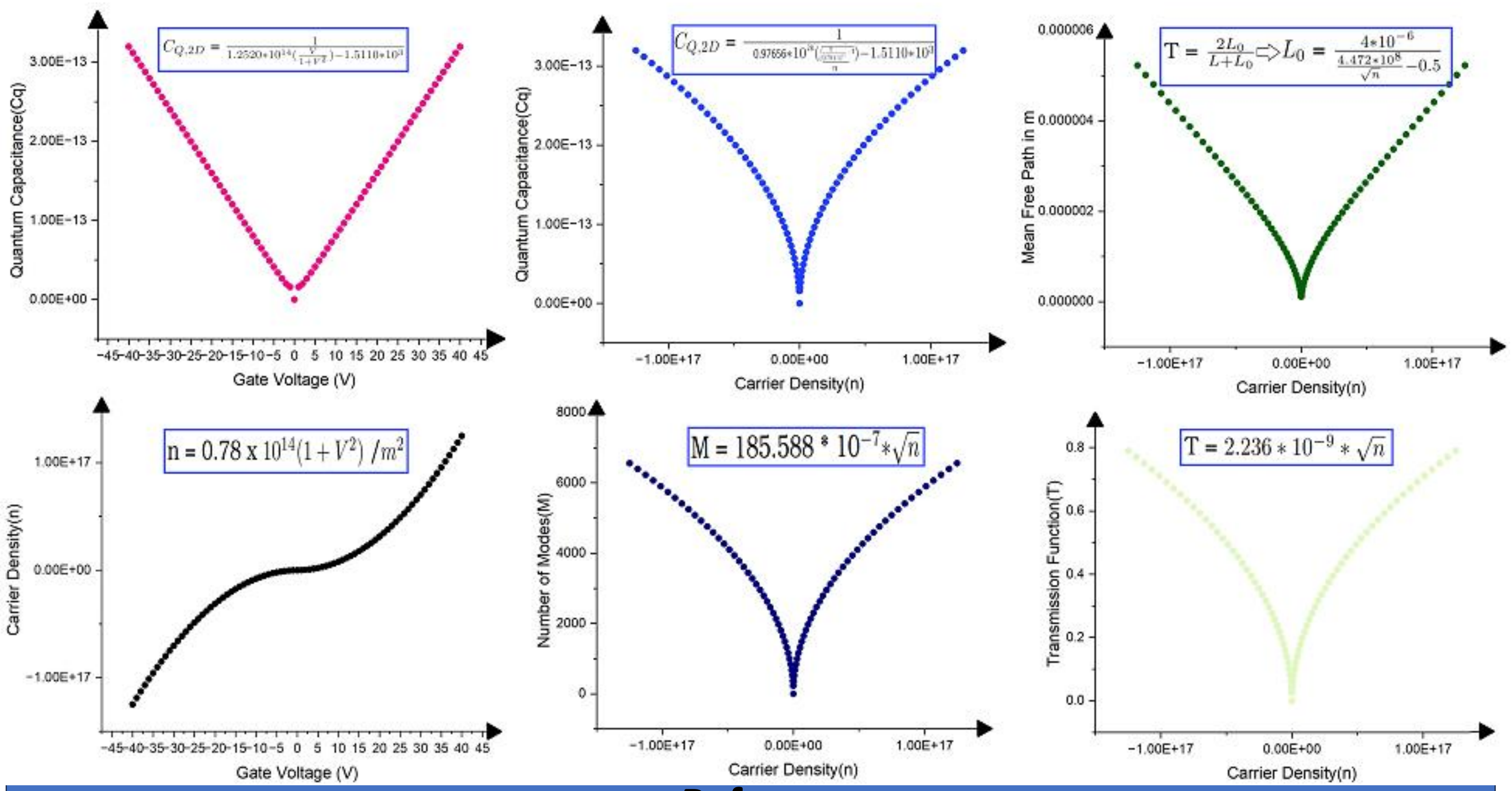


What is Quantum Capacitance ?!

Various Probing's/Characterizations of 2D Materials and what it gives?

1. Angle Resolved Photoemission Spectroscopy.
   - Actual many body interaction band Structure of 2D material.
2. Optical Microscopy.
   - Visually see graphene and BN contrast on Si – SiO2 substrate and identify the number of layers from contrast observed.
3. Scanning Electron Microscopy.
   - Number of Graphene layers and surface defects.
4. Transmission Electron Microscopy.
   - Characterization of Defects (Point , Dislocation , Grain Boundaries etc.)
   - Type of Graphene edges => Zigzag , Armchair , Klein Edge.
   - Number of layers of Graphene.
5. Scanning Probe Microscopy and Atomic Force Microscopy
   - Height of Graphene , hBN Flakes, Work Potentials , Charge Impurities in the 2D material.
   - Landau Levels by Conductance Measurements , Lattice Mismatch , AFM Lithography.
   - Quality of CVD grown graphene by K.V.M
6. Raman Spectroscopy
   - Number of layers of graphene , Defects , Quality of CVD by K.V.M
   - Phonon Velocity , Fermi Energy , Twist Angle of Twisted Bilayer Graphene.

Quantities Extracted From Quantum Capacitance for Monolayer Graphene



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