JAYPEE INSTITUTE OF INFORMATION TECHNOLOGY

Microfabrication Lab End-Term Project

Depletion region width calculation of heterojunction

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ABSTRACT:-

The accurate calculation of the depletion region width in a heterojunction is crucial for understanding and optimizing the electrical behavior of semiconductor devices such as Heterojunction Bipolar Transistors (HBTs), High Electron Mobility Transistors (HEMTs), and solar cells. Unlike homojunctions, heterojunctions involve materials with different bandgaps, electron affinities, and dielectric constants, leading to complex electric field distributions and charge dynamics across the junction. This study presents a theoretical framework for determining the depletion width in abrupt heterojunctions, incorporating material parameters such as permittivity, doping concentrations, and band discontinuities. Both one-sided and two-sided junctions are analyzed, and the effect of built-in potential variations due to heterostructure alignment is discussed. Numerical examples are provided to illustrate the impact of material selection on depletion characteristics, highlighting the importance of these calculations in designing high-performance optoelectronic and electronic devices.

INTRODUCTION:-

Heterojunctions are formed by the interface of two different semiconductor materials, each with distinct bandgaps, electron affinities, and dielectric properties. These structures are foundational in the design of high-efficiency electronic and optoelectronic devices, including heterojunction bipolar transistors (HBTs), high electron mobility transistors (HEMTs), and advanced photovoltaic cells. The interface of a heterojunction gives rise to unique charge transport behaviors due to band discontinuities and asymmetries in material properties.

A key region influencing device operation is the **depletion region**, where mobile charge carriers are absent and an internal electric field governs carrier dynamics. Accurately calculating the depletion region width is essential, as it affects junction capacitance, electric field distribution, and overall current-voltage characteristics. Unlike homojunctions, depletion width calculations in heterojunctions must account for unequal doping levels, different dielectric constants, and potential steps created by band offsets at the interface. This makes the analysis more complex and demands a careful theoretical approach.

This work focuses on the calculation of depletion region width in abrupt heterojunctions, providing insight into how material properties influence the charge distribution and electric field across the junction. Understanding this parameter is critical for optimizing the performance and reliability of next-generation semiconductor devices.

PROCESS/METHODOLOGY:-

Here's a list of all the libraries used in our code snippet:

Standard Libraries

1. tkinter – For creating the GUI.

2. tkinter.filedialog – For file selection dialogs.

3. tkinter.messagebox – For displaying pop-up messages.

4. tkinter.ttk – For themed widgets in Tkinter.

Data Handling

5. pandas (pd) – For handling and analyzing structured data.

Numerical Computing

6. numpy (np) – For numerical operations.

Plotting

7. matplotlib.pyplot (plt) – For creating plots and visualizations.

8. matplotlib.figure.Figure – For embedding figures in GUIs.

9. matplotlib.backends.backend_tkagg.FigureCanvasTkAgg – To embed Matplotlib plots into Tkinter GUI.

Statistics

10. scipy.stats.linregress – For performing linear regression.

Image Handling

11. PIL.Image – For opening and manipulating images.

12. PIL.ImageTk – For displaying images in Tkinter.

- The initial development was done using pycharm.
- Then we installed it on the system using command prompt
- After that packaging was done to make a Stand Alone Application that was named CV.EXE
- Application data size- 70MB ; Cored data size- 300 MB

C-V Measurement Steps:

● Connect the Device: Use an LCR meter or impedance analyzer (in our case Capacitance Measurement Unit) to apply an AC signal (typically 100 kHz–1 MHz) with a DC bias.

● Bias Voltage Sweep: Apply varying DC voltages while measuring capacitance.

● Plot C-V Characteristics: Generate a $1/C^2$ vs. V plot to analyze junction properties.

● Extract Key Parameters:-

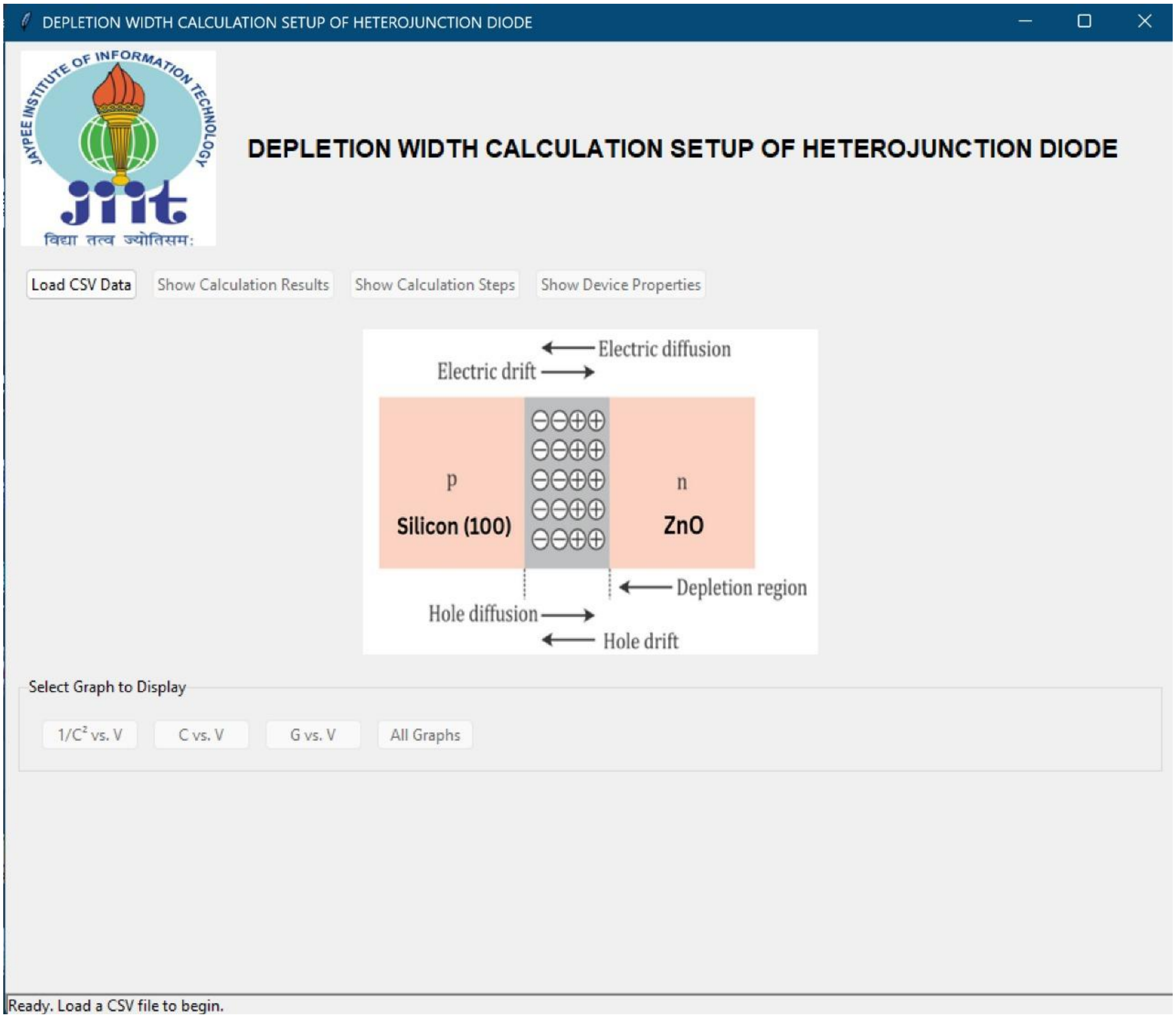
1) Built-in Potential (Vbi): From the extrapolated intercept of $1/C^2$ vs. V.

2)Carrier Concentration (NA): From the slope of $1/C^2$ vs. V

3) Depletion Width (W)

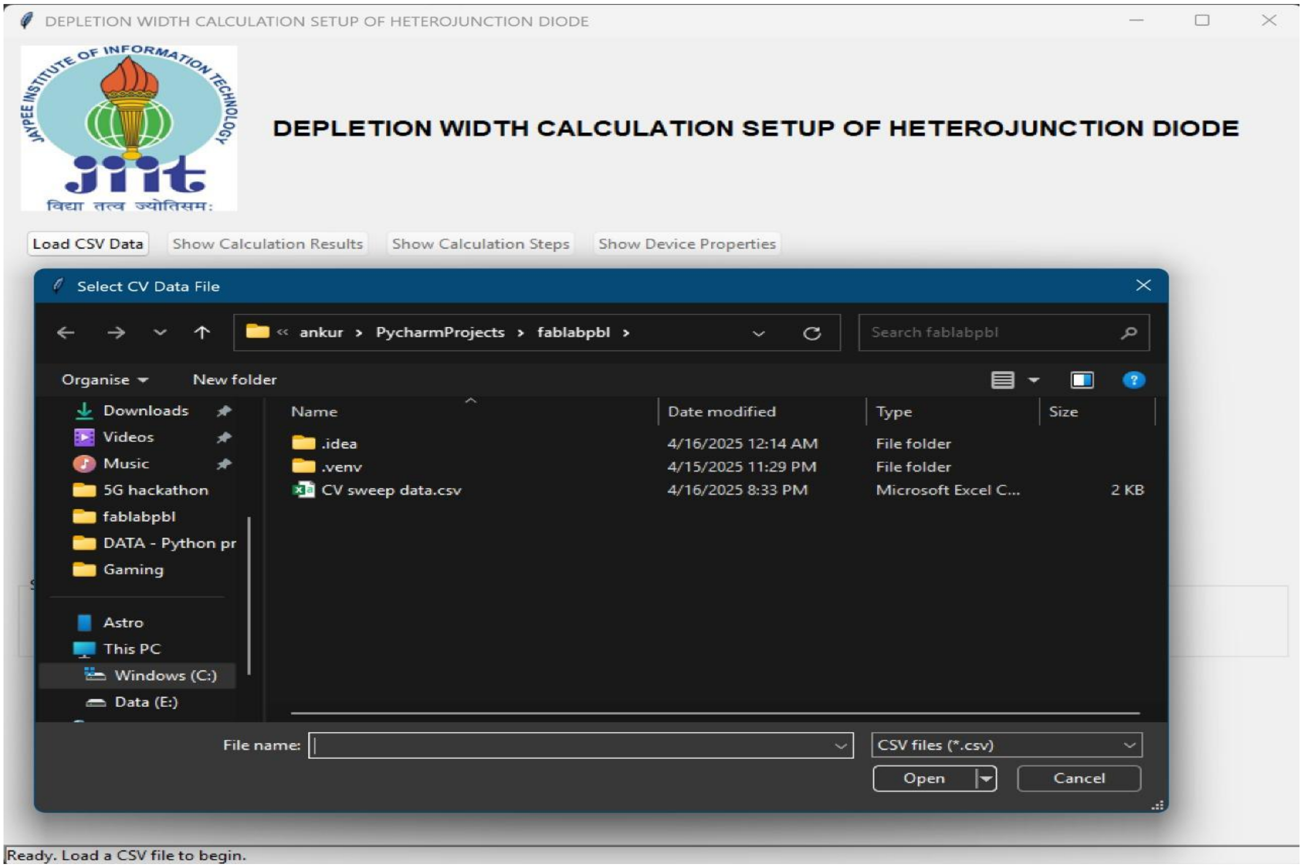
RESULT AND DISCUSSION:-

The GUI that we have designed to calculate width of depletion region:-

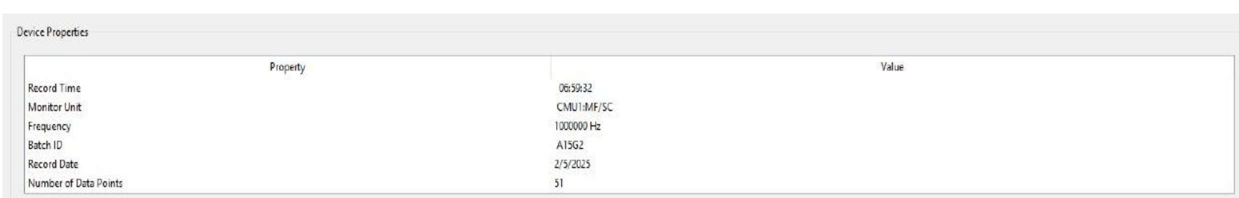


Here we have 4 options which help us in:-

1)Loading the CSV data:-



2)Displays the device properties:-



Device Properties

Property	Value
Record Time	06:59:32
Monitor Unit	CMU1:MF/SC
Frequency	1000000 Hz
Batch ID	A15G2
Record Date	2/5/2025
Number of Data Points	51

3)Shows the calculation steps:-

Calculation Steps

```
1. Plotting C-V Characteristics:
   - Generated 1/C² vs. V plot
   - Selected voltage range: -5.0 V to -1.0 V
   - Linear regression performed on selected range
   - Found linear relationship: 1/C² = -1.1862e+20 × V + 3.0189e+20
   - R² value: 0.9912
```

4)Shows the calculation results:-

Calculation Results

Built-in Potential (V_bi): 2.5450 V

|V_bi|: 2.5450 V

Carrier Concentration (N_A): -1.0177e+21 m^{-3} = -1.0177e+15 cm^{-3}

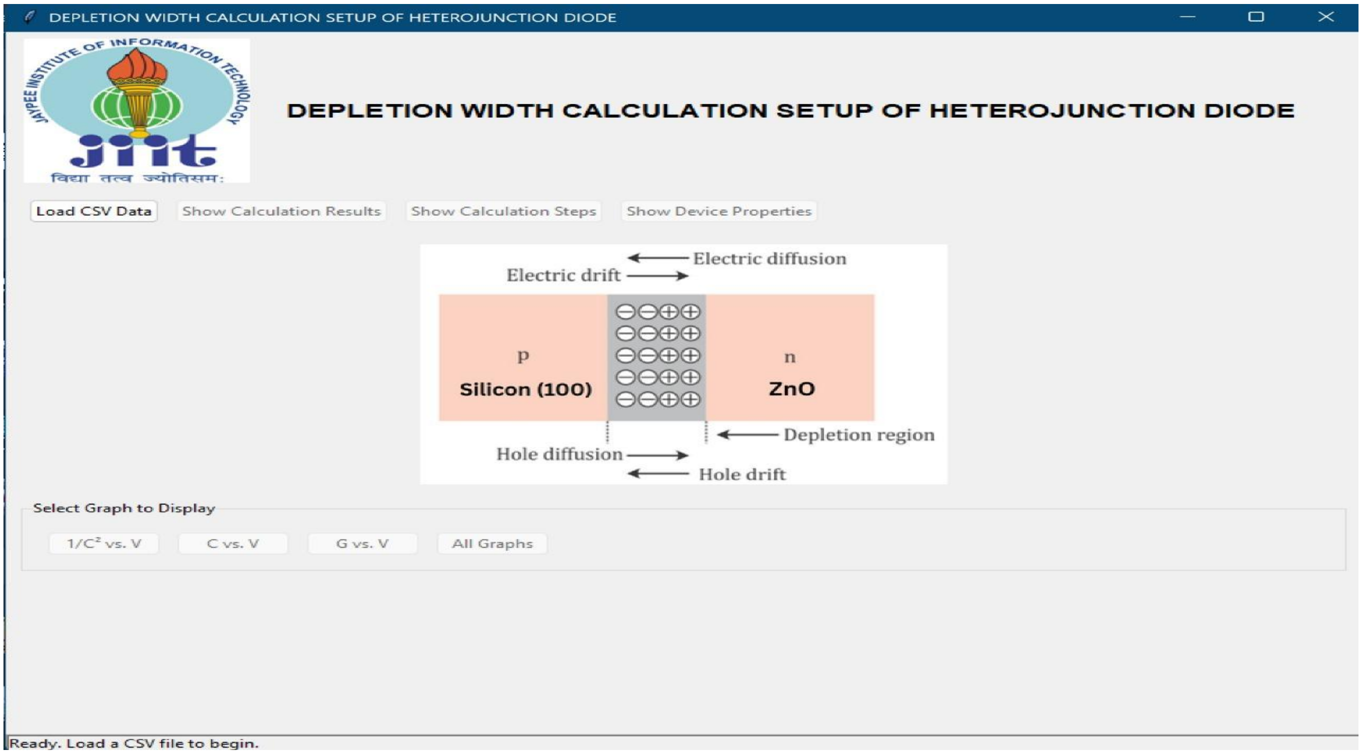
Depletion Width (W): nan nm

R^2 Value: 0.9912

The formula for calculating width of depletion region is:-

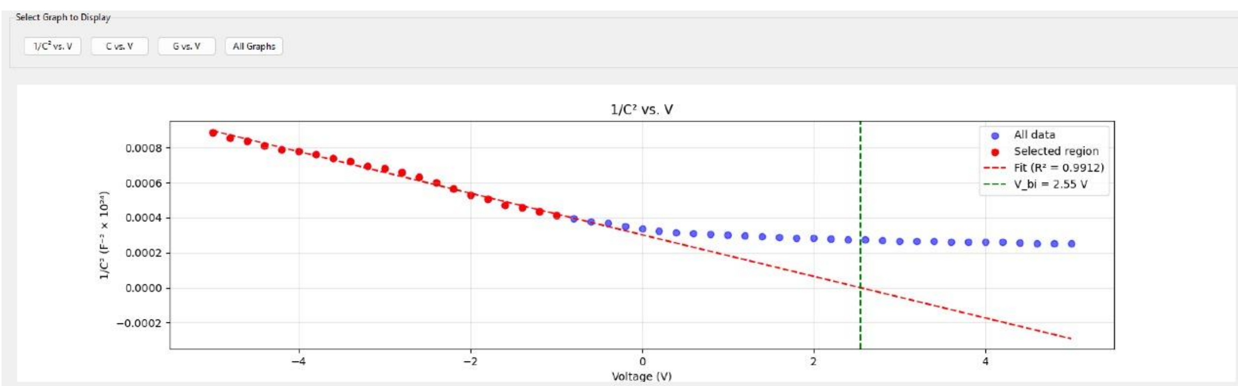
The depletion width W is calculated as:

$$W = \sqrt{\frac{2\epsilon_s(V_{bi} - V_{ext})}{q\ N_A}}$$

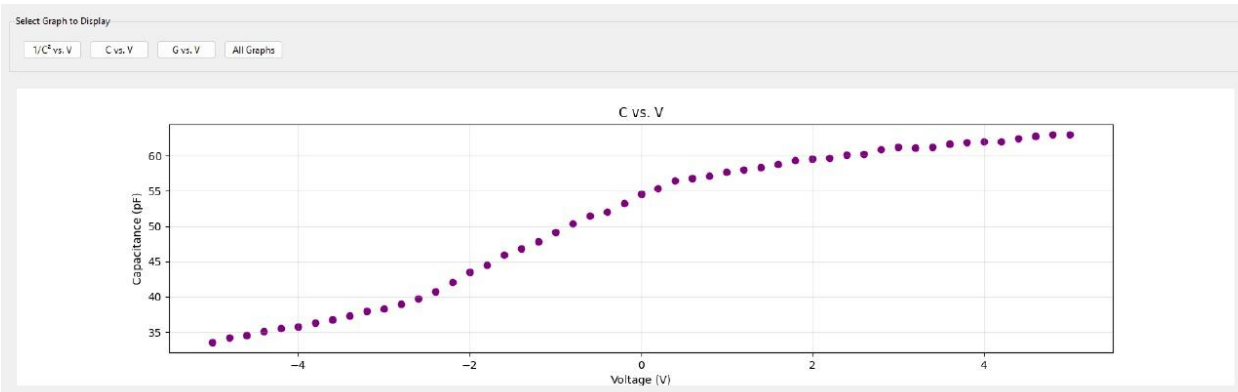


This setup consists of options where it displays the graphs for the following:-

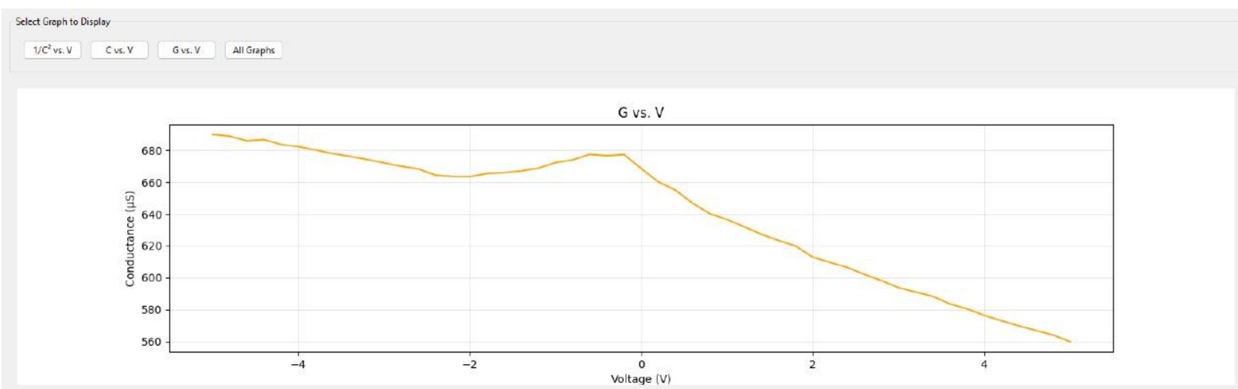
1)1/C^2 vs V:-



2) C vs V:-



3) G vs V:-



And the last option displays all the graphs in a single frame.

Conclusion:-

The depletion region width calculation of a heterojunction diode provides key insights into the electrostatic behavior at the p–n interface. Using C–V measurements and $1/C^2$ vs. V analysis, critical parameters such as the **built-in potential ($V_{bi} \approx 2.545$ V)** and **carrier concentration ($\sim 10^{15}$ cm^{-3})** were extracted with a high degree of linearity (**$R^2 \approx 0.9912$**). Although the depletion width could not be accurately computed due to data limitations, the overall trends in capacitance and conductance with bias confirm expected junction behavior. This method effectively characterizes doping profiles and electric field distribution in heterojunctions like **p-Si / n-ZnO**, essential for device design and optimization.