Varactor Structure, Idea of Operation, Characteristics And Application

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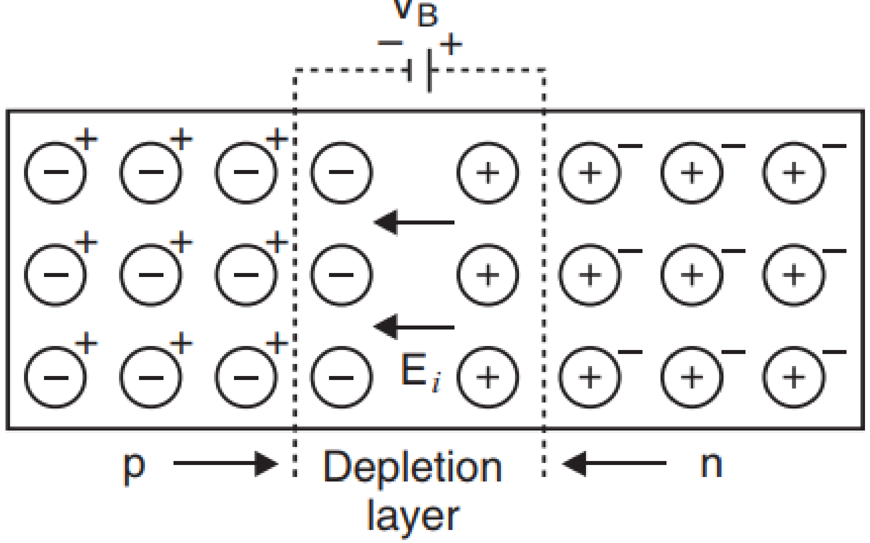
introduction

P-n junction semiconductors have gained wide use in a large array of electronic devices
This is due to the fact that the space charge region is voltage dependent and can be easily controlled



The varactor

One of the devices that is bulilt on this principle is the varactor

(variabel reactor)

Which refers to a voltage-variable capacitance of a reverse-biased p-n junction

Contents of the presentation

In this presentation we will talk about

- preliminary needed knowledge
- The structure of the varactor
- Idea of operation
- Characteristics
- Applications
- Numerical evaluation
- The conclouson

PRELIMINARIES

Gauss' law

Which describes the relation between the electric field and charge Density.

Capacitance

Which I the ability of a component or circuit to collect and store energy in the form of an electrical charge.

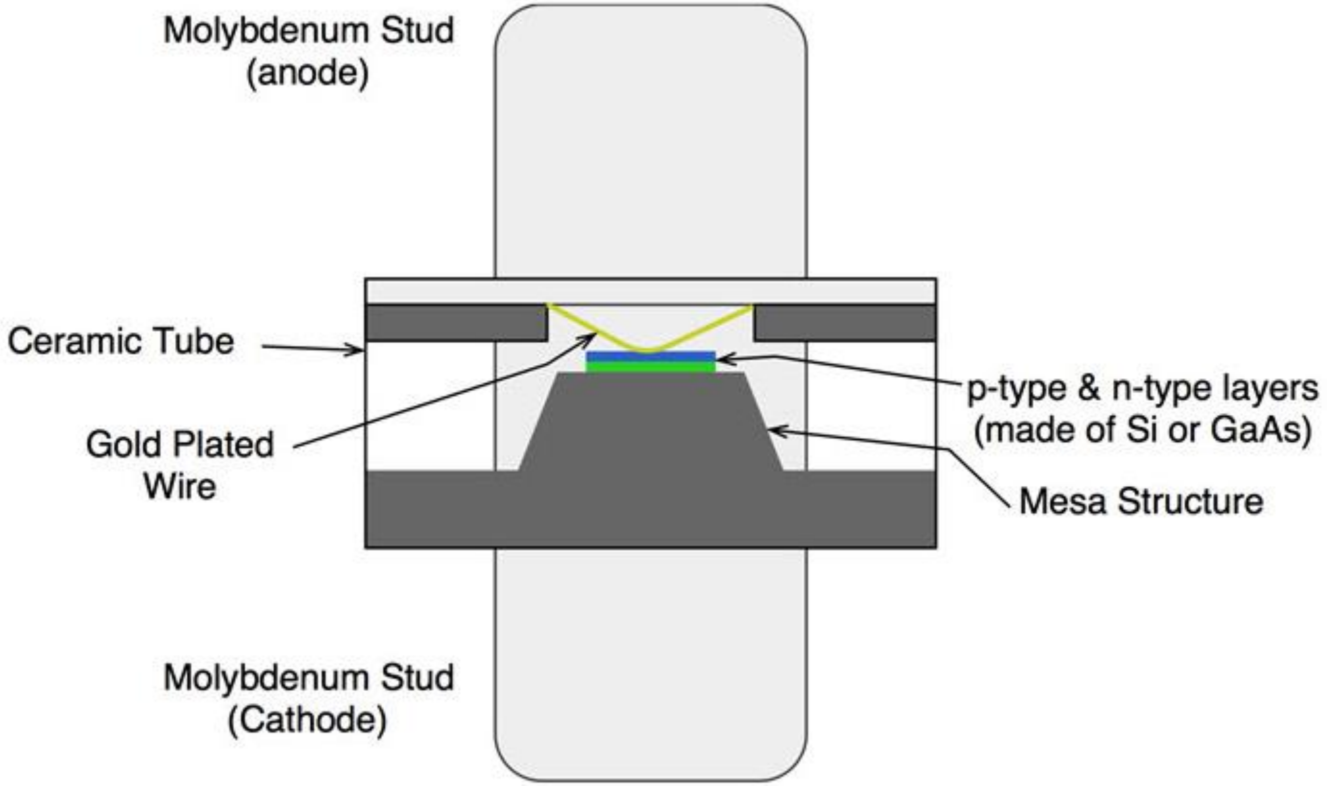
Structure

The varactor isn't manufactured like a normal diode it's manufacturing prosse has to follow certain specifications to optimize it's operation around the reverse bias junction capacitance

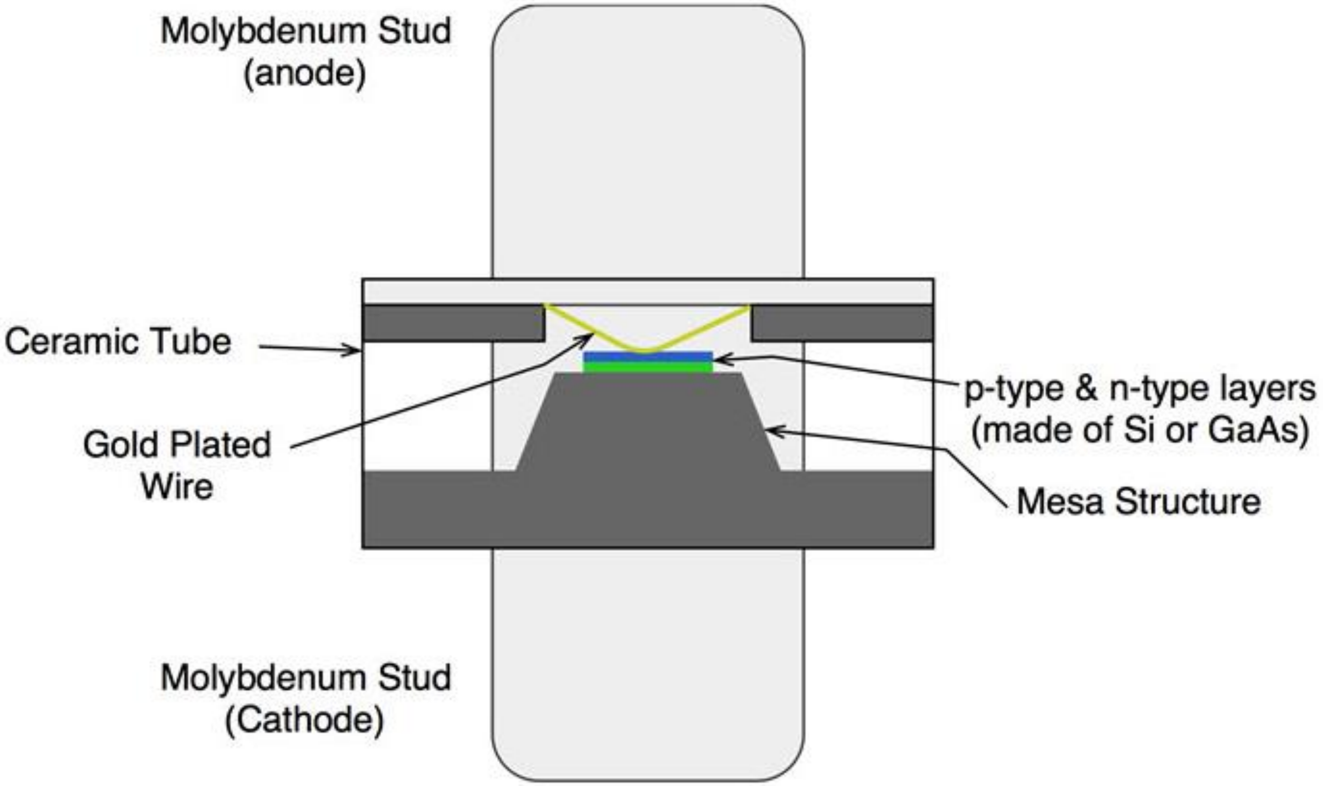
The p-type and n-type layers of the varactor are either silicon or gallium arsenide depending on the application.

For low frequency applications :silicon is used

For high frequancy applications : gallium arsenide is used



p-type semiconductor and a n-type semi conductor are sandwiched together and the n-type is attached to the mesa structure and a gold plated molybdenum stud is attached to the n-type semiconductor so it acts as the cathode terminal

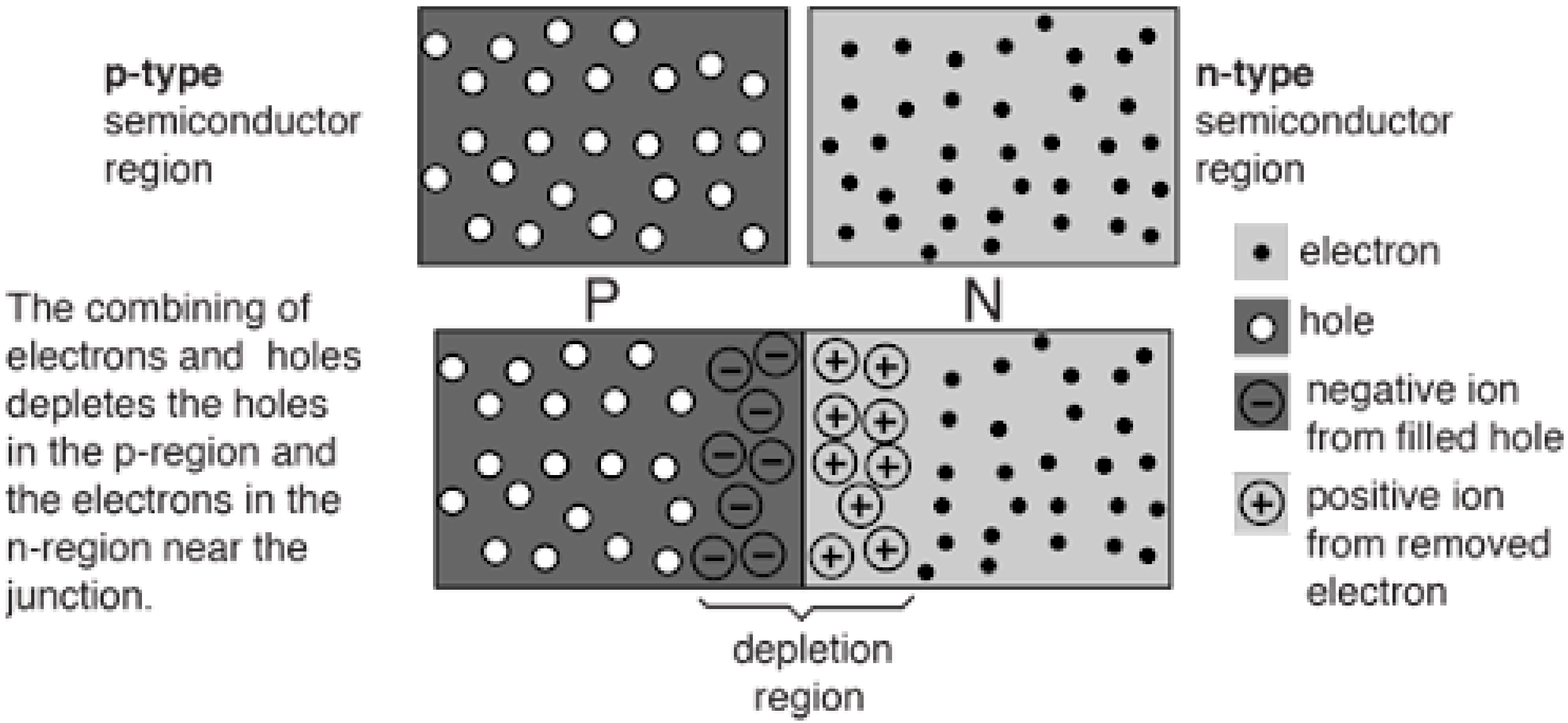


And the p-type semiconductor is connected to another gold plated molybdenum stud that acts as the anode and the whole structure is encased in a ceramic tube

Idea of operation

- Let's consider a normal p-n junction diode the n material has a large concentration of electrons and the p material has a large concentration of hole.
- holes diffuse from the p side into the n side, and electrons diffuse from n to p.
- The net positively and negatively charged regions are referred to as the space charge region (also called depletion region)

Idea of operation



Idea of operation

In a p-n junction there are basically two types of capacitance associated with it

1. The First type of capacitance :

- **The junction capacitance :**
- Due to the dipole the uncompensated donor ions (N + d) and the uncompensated acceptors (N − a) in the transition region.
- Dominant under reverse-bias conditions.

Idea of operation

2.The second type of capacitance:

- **The charge storage capacitance(diffusion capacitance)**
- Arising from the lagging behind of voltage as current changes, due to charge storage effects in the neutral region outside the depletion region.
- Dominant when the junction is forward biased.

Our main foucs is the juction capacitance since we are studying the varactor

Idea of operation

- The capacitance of the varactor is slightly more difficult to calculate than is the usual parallel plate capacitance
- But we can obtain it in a few steps, starting by using the general definition of the capacitance.

$$C = \left| \frac{dQ}{dV} \right|$$

Idea of operation

- The width of the depletion region at equilibrium is

$$W = \sqrt{\frac{2\epsilon V_0}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)}$$

- But since we are dealing with non-equilibrium case with voltage V applied on the p-n junction.
- the proper expression for the width is

$$W = \sqrt{\frac{2\epsilon (V_0 - V)}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)}$$

Idea of operation

- We can calculate the the charge on each side of the dipole can be calculate from

$$|Q| = qA\frac{N_d N_a}{N_a + N_d}W = A\sqrt{2\epsilon q(V_0 - V)\frac{N_d N_a}{N_a + N_d}}$$

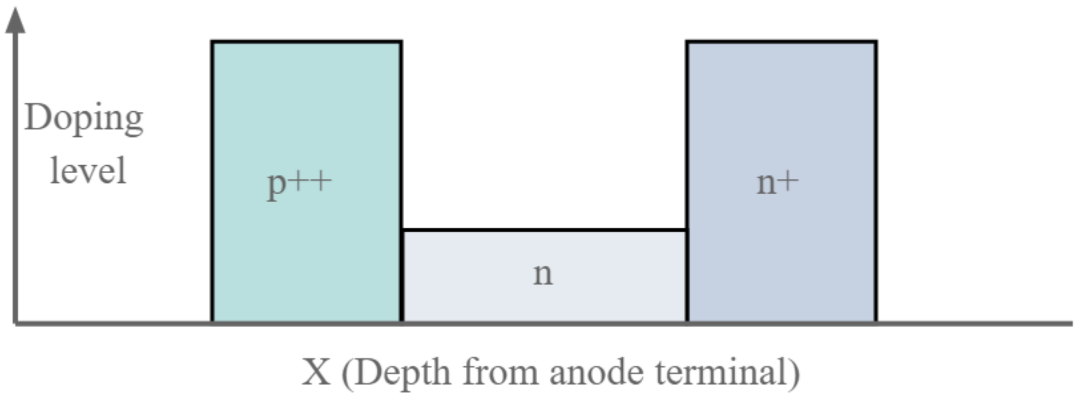
- By substituting in the capacitance general equation we get that:

$$C_j = \left|\frac{dQ}{d(V_0 - V)}\right| = \frac{A}{2}\sqrt{\left[\frac{2q\epsilon}{(V_0 - V)}\frac{N_d N_a}{N_a + N_d}\right]}$$

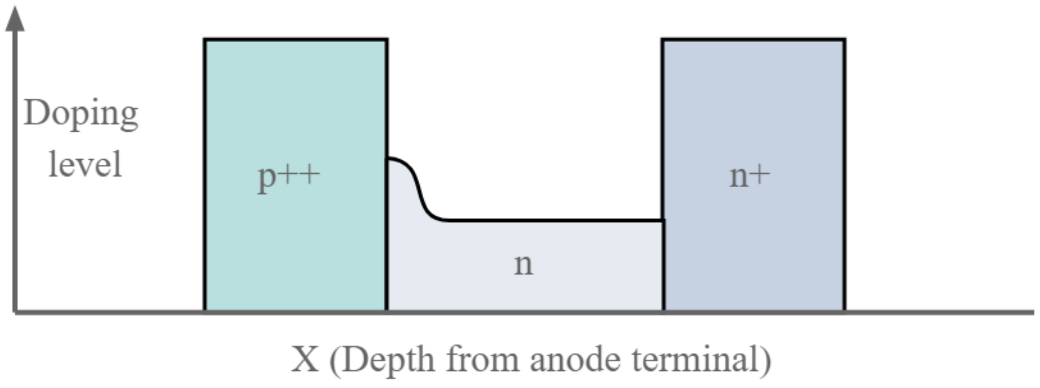
CHARACTERISTICS

Theorem 1:

- Capacitance of a varactor Depends on doping profile wheter it's abrupt or hyper abrupt



abrupt



Hyper abrupt

CHARACTERISTICS

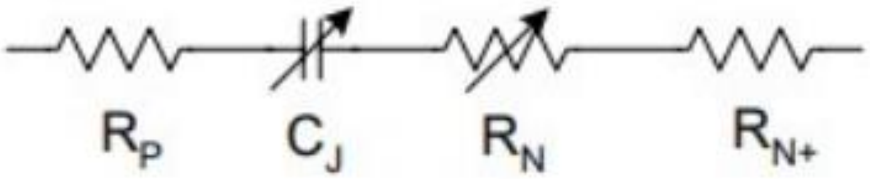
- In an abrupt junction diode, the doping concentration of the cathode layer with respect to distance from the pn junction is relatively constant.

- In a hyperabrupt junction, the carrier concentration in the cathode layer is reduced exponentially as the distance from the junction increases. This will cause the capacitance to be much more sensitive to voltage changes and give larger capacitance values.

CHARACTERISTICS

Theroem 2 :

- Equivalent circuit of varactor and Quality Factor (Q). Varactor diodes can be modelled as follows:



- Where Rp is the resistance of the p-layer, Rn+ is the resistance of the substrate layer, Cj is the equivalent capacitor of the varactor and Rn is the cathode layer resistance.
- Rn is a variable resistance because it's dependent on the depletion layer width.
- The total equivlant impedance of the device will be calculated as :

$$\begin{aligned} Z_t(V_r) &= R_p + R_{n^+} + R_n(V_r) - jX_{cj}(V_r) \\ &= R_t(V_r) - jX_{cj}(V_r) \end{aligned}$$

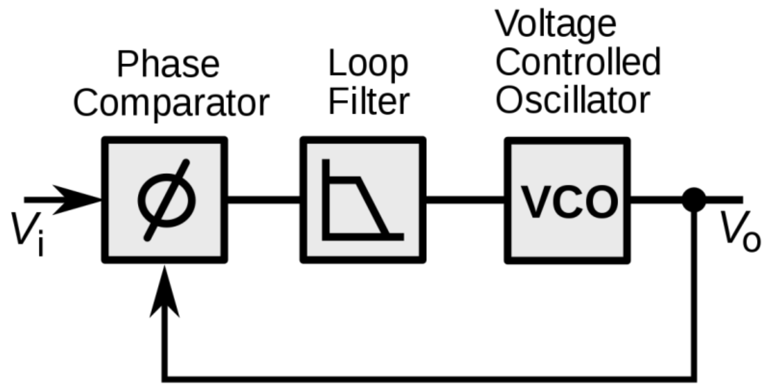
CHARACTERISTICS

- Quality factor of devices The quality factor can be defined as a way to determine how well a device will perform.
- The quality factor of varactor will be shown to be inversely proportional to frequency, so typically there is a specific maximum frequency rating for each varactor.
- The quality factor for any varactor can be obtained from the following equation :

$$Q = \frac{Energy_{stored}}{Energy_{dissipated}} = \frac{Im(Z_t(V_r))}{Re(Z_t(V_r))}$$
$$= \frac{X_{cj}(V_r)}{R_t(V_r)} = \frac{1}{\omega C_j(V_r) R_t(V_r)}$$

Practical Applications

- Resonators
- Function generators or detectors
- Phase-locked loops
- Filters
- Audio modulation/output:
- VCO's (voltage controlled oscillators)



NUMERICAL EVALUATION

Theorem 1:

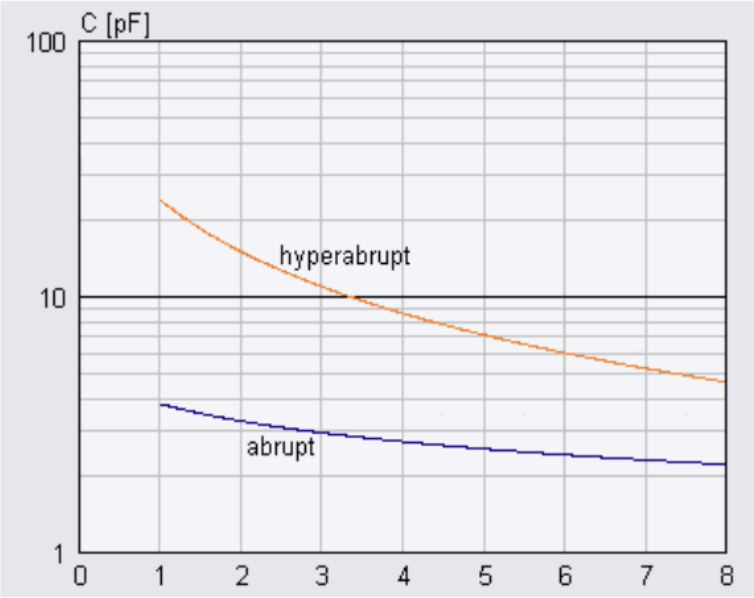


Fig. 9: $C - V$ characteristics without taking log with both types on same graph to show in C values for the same reverse bias voltage.

It is shown that the capacitance of hyper abrupt junction varactors is higher than that of abrupt junction varactors for the same reverse bias voltage, as was suggested by the characteristics.

NUMERICAL EVALUATION

Taking log in both sides before graphing will make it a simpler process to draw.

in the hyper abrupt junction C will be a function in Vr, therefore the log(C)−log(Vr +V0) graph for the hyper abrupt junction will not be linear.

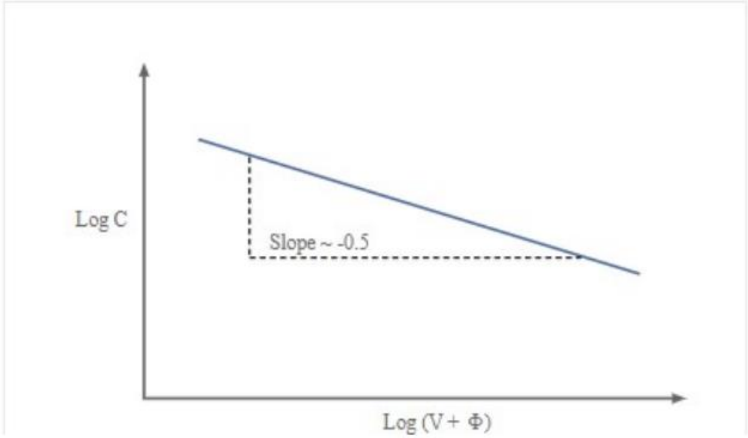


Fig. 10: Log C - log V curve of abrupt varactor.

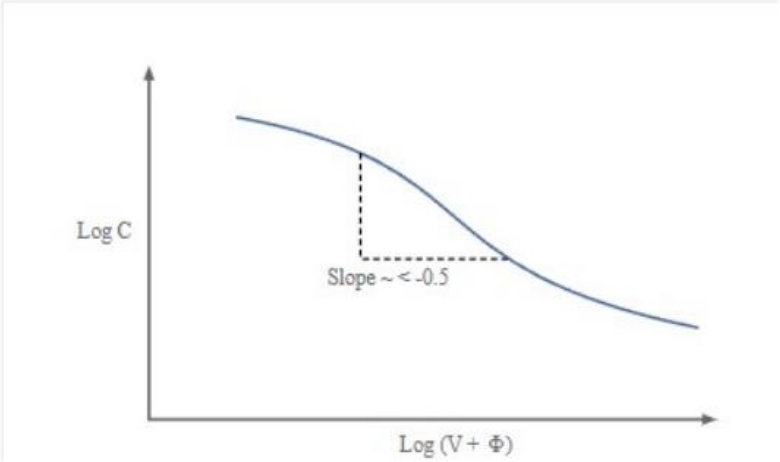


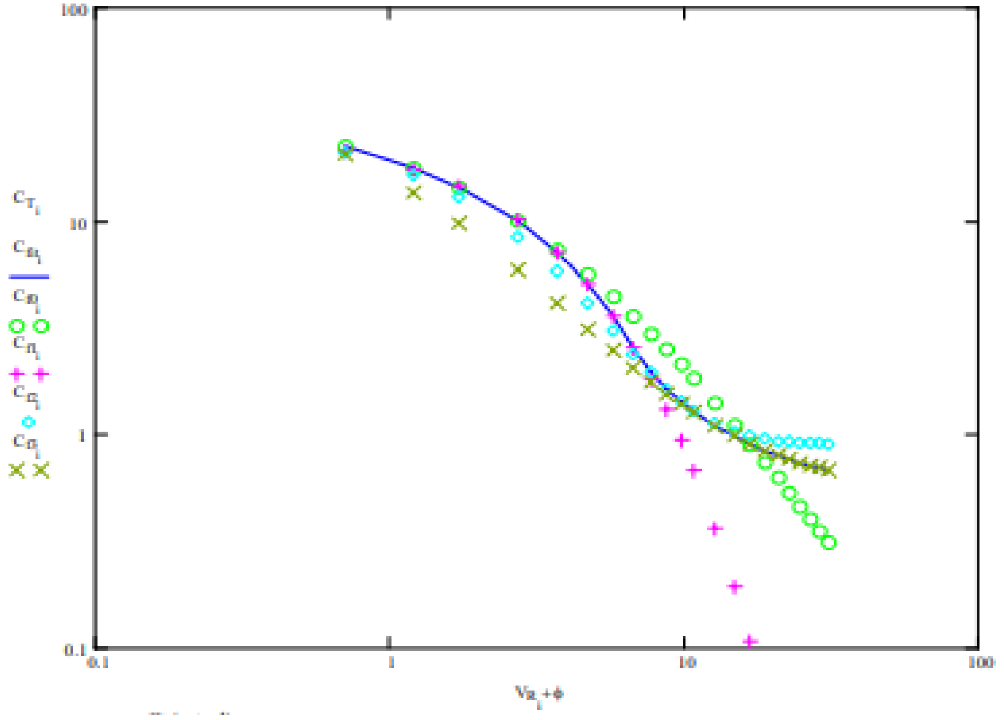
Fig. 11: log C - log V curve of hyper abrupt varactor.

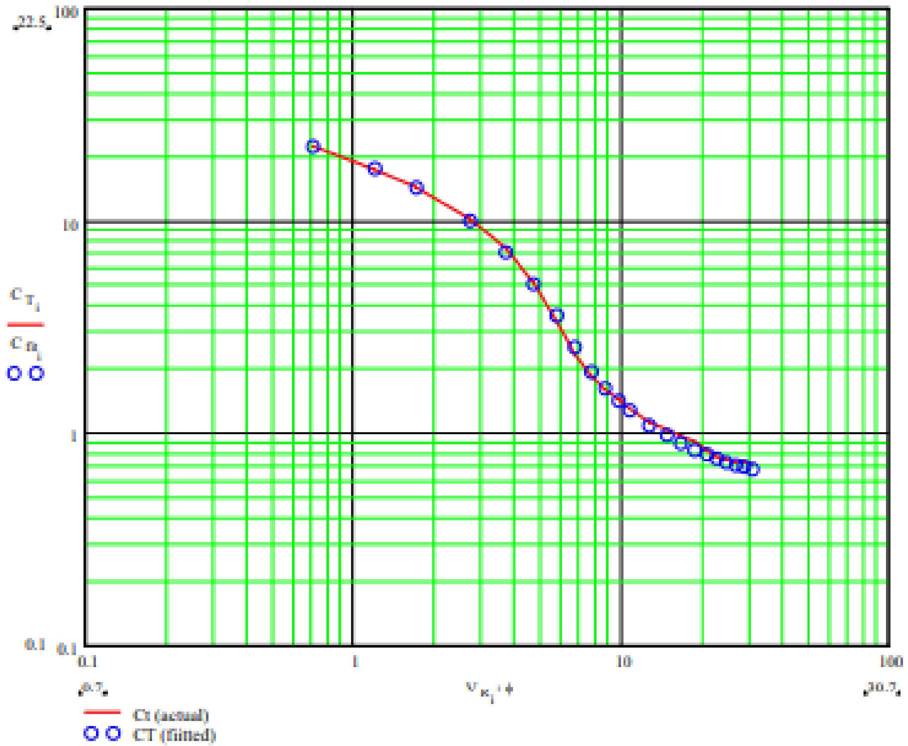
Practically Drawing Hyperabrupt CV curve

- We can graph the CV curve in a piece-wise manner which will obtain a very reasonable approximation of the real graph. This can be done by varying the parameters multiple times in the following equation at set values such that every graph made has overlapping points with the real graph until enough points are obtained to perform fitting.

$$C_j = \frac{C_{j0}}{\left(\frac{V_0 - V_r}{V_0}\right)^M}$$

- The first picture represents the first step described (varying values of each parameter) while the second picture shows the end product after fitting





NUMERICAL EVALUATION

the quality factor Q decreases dramatically as the frequency increases.

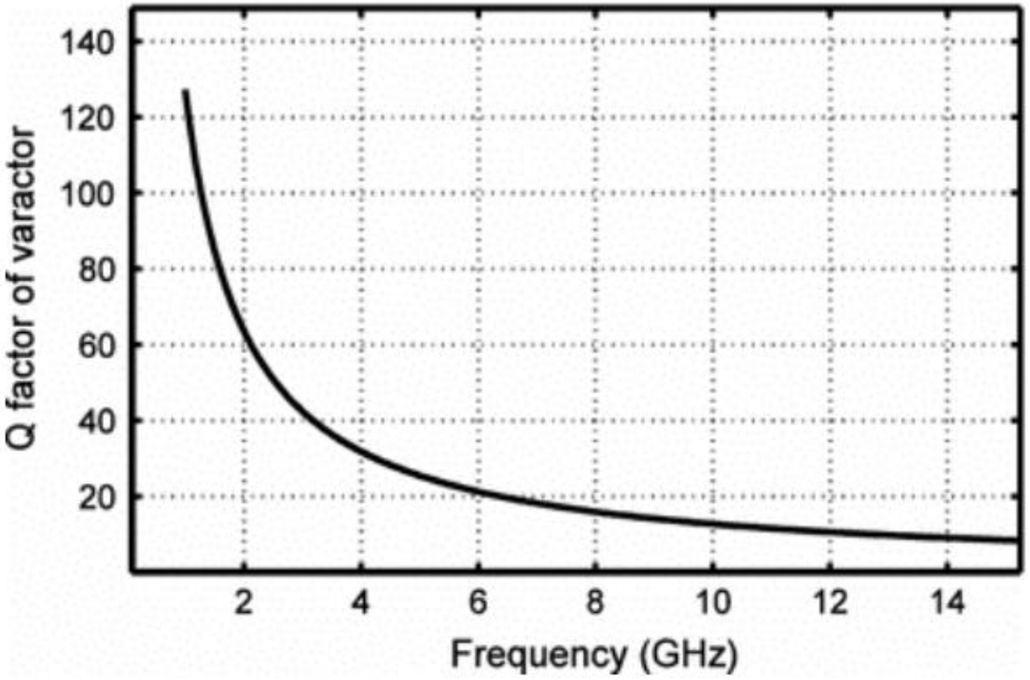


Fig. 12: Simulated Q Factor of Varactor Vs Frequency at turning voltage of 0.2 V.

It should be noted that the hyper abrupt capacitor experiences this drop earlier than normal abrupt capacitors.

limitations

- At large signal amplitudes, it can introduce distortions and intermodulation
- Requires relatively large reverse voltage for noticeable change in capacitance
- . Their operation is dependent on using them in backward bias

conclusions

- What was done:
- Showcased the basics of varactors, its types and what factors does this type classification depends on.
- Possible structures
- operation idea
- Numerical evaluation for visualizing characteristics
- Practical applications.
- Limitations in use.
- Only varicaps(p-n junction varactors) were studied. Varactors continue to improve and new types exist nowadays, like MOS varactors or thin film BST varactors, which offer the same usability but with greater efficiency and speeds.