Design of silicon PIN photodetector

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In this extended tutorial we are asked to design a PIN silicon photodetector under the given condition of various parameter like dark current,responsivity,capacitance,transit time.

1 My approach

I have planned to meet the criterias given by putting various restrictions on W and d as given by their respective equations.
Assumptions and notations:

- The depletion regiion occupies whole of the nuetral-n region in between P+ and N+ region. (We generally aim to increase the length of the depletion region as much as possible to increase the current flowing when the photodiode is excited.This means that we need a large depletion region)
- Neglecting the transit time delay due to diffusion in the heavily doped regions(Given)
- The shape of the diode is cylindrical with constant diameter throughout.
- All lenghts are taken in cm, time in seconds,voltage in Volts.
- In all the graphs below x-axis represents the W(in cms) and Y-axis represents the value of 'd'(in cms).

1.1 Condition on transit time

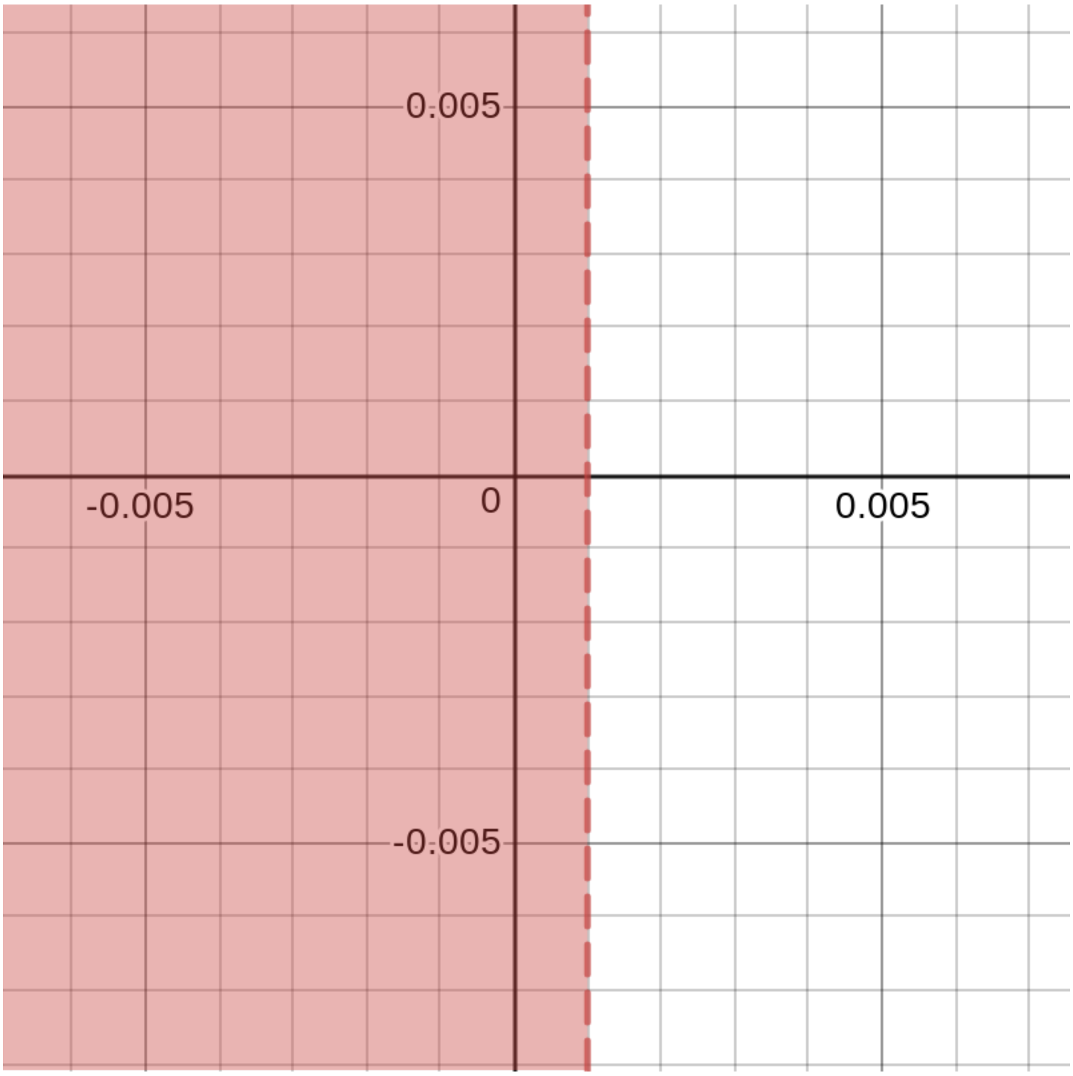
Expression for transit time:

$$t_{transit} = \frac{W}{v_{sat}}$$

Condition to be met : $t_{transit} < 100ps$ Given: $v_{sat} = 10^7 cm/s$

Arrived condition:

$$\frac{W}{V_sat} < 10^{-10}$$
$$W < 10^{-3}$$



This puts a upper limit on the value of W.

1.2 Condition on capacitance

It is given that the detector will be operating in reverse bias.Hence we can safely assume that the contra=ibution to the capacitance will be majorly from the Junction capacitance since the value of the diffusion capacitance will be low. Expression for capcitance:

$$C = \frac{A\epsilon}{W}$$

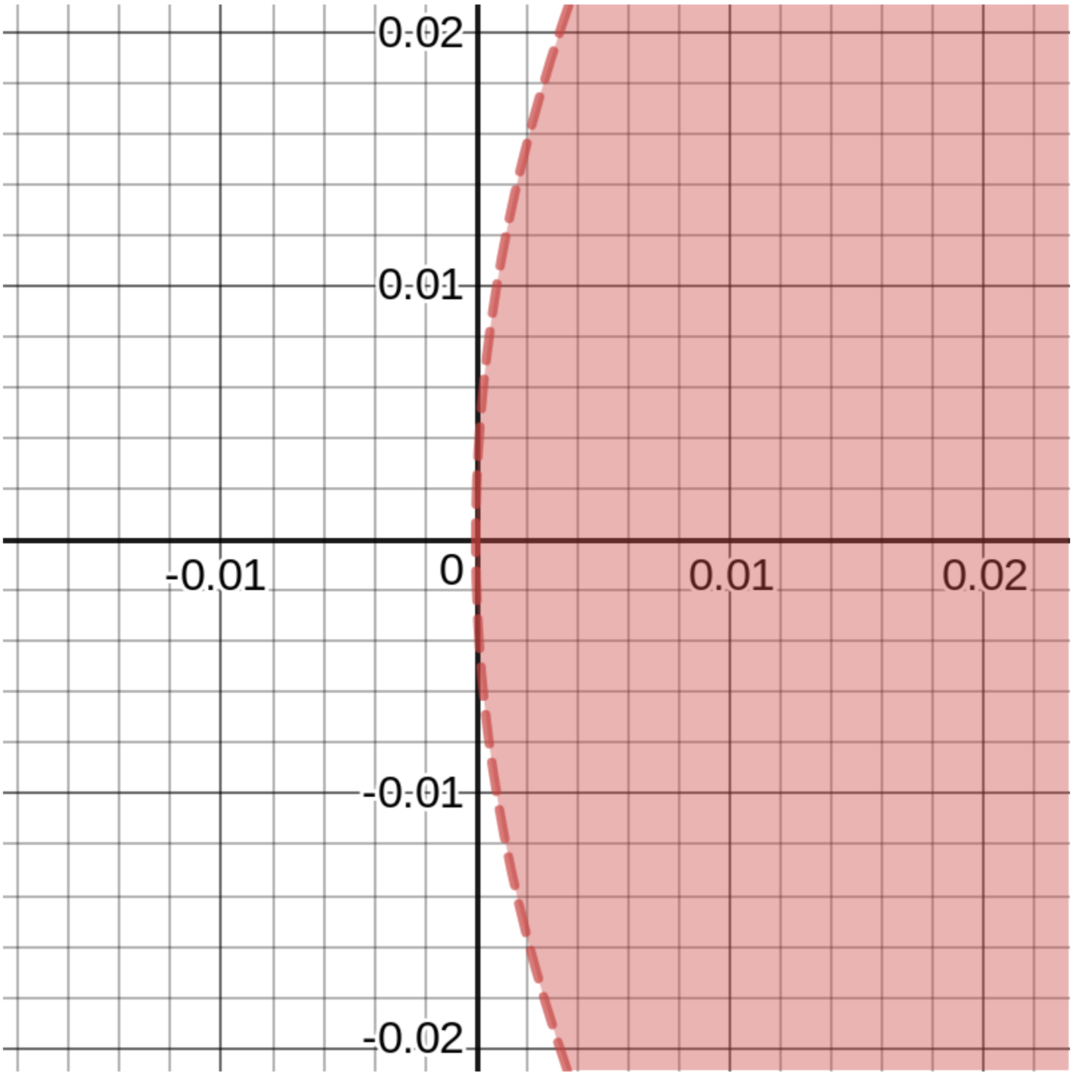
Condition to be met : $C < 100fF$ Given:
$\epsilon_r = 11.9$
$\epsilon_0 = 8.85 * 10^{-14}$

Arrived condition:

$$\frac{\epsilon A}{W} < 10^{-13}$$

we know that: $A = \frac{\pi d^2}{4}$

$$\frac{W}{d^2} > 8.271420$$



This puts a condition bewtween relative values of W and d.

1.3 Condition on Dark Current

Dark current is the current flowing when the diode is not illuminated.This will be because of the applied reverse bias.The value of the dark current must be kept low inorder to increase the sensitivity of the diode. Expression for dark current:

$$I = I_0(e^{\frac{-V_r}{V_t}} - 1)$$

The expression of I_0 for a simple p-n junction is given by:

$$I_0 = Aq(n_i)^2(\frac{D_p}{L_pN_d} + \frac{D_n}{L_nN_A})$$

Here since the length of the P+ region is very less, we will be replacing L_n by W_p. Also since the lenght of the N+ region is long we will keep L_p in the equation.

Hence the equation modifies to:

$$I_0 = Aq(n_i)^2(\frac{D_p}{L_pN_d} + \frac{D_n}{W_pN_A})$$

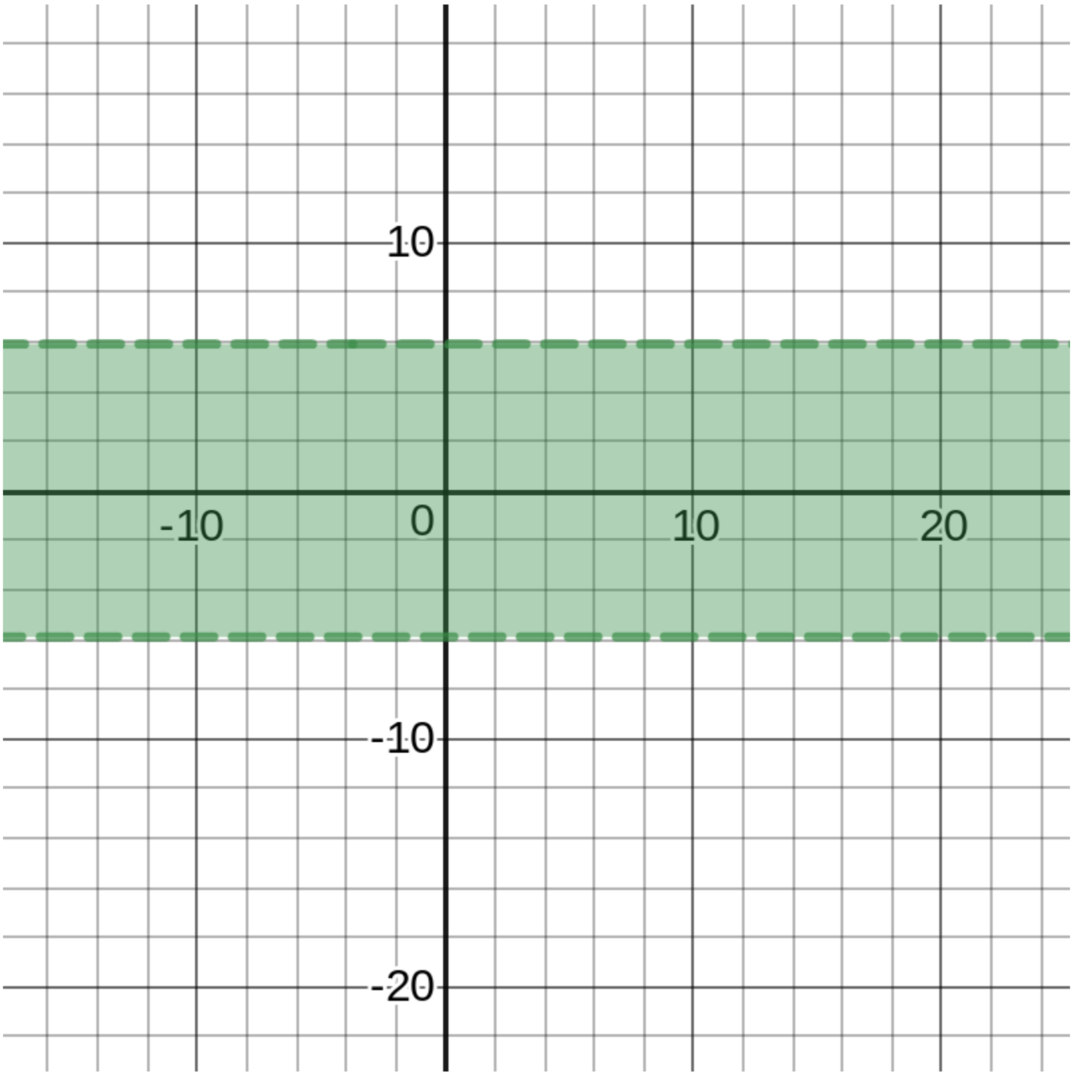
$$I_0 = d^2(2.86983 * 10^{-14})$$

Condition to be met : $Darkcurrent << 1pA$

Arrived condition:

$$100 > |d^2 * (2.86983) * (e^{\frac{-V_r}{0.026}} - 1)|$$

Here we need to put the modulus as the current value will be reversed in reverse bias!



This puts a condition bewtween relative values of W and d.

1.4 Condition in Responsivity

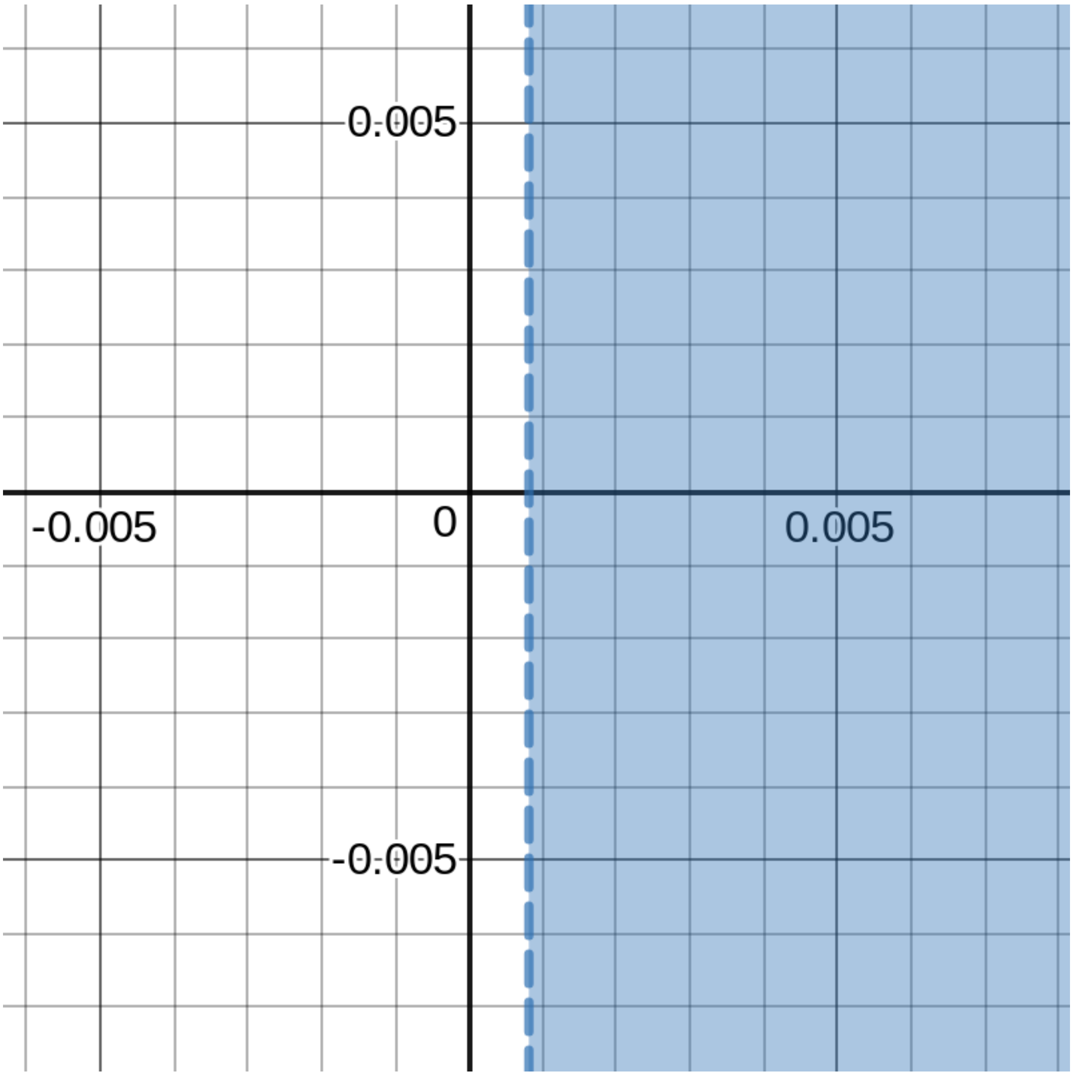
Here we will be needed to calculate the quantum efficiency and use it in the expression for Responsivity.We are given the value of the wavelength of light incident. Expression for η:

$$\eta = e^{\alpha W_p} - e^{-\alpha(W+L_p)}$$

Condition to be met : $Responsivity > 0.45A/W$
We know that $L_p = \sqrt{D_p \tau_p}$
Arrived condition:

$$\eta > 0.881796$$

Here I have not soved for the value of W explicitly since the equation is quite complicated. I will later use a graphing software to numerically find the restriction on the value of η and hence on the value of W



This puts a condition bewtween relative values of W.

1.5 Results and Conclusion

Hence through this discussion,equations and numerical methods we are able to come up with the value of W and d which are suitable for proper operation of the photodiode under specified conditions.The values of W and d was found out by looking at the intersection of all the regions mentioned by the inequalities.A seperate file has been uploaded with the calculated values of W and d.