

# TCAD for electronic devices part 4

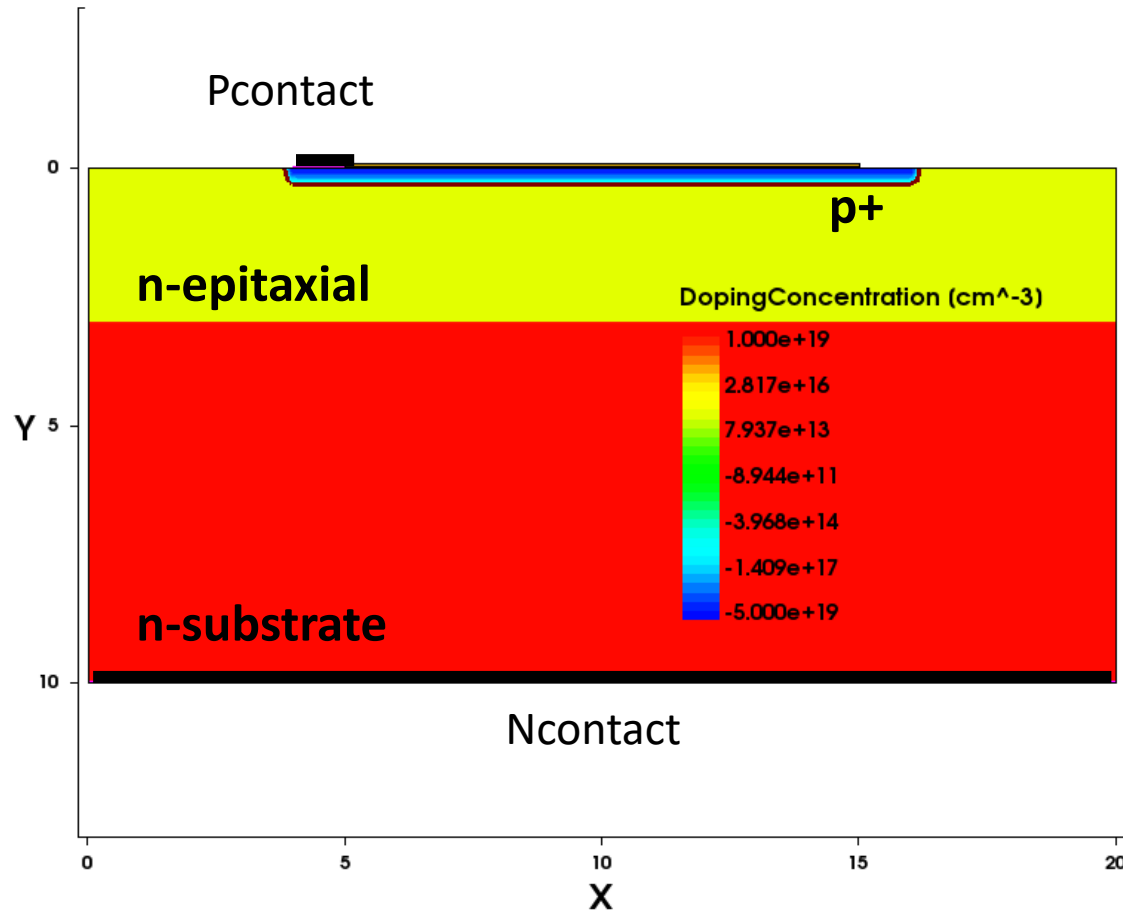
Microelectronics devices, sensors and  
MEMS

Academic Year 2023/2024

Lucio Pancheri

lucio.pancheri@unitn.it

# Example 1. Photodiode

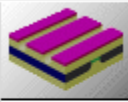
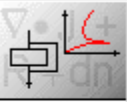


Optical window with  
Antireflective Coating (ARC)  
(x1 = 5 : x2 = 15)

30nm Silicon Oxide  
60nm Silicon Nitride

File: P4EX1\_Photodiode\_sde.txt

# Example 1a. Forward bias

Project Scheduler			
			
	SDE	SDEVICE	
			Popt
1	[n8]: --	[n9]: --	[n5]: 5
2			[n10]: 10
3			[n11]: 15

Simulate I-V curves with:

$$V(\text{Ncontact}) = 0$$

$$V(\text{Pcontact}) = 0 \rightarrow 0.75\text{V}$$

Plot the I-V curves for the 3 different optical power densities

Report the maximum electrical power generated at  $P_{\text{opt}} = 15 \text{ W/cm}^2$  in the shared spreadsheet:

<https://docs.google.com/spreadsheets/d/1IVVuYz--40sHPwWE4pYOevZ1eQrdjCjwVpUHHLtRXj4/edit?usp=sharing>

File: **P4EX1\_Photodiode\_sdevice1.txt**

# Example 1a. Maximum power calculation

In svisual, create a new variable representing the power (voltage x current, with negative sign) and plot it as a function of Pcontact voltage.

**Create New Variable** [X]

**Input**

Dataset:

Variables	Operators	Functions
Pcontact DisplacementCurrent	+	abs
Pcontact eCurrent	-	acos
Pcontact hCurrent	*	acosh
<b>Pcontact TotalCurrent</b>	/	asin
Pcontact Charge	^	asinh
LayerStack(unnamed_0) R_TE		atan
LayerStack(unnamed_0) T_TE		atanh
LayerStack(unnamed_0) A_TE		bessel_j0
LayerStack(unnamed_0) R_TM		bessel_i1

**Output**

Formula:

New Variable Name:

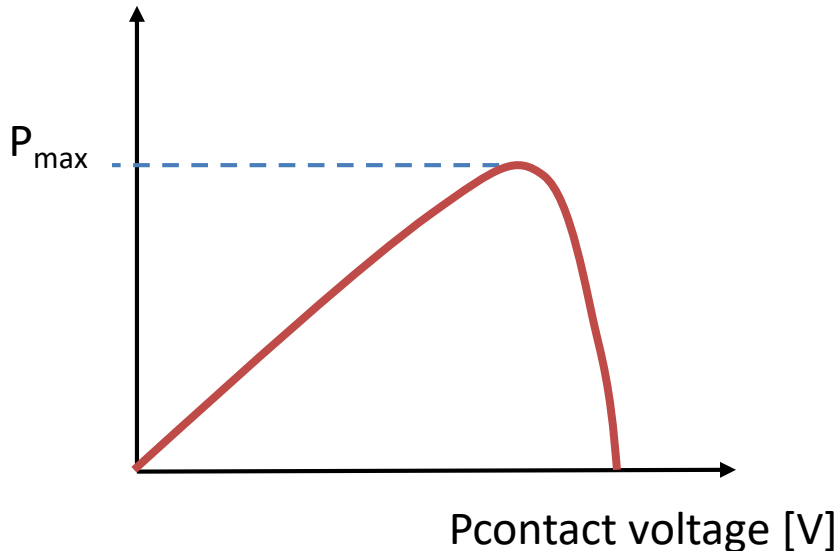
New Dataset Name:  ☐ New Dataset

# Example 1a. Maximum power calculation

In svisual, after plotting the PV curves, open the «Calculate Scalar» dialog box from menu Tools

Use function `vecmax(<curve_name>)` to calculate the maximum power

Power [W]



Calculate Scalar

Input

☒ Variables ☐ Curves

Dataset: n3\_des

Variables	Operators	Functions
Pcontact InnerVoltage	+	min
Pcontact QuasiFermiPotential	-	minmax
Pcontact DisplacementCurrent	*	negative
Pcontact eCurrent	/	pow
Pcontact hCurrent	^	rms
Pcontact TotalCurrent		sign
Pcontact Charge		sin
LayerStack(unnamed_0) R_TE		sinh
LayerStack(unnamed_0) T_TE		sqrt
LayerStack(unnamed_0) A_TE		tan
LayerStack(unnamed_0) R_TM		tangent
LayerStack(unnamed_0) T_TM		tanh
LayerStack(unnamed_0) A_TM		vecmax
LayerStack(unnamed_0) R_Total		vecmin
LayerStack(unnamed_0) T_Total		vecvalx
LayerStack(unnamed_0) A_Total		vecvaly
Power_n3		veczero

Formula: `vecmax(<Power_n3:n3_des>)`

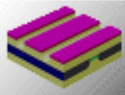
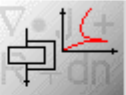
Calculate

Output

Result: 7.60897703579e-8

Close

# Example 1b. Reverse bias

Project Scheduler			
	 SDE	 SDEVICE	
			WL
1	[n8]: --	[n12]: --	[n9]: 0.4
2			[n13]: 0.6
3			[n14]: 0.8

Simulate I-V curves with:  
 $V(\text{Pcontact}) = 0$   
 $V(\text{Ncontact}) = 0 \rightarrow 10\text{V}$

Plot the **I-V curves** for the 3 different wavelengths and **calculate the responsivity** ( $R = I_{\text{ph}}/P_{\text{opt}}$  [A/W]) for each wavelength  
Report the responsivity in the spreadsheet

File:

P4EX1\_Photodiode\_sdevice2.txt

# Example 1b. Responsivity calculation

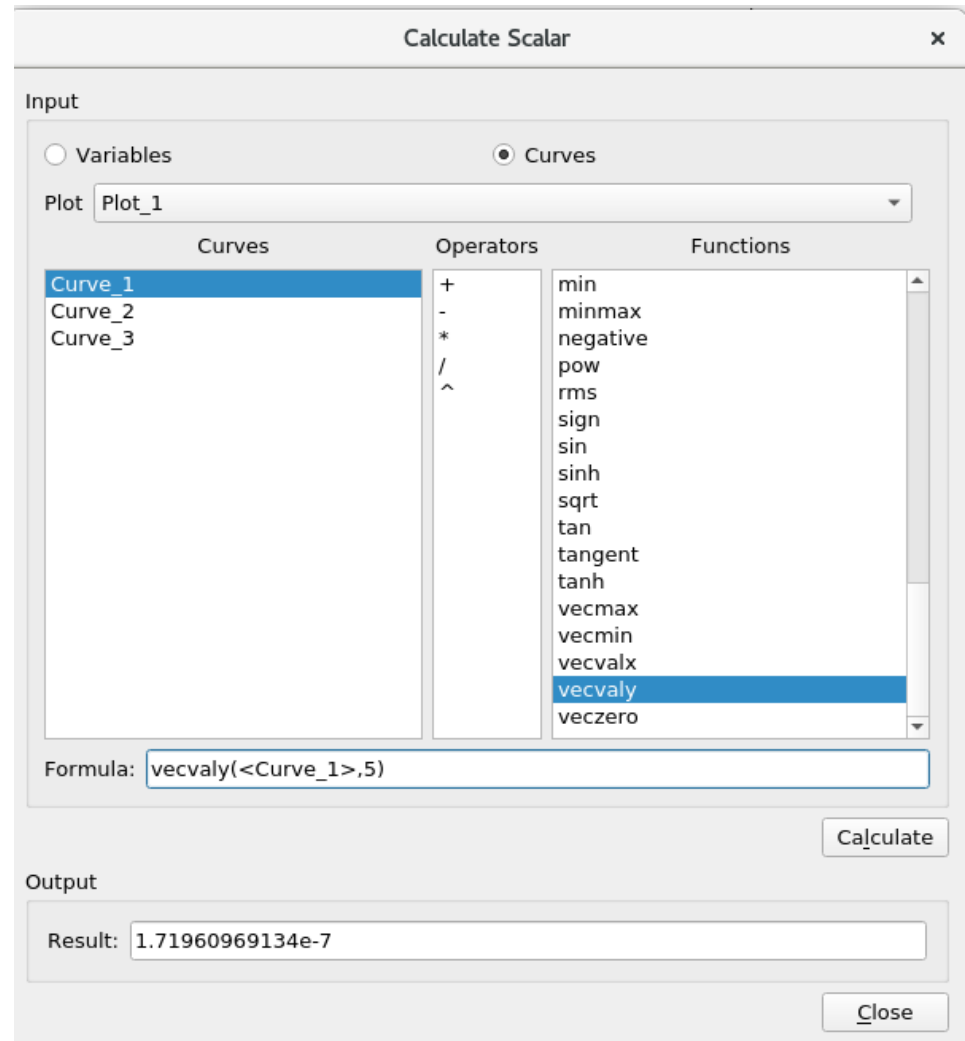
Responsivity:

$$R = \frac{I_{ph}}{P_{opt}}$$

In svisual, after plotting the IV curves in reverse bias,  
Open the «Calculate Scalar» dialog box from menu Tools

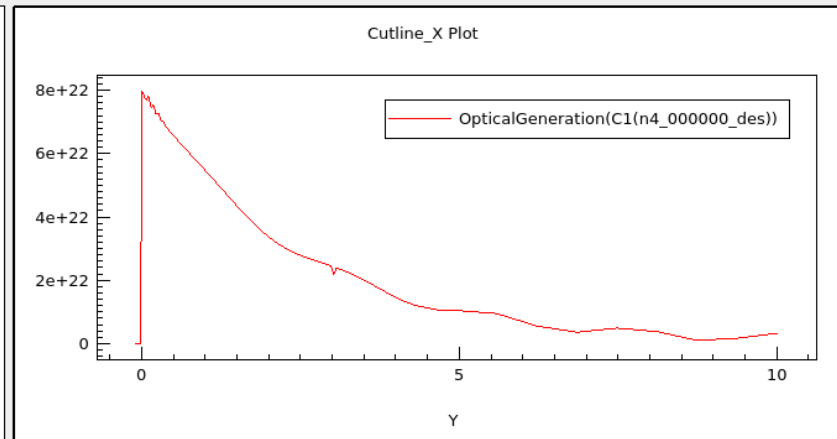
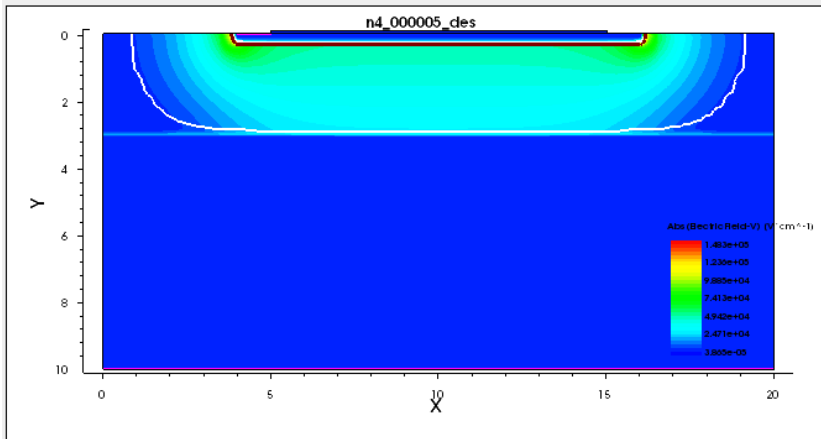
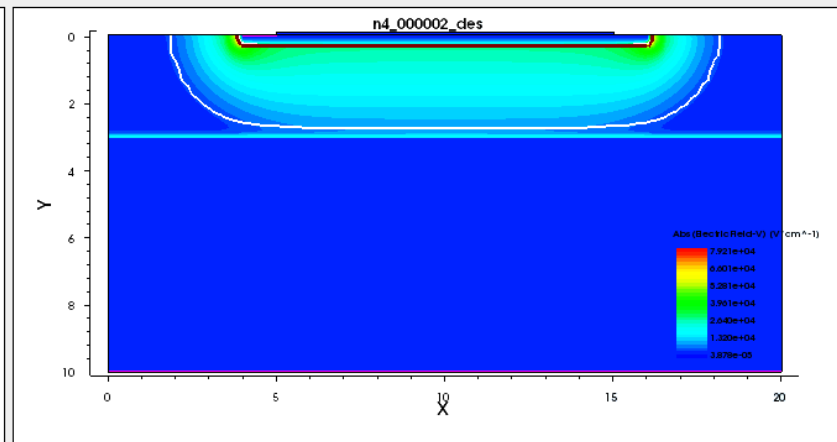
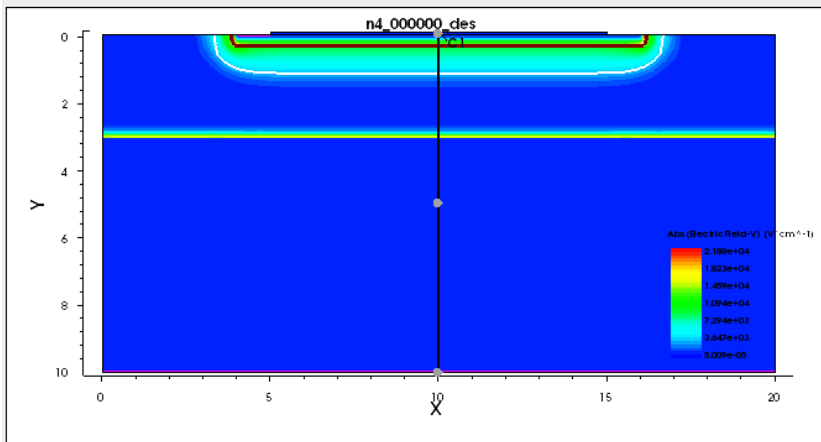
Estimate the current at 5V on the 3 curves using the function  
`vecvaly(<Curve_name>, x_value)`

The optical power is 10W/cm<sup>2</sup>,  
the device area is 10μm x 1μm





# Example 1b

- Plot the **optical generation rate** for the 3 wavelengths
- Plot the **electric field** at 0V, 4V and 10V reverse bias



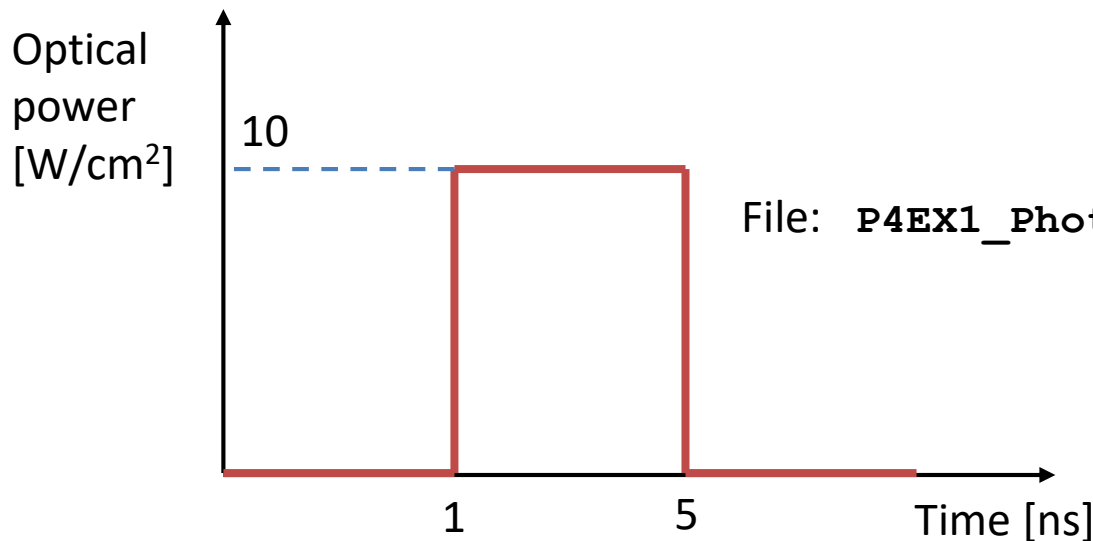


# Example 1c. Transient simulation

Project		Scheduler	
			
			Vbias
1	[n8]: --	[n12]: --	[n9]: 0
2			[n13]: 5
3			[n14]: 10

Simulate the transient response to a light pulse at 3 different bias voltages: 0V, 5V, 10V

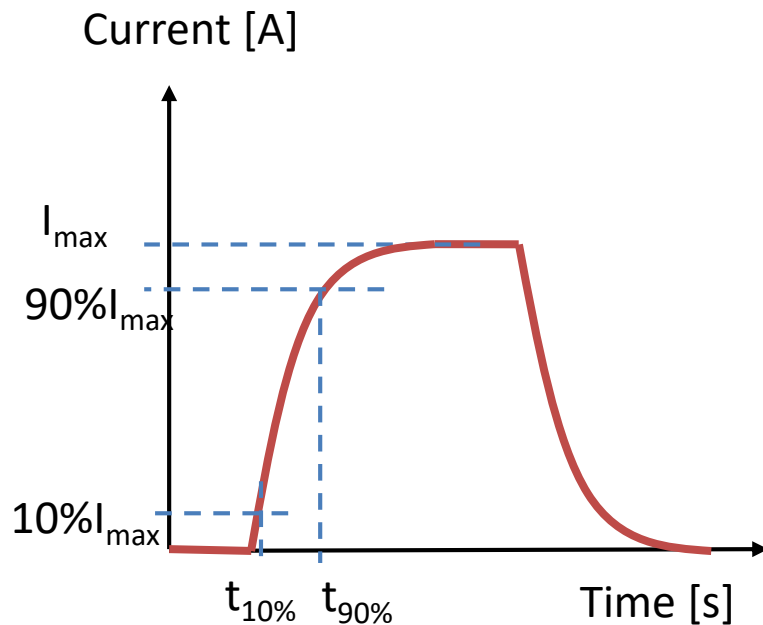
Plot and compare the photo-current vs. time for the 3 voltages. Report the **rise time 10% - 90%** in the spreadsheet



File: P4EX1\_Photodiode\_sdevice3.txt

# Example 1c: rise time calculation

Use functions  
`vecvalx(<curve_name>, y_value)`  
and `vecmax(<curve_name>)`



Calculate Scalar

Input

☐ Variables ☒ Curves

Plot Plot\_1

Curves	Operators	Functions
Curve_1	+	min
Curve_2	-	minmax
Curve_3	*	negative
	/	pow
	^	rms
		sign
		sin
		sinh
		sqrt
		tan
		tangent
		tanh
		vecmax
		vecmin
		vecvalx
		vecvaly
		veczero

Formula: `vecvalx(<Curve_2>,vecmax(<Curve_2>)*0.9)`

Calculate

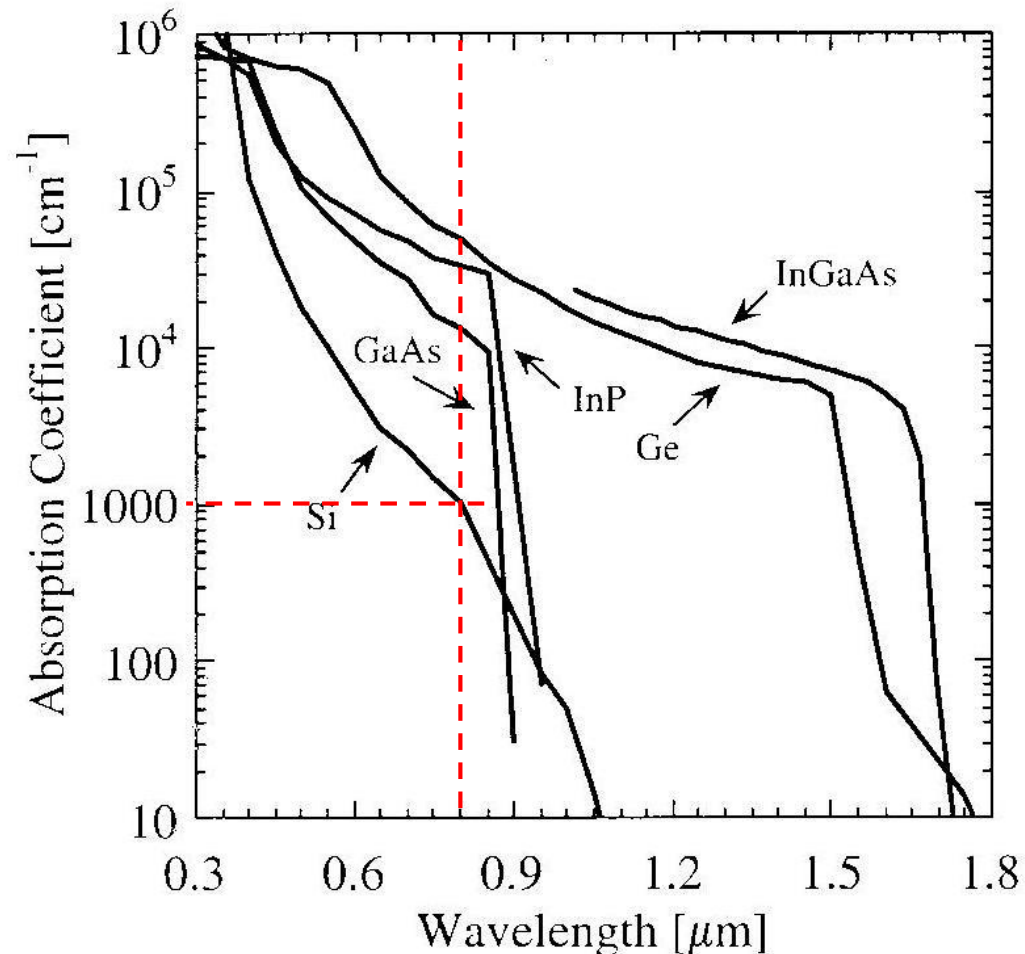
Output

Result: 1.24496974399e-9

Close

# Exercise 1. Optimization for NIR light

- Modify the device geometry/doping to improve the responsivity at 800nm: parametrize the epitaxial layer thickness (5, 10 and 15  $\mu\text{m}$ ) and use the reverse bias simulation to analyze the photocurrent. Report the **responsivity** at 800nm for the different thicknesses in the spreadsheet
- Simulate the transient response of the new device with 800-nm light and report the **rise time at  $V_{\text{bias}} = 5\text{V}$**  for the 3 different thicknesses in the spreadsheet.



Handbook of Optical Constants of Solids, edited by Edward D. Palik, (1985), Academic Press NY.