EECS 2077
Semiconductor Devices

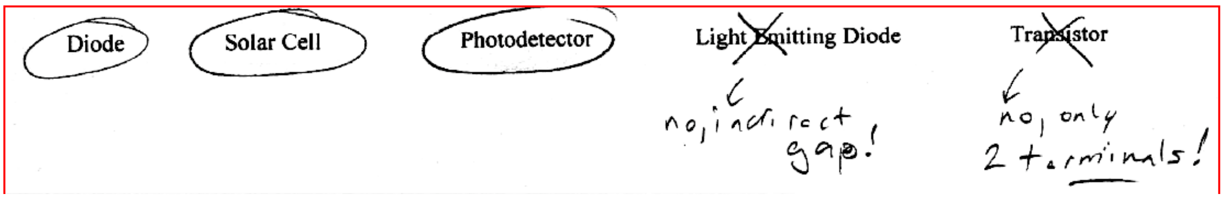
19 - Lasers

Name:____________________________

In-Class Problems

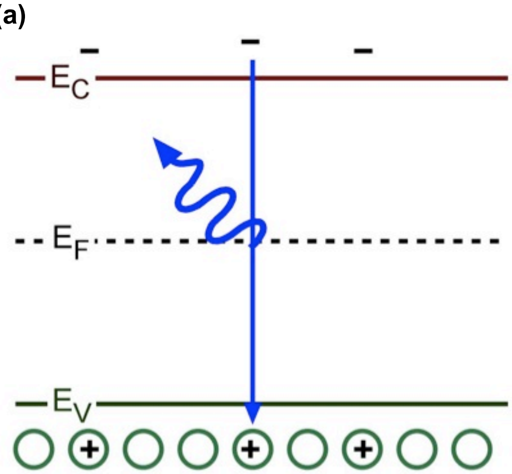
(1) We form a simple PN junction in Si, which of the following devices can be made from this PN junction in Si? Simply circle them.

Diode   Solar Cell   Photodetector   Light Emitting Diode   Transistor

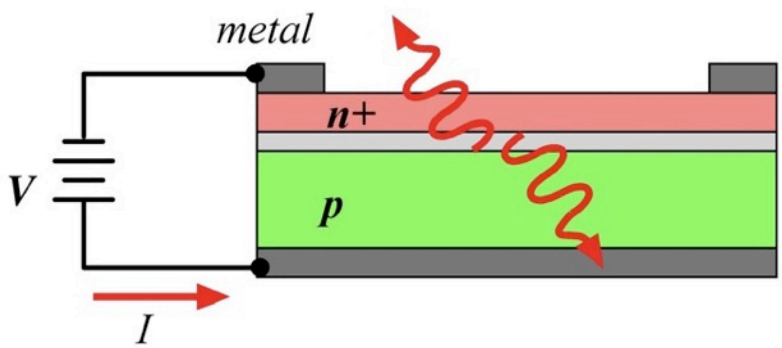


(2) See the light emitting devices below. For the band-diagram in (a), there are TWO things that we can see that shows us that this is not a LASER, what are they? For the device diagram in (b), the device requires TWO device structure modifications to become a laser, what are they?

(a)

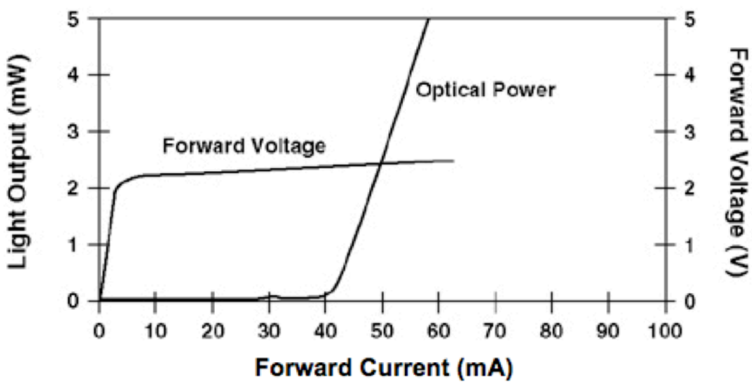


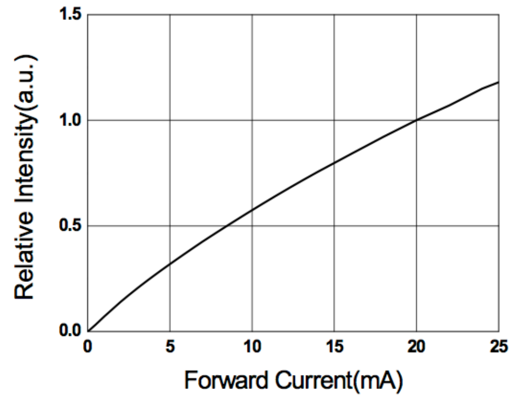
(b)



(a) 1-The emission is spontaneous. 2- It is clear we don't have population inversion.
(b) 1- Need a double heterojunction, else can't achieve population inversion. 2- need mirrors!

(3) Here are two light emitting semiconductor devices. Label on each diagram where any of the following are occurring: no emission (N), spontaneous emission (S), lasing (L):





Left one is a laser, everything below 40 mA is spontaneous emission, and above 40 mA lasing takes over. Right one is a diode, all spontaneous emission. For both curves, only at 0 mA is there no emission.

(4) Lasers use mirrors which are:

___ made of highly reflective metal like Al or Ag, because they are inexpensive
_X_ made of alternating refractive index dielectric layers that allow multiple back-reflections in the laser without loss
___ both
___ neither

(5) See the product spec sheet below. Using only the spec sheet, answer these questions:

(a) at maximum, what is the bandgap energy of InAlAs?
(b) in the block diagram, on what component does the light shine?
(c) for the photodetector portion, what is its reverse saturation current?

CEL

RECEIVER

NR4210 Series

InAlAs APD RECEIVER WITH INTERNAL PRE-AMPLIFIER FOR 10 Gb/s APPLICATIONS

DESCRIPTION

The NR4210 Series products consist of InAlAs-APD (avalanche photo diode) ROSAs (Receiver Optical Sub-Assembly) with internal pre-amplifiers designed for 10 Gb/s long-reach optical transceivers such as the XENPAK/X2/XFP. These modules are ideal as receivers for IEEE 10G BASE and SONET OC-192 systems.

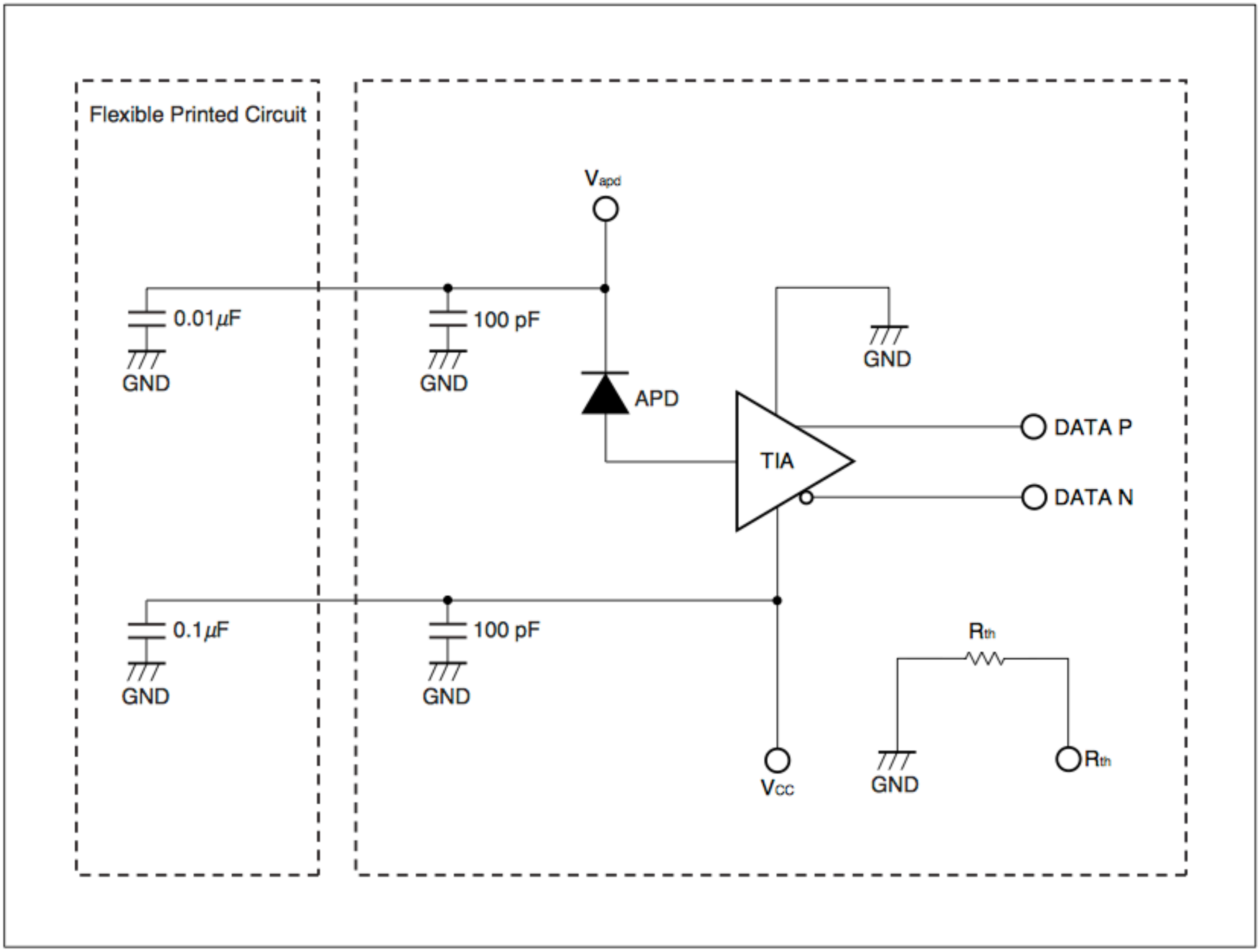
FEATURES

- XMD-MSA compliant ROSA
- 10 Gb/s high sensitivity InAlAs-APD
- +3.3 V SiGe transimpedance pre-amplifier
- Minimum receiver sensitivity $\overline{P_r}$ = –28 dBm
- Operating case temperature T_C = –5 to +85°C
- Transimpedance Z_t = 2 000 Ω (Single-ended)
- Cut-off frequency fc = 8 GHz
- With flexible printed circuit

ELECTRO-OPTICAL CHARACTERISTICS (T_C = –5 to +85°C, V_{CC} = +3.3 V, λ = 1 550 nm, unless otherwise specified)

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
APD Sensitivity	S	λ = 1 310 nm, M = 1	0.75	0.9		A/W
		λ = 1 550 nm, M = 1	0.75	0.9		
APD Breakdown Voltage	V_{BR}	I_D = 10 μA	25	30	35	V
Temperature Coefficient of APD Breakdown Voltage	δ *1	T_C = +25 to +85°C	0	0.02	0.05	V/°C
APD Dark Current	I_D	$V_R = V_{BR} \times 0.9$, T_C = +25°C			0.7	μA

BLOCK DIAGRAM



(6) Recent press release on a new device used to modulate a continuous laser signal into 1's and 0's of optical pulses for high-speed fiber communications. This is an example of how you can start to reverse engineer some-else's technology using not much more than a press-release. Is a bit challenging to figure out at first.

(a) Explain how you believe that this device works. *Hint, see slide 20 of the lecture, but note that in the press release statement below, they use an MOS approach (not a PN junction) to modulate carrier concentration and therefore cause a change in refractive index. If you answer part (a) correctly, you will realize that to achieve a maximum change in refractive index for the two waveguide arms (sides) you will apply some sort of voltage to both arms of the interferometer. Use MOSFET terminology in your answers.*

(b) Assume the device uses the standard telecom wavelength of 1.5 μm light (which is low enough energy that Si does not absorb it!), and the refractive index of the waveguide is nominally n=3.5. Calculate how much difference in refractive index is needed between the two arms of the waveguide to cause a logic zero (0) to be created at the output of this modulator?

- Hint, 1st calculate the actual wavelength for 1.5 μm light inside this Si material (remember, it will decrease it according to λ/n).

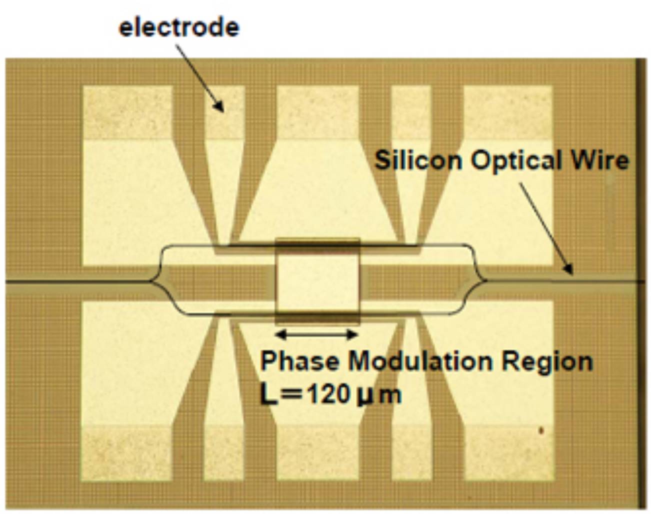
- Then figure out how many of these wavelengths you can fit along one arm using the length stated in the press release.

- Then remember to get negative interference (create a logic zero) you simply need to be a half-wavelength out of phase, and calculate how much as a % this is of the total number of wavelengths along one arm. Multiply this % by the refractive index and you have the amount by which you need to change the refractive index!

(c) Next, do a sanity check for your answer using this equation, to determine if such a change in refractive index is even possible for Si:

$$\Delta n \cong 3\times10^{-21}(cc) \quad \times \ \Delta N(\frac{1}{cc})$$

(d) Lastly, they are clearly bragging in the press release about how compact this size is. From an end user perspective, this is nice, but not a major advantage (is already pretty small). However, from a manufacturing and profit perspective for the company, this is a big deal… why?



Tokyo, March 23, 2010 - NEC Corporation (NEC; TSE: 6701), announced today the successful development of a silicon MOS (metal-oxide-semiconductor) optical modulator that boasts a leading power-consumption efficiency of less than 1mW/Gbps, a compact size of 120 µm in length and high-speed operation of 25Gbps. The device has only one-tenth the power consumption when compared to conventional PN-type silicon optical modulators.

(a) Both sides of the waveguide are electrically active (it appears). One side will use MOS depletion, and the other side MOS accumulation to change the refractive index between the two arms, causing interference as light meets up at the outputs from the two arms. Better than having to forward bias a diode (lots of current flow). Does not matter if is holes or electrons, you just want the largest difference in charge between the two waveguides.
(b) We need to shift the light by ½ a wavelength. In Si, 1.5 µm light will have a wavelength of 1.5 µm/3.5 = 0.43 µm. Along 120 µm, there are 280 full phases of the wavelength, and we need to change it by ½ phase which would be 0.5/280 or 0.18%, 0.18% of n=3.5 is a change in refractive index of n=0.0063.
(c) Using the equation, we can predict the change in carrier concentration that is needed is 2E18/cc. That makes sense, because we could easily have one arm of the device accumulate up to 2E18/cc and the other arm of the device deplete carriers (effectively 0/cc).
(d) Twice number of devices per substrate! Twice the profit (almost).

And… check it out. I did the calculations above, and guessed how it might work, based only on the press release information. I then searched and found this paper which verifies that the calculations above are fairly accurate :)

http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05465181

(7) Simulate a 1D photonic crystal reflector for a RED laser using a very nice MATLAB script file written by David Kiesewettter, Hunter Covington, and Matt Farr (class of 2015). See the zip file on blackboard for everything you need.

Use input n_o=1 (air), first layer n_1=1.46 (SiO_2), second layer n_2=2.35 (TiO_2), output n_o=1 (air). Plot from 400 nm to 900 nm, 500 data points. You should:

(a) simulate 3 layer repeats for λ_o=633 nm and each layer thickness equal to $\lambda_o/4n$;

(b) simulate 10 layer re peats for λ_o=633 nm and each layer thickness equal to $\lambda_o/4n$;