

# Modulator Basics

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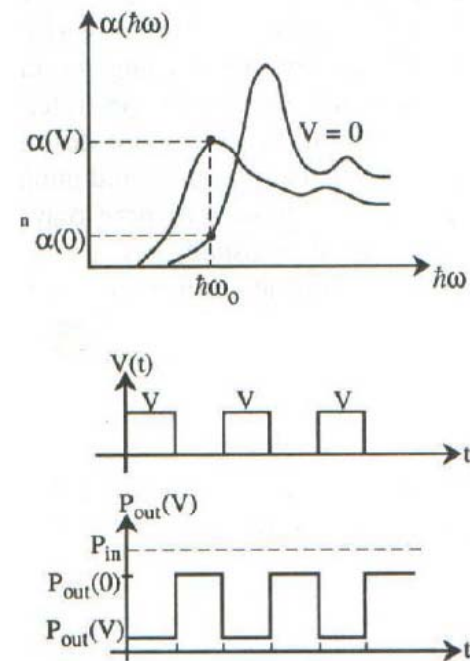
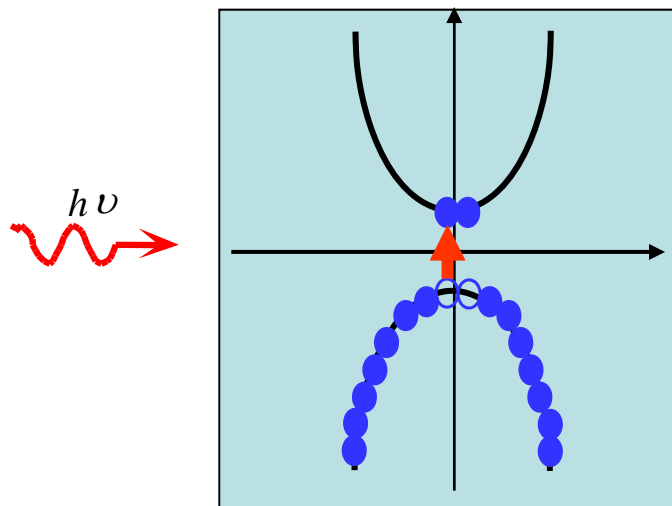
How to modulate light?

- Direct Modulation: Turn Laser On and Off!
- Simple, but performance degrading due to chirping (shift in lasing frequency) and limited extinction ratio

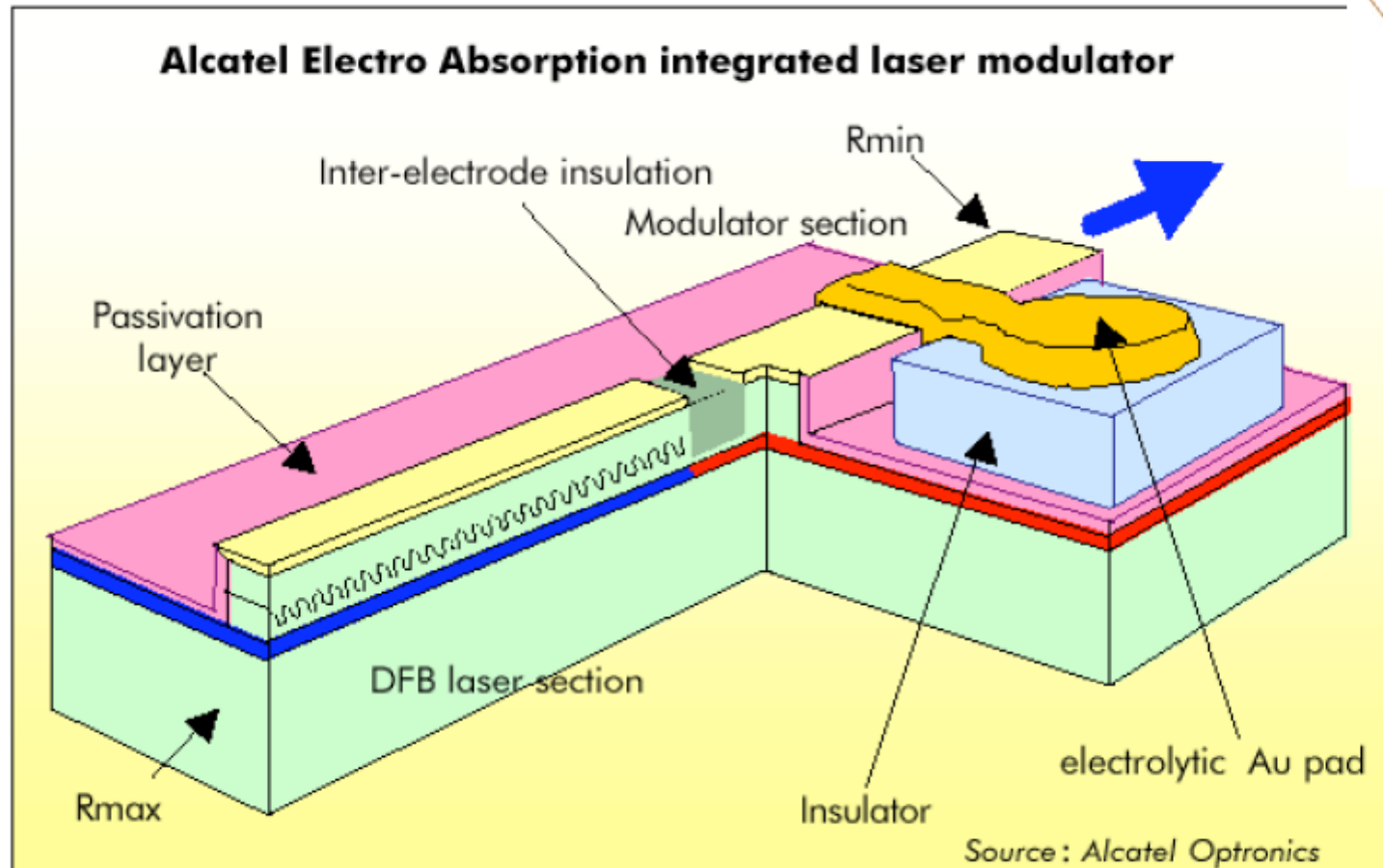
# Modulator Basics

How to modulate light?

- EA (Electro-Absorption) modulator:  
Change the amount of absorption with voltage  
Usually realized with semiconductor materials



# Modulator Basics



- 10Gb/s module,  $I_{th} = 20\text{mA}$ ,  $P_{max} = 4\text{mW @}80\text{mA}$ , extinction ratio = 15dB for -2.5V

# Modulator Basics

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How to modulate light?

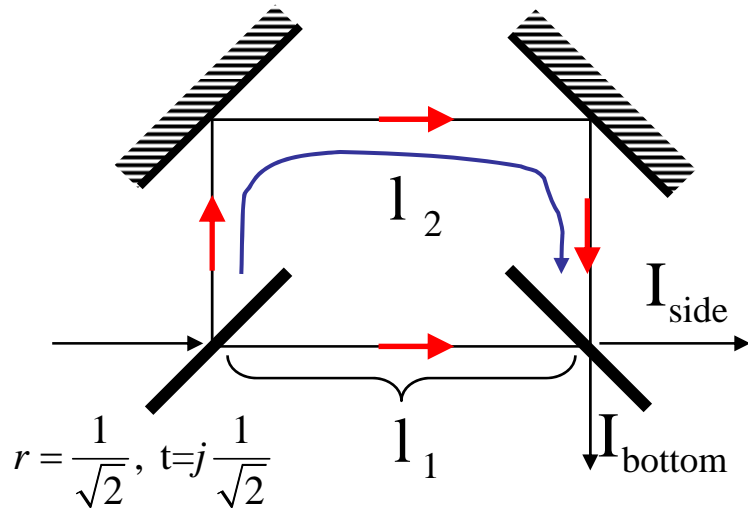
– EO (Electro-Optic) modulator:

Change refractive index with voltage → Light modulation with interference

→ Mach-Zehnder interferometer (MZ modulator)

# Modulator Basics

## Mach-Zehnder Interferometer:



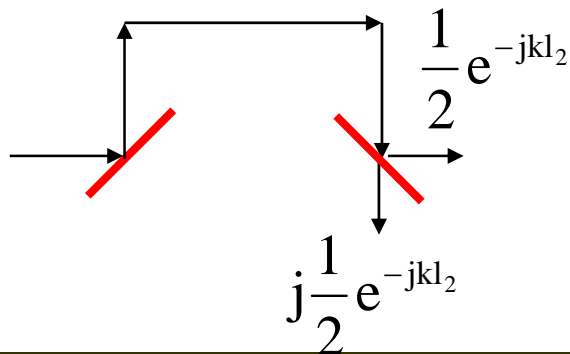
$$E_{out, side} = \frac{1}{2} \left( e^{-jkl_2} - e^{-j2kl_1} \right) = \frac{1}{2} e^{-jk\frac{l_2+l_1}{2}} \left( e^{-jk\frac{l_2-l_1}{2}} - e^{jk\frac{l_2-l_1}{2}} \right)$$

$$I_{out, side} = \sin^2 \left( k \frac{l_1 - l_2}{2} \right)$$

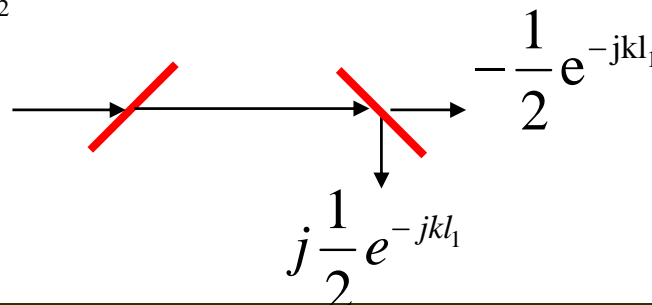
$$E_{out, bottom} = \frac{j}{2} \left( e^{-jkl_1} + e^{-jkl_2} \right) = \frac{j}{2} e^{-jk\frac{l_1+l_2}{2}} \left( e^{-jk\frac{l_1-l_2}{2}} + e^{jk\frac{l_1-l_2}{2}} \right)$$

$$I_{out, bottom} = \cos^2 \left( k \frac{l_1 - l_2}{2} \right)$$

Case#1

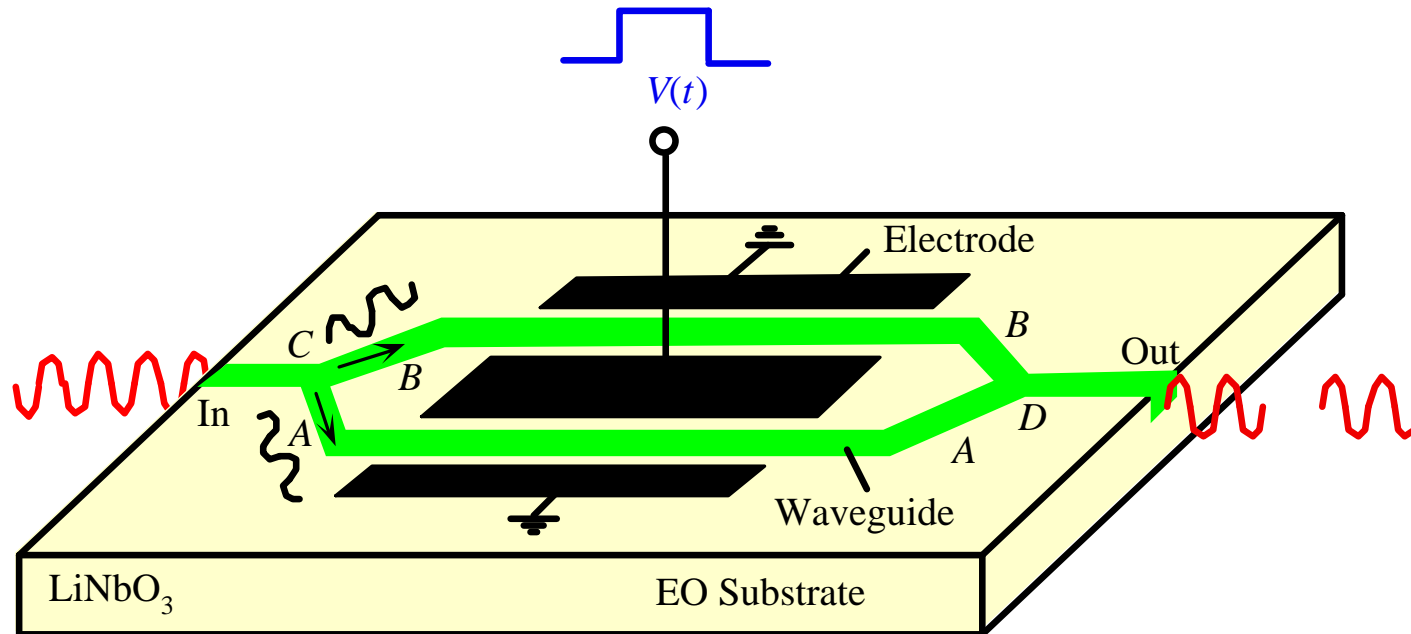


Case#2



# Modulator Basics

## Mach-Zehnder Interferometer (Modulator)



Efficient and fast change of refractive index in  $\text{LiNbO}_3$  by voltage

➔ Most popular high-speed modulator for optical communications

How to realize the same function with CMOS technology?