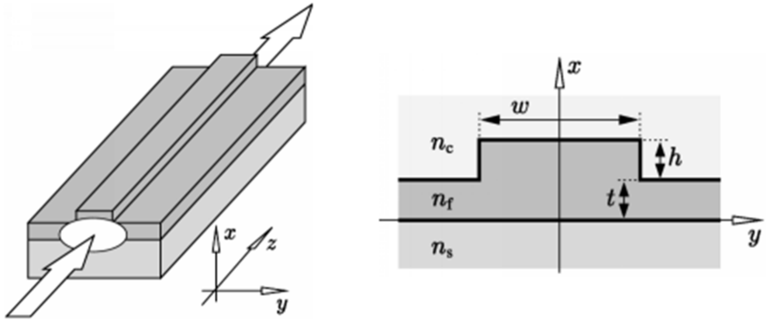
Lect. 17: Planar Dielectric Waveguides



Requirements for planar dielectric waveguides

- Precise control of dimension and refractive index
- Low loss at desired λ
- Mass production
- Electrical control of refractive index (Electro-optic effect)
- Integration (Photonics Integrated Circuit)

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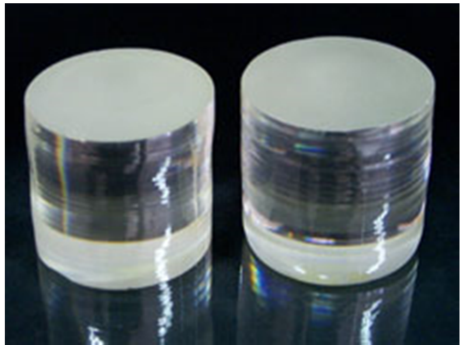
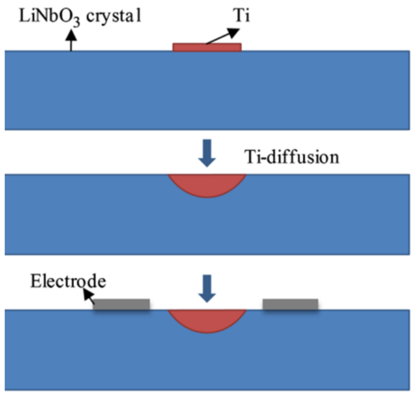
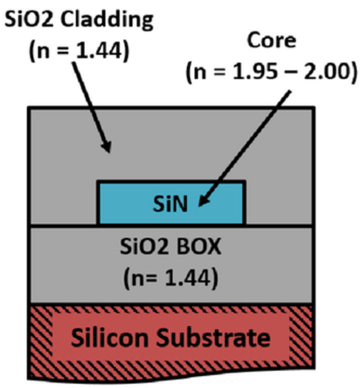
Materials used for waveguides

– Ceramics : $LiNbO_3$ (Lithium Niobate) with Ti doping for core





– Si_3N_4 (core) / SiO_2 (cladding) typically on Si wafer



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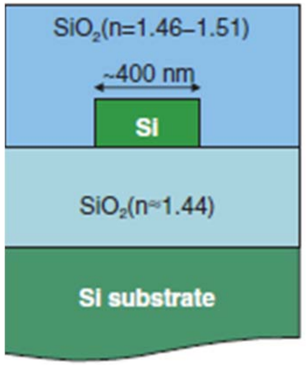
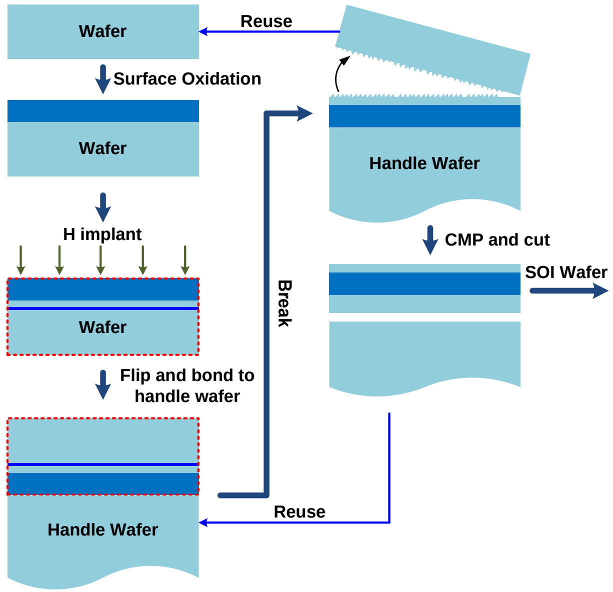
Materials used for waveguides

– SOI (Si on Insulator) Si (core)/ SiO_2 (cladding) ➔ Si Photonics





- Si is transparent to 1.5μm light
- Si fabrication technology is very mature
- Si photonics provides possibility of integrating photonics and electronics on Si wafer

SOI wafer fabrication

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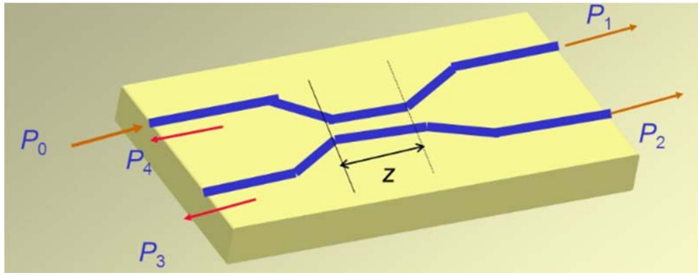
Photonic circuits based on planar waveguides

– Directional coupler



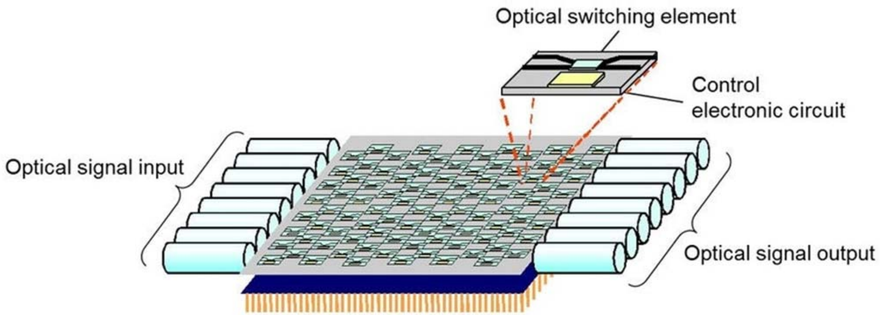
$$P_1 = P_0 \cos^2(\kappa z)$$

$$P_2 = P_0 \sin^2(\kappa z)$$

κ : Coupling coefficient

Used for dividing light into various waveguides ➔ Beam splitter

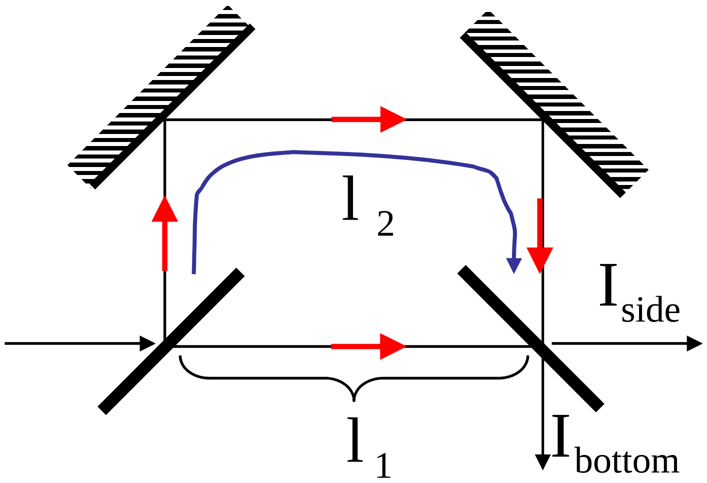
In many materials, the refractive index can be changed by an applied voltage (Electro-optic effect) ➔ Tunable optical power diver



Optical signal routing

➔key network function

Mach-Zehnder Interferometer:



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

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

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

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

Realize M-Z interferometer with waveguides

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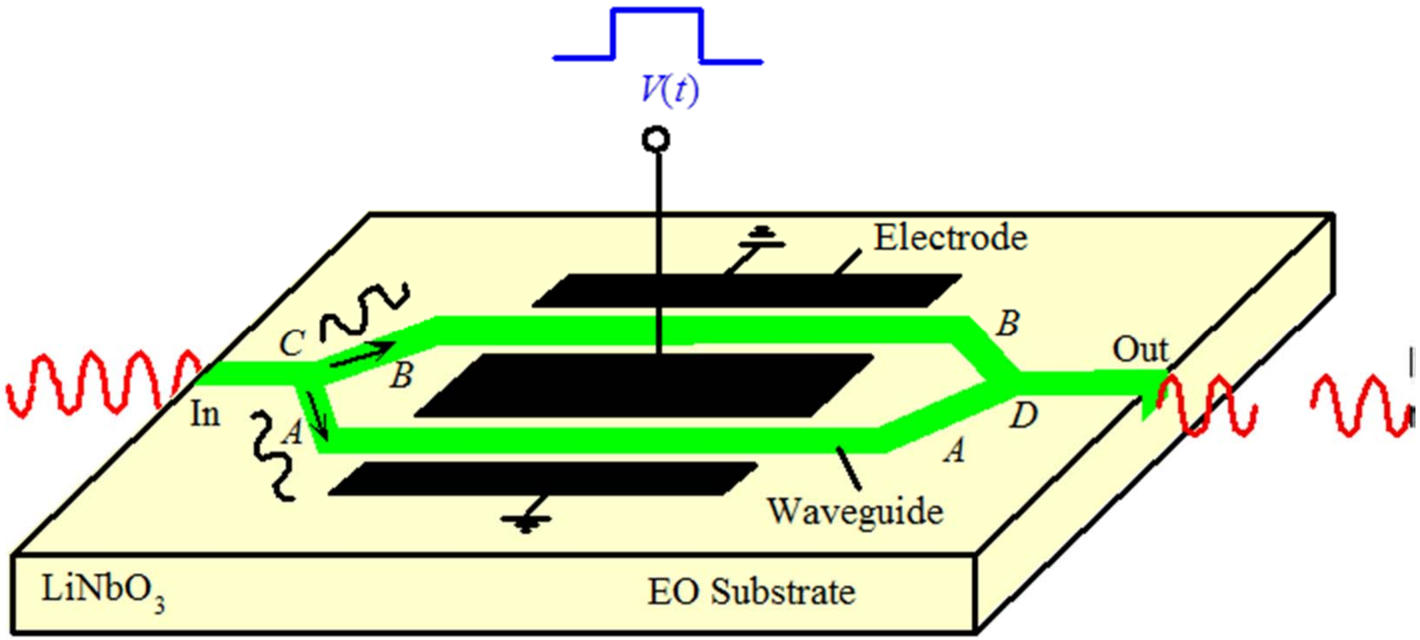

With voltage applied, light travelling in two different arms experiences different amount of phase shift

➔ Modulation of output intensity

Mach-Zehnder Modulator (MZM) : A key element in optical communication

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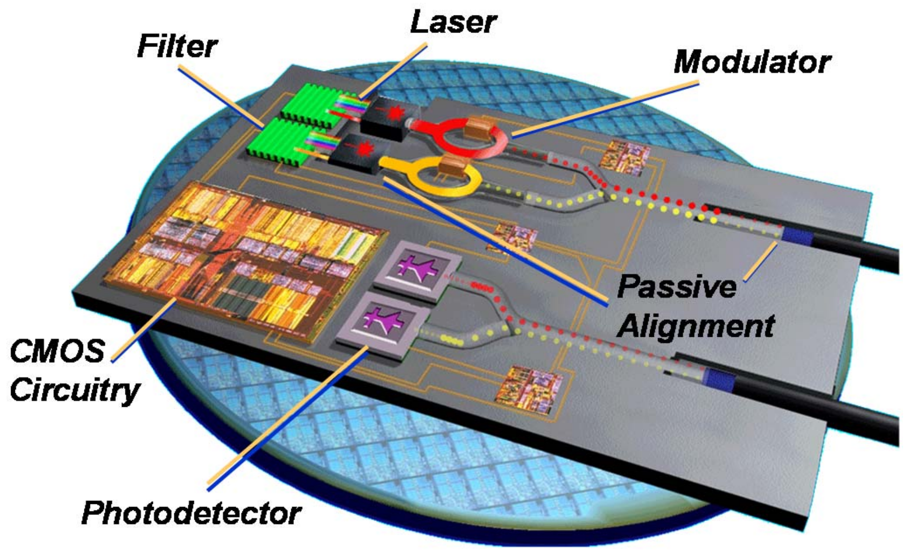
Si Photonics: Future of electronics and photonics



(Intel, 2006)

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Homework:
(See the figure next page. Assume P_{out} has $\cos^2$ dependence on P_{in})

Consider a Mach-Zehnder interferometer shown below. The refractive index that $1.5\,\mu m$ light experiences while traveling inside the interferometer is 3.5 when no bias voltage is applied. Due to manufacturing problems, $l_1 = 100\,\mu m$ and $l_2 = 100.1\,\mu m$ are not the same.

(a)(10) What is the output power when the input power is $1mW$ at $1.5\,\mu m$ and no bias is applied?

We want to use the interferometer as an optical on/off switch by applying voltage to the upper arm as shown. The refractive index of the upper arm increases 0.001 per 1 volt applied.

(b)(10) What is the voltage with the smallest absolute value that needs to be applied to make the switch on?

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Homework: