Silicon Photonics
矽光子學

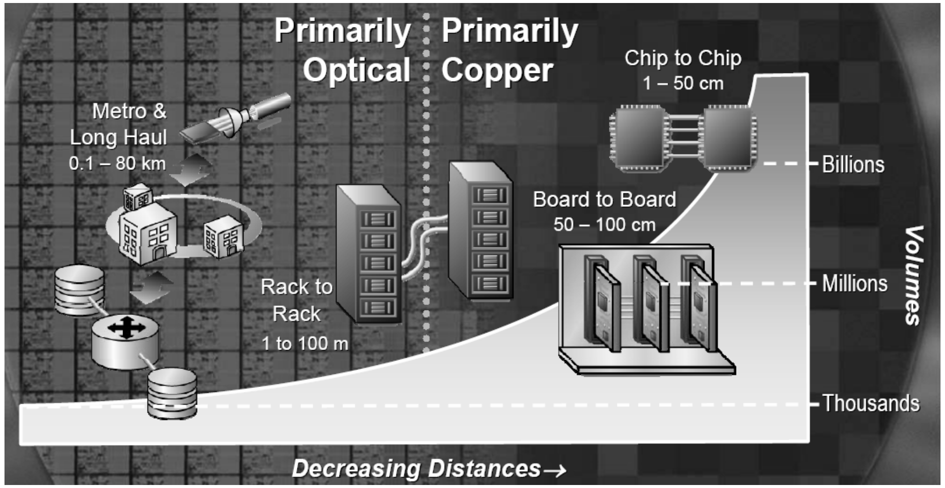
課程編號：**941 U0460**
科目名稱：矽光子學
授課教師：黃鼎偉
時間地點：一**678** 明達館 **303**

Outline

- Introduction
- Silicon Waveguide
- Building Blocks of Silicon Photonics
- Applications
- Summary

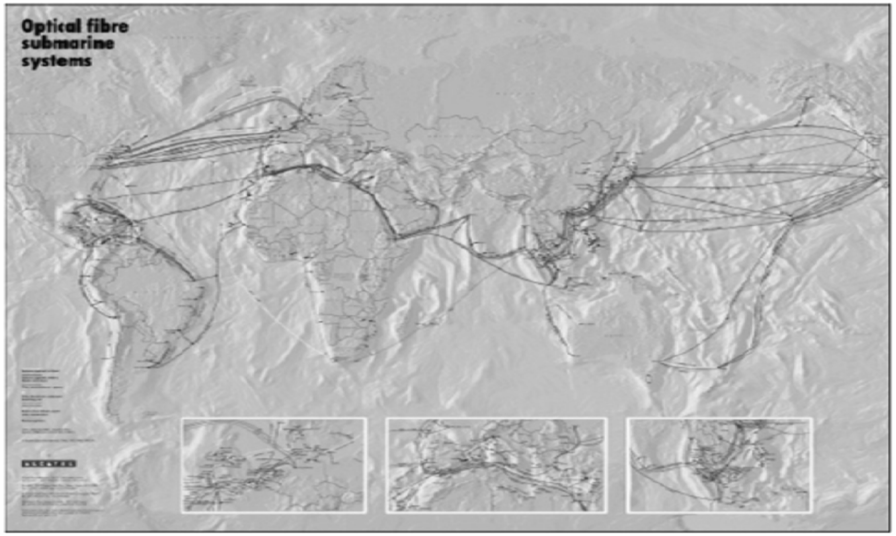
Introduction

Today's High Speed Interconnect



Source: Intel

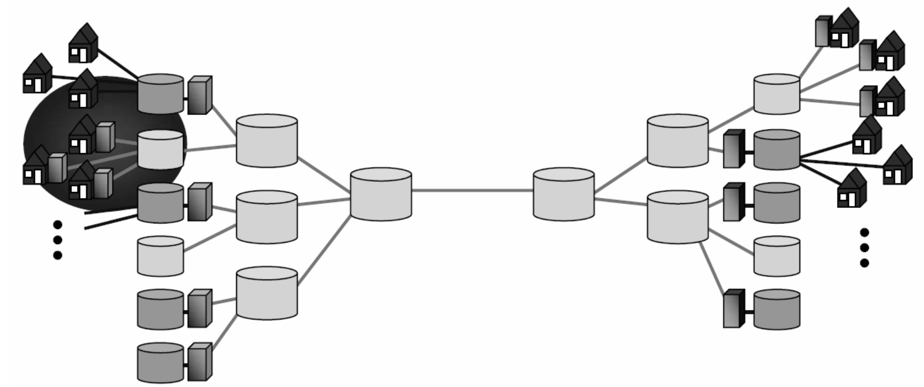
Global Optical Network



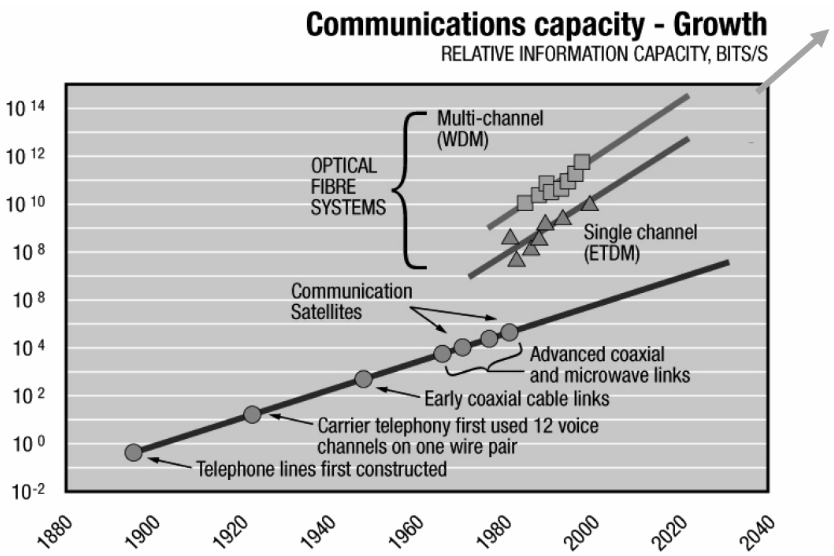
Fiber To The Home (FTTH)

- FTTH: High speed data communications, television and telephone services for every home.

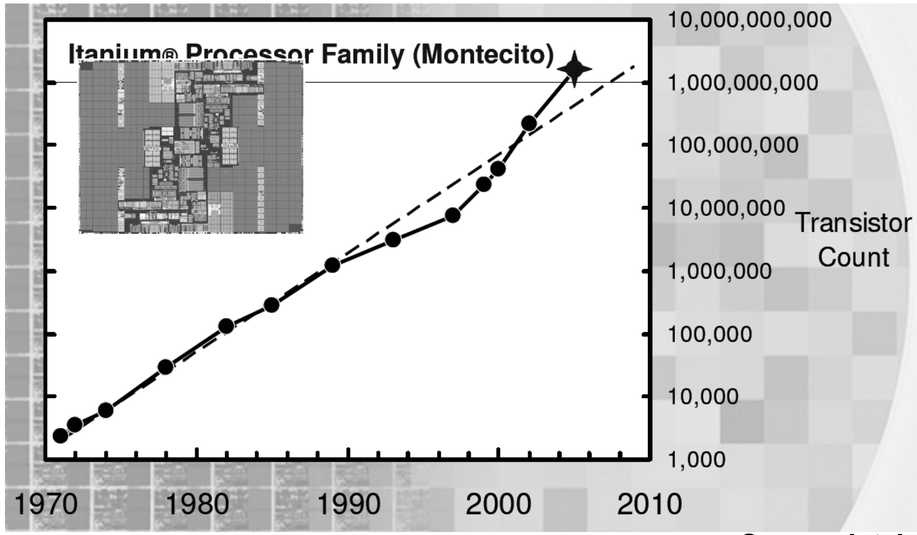
⇨A lot of cheap FTTH transceivers are required.



Capacity of Communication Systems

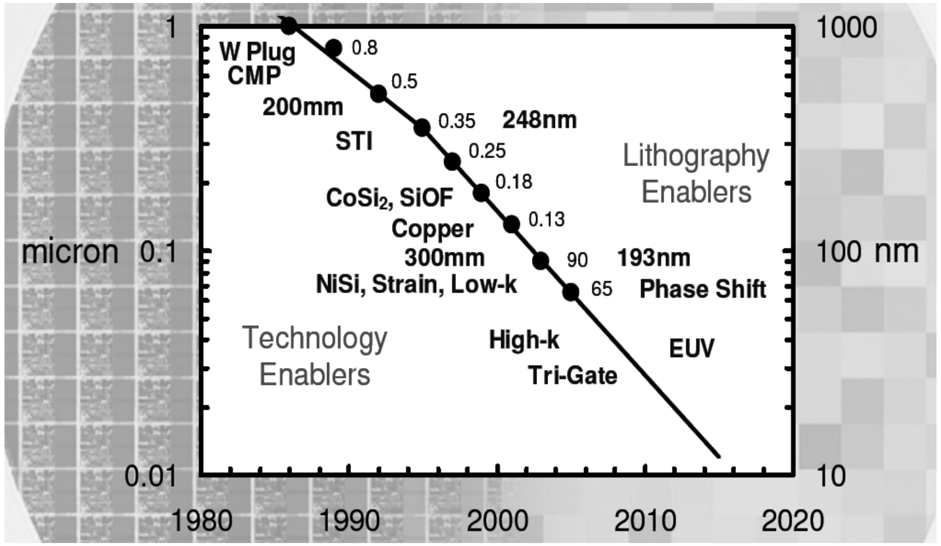


Moore's Law for Microelectronics



Source: Intel

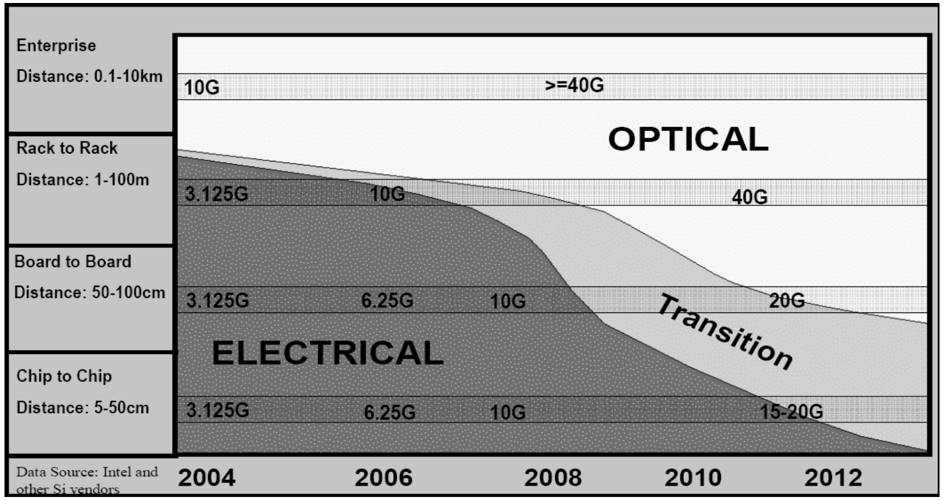
Scaling of Microelectronics



Source: Intel

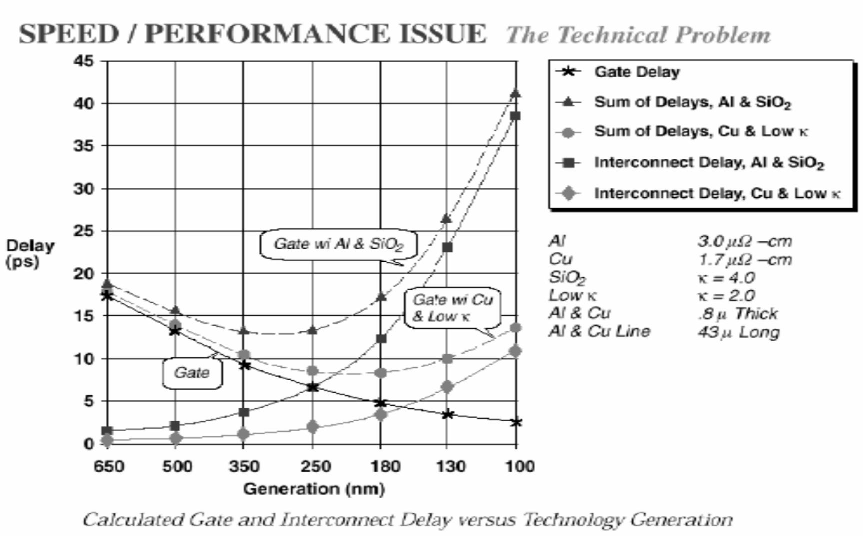
Electrical or Optical Interconnect?

- Integrated OEICs are required for high speed short distance optical interconnect in the future



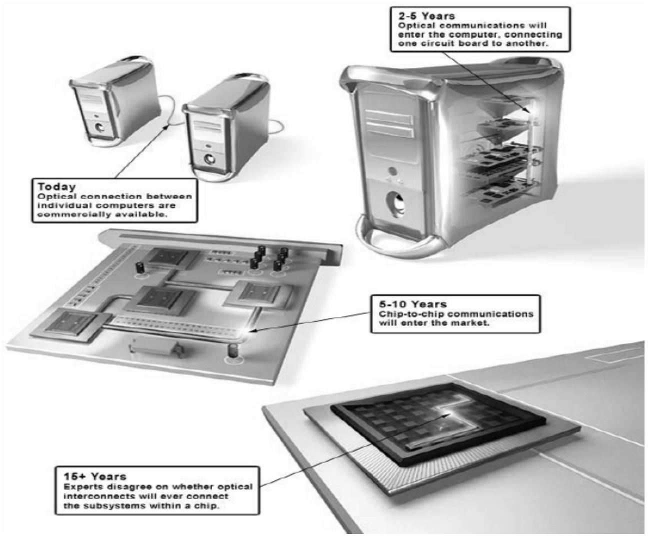
Source: Intel

Speed/Performance Issue



Optical Interconnect in the Future

- Chip to Chip
  > 10 Gbps
- On-Chip
  > 20 Gbps



Why Silicon?

- Silicon Photonics: Integrating photonics onto the silicon platform to form silicon devices that use LIGHT instead or together with electrons
- For shrinking anything, it's hard to do better than Silicon…

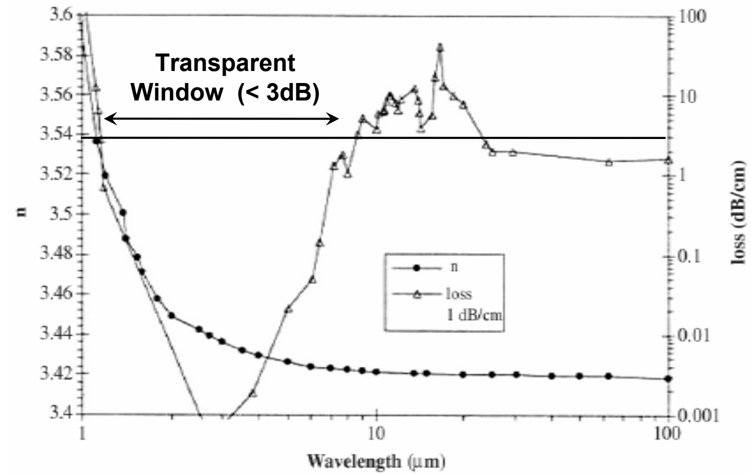
⇨Since billions of dollars have already been invested in processing Silicon and SOI

- Working in Si means less process engineering
  - High yield and repeatability
  - Processes are developed in industry
  - Commodity materials

Silicon Waveguide

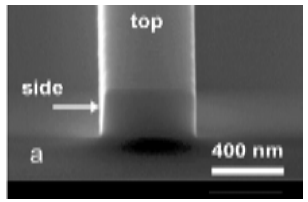
Optical Properties of Silicon

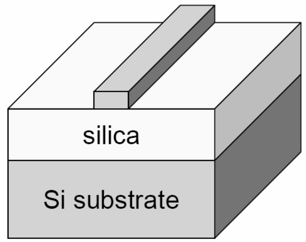
- **Transparent at telecom wavelengths (1.55 & 1.3 μm)**



Silicon-On-Insulator (SOI) Waveguide

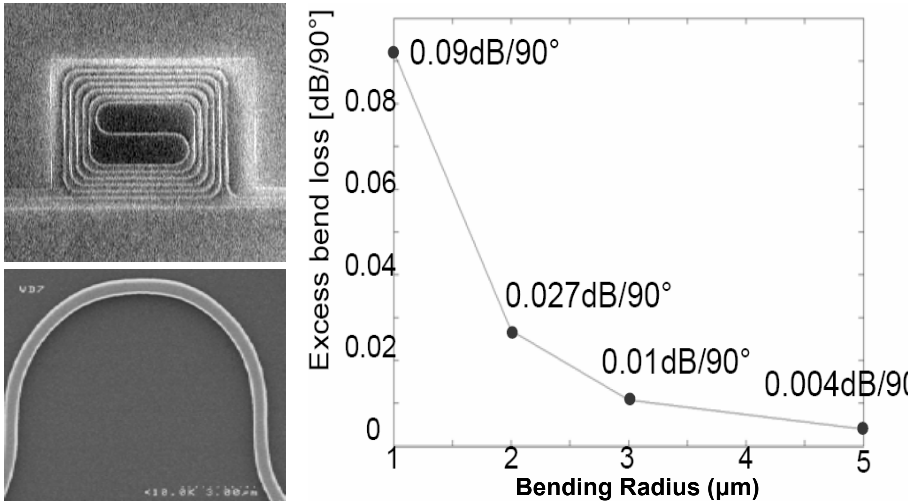
- **High refractive index contrast**
  - In-plane: 3.45(Si) to 1.0 (air)
  - Out-of-plane: 3.45 (Si) to 1.45 (SiO_2)
- **Typical dimensions:**
  - Thickness: 200 nm
  - Width: 500 nm
  - Required accuracy: 1-10 nm
- **Compatible with CMOS processes**
  - Silicon-On-Insulator: SOI (n = 3.45)
  - α_s,TE = 3.6 ± 0.1 dB/cm





Y. A. Vlasov and S. J. McNab, Optics Express, v. 12 (8), pp. 1622-1631 (2004).

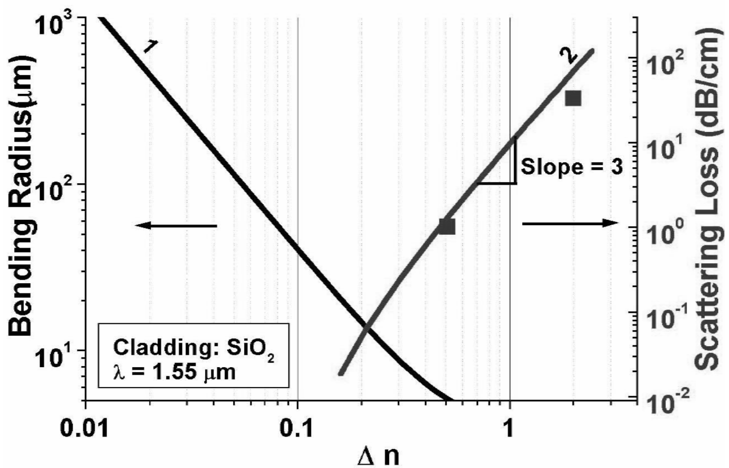
Waveguide Bends & Bending Loss



Source: IMEC

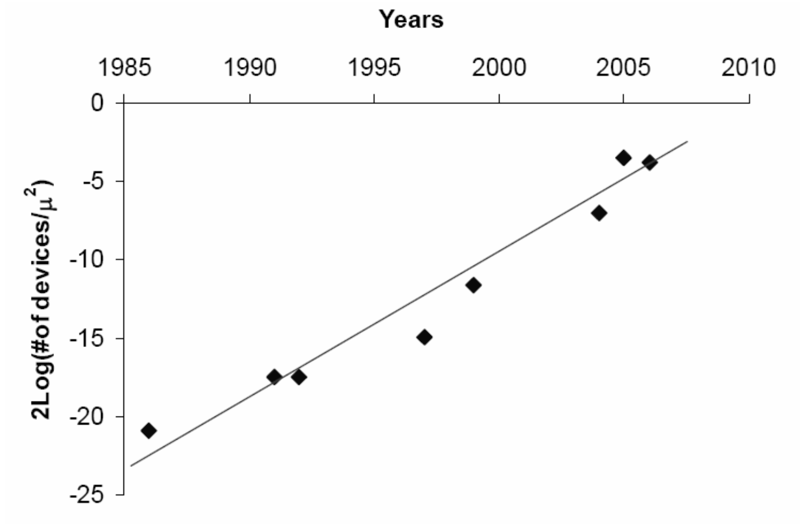
Refractive Index Contrast Δ n

- Scattering Loss ↑ as Δn ↑
- Bending Radius ↓ as Δn ↑



Lee and Sparacin, MIT

Moore's Law for Silicon Photonics

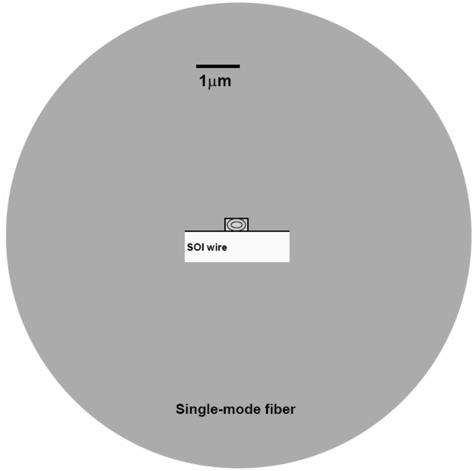


Building Blocks of Silicon Photonics

Fiber to SOI Waveguide Coupling Issue

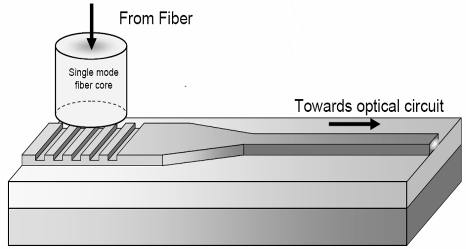
Fiber: 8.3 um dia.
SOI WG: 0.2 x 0.4 um

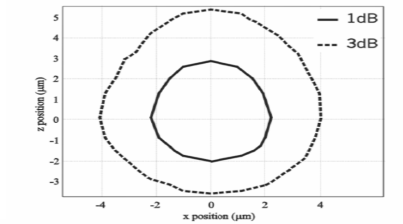
Important Coupling Issue:
- **Low loss**
- **Large bandwidth**
- **Coupling tolerance**
- **Fabrication**
- **Limited extra processing**
- **Tolerant to fabrication**
- **Polarization**

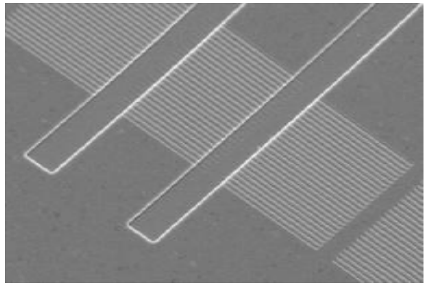


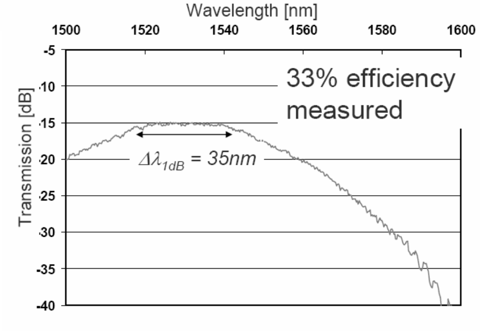
Source: IMEC

Grating Coupler





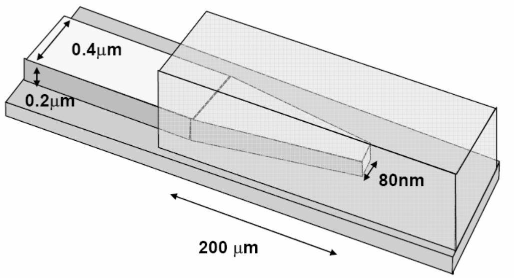


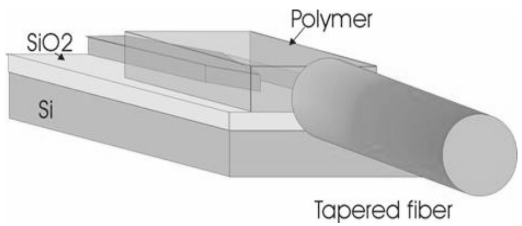


Source: IMEC

Inverse-Taper Coupler

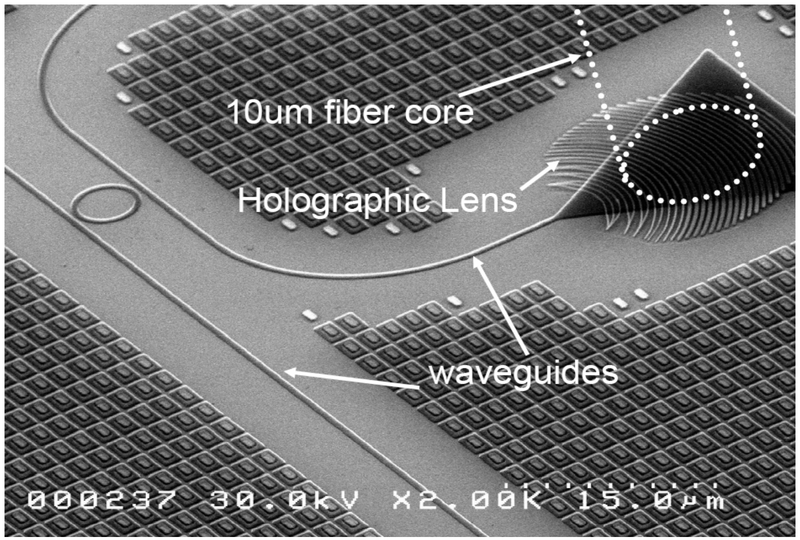
- Inverse-Taper
- Overcladding
  - Polymer
  - SiO_2
  - SiN_x
- Loss < 4 dB





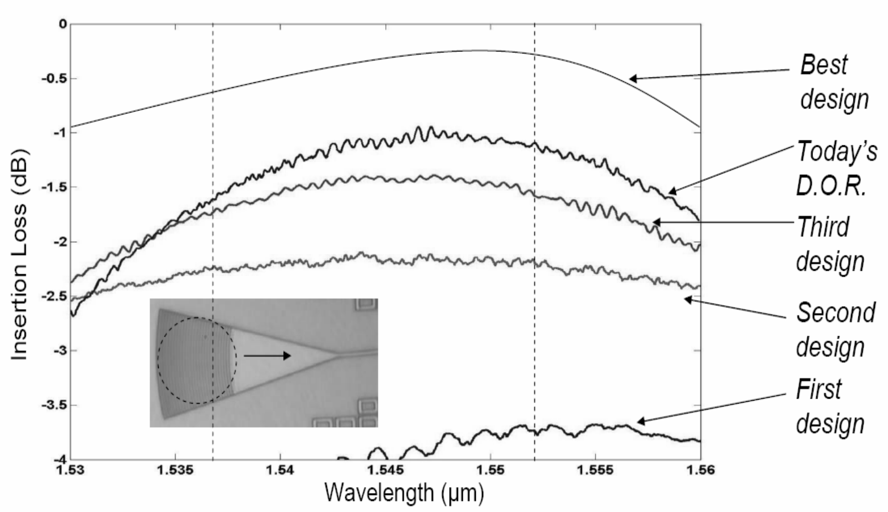
Source: IMEC

Holographic Lens Coupler



Source: Luxtera

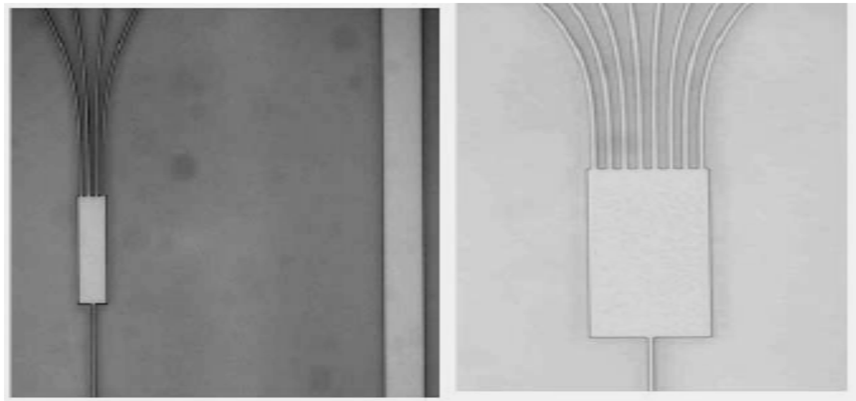
Holographic Lens Coupler



Source: Luxtera

Branching Device

1x4 & 1x8 MMI Splitter

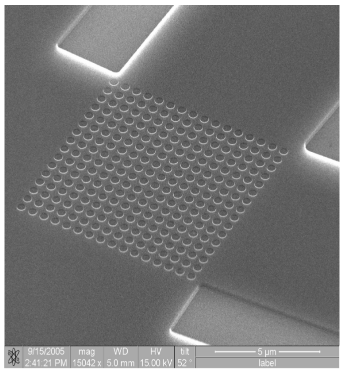


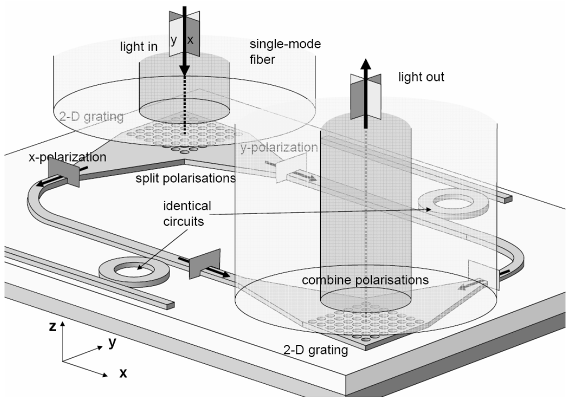
(A) 1x4 MMI w=7 µm; L= 19 µm. (B) 1x8 MMI w= 15 µm; L= 49 µm

V. Nguyen, J. Michel and L. C. Kimerling,(2006).

2D Grating Coupler

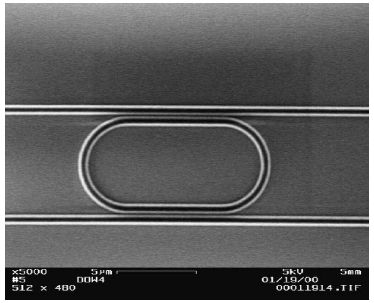
- **20 % efficiency**
- **1dB bandwidth ~ 35 nm**
- **Extinction ratio > 18dB**

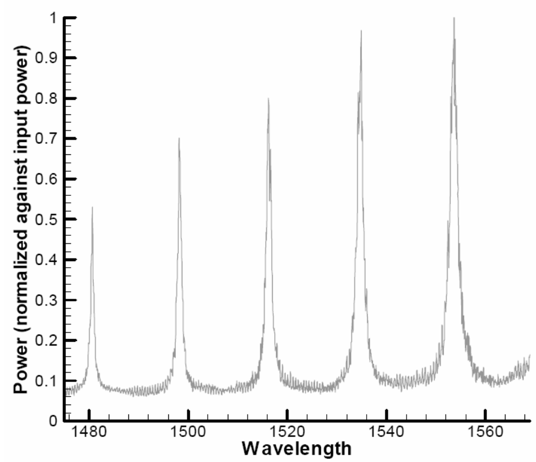




Source: IMEC

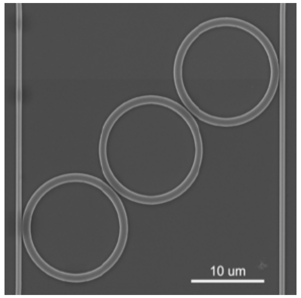
Race Track Resonator Type Filter

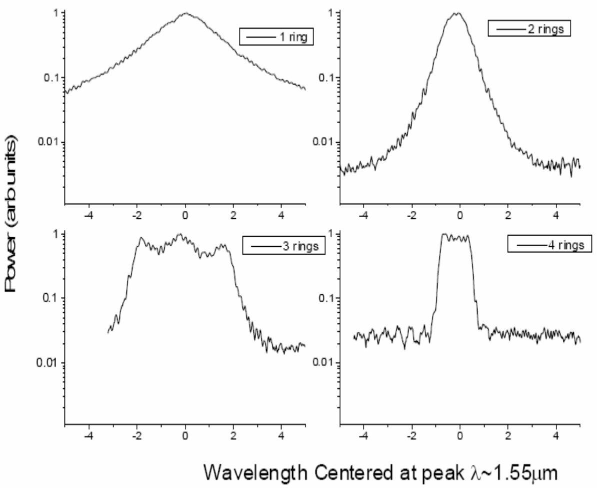




Lim, Maki, Little, MIT

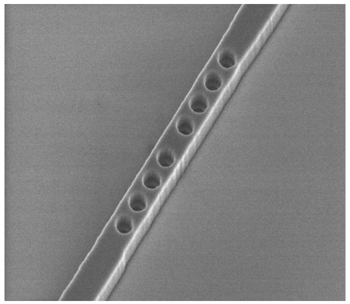
Multiple Ring Resonator Type Filter

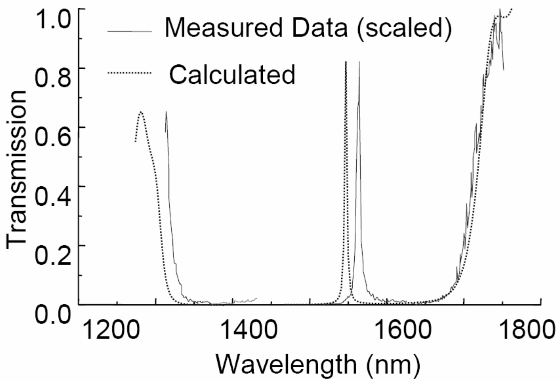




T. Barwicz, M. A. Popovic, P. T. Rakich, M. R. Watts, H. A. Haus, E. P. Ippen and H. I. Smith," Optics Express, v. 12 (7), pp.1437-1442 (2004).

Photonics Crystal Resonator Type Filter



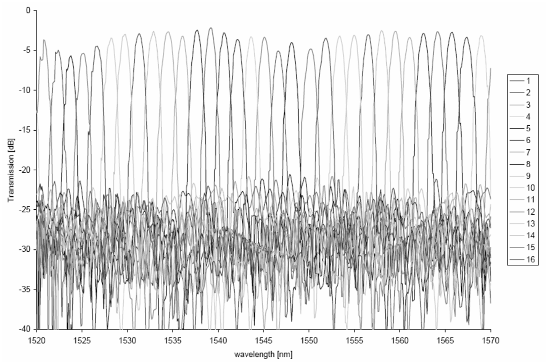


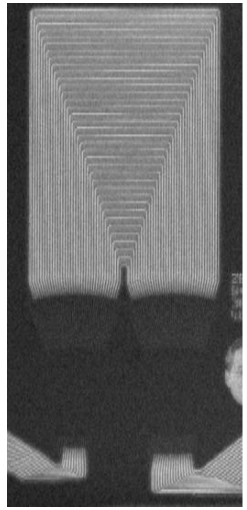
Foresi, Smith, Joannopoulos and Ippen, MIT

AWG (Arrayed Waveguide Grating)

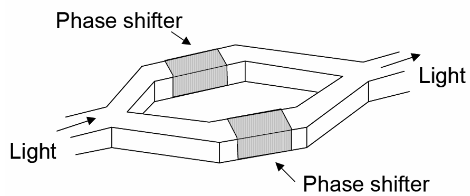
16-channel AWG, 200GHz
- **200μm x 500μm area**
- **-3dB insertion loss**
- **-15dB to -20dB crosstalk**

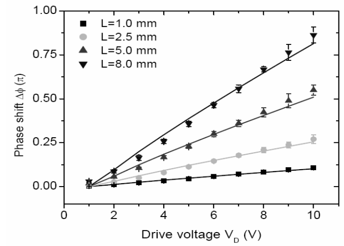
Source: IMEC

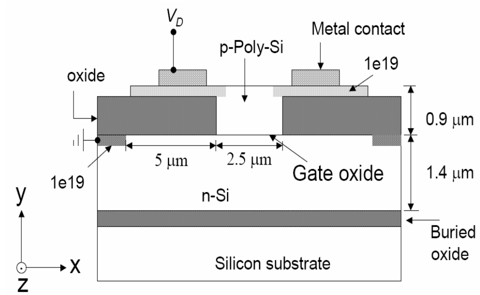


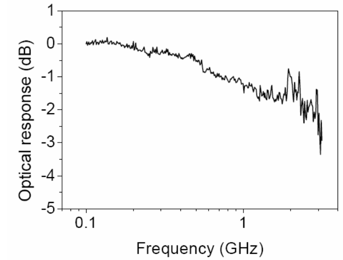


Mach-Zehnder Modulator



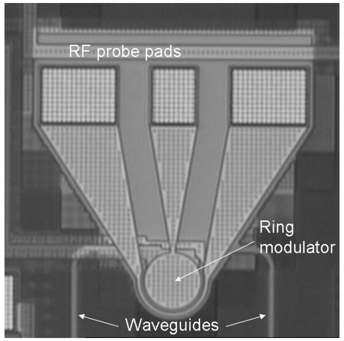


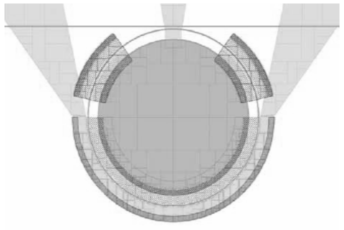


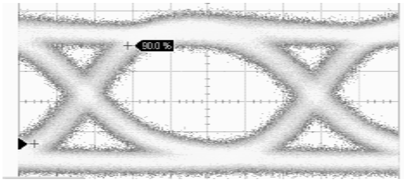


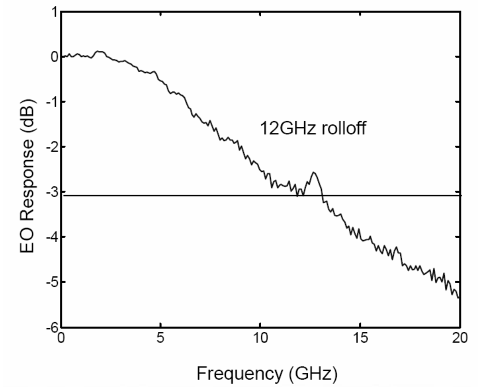
Source: Intel

Ring Resonator-Type Modulator



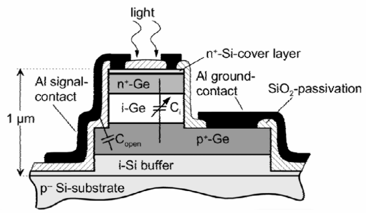


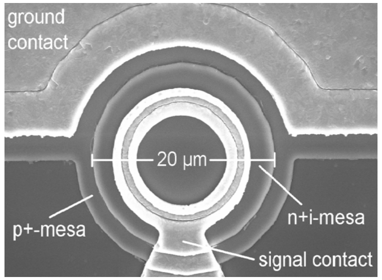


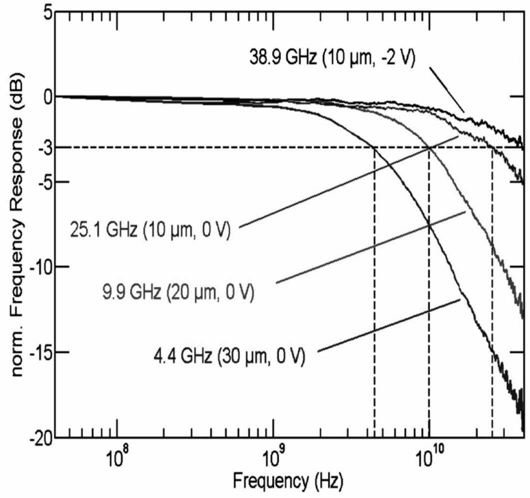


Source: Luxtera

Ge Detector Integrated on Silicon

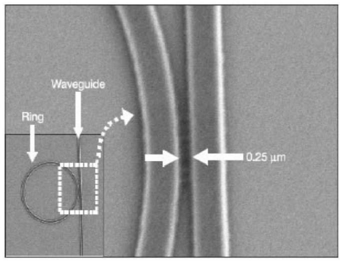


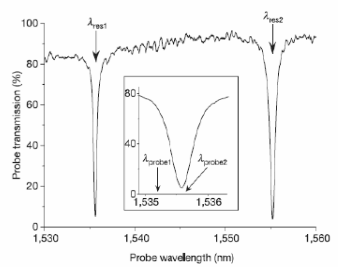


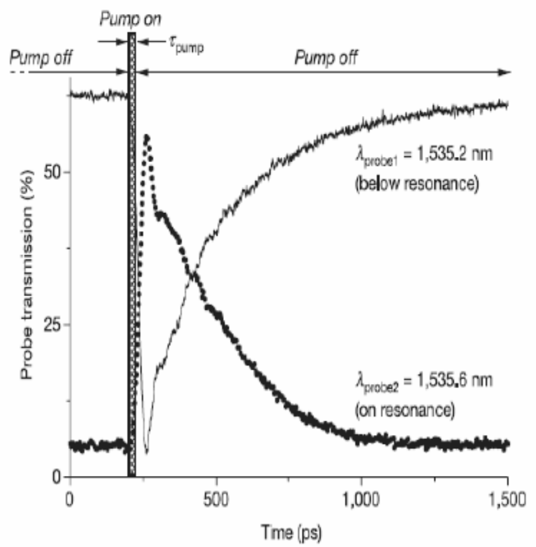


Source: IMEC

All-Optical Ring Resonator Type Modulator

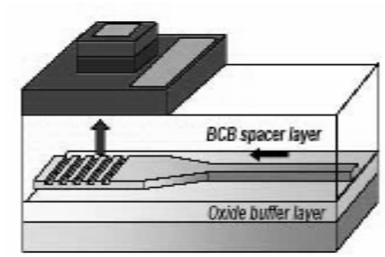


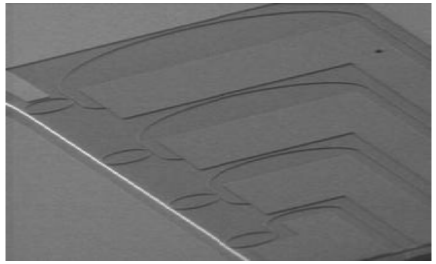


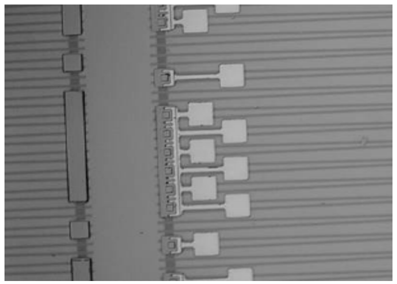


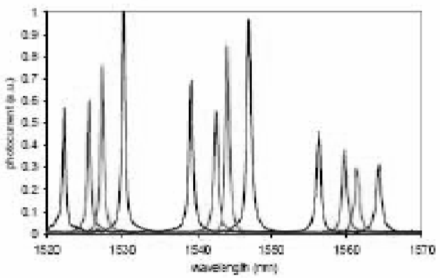
Lipson et al. Cornell Univ. (2005)

InGaAs Detector on Silicon



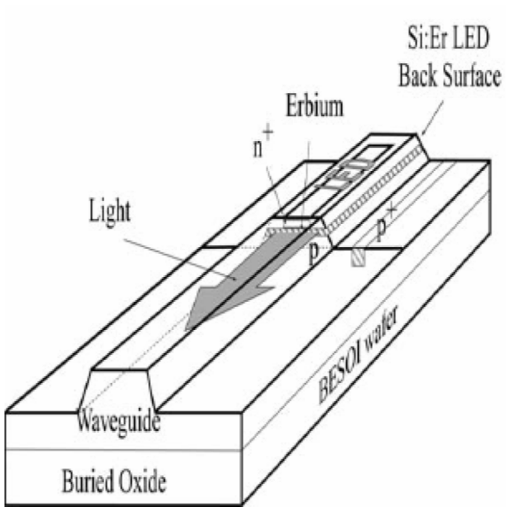


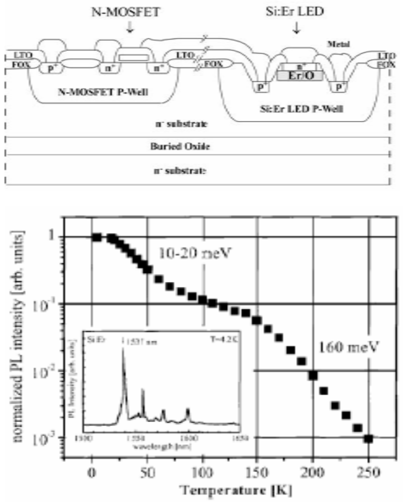




Source: IMEC

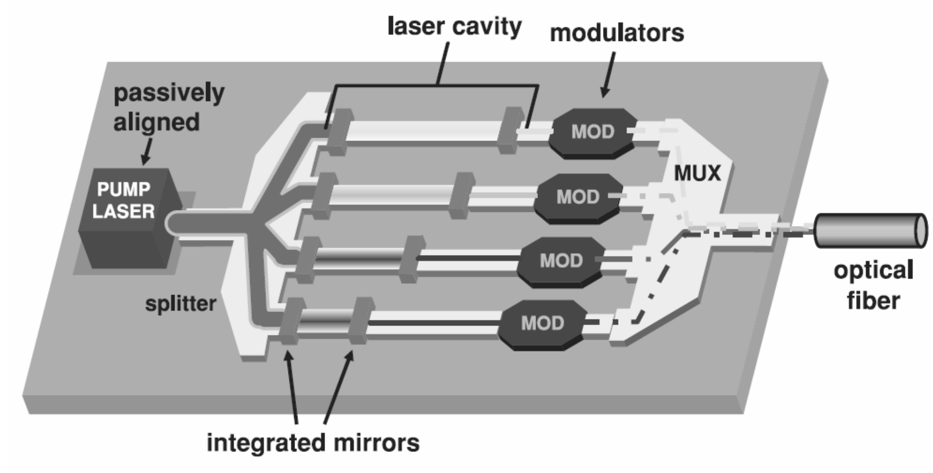
Erbium-doped Silicon LED/Laser





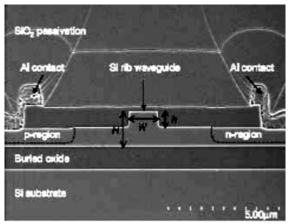
T. D. Chen, M. Platero, M. Opher-Lipson, J. Palm, J. Michel and L. C. Kimerling, Physica B, v. 273-274, pp. 322-325 (1999).

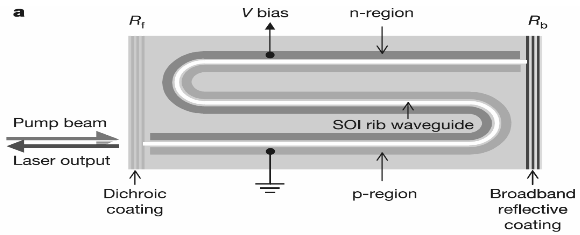
Silicon Raman Laser

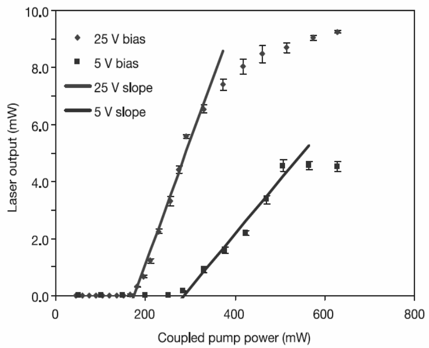


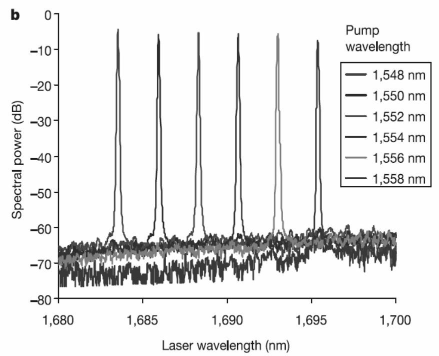
Source: Intel, NATURE 3346- 3/2/2005

Silicon Raman Laser



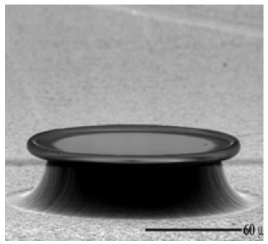


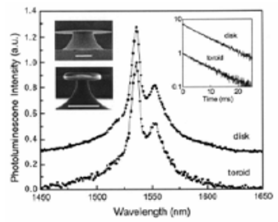


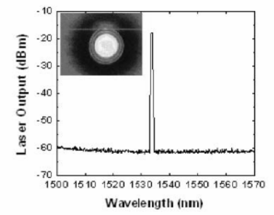


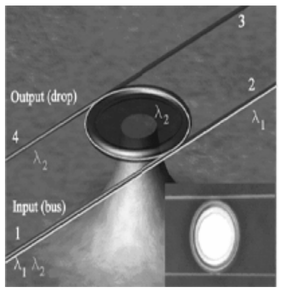
Source: Intel, NATURE 3346- 3/2/2005

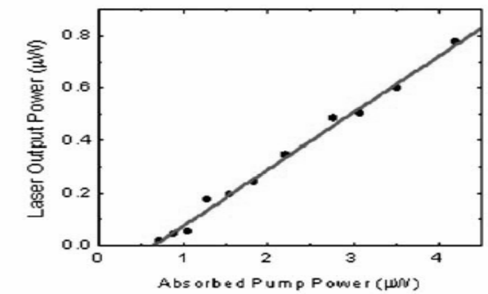
Silicon Toroid Laser





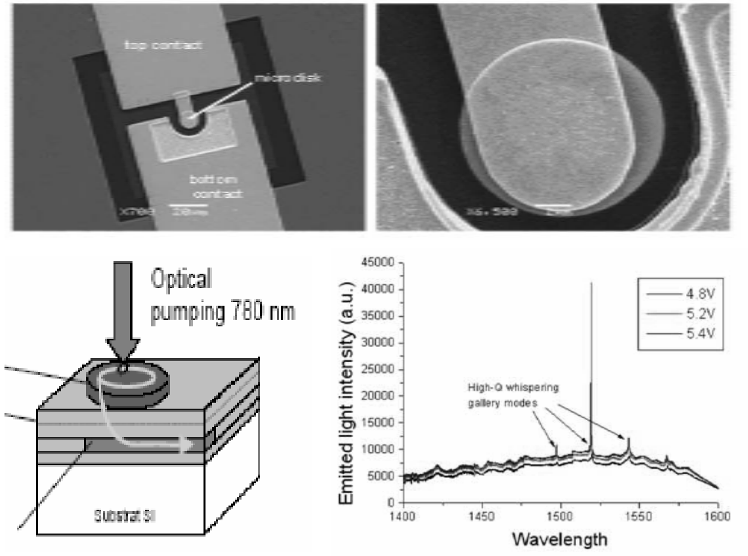






D. K. Armani, T. J. Kippenberg, S. M. Spillane and K. J. Vahala," Nature, v. 421, pp. 925-928 (2003

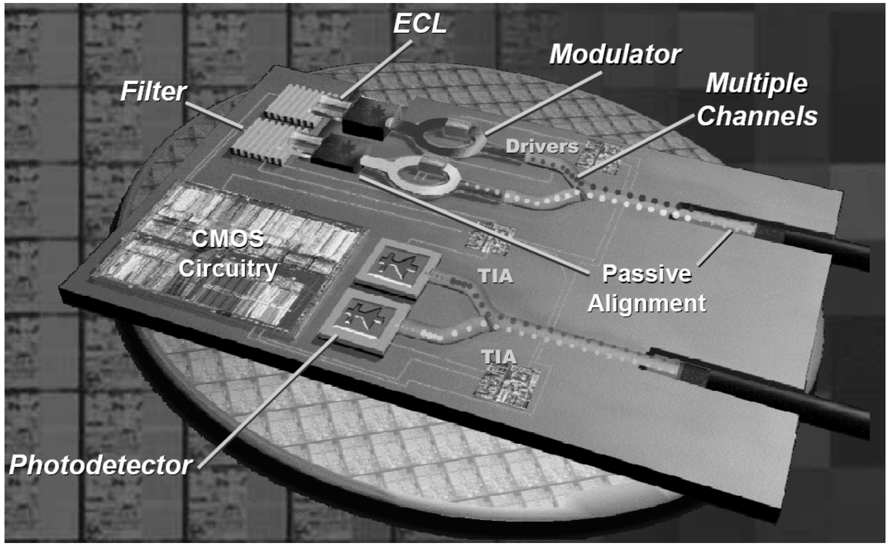
Silicon Disc Laser



Source: IMEC

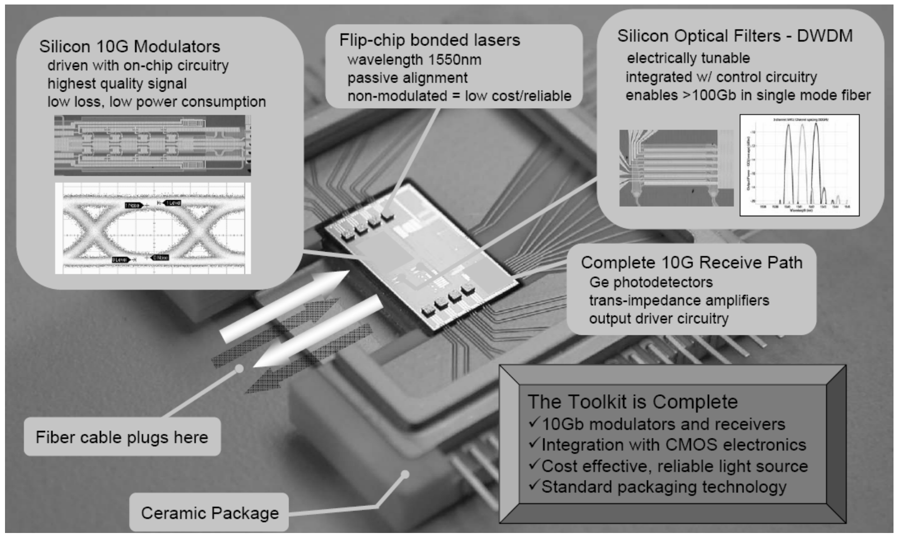
Applications

Intel's Silicon Photonics Platform



Source: Intel

Luxtera's CMOS Photonic IC

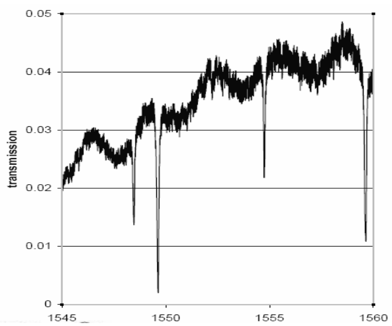


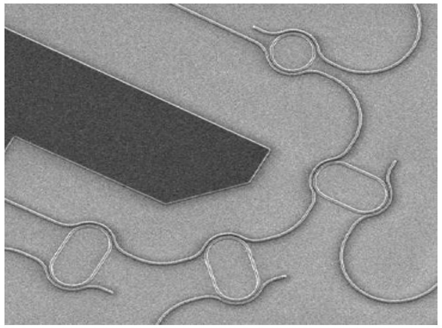
Source: Luxtera

Strain Sensor

2-D Strain sensor with 4 ring resonators

- **X and Y strain**
- **shear**
- **calibration (temperature, ...)**



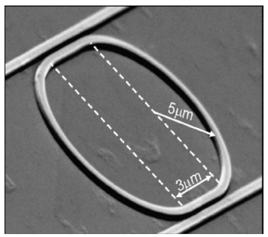


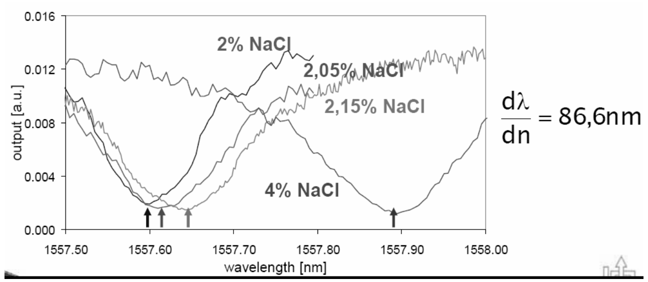
Source: IMEC

Bio-chemical Sensor

Measure salt concentration

- **Fluid overcladding**
- **Refr. index ~ Salt concentration**
- **Response of ring ~ refr. Index**
- **Q = 20000 →minimum Δn ~ 5e-5**





Source: IMEC

Summary

Summary

- **Silicon photonics is a generic technology with a wide range of high volume applications for which the industrial technology base largely exists today.**
- **Advantages**
  - **Economy of Scale for Photonics**
  - **Overcome the Interconnection Bottleneck**
  - **Lead to convergence of computing and communications**