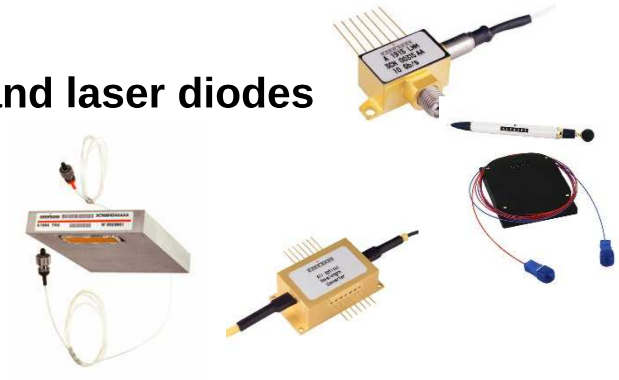
Part 2
Optoelectronic Components

♦ Optical components and product families

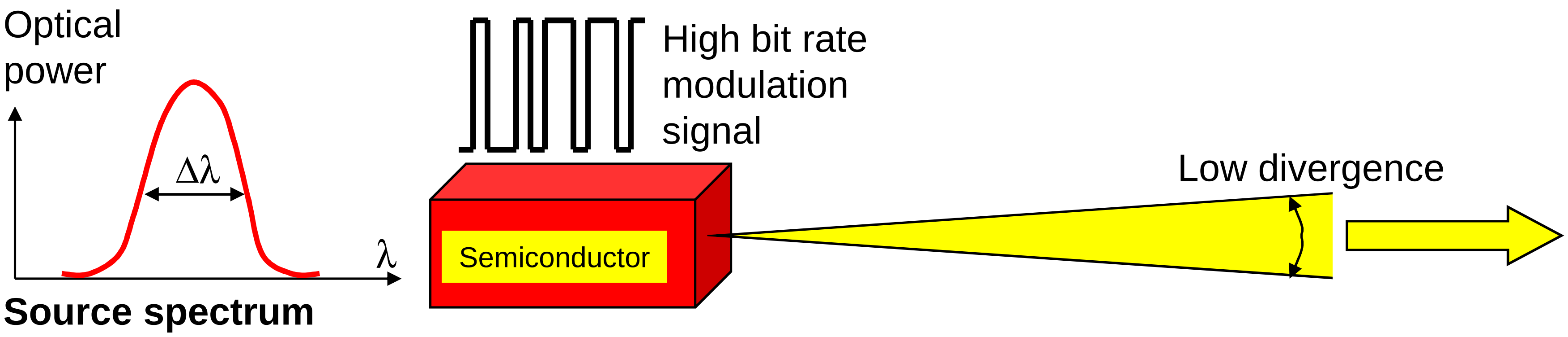
- **Active optical components**
  - **Light sources : light emitting diodes and laser diodes**
  - **Detectors and optical receivers**
  - **Optical amplifiers**
  - **Components for the optical routing**



- **Passive optical components**
  - **The FBG technology**
  - **Components realized using the FBG technology**
  - **The AWG technology and associated components**
  - **Optical connectors**

Light sources (1)

- **Main characteristics required**
  - **Semiconductor source (compact and easy to implement)**
  - **High emitted optical power**
  - **Low divergence beam for better coupling efficiency to fiber**
  - **Narrow spectral width for reducing chromatic dispersion and for dense WDM application**
  - **Possibility of high bit rate modulation**



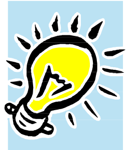
Light sources (2)

- Two possible candidates
  - LED (light emitting diode)
  - LD (laser diode)

- The light emitting diode (LED) : not performant enough

  - Low emitted power (some tens microwatts µW)
  - Too high beam divergence thus bad coupling efficiency to fiber
  - Broad spectral width (some tens nm)

- The laser diode (LD) : the best appropriate source
  - High emitted power (some tens milliwatts mW)
  - Very low beam divergence (high coupling efficiency to a singlemode fiber)
  - Very narrow spectral width, well matched to WDM systems



Light sources (3)

- **The optical power of a source**
  - **Explained either in milliwatts (mW), or in dBm (dB reported to 1mW)**
  - **Power (dBm) = 10 log Power (mW)**

Power in mW	Power in dBm
1 mW	0 dBm
2 mW	+ 3 dBm
4 mW	+ 6 dBm
10 mW	+ 10 dBm
100 mW	+ 20 dBm
Multiply by 2	Add 3 dBm
Divide by 2	Substract 3 dBm
Multiply by 10	Add 10 dBm
Divide by 10	Substract 10 dBm

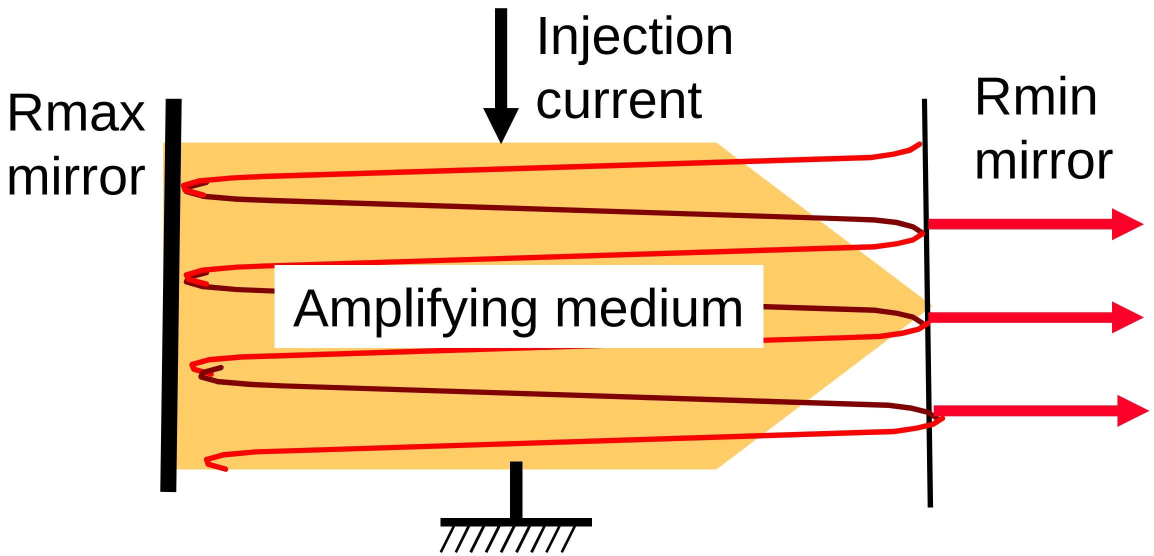
Examples :

+ 23 dBm
= +20 dBm +3 dBm
= 100 x 2 = 200 mW

- 26 dBm
= -20 dBm - 6 dBm
= 1/100 x 1/4 mW
= 0.01 x 0.25 mW
= 0.0025 mW
= 2.5 µW

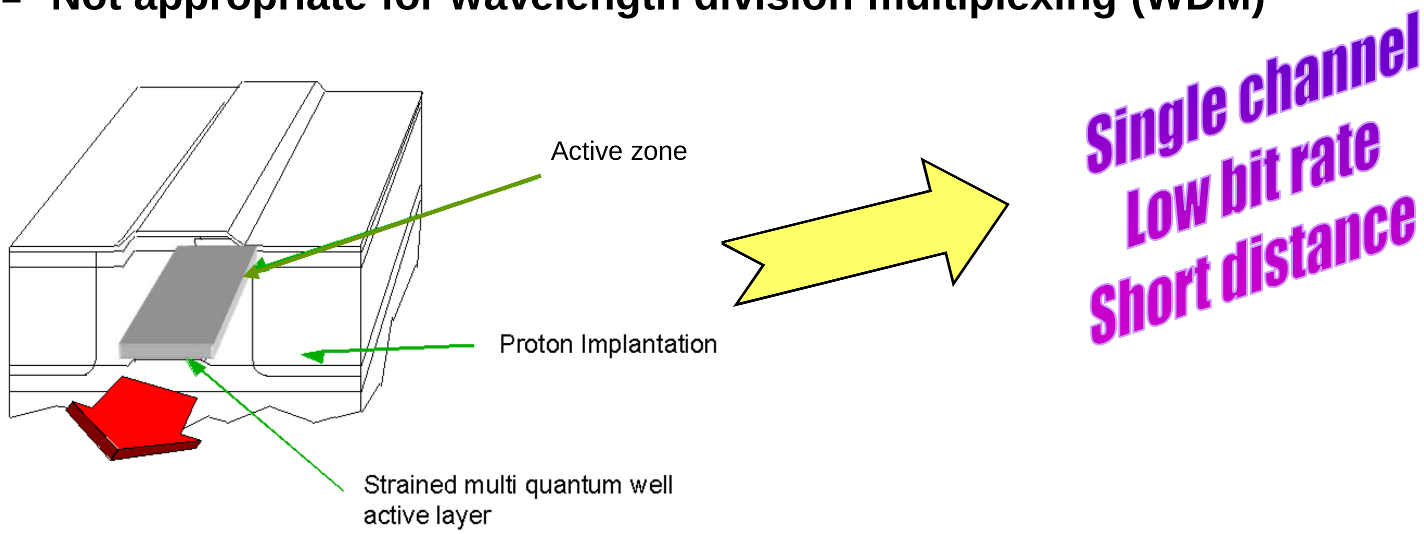
Laser diodes (1)

- **LASER = Light Amplification by Stimulated Emission of Radiation**
- **Laser = amplifying medium in a resonant cavity (Fabry-Perot)**
- **Semiconductor laser (or laser diode)**
  - Amplifying medium : diode type junction
  - Pumping technique : injection current
  - Resonant cavity : cleaved facets of the laser chip



Laser diodes (2)

- **Two categories of laser diodes (1)**
  - **FP : Fabry-Perot type laser diode**
    - **The most simple structure**
    - **Broad spectrum (multiple rays) => limitation due to chromatic dispersion**
    - **Used for short distance links**
    - **Not appropriate for wavelength division multiplexing (WDM)**

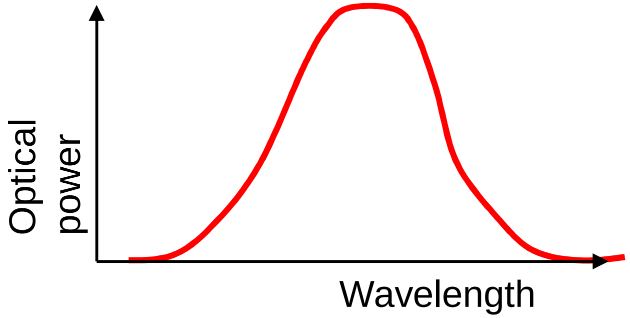


Laser diodes (3)

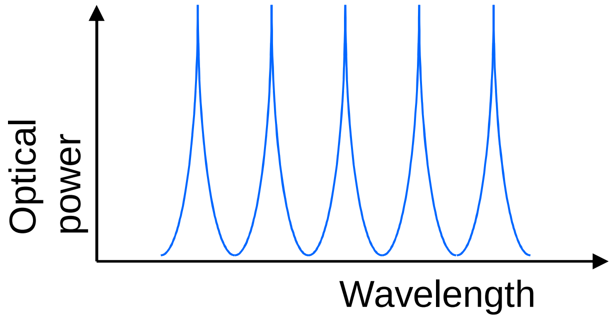
Fabry-Perot laser diode spectrum

Single channel
Low bit rate
Short distance

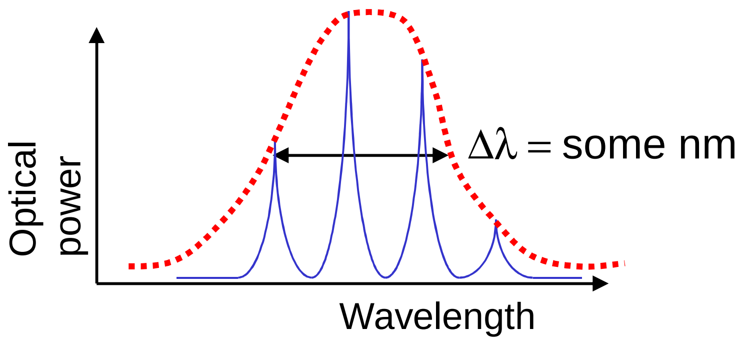
Active material gain curve



Fabry-Perot cavity spectrum (comb)

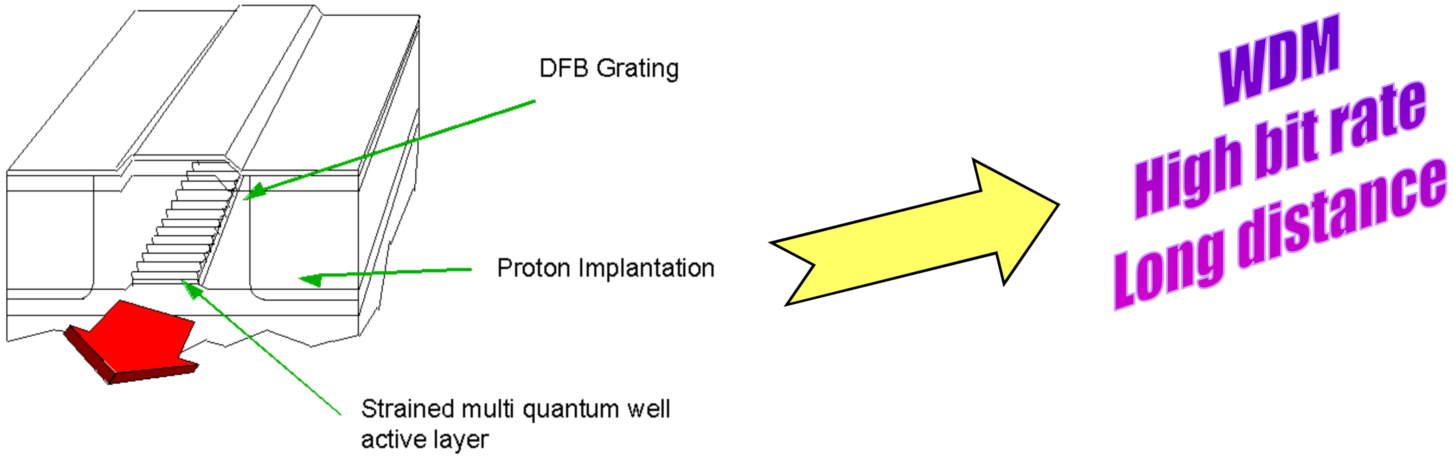


Fabry-Perot laser diode spectrum



Laser diodes (4)

- **Two categories of laser diodes (2)**
  - **DFB : Distributed Feed-Back laser diode**
    - **More complex structure (integrated diffraction grating)**
    - **Narrow spectrum (single longitudinal mode) ==> very low chromatic dispersion**
    - **Well suited to long haul links and to WDM systems**

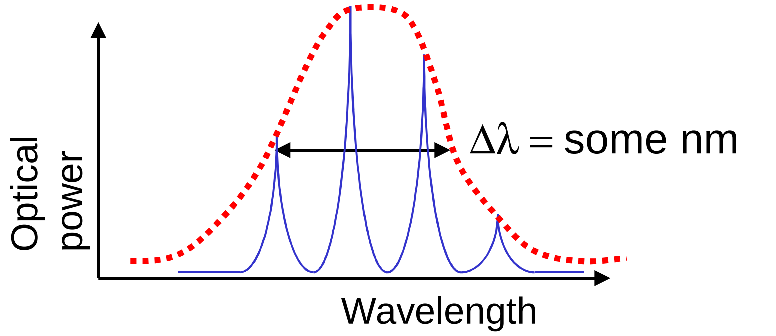


Laser diodes (5)

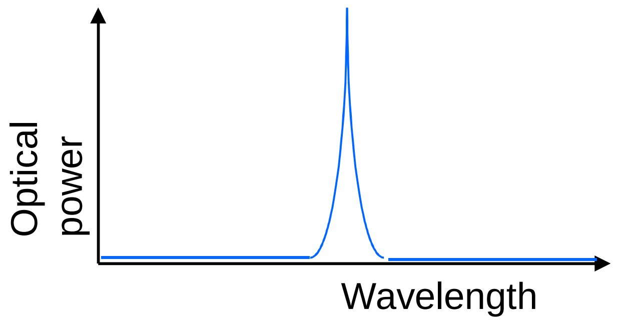
DFB laser diode spectrum

WDM
High bit rate
Long distance

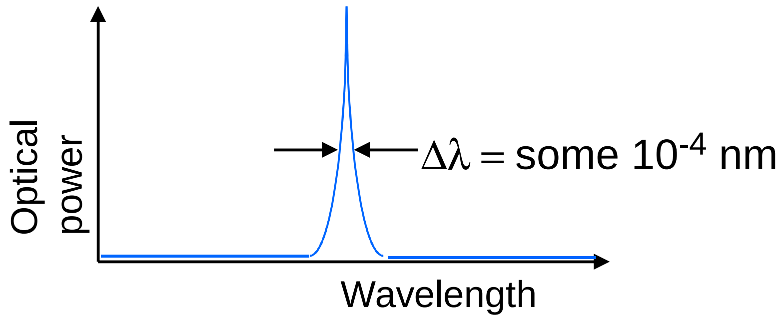
Fabry-Perot laser diode spectrum



Diffraction grating filtering

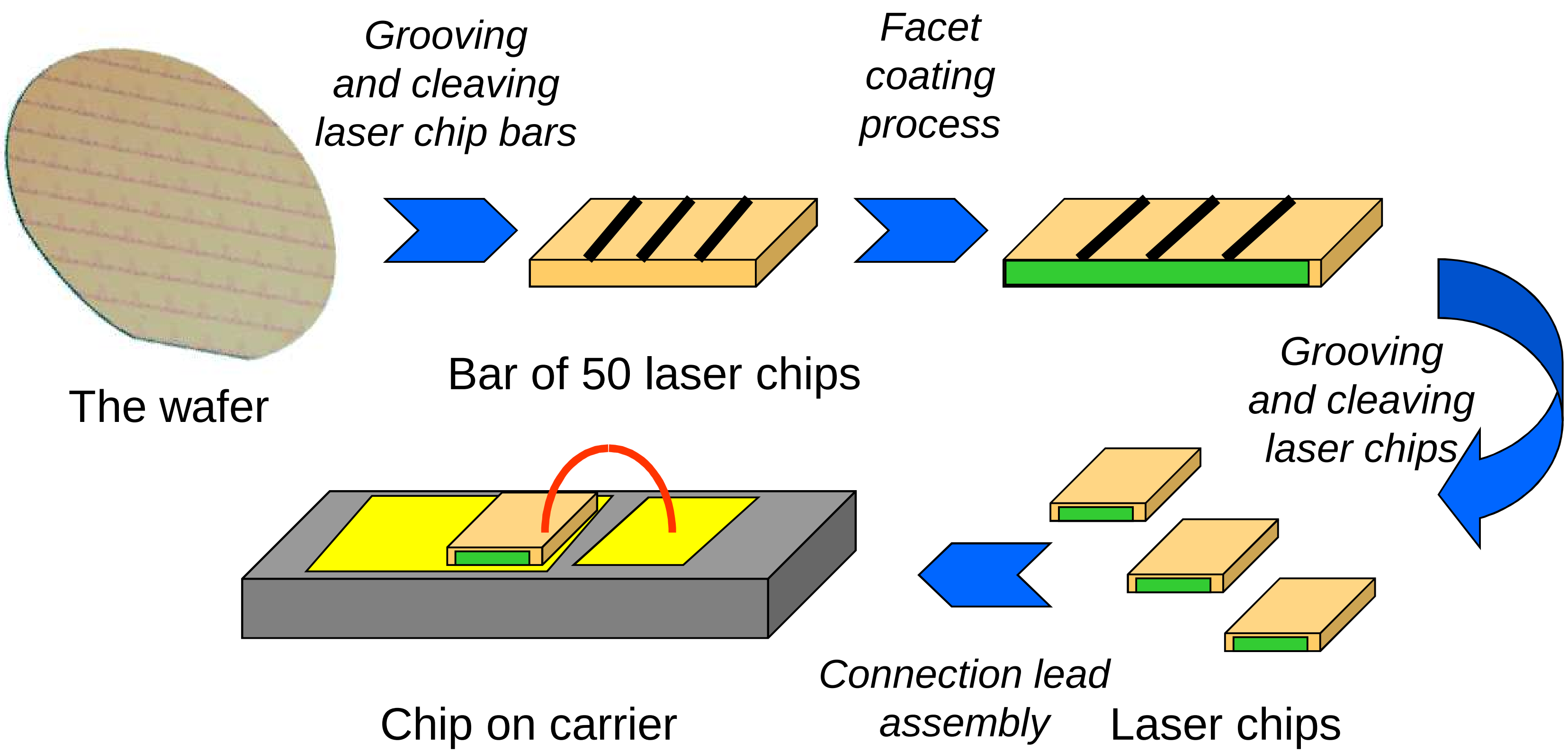


DFB laser diode spectrum



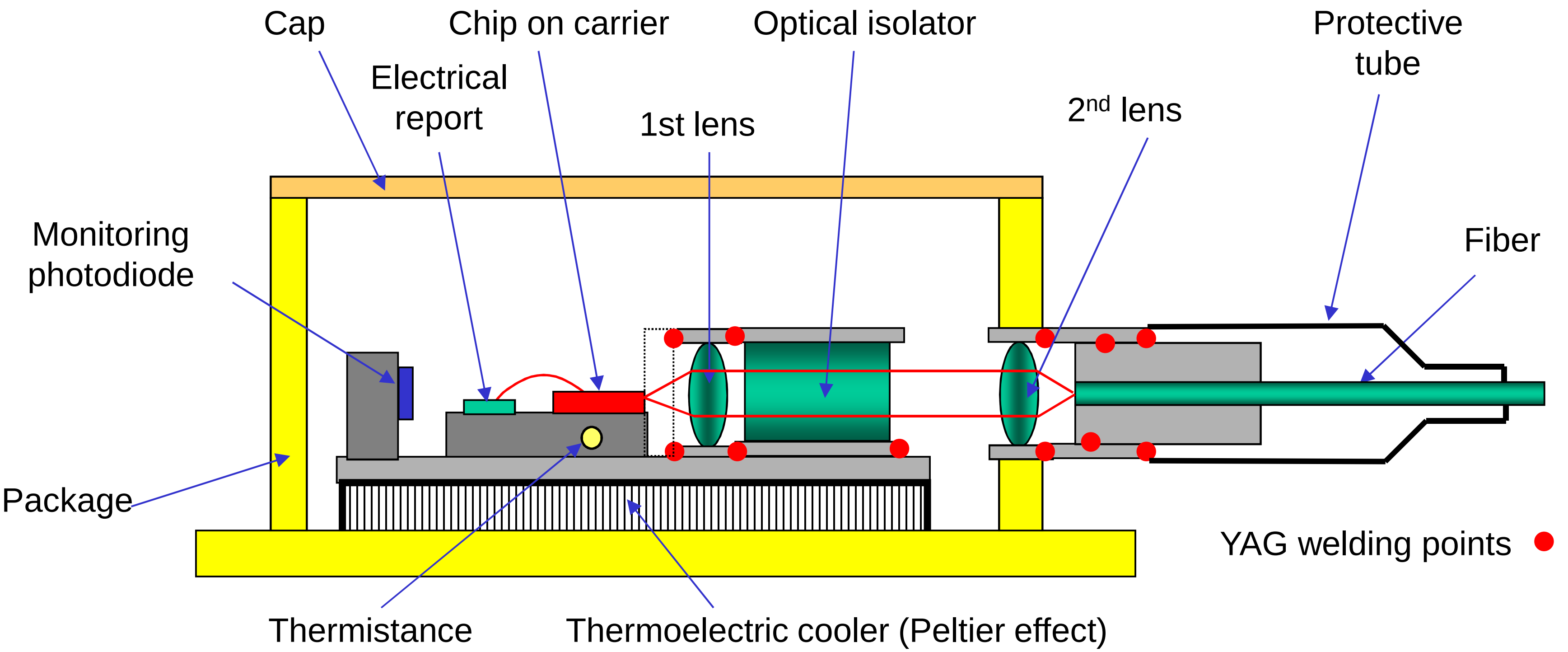
Laser diodes manufacturing

- **From the wafer to the chip-on-carrier (COC)**



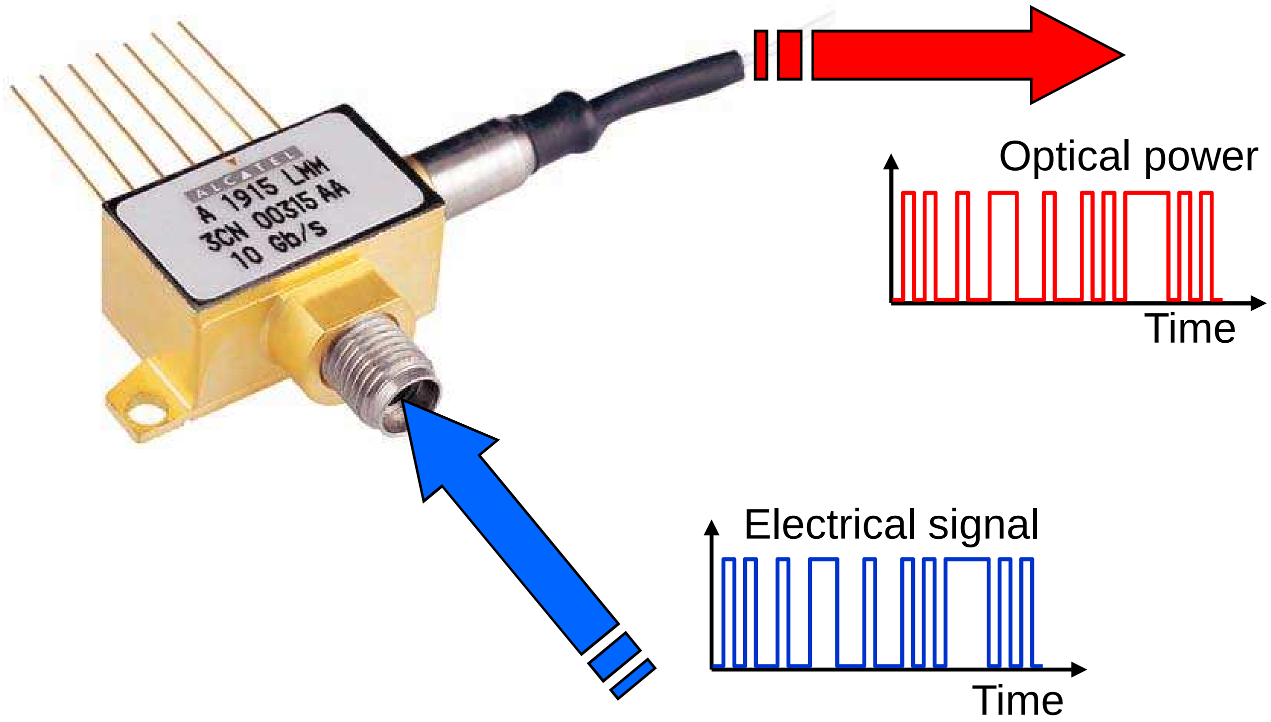
Laser diodes packaging

- Packaging of a transmitter module with an optical isolator



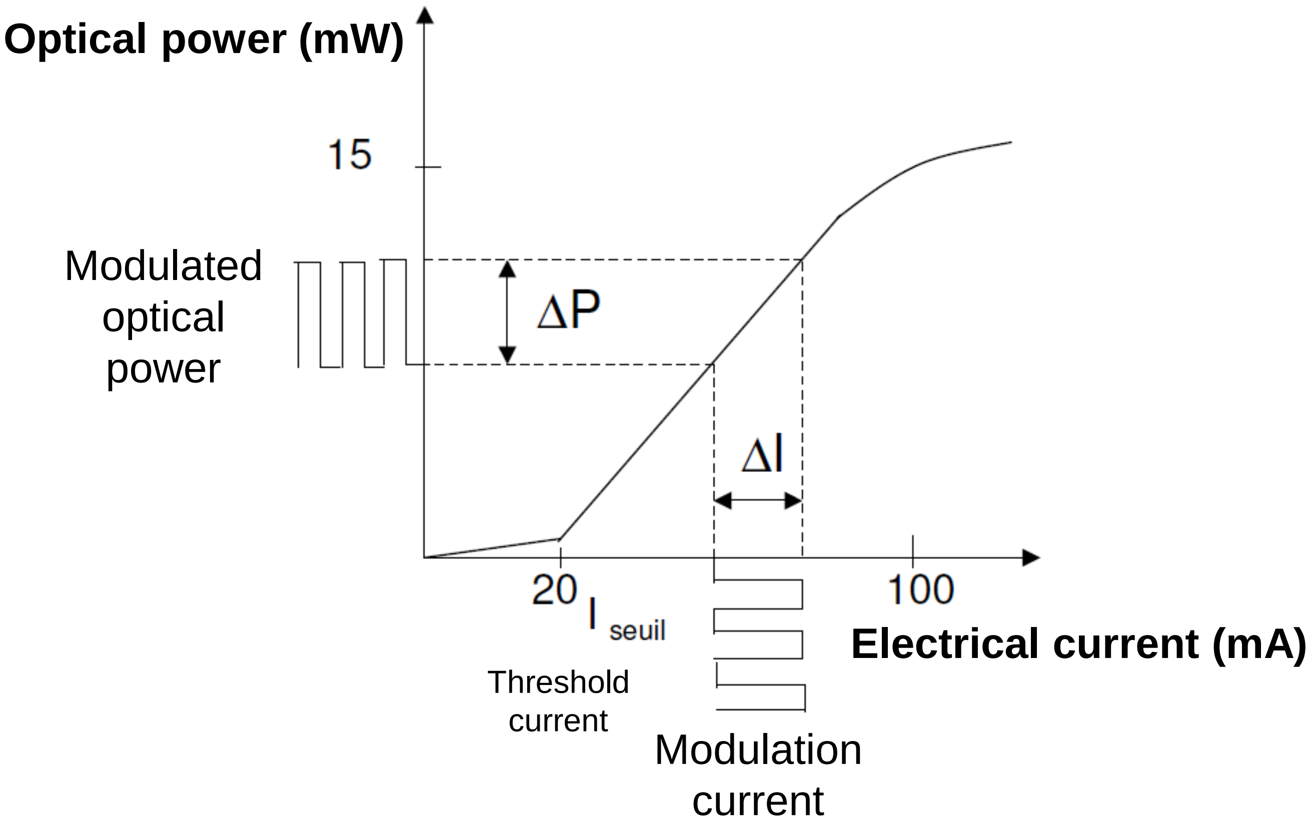
Laser diode modulation

- **Modulating an optical source**
  - **Transforming the electrical signal variation into an optical power variation**



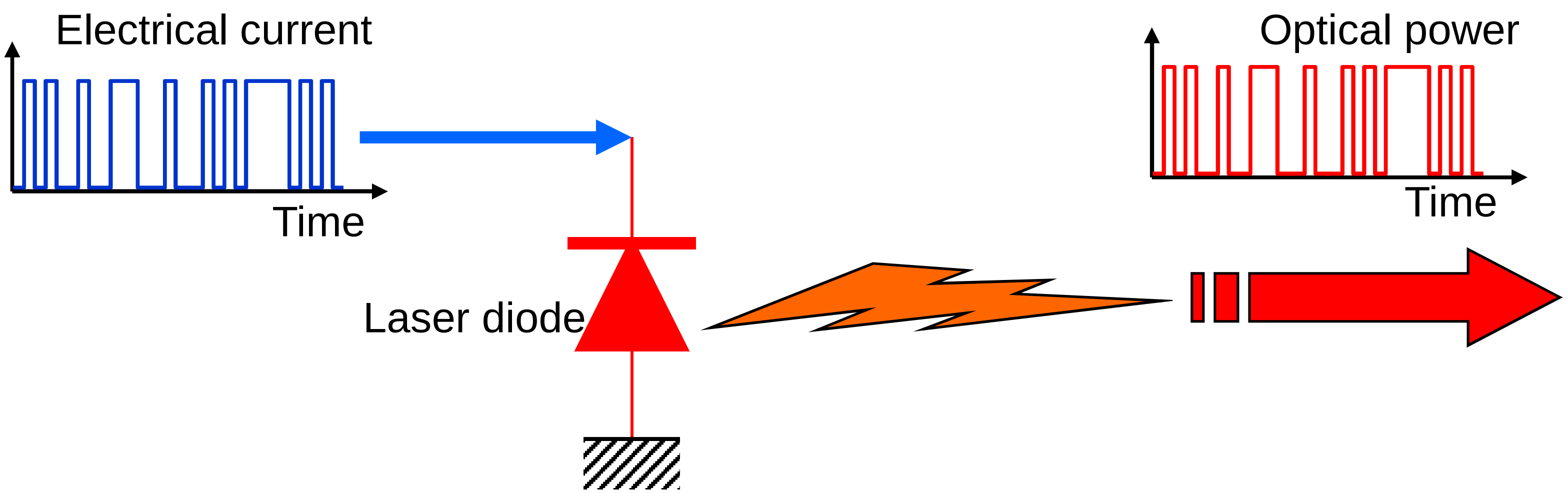
Transfer characteristics of a laser diode

- Optical power vs electrical current characteristics of a laser diode



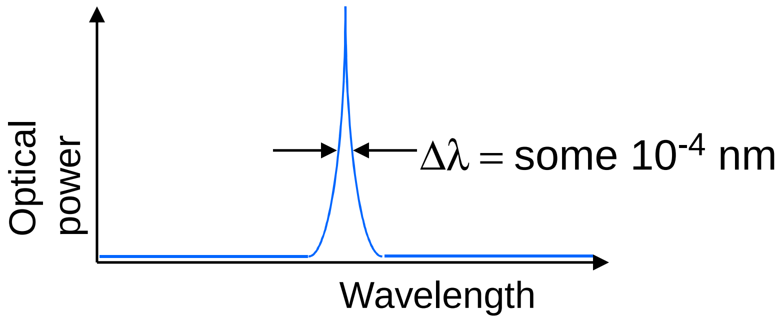
Direct modulation of a laser diode

- **Direct modulation (1)**
  - **The laser diode is directly modulated by an electrical current (injection current)**

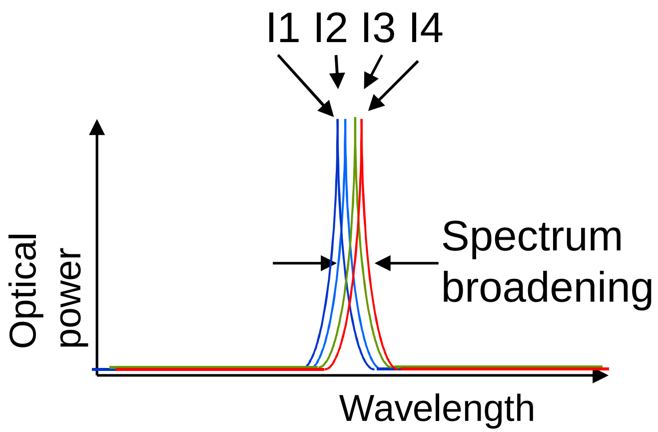


Direct modulation of a laser diode

- **Direct modulation (2)**
  - **Main problem inherent to direct modulation : the chirp**
  - **It is the optical frequency variation due to injection current modulation**
  - **The chirp induces laser diode spectrum broadening, which limits transmission distance due to a higher chromatic dispersion of the fiber**



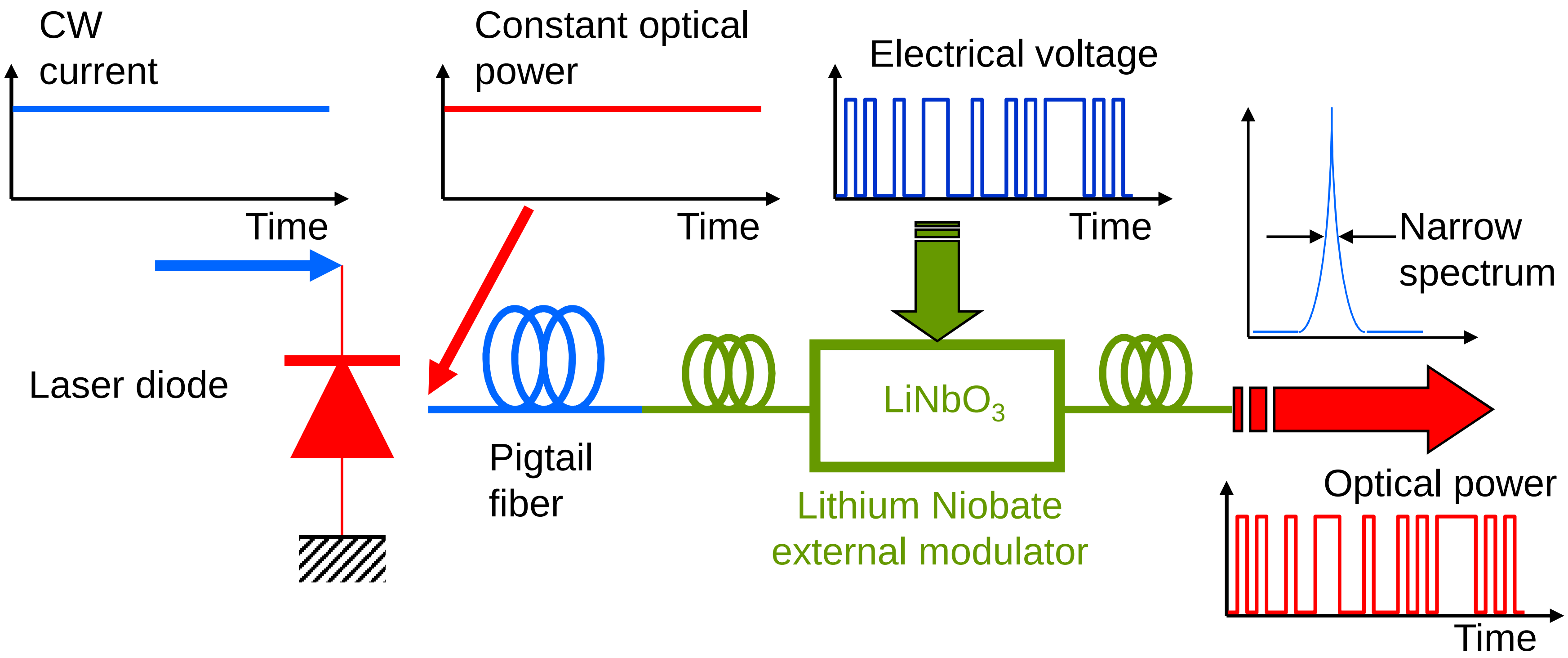
Constant modulating current
= CW spectrum => No chirp



Direct modulation = current variation
Spectrum broadening due to chirp

External modulation of a laser diode

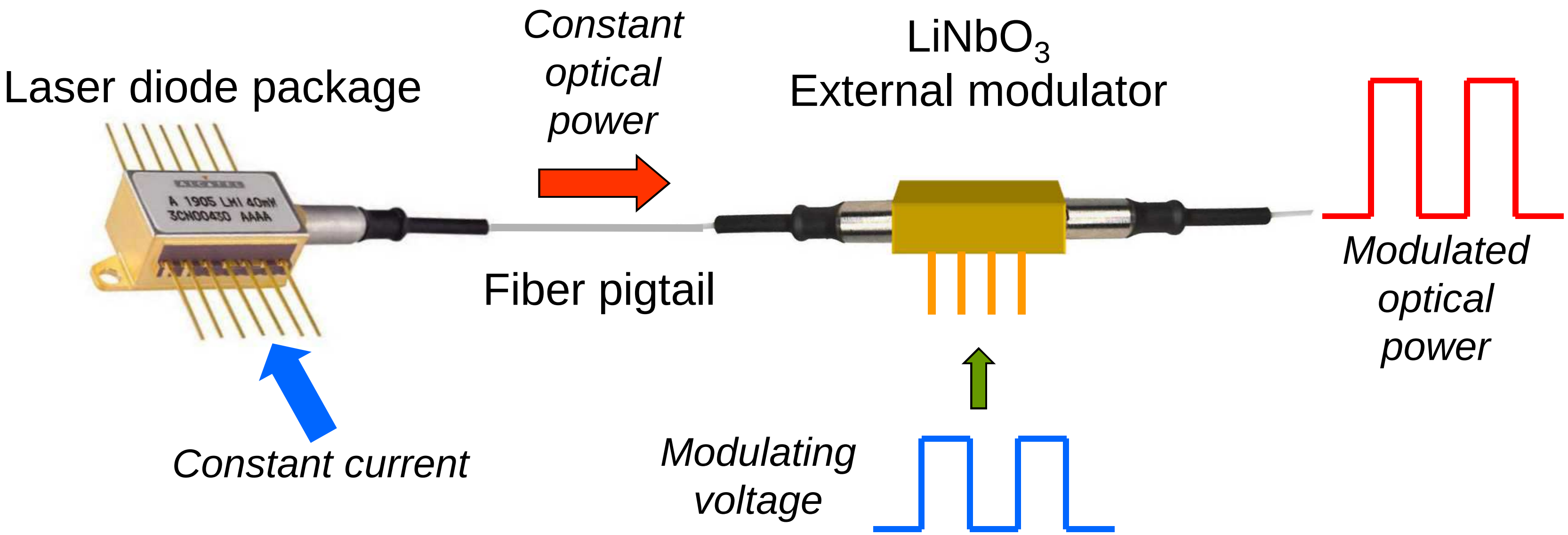
- **External modulation (1)**
  - **Modulation method to avoid laser diode chirp**
  - **Allows to significantly increase transmission distance**



External modulation of a laser diode

- **External modulation (2)**
  - **Two technologies of external modulation**
    1. **Use of an external modulator device separated from the laser diode (as Lithium Niobate modulator)**

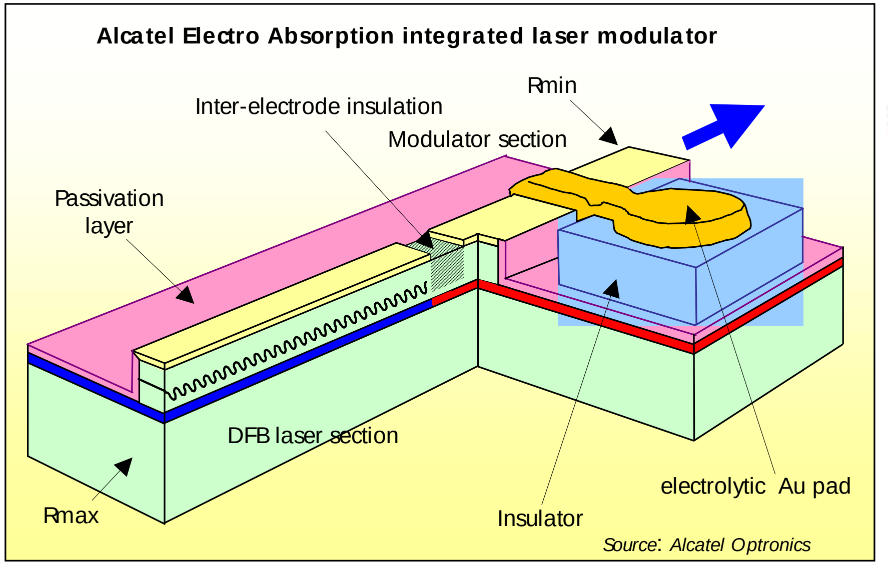
       - The laser diode is not directly modulated and provides a constant optical power entering the external modulator



- **External modulation (3)**
  - **Monolithic integration technology**

    2. Monolithic integration of the laser diode and the external modulator on the same substrate

    - The external modulator is usually an Electro-Absorption (EA) modulator
    - Its absorption coefficient is depending on the modulation voltage
    - This kind of modulator shows a low chirp limiting transmission distance

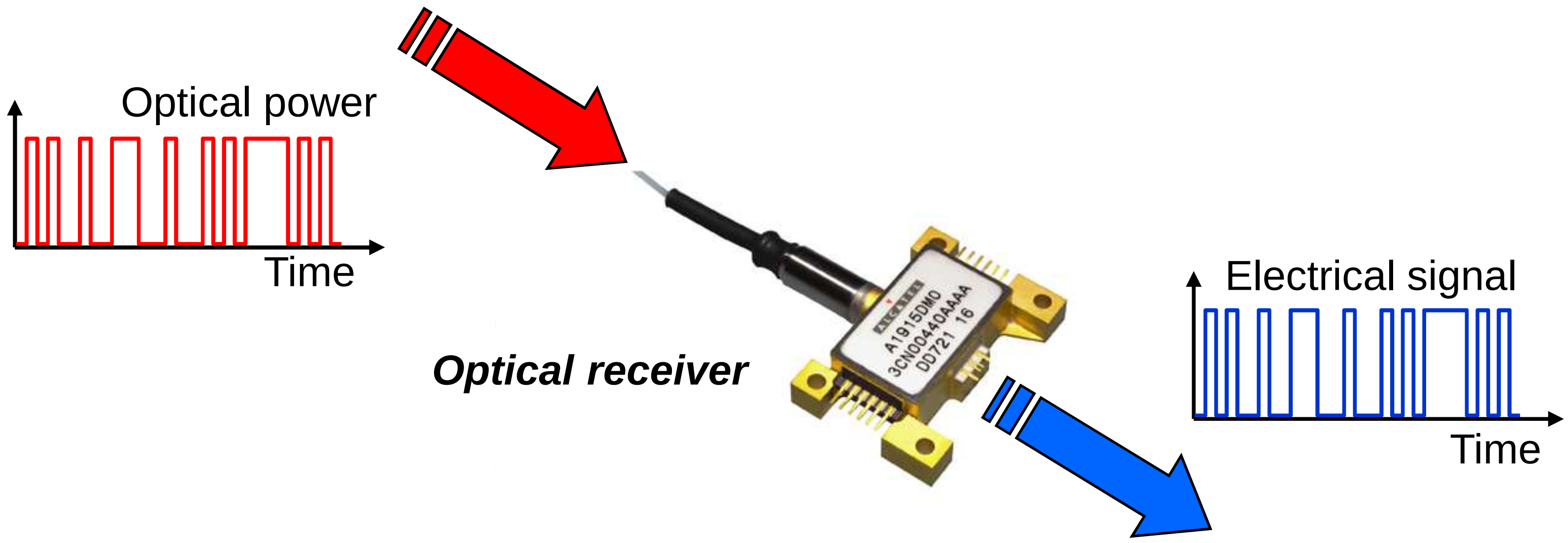


Comparison of laser diode modulations

- **Comparison of the three technologies**
  - **Direct modulation by the injection current :**
    - **Used for bit rates up to 2.5 Gbit/s**
    - **Maximum transmission distance : 90 km (1800 ps/nm source)**
  - **External modulation with separated laser diode and $LiNbO_3$ external modulator :**
    - **Use for very high bit rates up to 40 Gbit/s**
    - **Almost illimited transmission distance (transoceanic systems)**
  - **Integrated laser-modulator (ILM) :**
    - **Used for medium bit rates (2.5 Gbit/s or 10 Gbit/s)**
    - **Transmission distance limited by the proper chirp of the EA modulator**
      - At 2.5 Gbit/s : from 360 km (7200 ps/nm) to 640 km (12800 ps/nm)
      - At 10 Gbit/s : from 40 km (800 ps/nm) to 80 km (1600 ps/nm)

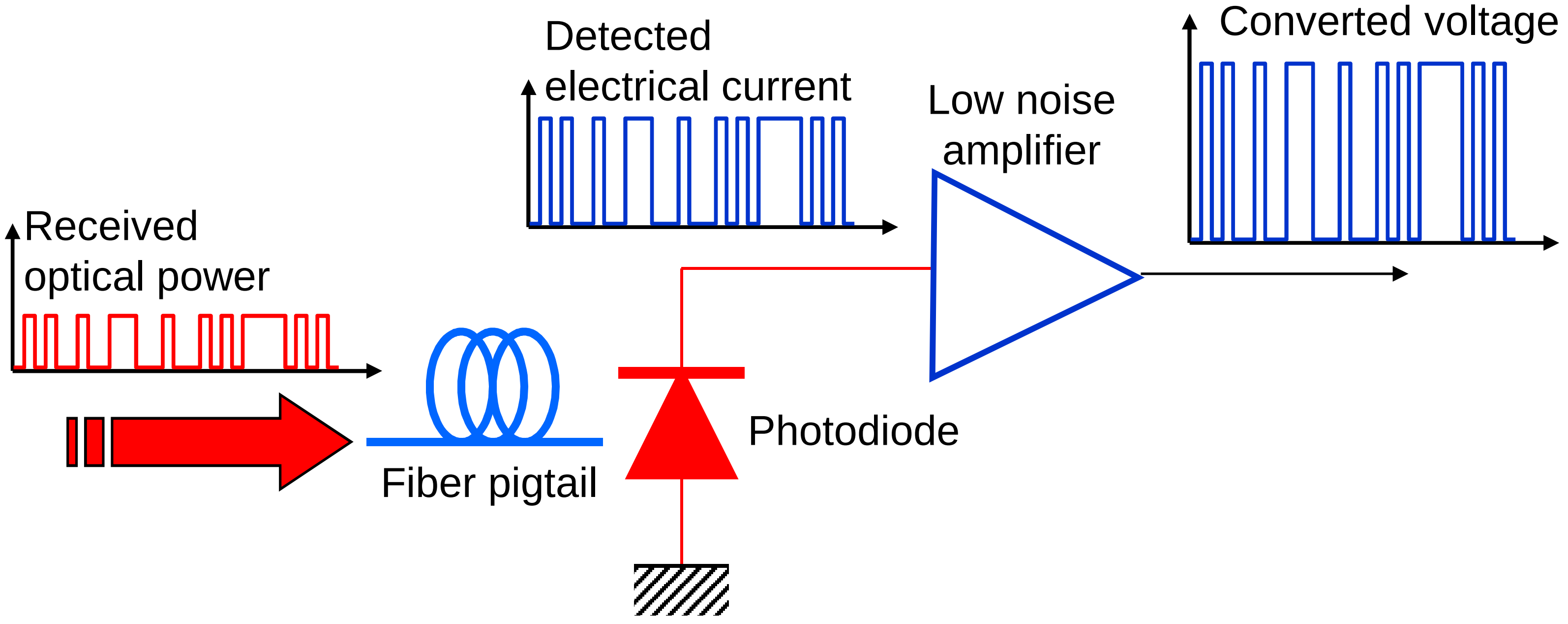
Detectors and optical receivers

- **The optical receiver transforms the modulated optical power detected into a modulated electrical signal**
- **It consists of an optical detector (photodiode) followed by electrical circuits processing the detected signal**



Optical detectors : photodiodes

- **A photodiode transforms the optical power received into an electrical current (photocurrent)**
- **This signal is electrically amplified (low noise amplifier) and then processed. This function is realized by the optical receiver (photodiode followed by processing circuits)**

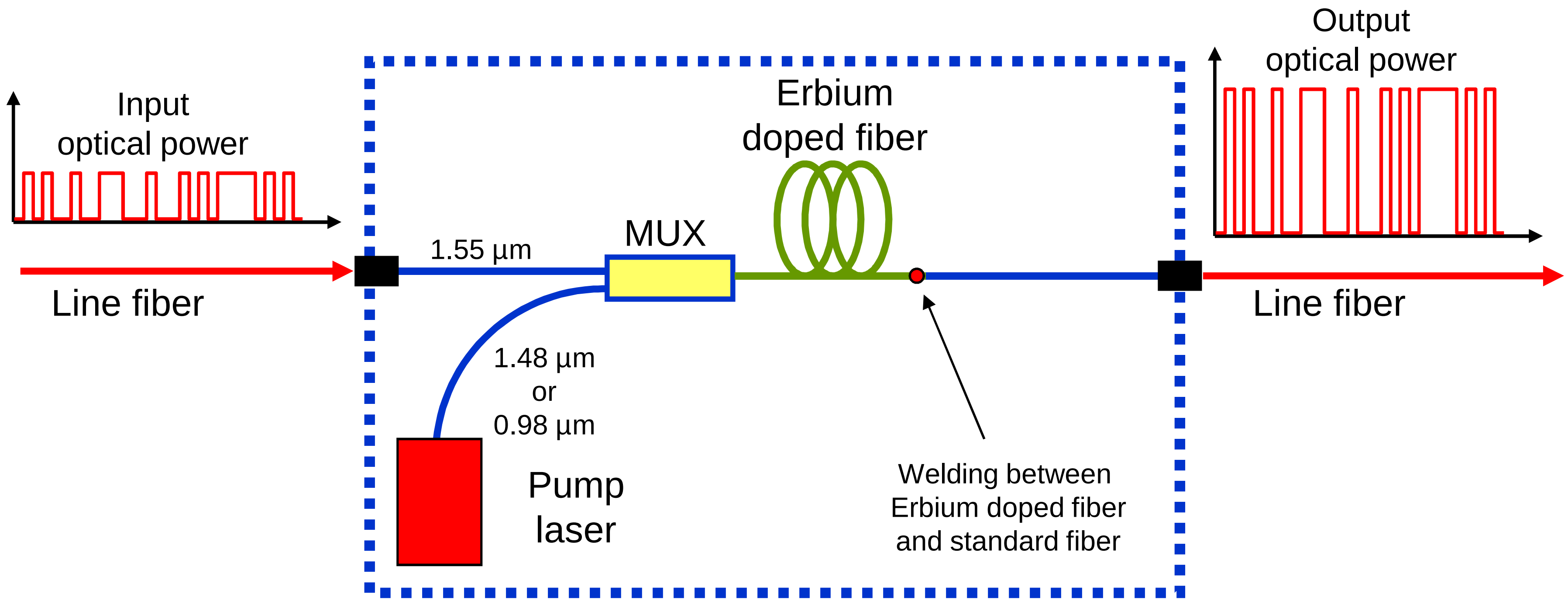


Types of photodiodes

- **Two main types of photodiodes**
  - **PIN photodiode (Positive-Intrinsic-Negative)**
    - Simple structure easy to implement
    - Used for very high bit rates (up to 40 Gbit/s)
  - **Avalanche photodiode (APD)**
    - More complex structure
    - Requires a high driving voltage
    - Allows to generate a higher detected current
    - Better sensitivity for detecting low levels of received optical power (long distance systems)
    - Used for bit rates up to around 10 Gbit/s

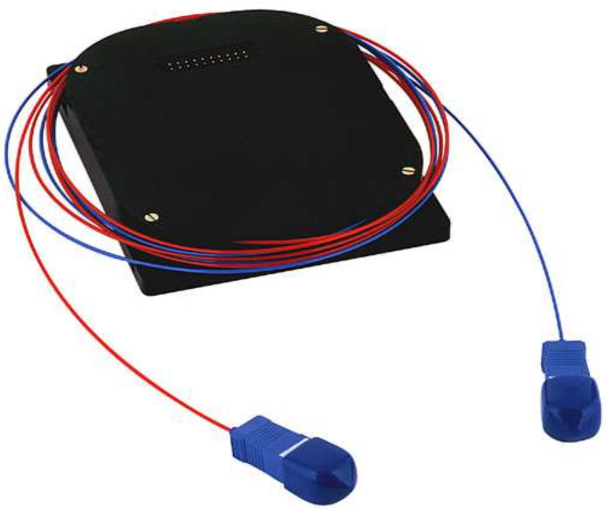
Optical Fiber Amplifiers (OFA)

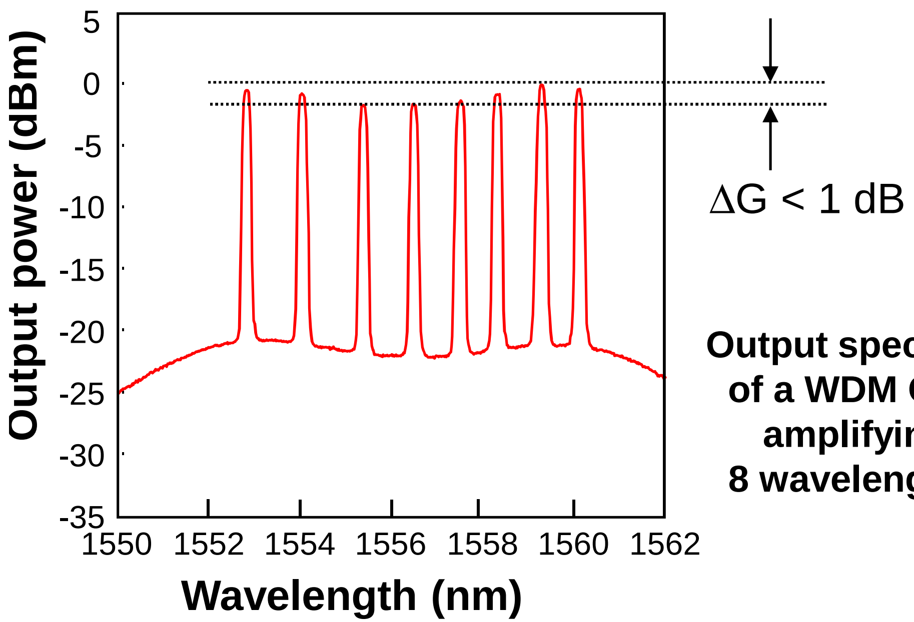
- Principle of the Erbium doped fiber amplifier (EDFA)
- Direct amplification of the optical power by energy transfer from pump wave to signal wave



OFAs for WDM application

- Specific characteristics of WDM OFAs
  - Requires a good flatness of gain spectrum
  - Need for a double stage structure with mid-stage access for add-drop multiplexing (ADM) application or for inserting a dispersion compensating fiber (DCF)

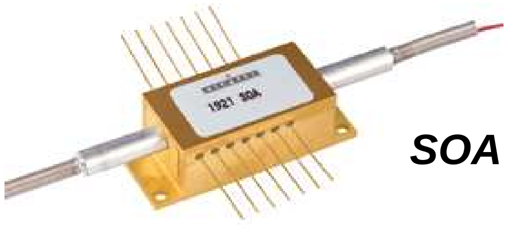




Output spectrum of a WDM OFA amplifying 8 wavelengths

Components for optical routing

- These components will be used in node equipments of future all optical networks
  - Optical routing requires basic functions as :
    - Optical switching (non-blocking switching matrices)
    - Wavelength conversion
  - These functions can be realized using the following technologies :
    - Semiconductor optical amplifier (SOA) for fast switching
    - Interferometric wavelength converter module (ICM) for wavelength conversion

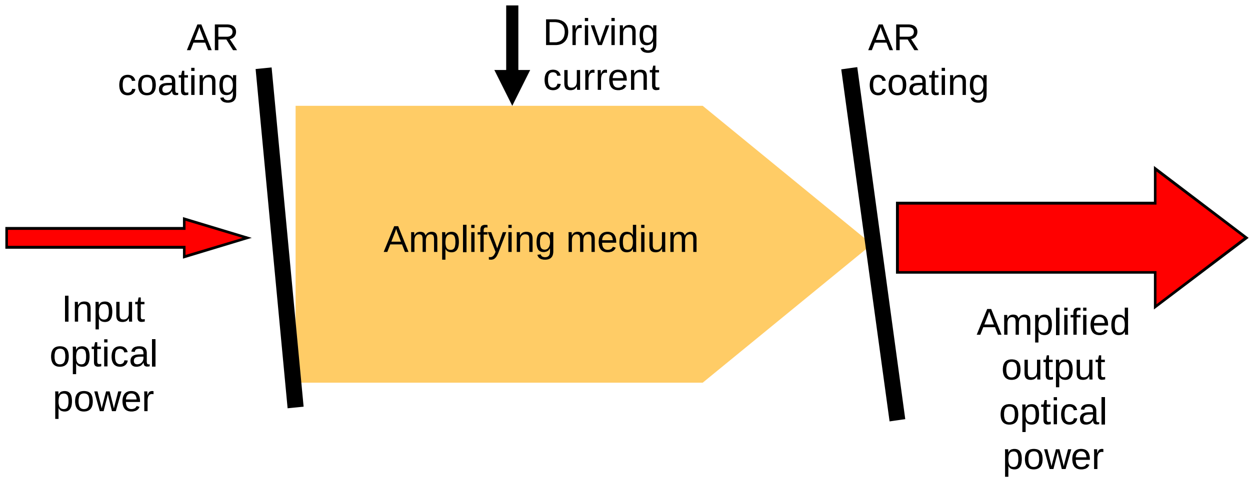


SOA

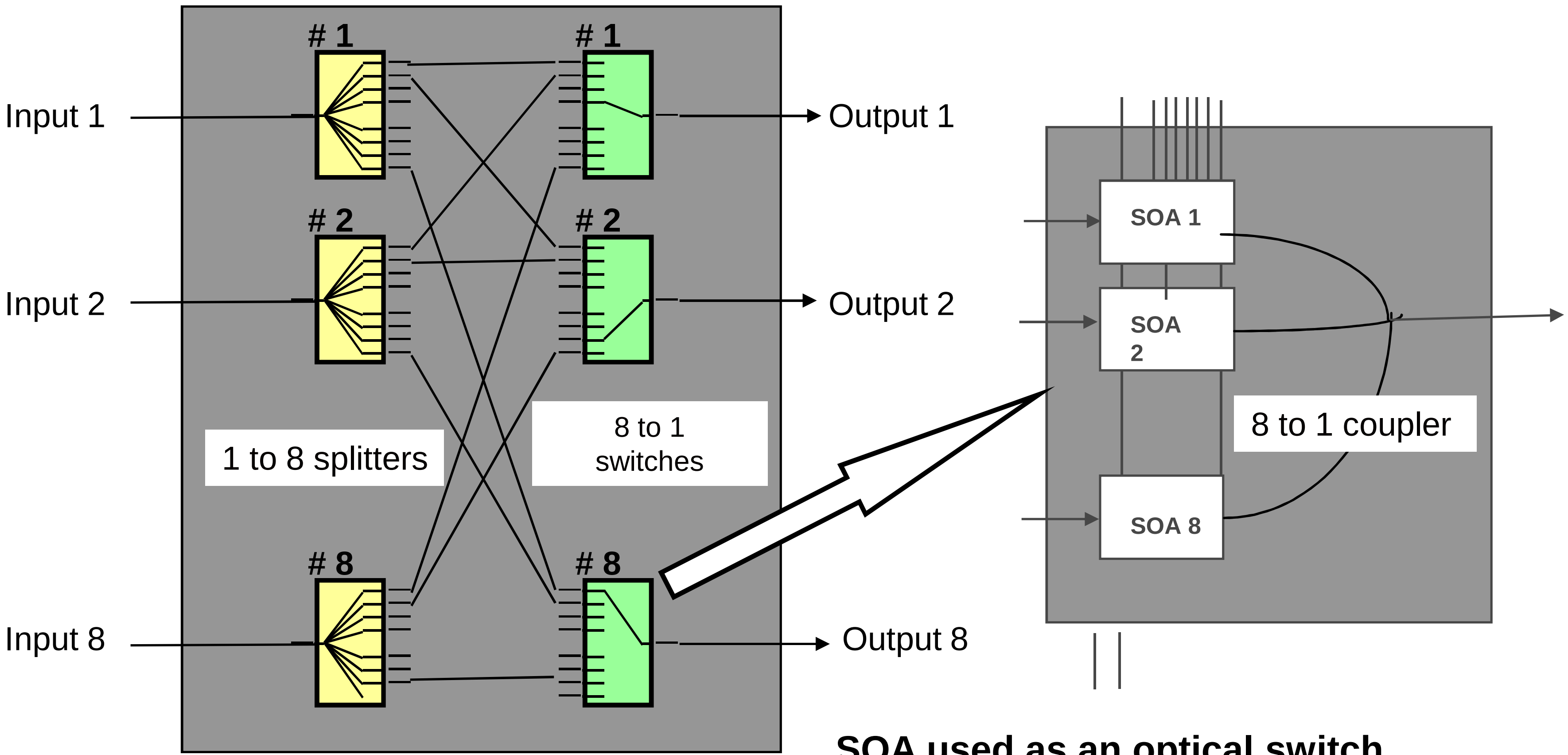
ICM

♦ SOA = Semiconductor Optical Amplifier

- **Structure**
  - Similar structure as for the semiconductor laser diode
  - Suppression of the resonant FP cavity through anti-reflection coating and angled cleaving the two facets of the chip
- **Quaternary amplifying medium : InGaAsP**
  - For amplification in the 1.55 µm range



Optical switching using SOA bars



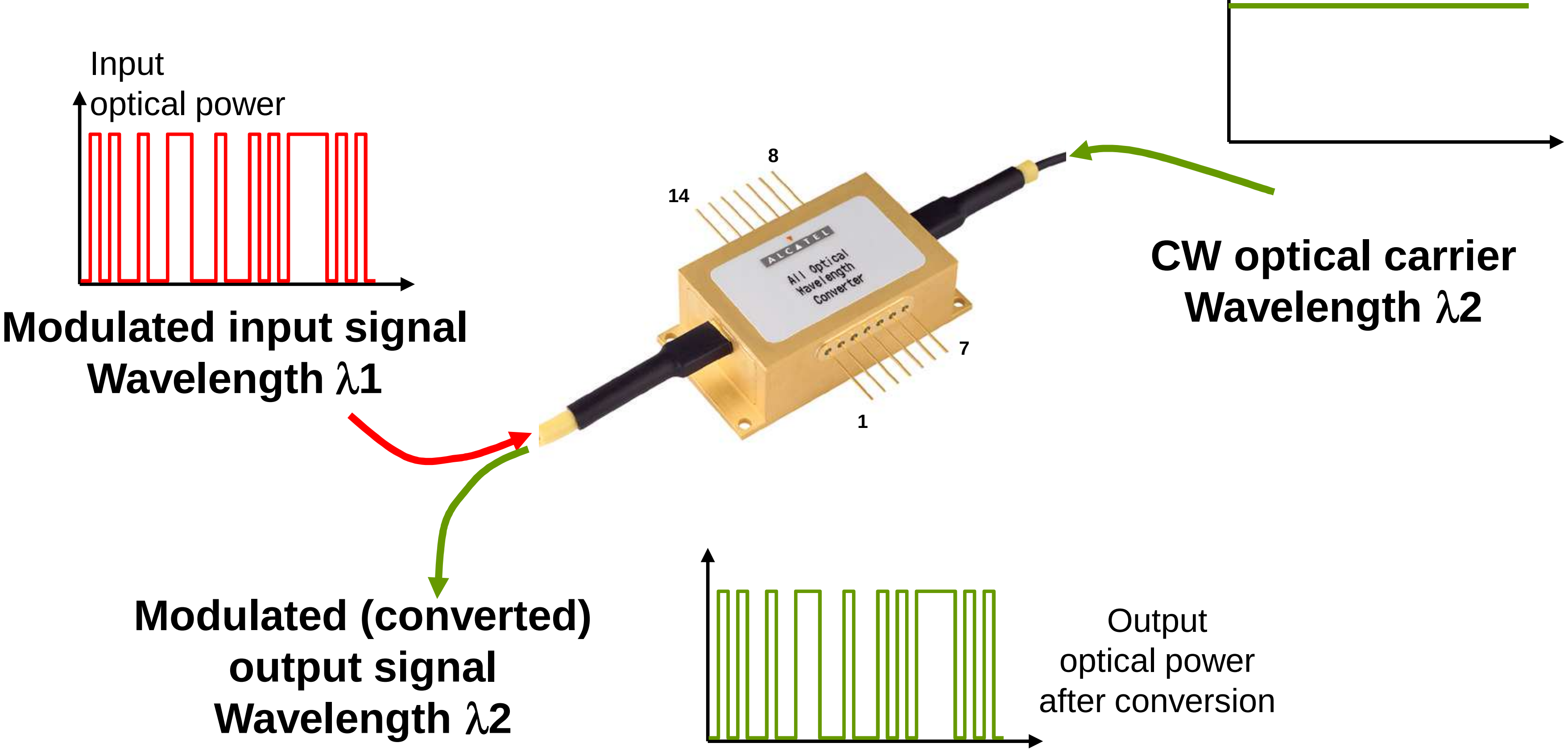
8 X 8 switching matrix
Possible extension up to 64 x 64

SOA used as an optical switch

- No switching loss due to SOA gain
- High speed switching time (some 10 ps)

Wavelength conversion

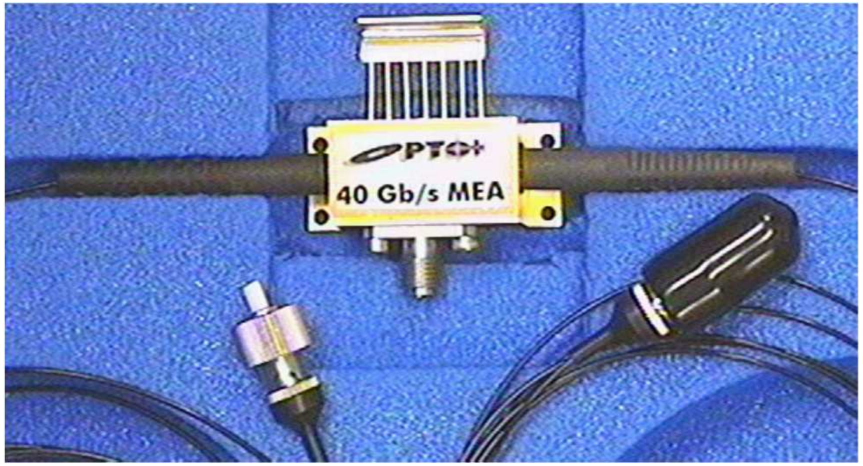
- **The interferometric converter module (ICM)**



Components for very high bit rate applications

- **Components dedicated to future 40 Gbit/s applications**
  - SDH standard : STM-256 frame
  - SONET standard : OC-768 frame
- **Electroabsorption (EA) modulator**
- **Integrated PIN-preamp receiver**
- **In the near future : integrated laser-modulator (ILM) source**

EA modulator for 40 Gbit/s applications

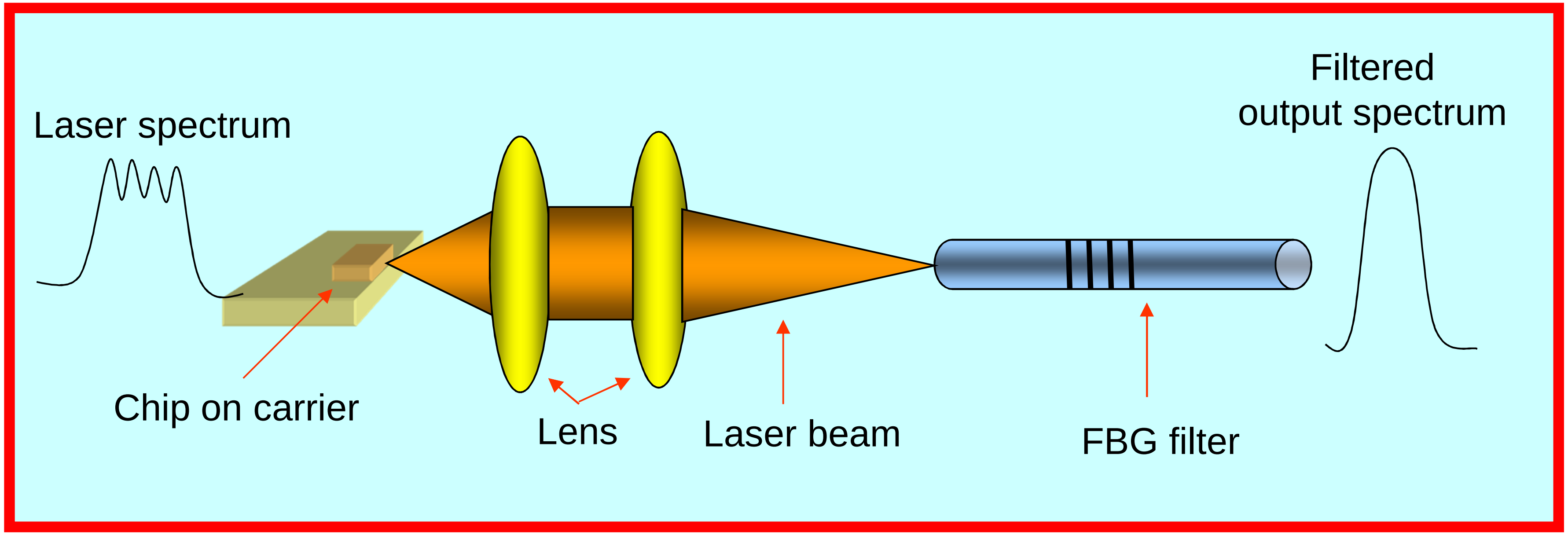


Passive components (1)

- **Passive components do not require any electrical energy for working**
- **Two specific technologies allow to realize passive components :**
  - **FBG (Fiber Bragg Grating) technology**
    - **Bragg grating made in a silica fiber**
    - **Used to realize compact optical filters**
      - Gain flattening filters for OFAs
      - Wavelength stabilizing filters for pump lasers
      - Band-pass filters for WDM application
  - **AWG (Arrayed Waveguide Grating) technology**
    - **Waveguide gratings made in silica-on-silicon platforms**
    - **Used for realizing wavelength MUX and DEMUX**

Passive components (2)

- **Example of use of a FBG filter as a band-pass filter**



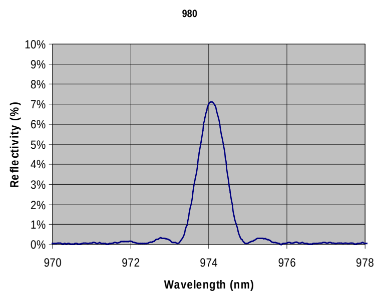
Passive components (3)

Mux/Demux

- Arrayed Waveguide Grating
- Silica on silicon based
- 16x100GHz, 40x50GHz or 40x100GHz channels
- Low input to output loss

Pump stabilizer

- FBG technology
- 1480 nm or 980 nm pump

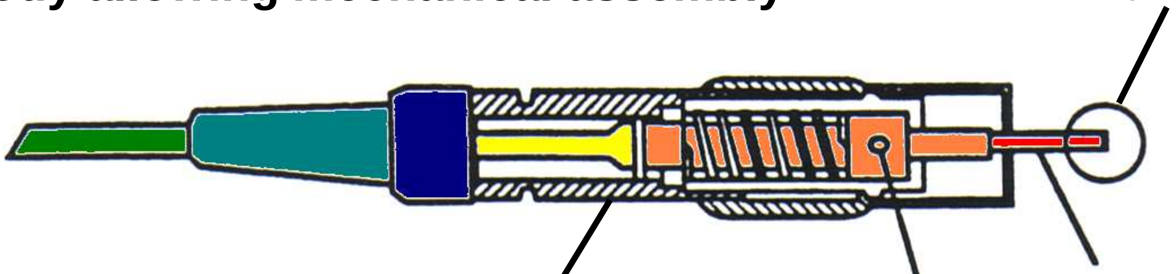


Wavelength filters

- FBG technology
- Band-pass filters
- ADM filters
- Gain flattening filters

Optical connectors (1)

- **An optical connector is used for a non-permanent assembly**
- **It consists in two main parts :**
  - **A ferule for placing and maintaining the fiber**
  - **A body allowing mechanical assembly**



- **Two types of ferules**
  - **Defined by the quality of the optical polished surface :**
    - PC (Physical Contact) : hemispheric polishing
    - APC (Angled-PC) : angled (around 7°) hemispheric polishing

Optical connectors (2)

- **Main types of optical connectors**
  - FC (field connector) with screw and positioning key : the most common
  - SC (subscriber connector) : push-pull type with plastic body
  - ST (standard connector) : with positioning key
  - E2000 : European connector with plastic body
  - MU : push-pull type miniature connector
  - LC (low cost) : small connector with plastic body

- **Main characteristics**
  - Insertion loss (or assembly loss) : < 0.5 dB
  - Return loss (or reflection loss) : < -50 dB (PC), < -60 dB (APC)

Main types of optical connectors