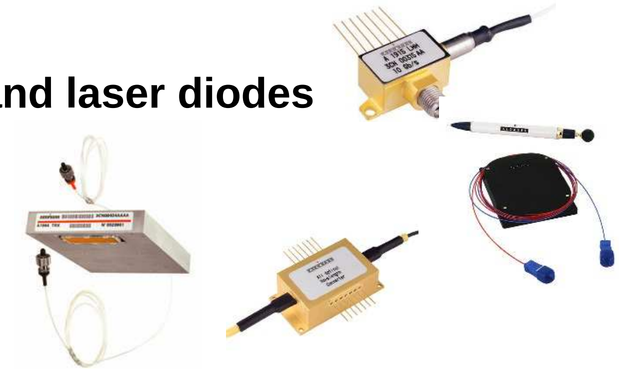
Part 2
Optoelectronic Components

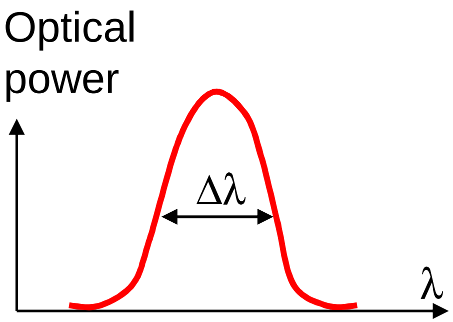
- ♦ **Optical components and product families**
  - **Active optical components**
    - **Light sources : light emitting diodes and laser diodes**
    - **Detectors and optical receivers**
    - **Optical amplifiers**
    - **Components for the optical routing**



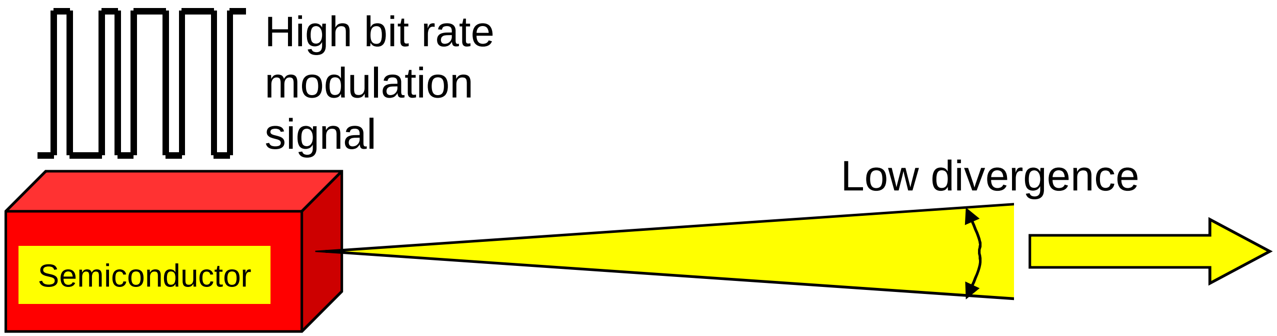
  - **Passive optical components**
    - **The FBG technology**
    - **Components realized using the FBG technology**
    - **The AWG technology and associated components**
    - **Optical connectors**

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**



Source spectrum



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

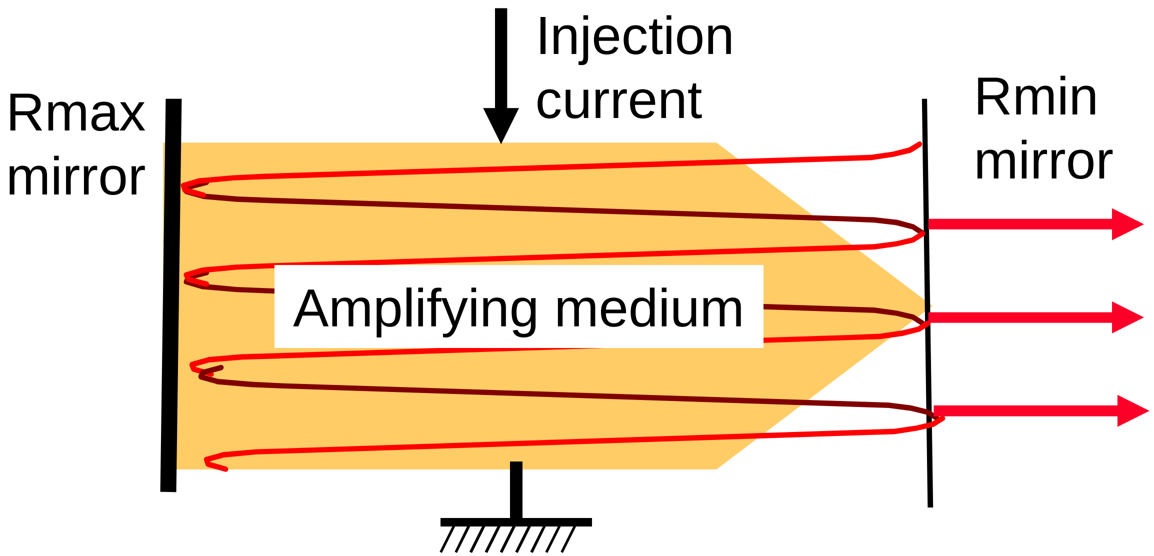
Examples :

+ 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

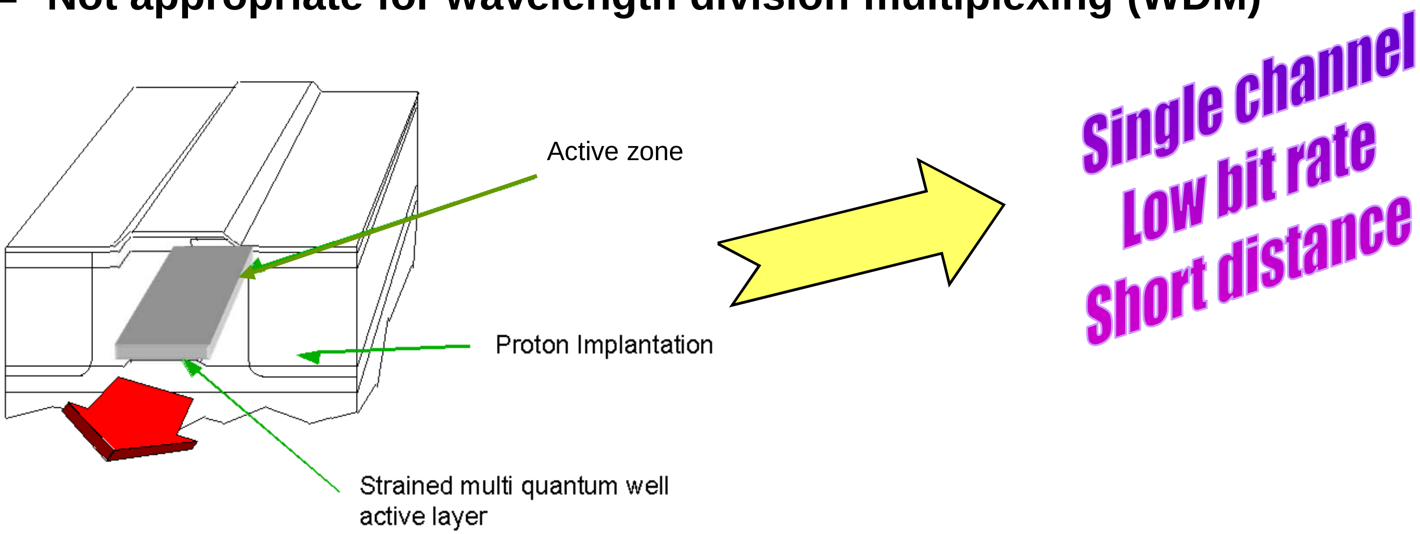
Laser diodes (1)

- **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)

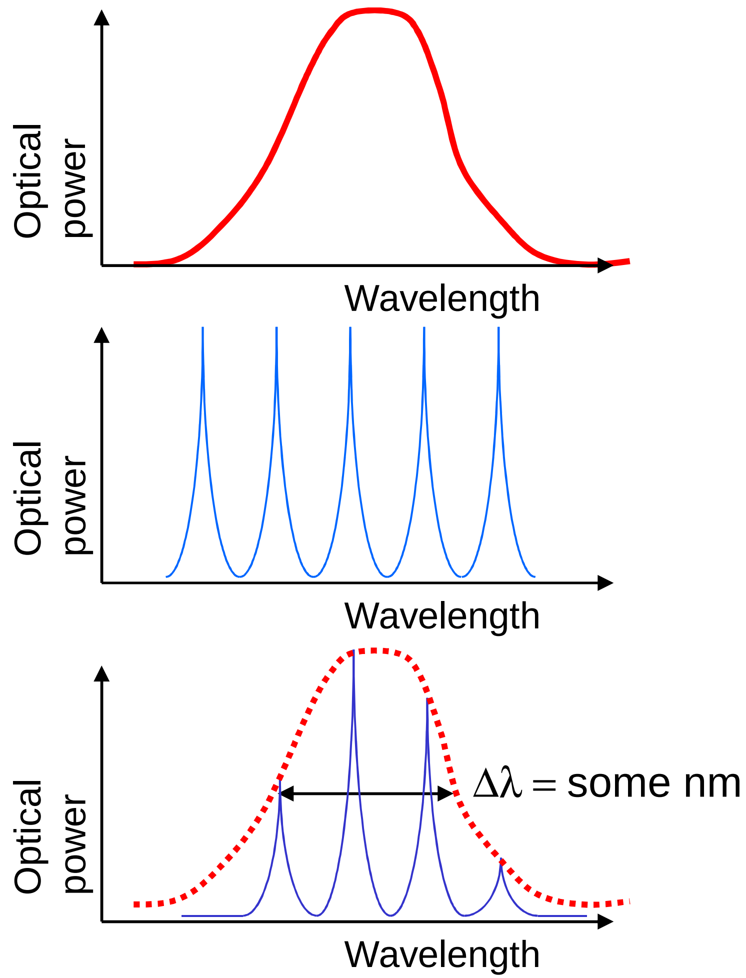
Fabry-Perot laser diode spectrum

Single channel
Low bit rate
Short distance

Active material gain curve

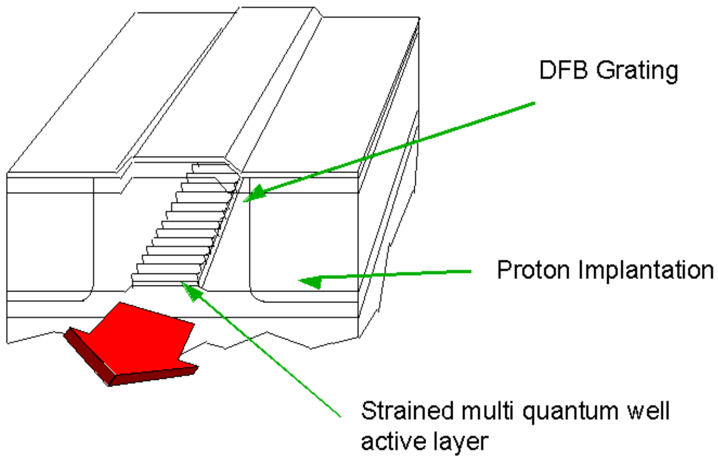
Fabry-Perot cavity spectrum (comb)

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**



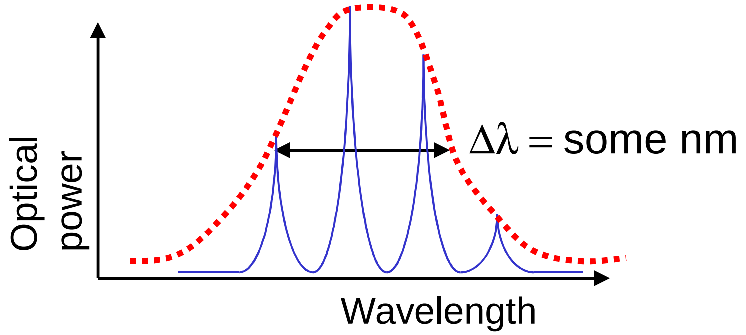
WDM
High bit rate
Long distance

Laser diodes (5)

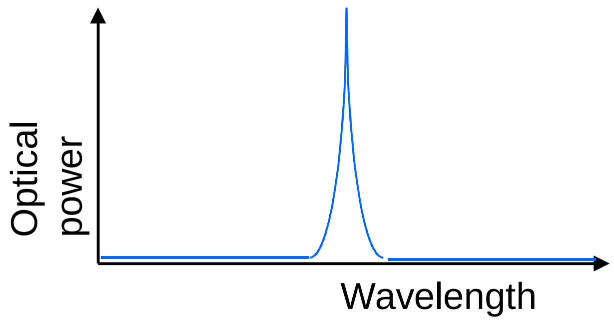
DFB laser diode spectrum

WDM
High bit rate
Long distance

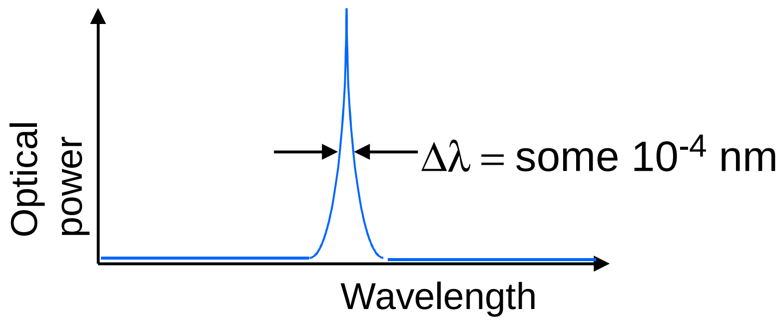
Fabry-Perot laser diode spectrum



Diffraction grating filtering

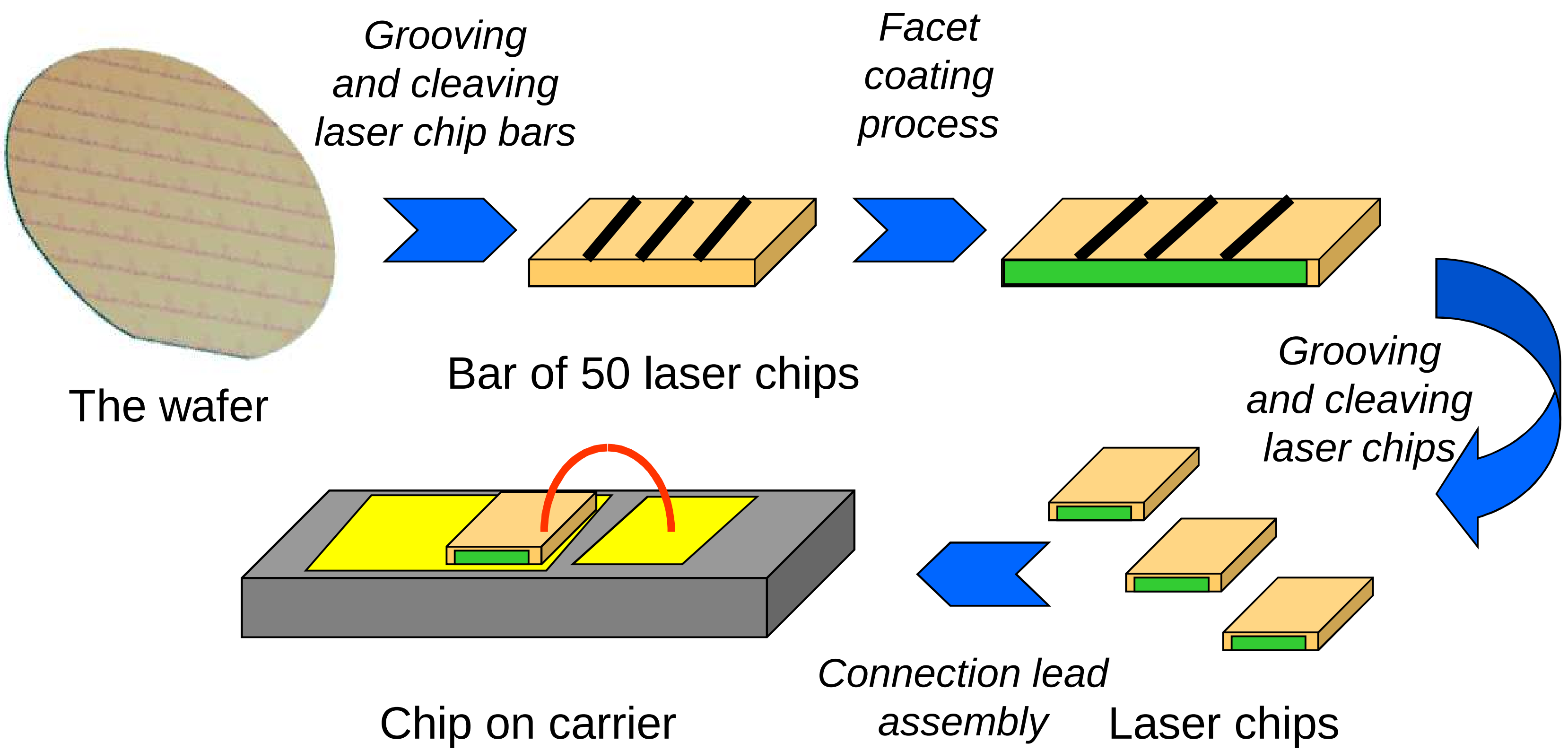


DFB laser diode spectrum



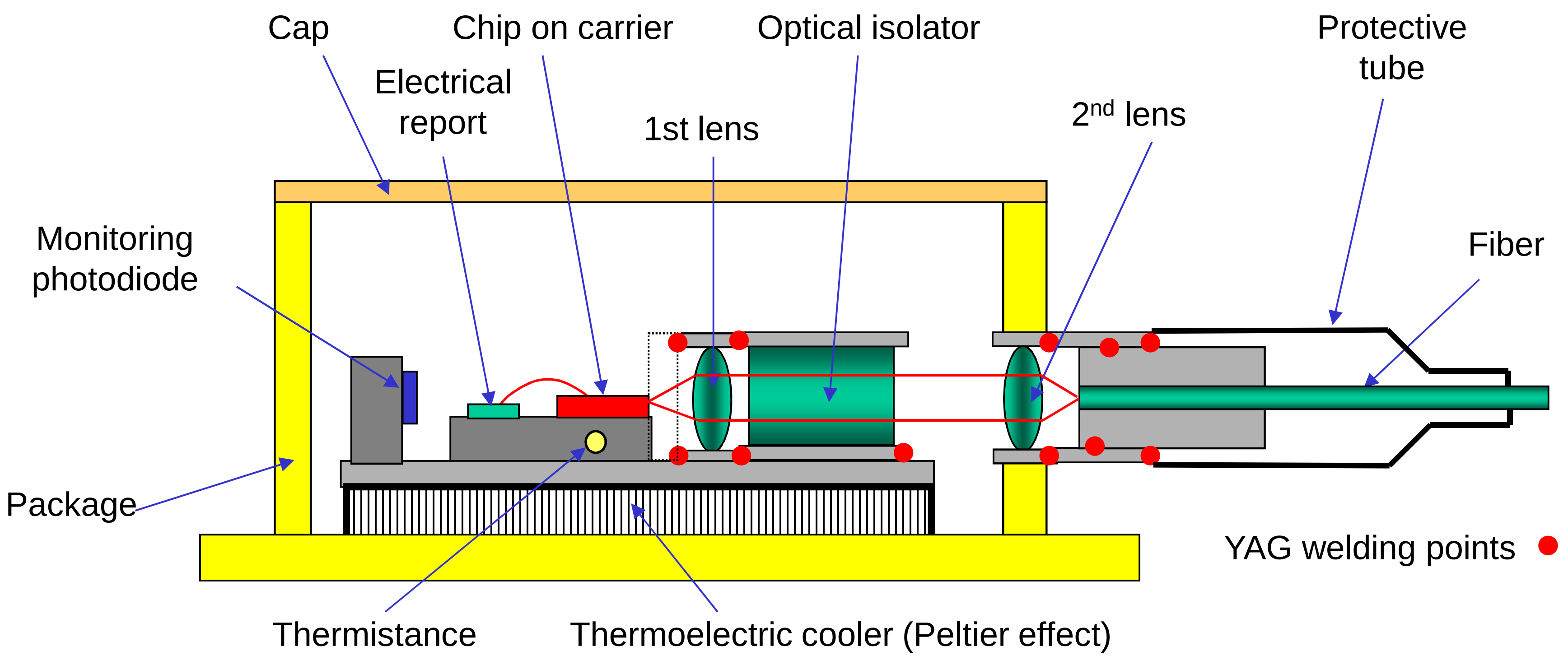
Laser diodes manufacturing

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



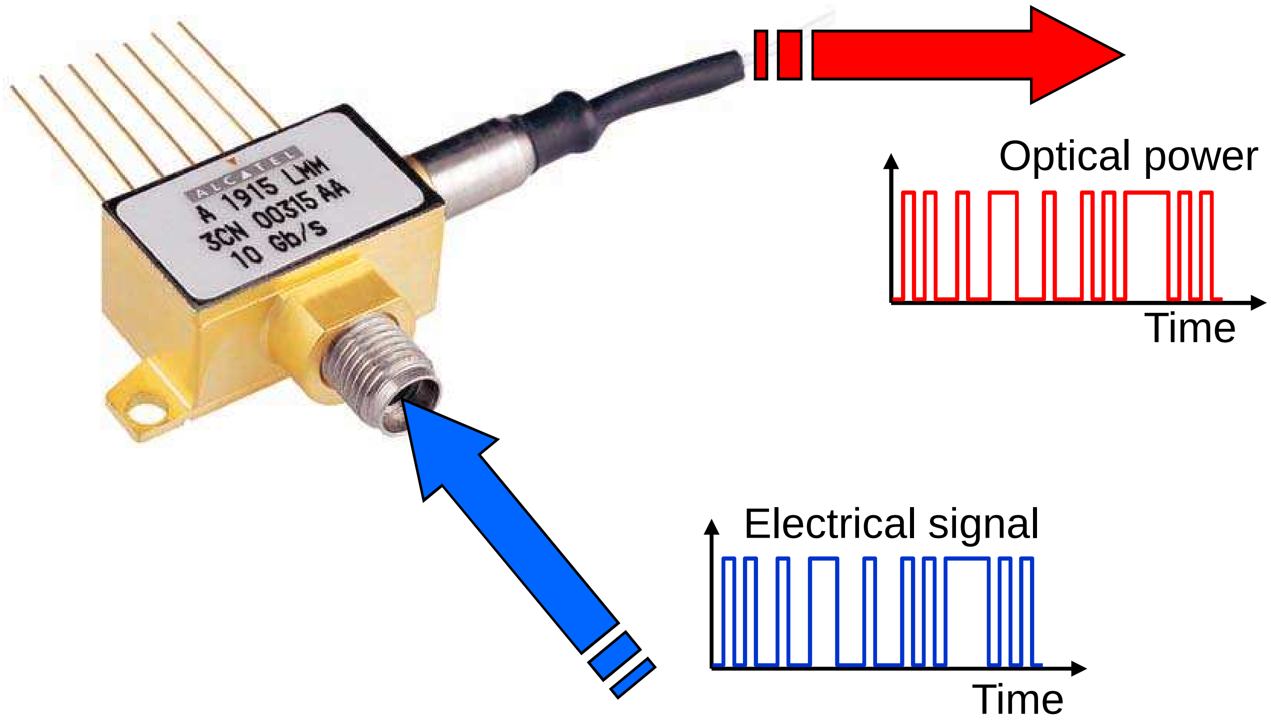
Laser diodes packaging

♦ **Packaging of a transmitter module with an optical isolator**



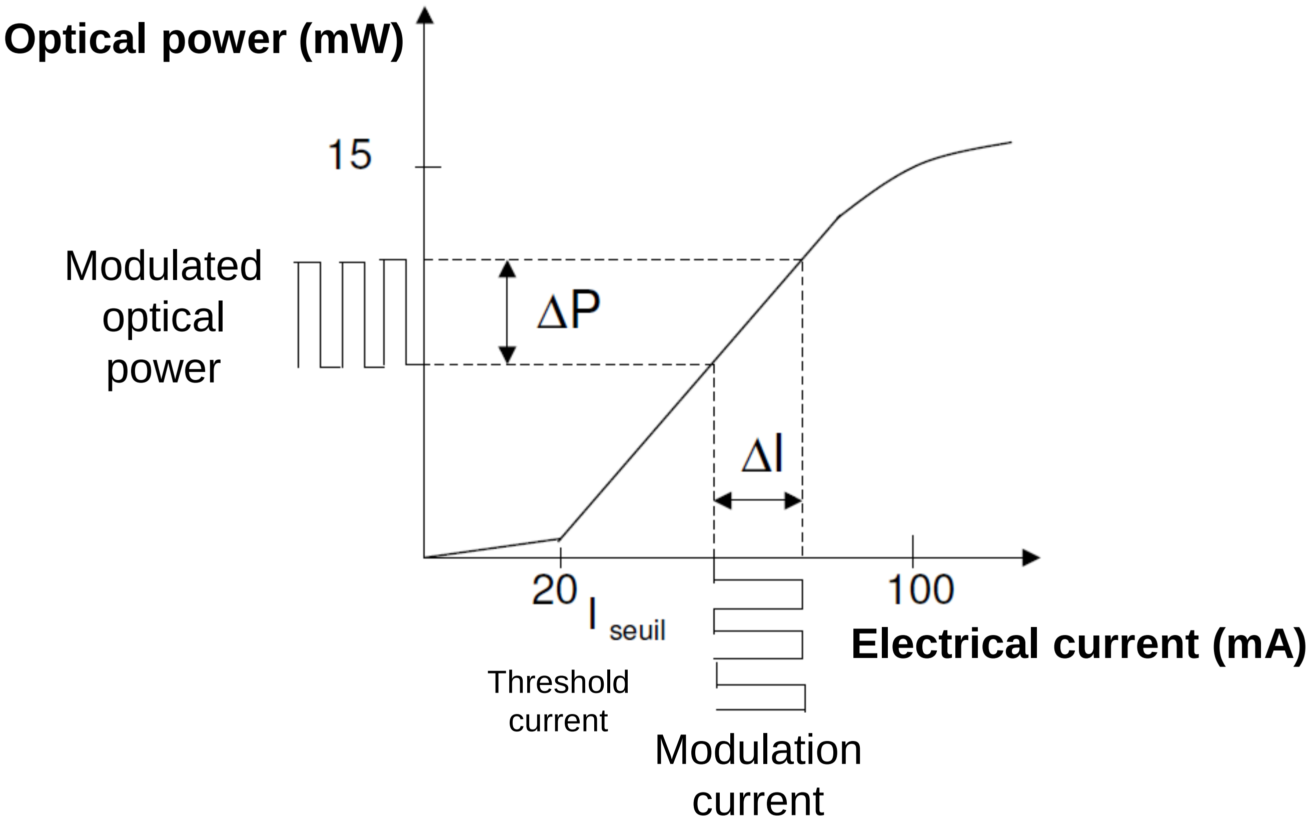
Laser diode modulation

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



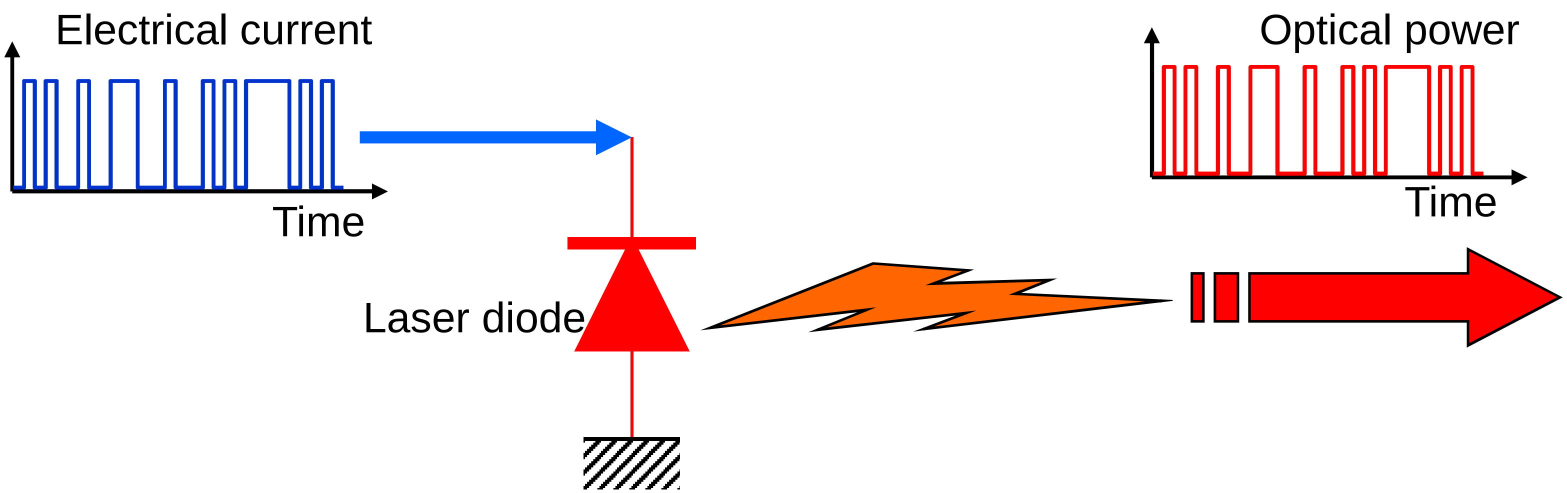
Transfer characteristics of a laser diode

- Optical power vs electrical current characteristics of a laser diode



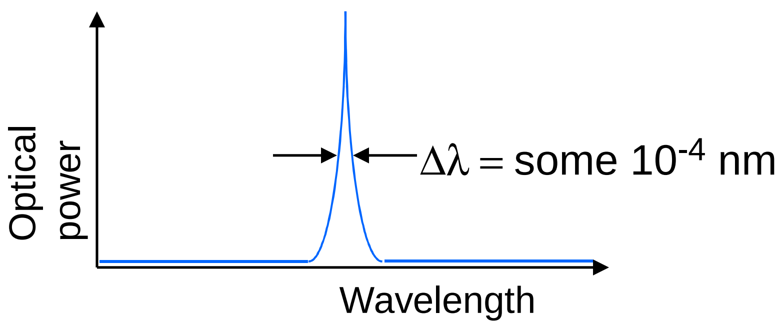
Direct modulation of a laser diode

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

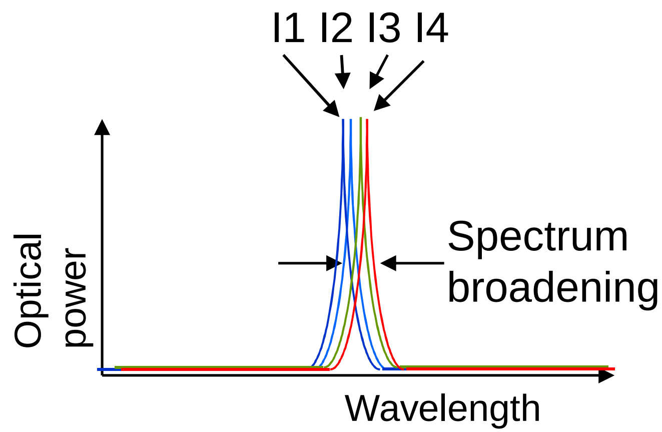


Direct modulation of a laser diode

- **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**



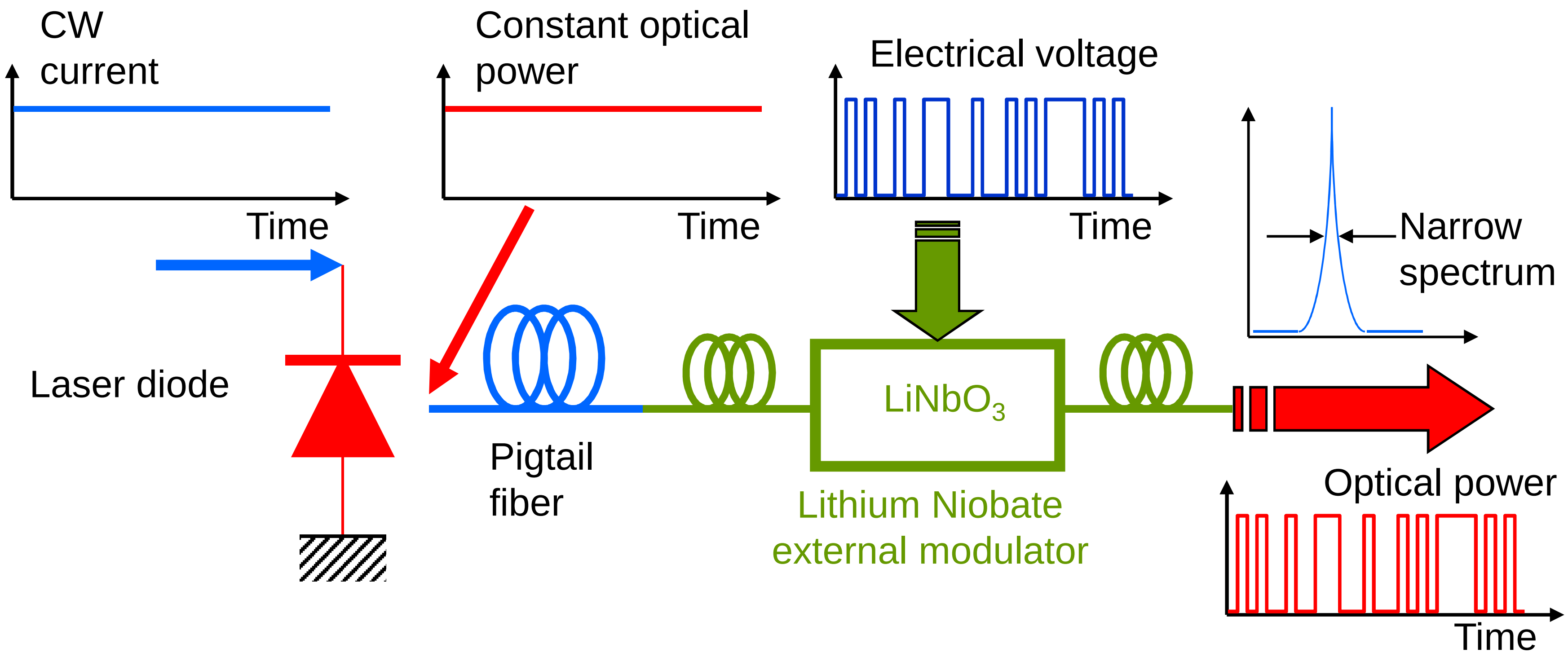
Constant modulating current
= CW spectrum => No chirp



Direct modulation = current variation
Spectrum broadening due to chirp

External modulation of a laser diode

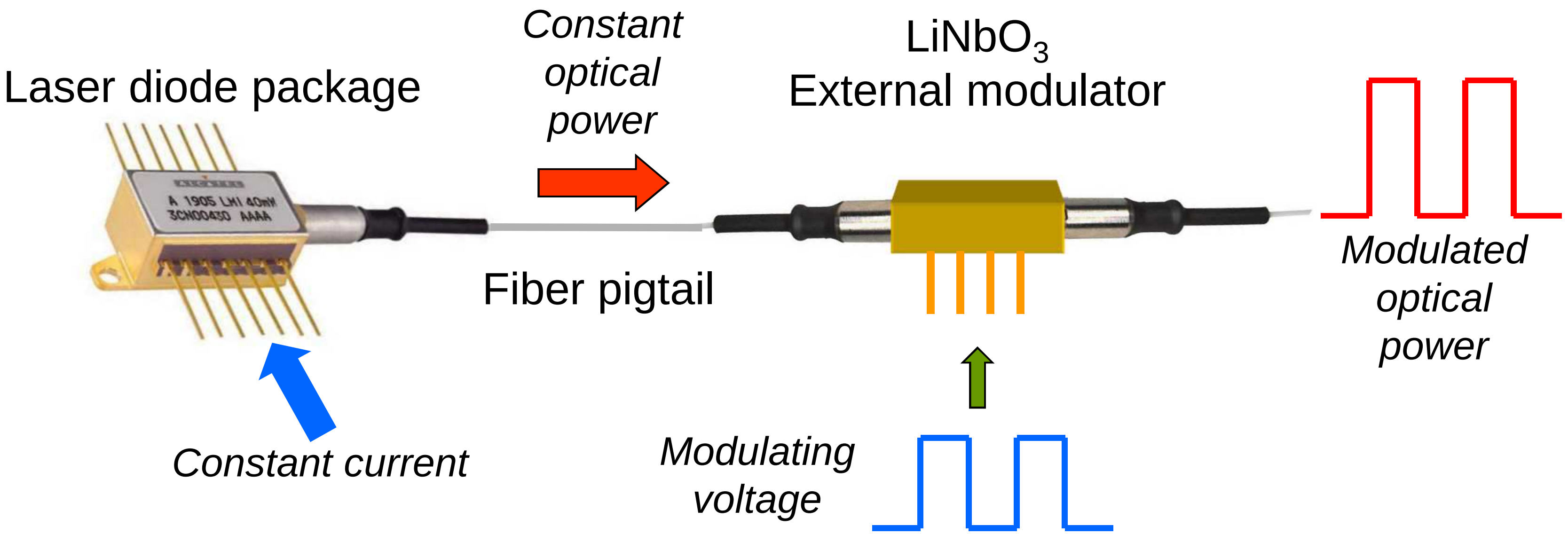
- **External modulation (1)**
  - **Modulation method to avoid laser diode chirp**
  - **Allows to significantly increase transmission distance**



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

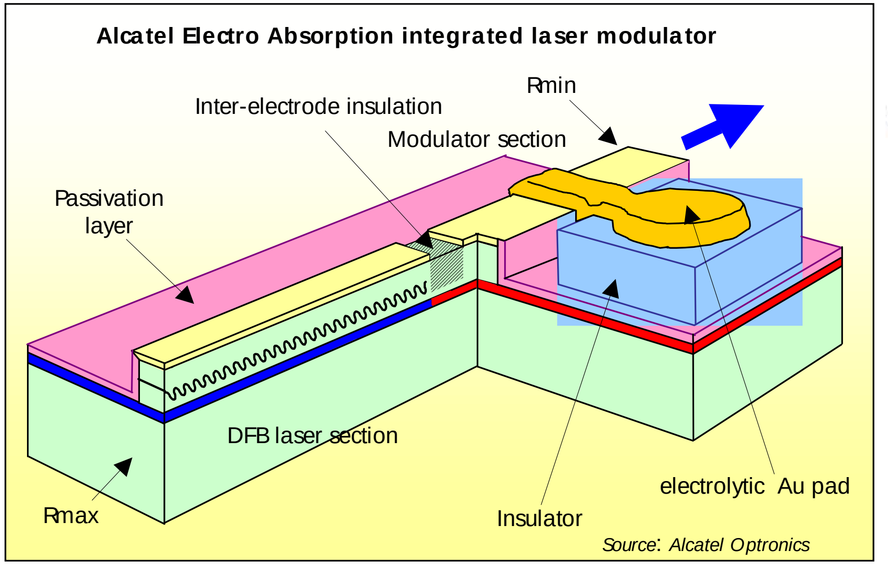


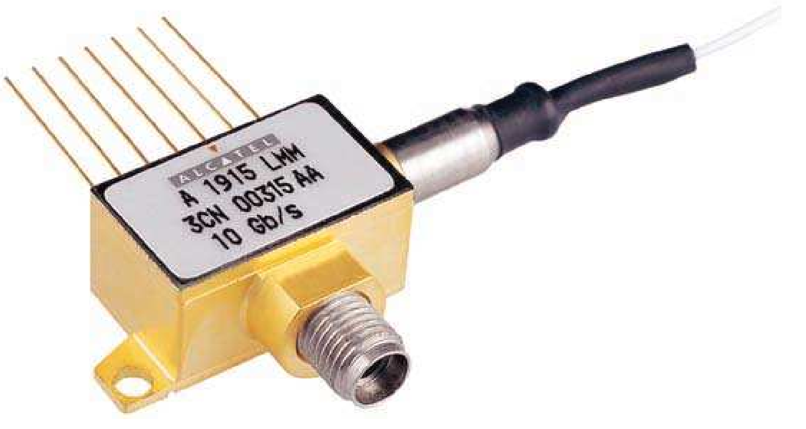
External modulation of a laser diode

- ♦ **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



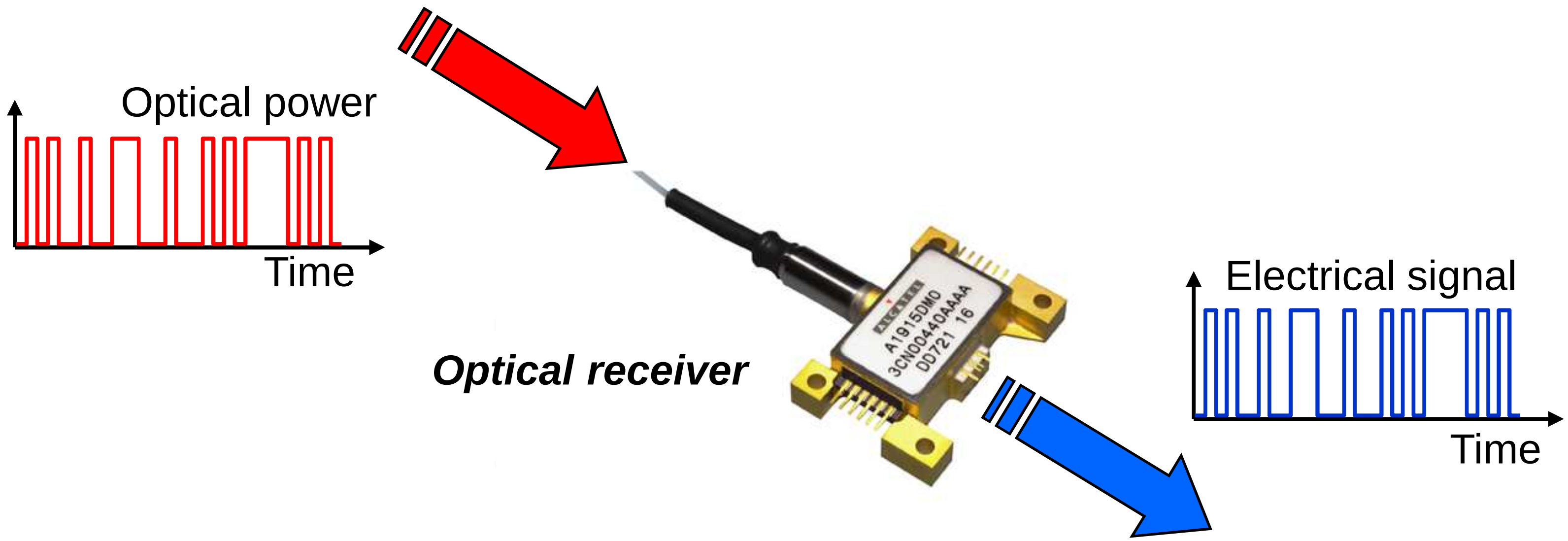


Comparison of laser diode modulations

- **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)

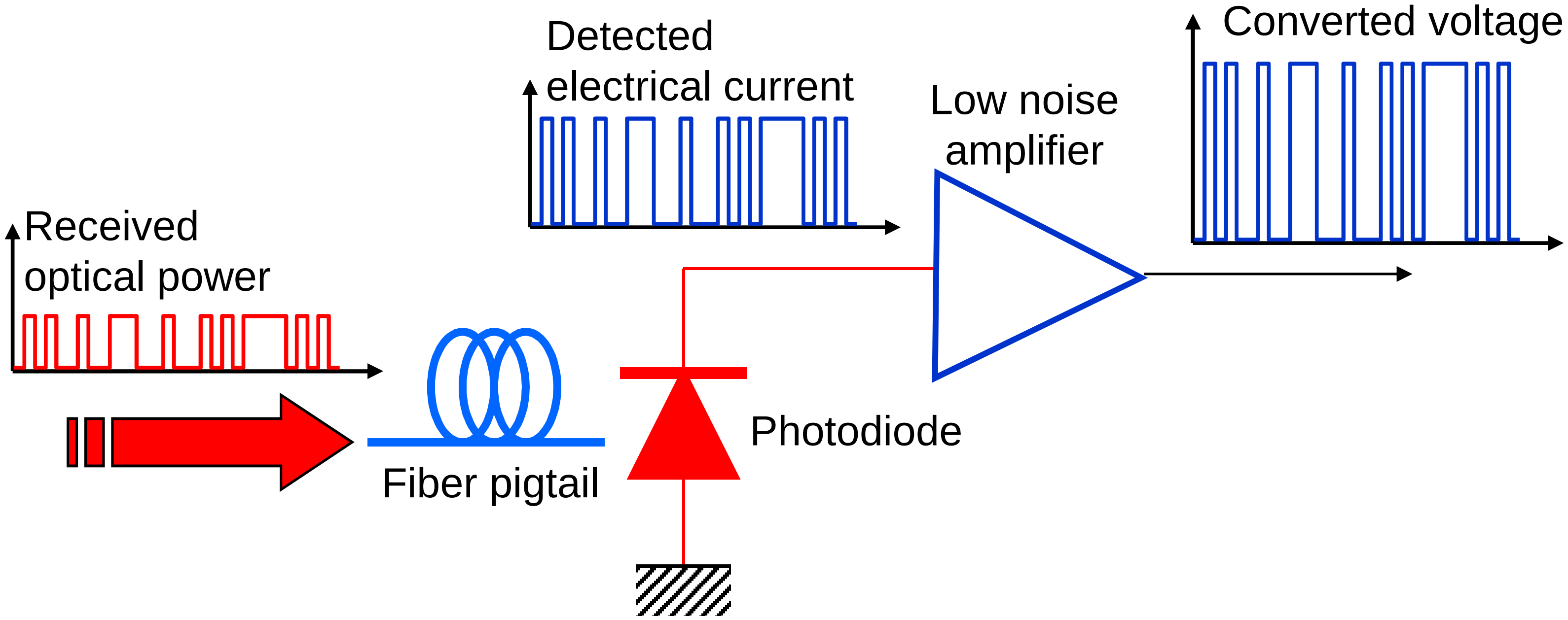
Detectors and optical receivers

- **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)**

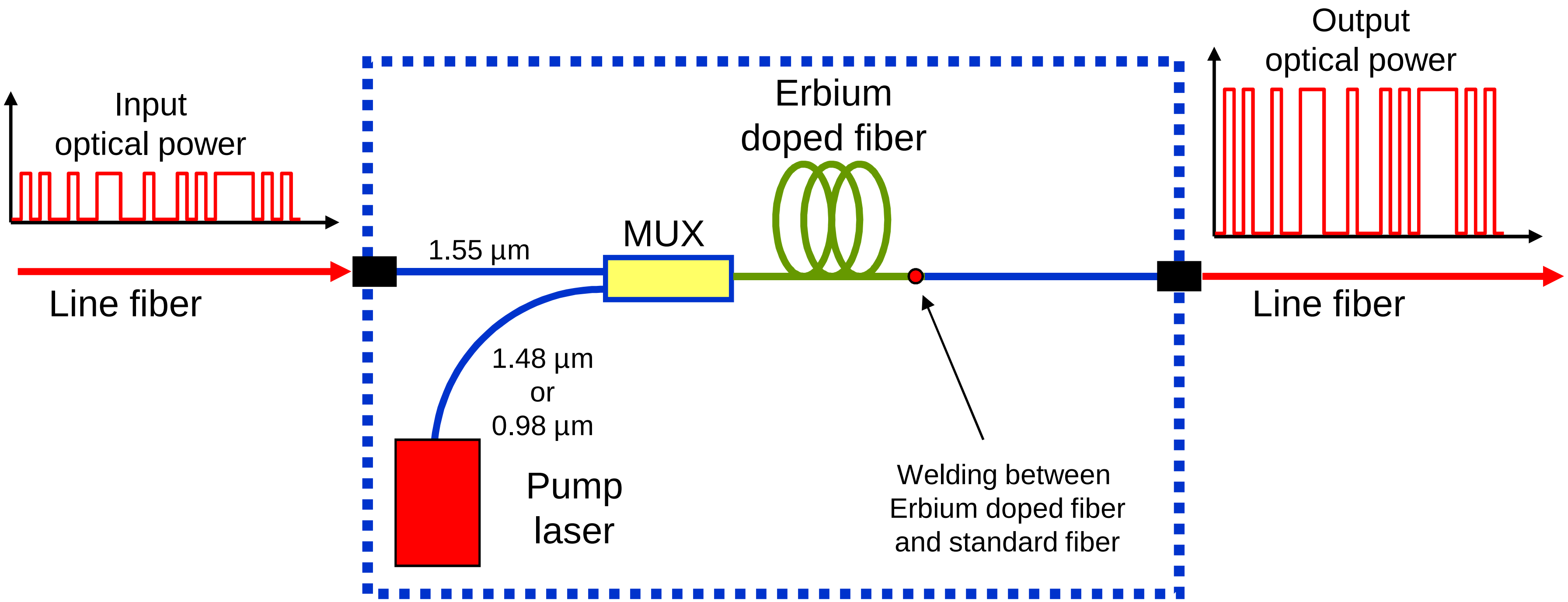


Types of photodiodes

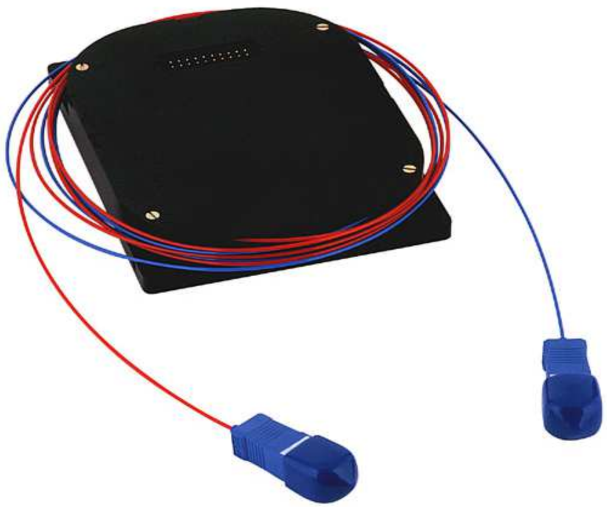
- **Two main types of photodiodes**
  - **PIN photodiode (Positive-Intrinsic-Negative)**
    - Simple structure easy to implement
    - Used for very high bit rates (up to 40 Gbit/s)
  - **Avalanche photodiode (APD)**
    - More complex structure
    - Requires a high driving voltage
    - Allows to 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

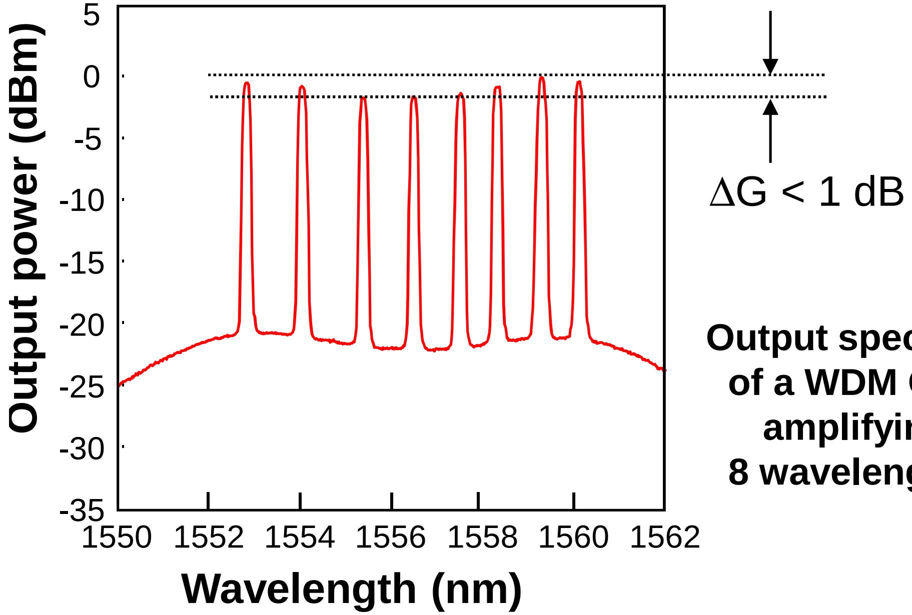
Optical Fiber Amplifiers (OFA)

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



- 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)

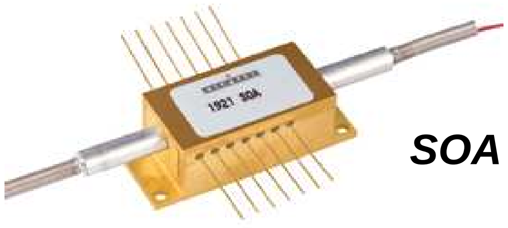




Output spectrum of a WDM OFA amplifying 8 wavelengths

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

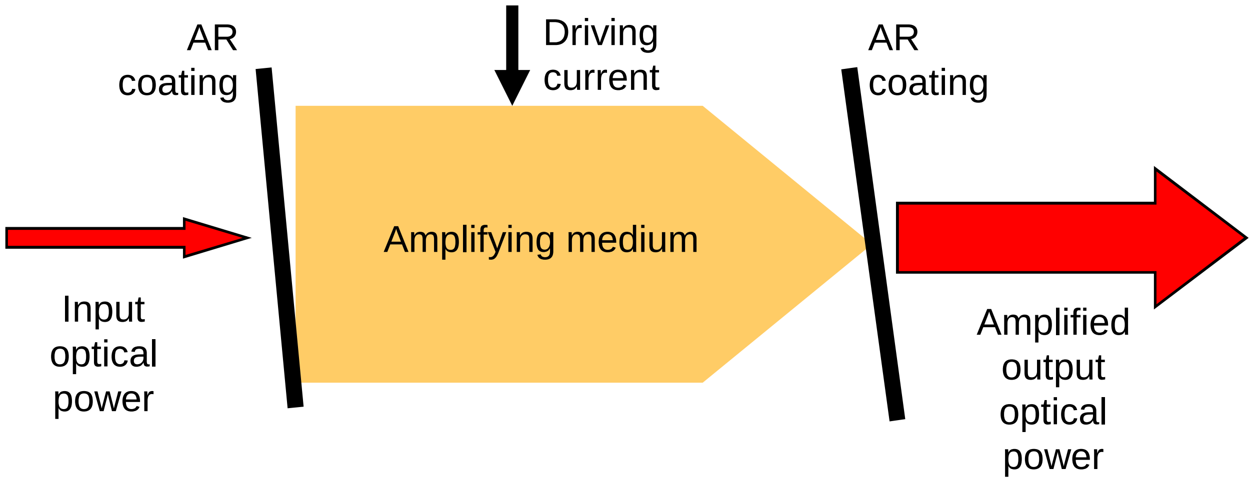


SOA

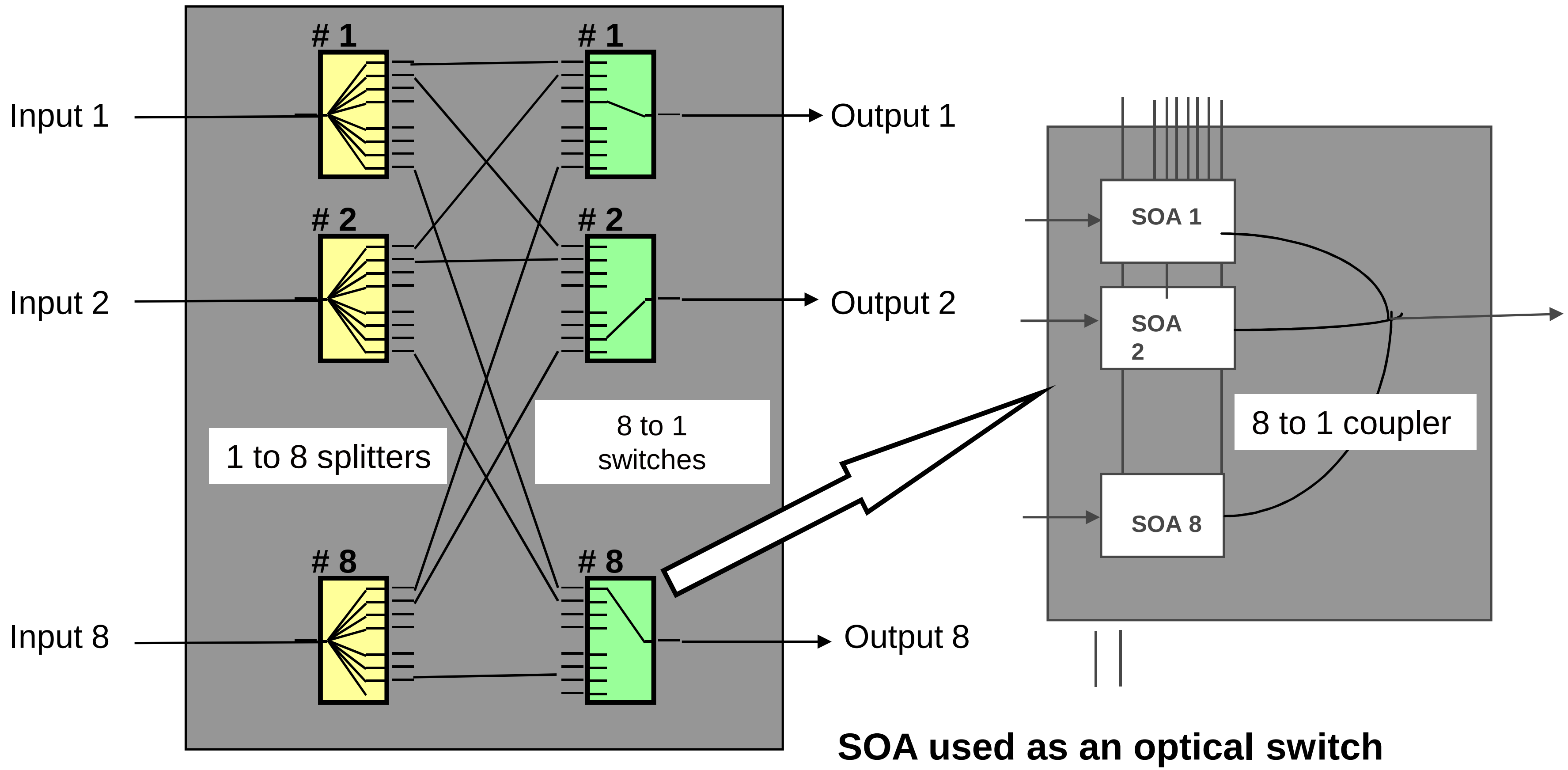
ICM

Semiconductor optical amplifier

- **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



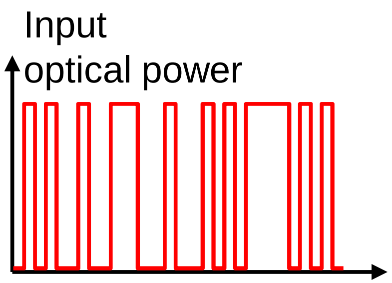
8 X 8 switching matrix
Possible extension up to 64 x 64

SOA used as an optical switch

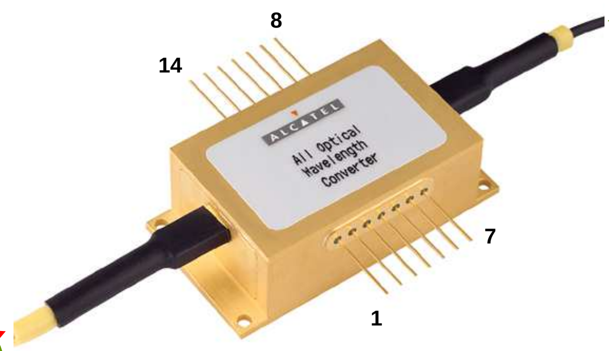
- No switching loss due to SOA gain
- High speed switching time (some 10 ps)

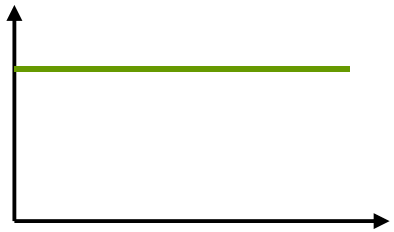
Wavelength conversion

- The interferometric converter module (ICM)



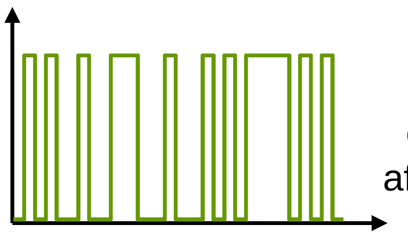
Modulated input signal
Wavelength λ1





CW optical carrier
Wavelength λ2

Modulated (converted)
output signal
Wavelength λ2

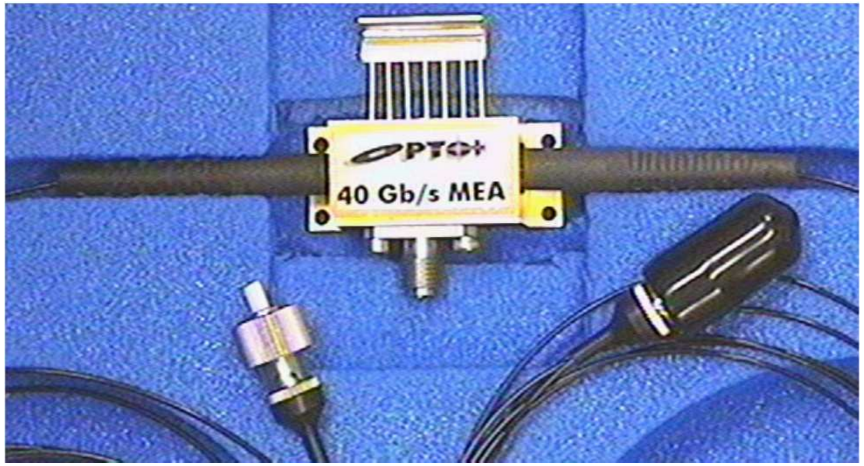


Output
optical power
after conversion

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

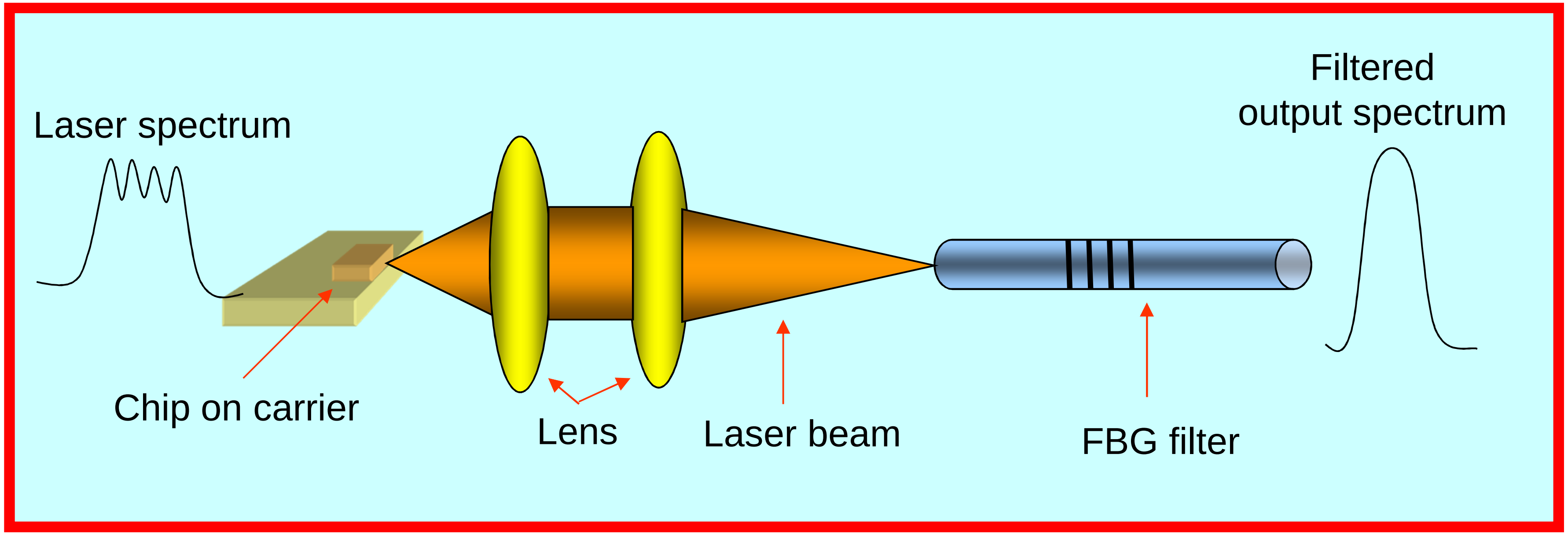


Passive components (1)

- **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**



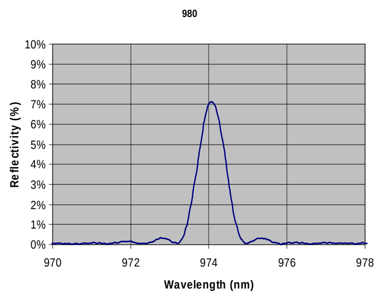
Passive components (3)

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

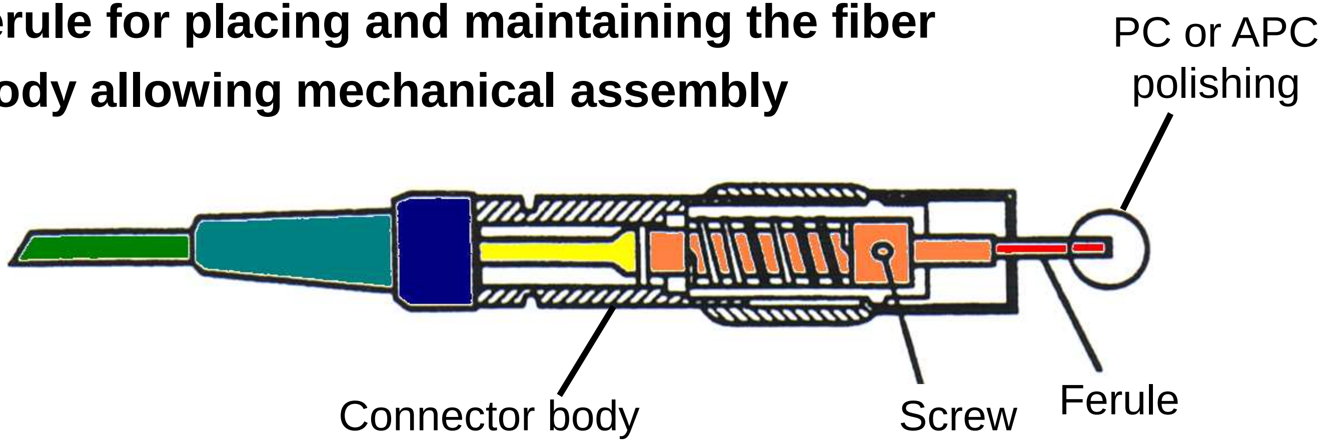


Wavelength filters

- 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