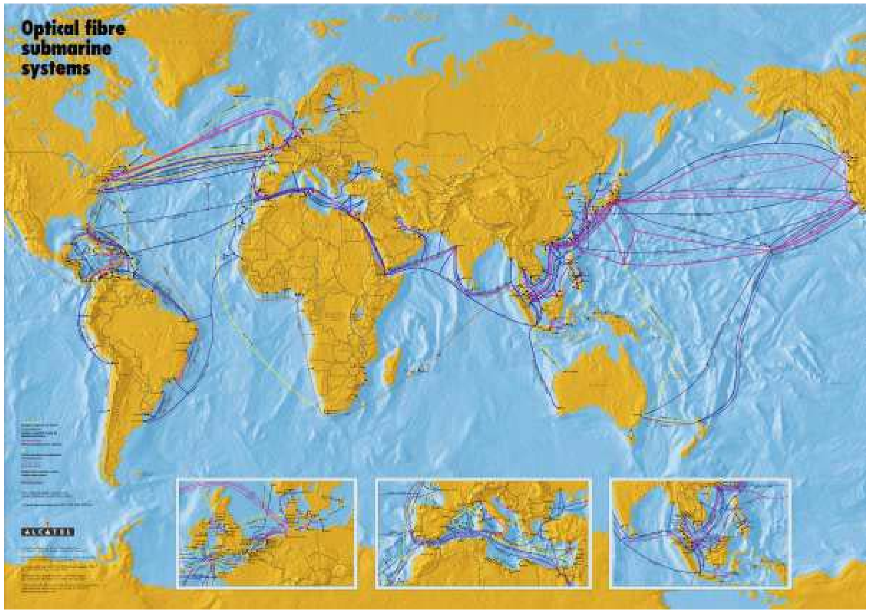
Topic 7

7. Optical Amplifiers

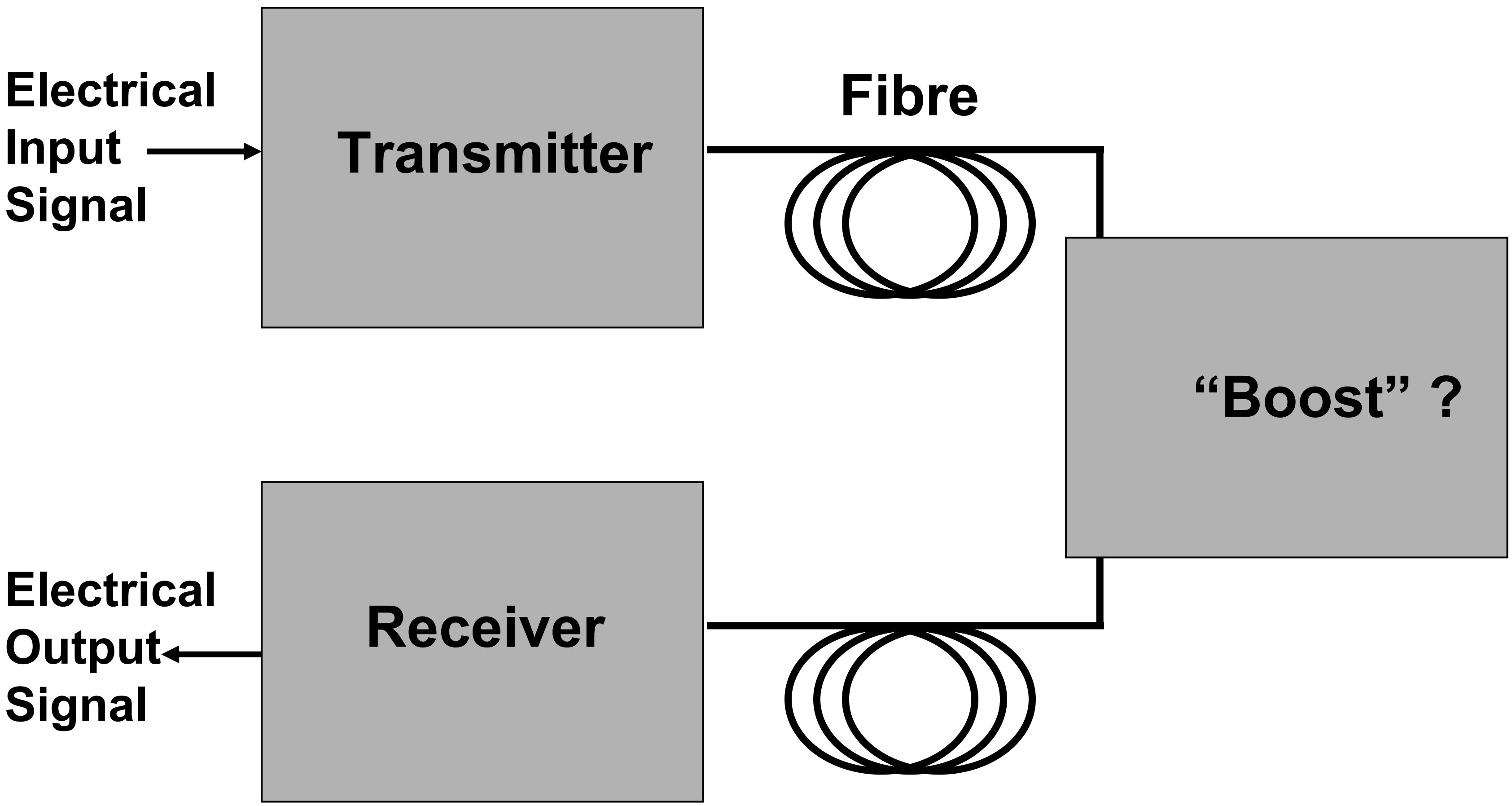
Introduction (i)



Transmission over a Long Distance

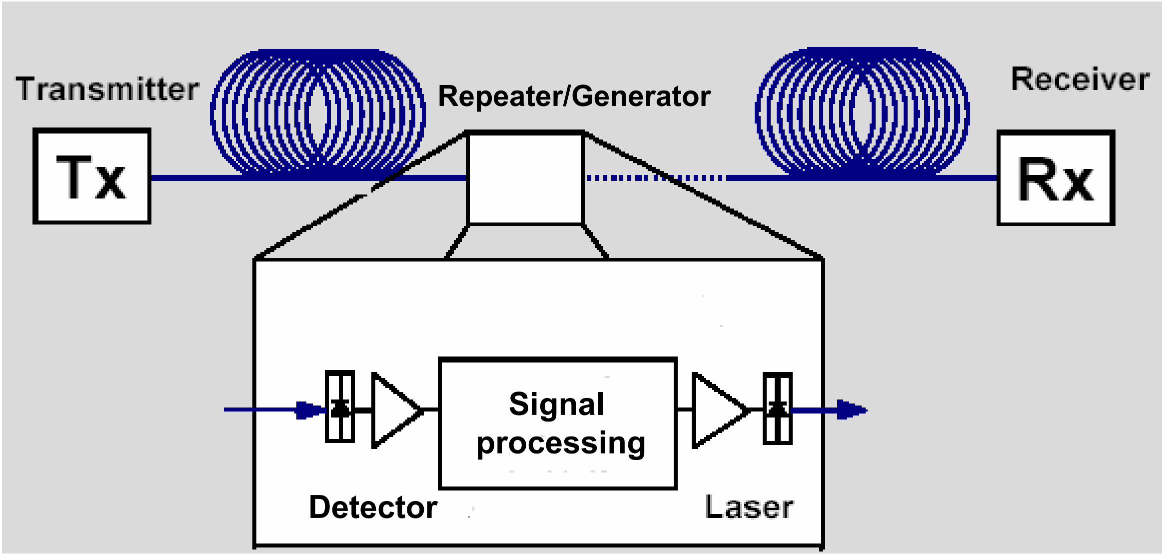
- ~10^4 km between Transmitter and Receiver
- Typically 0.2dB/km ~2×10^3 dB
- Require periodic “boost” to signal
- Must do this in simple and robust manner – manufacturer must guarantee that it will work for 25 years

Introduction (ii)



Optical Fibre System

Introduction (iii)



Traditional Optical Communication System:

Electronic amplifier

Optical signal/electrical signal $\Rightarrow$ Amplifying the electrical signal,
Retiming, Reshaping, Regenerating $\Rightarrow$ Electrical signal/optical signal

•It is difficult for practical applications in harsh environment in terms of maintenance (25 years operation)

• Performance is limited by speed of electronic circuits

Optical Amplifier

1. **Optical amplifier**:
   A photonic device which can amplify an optical signal without changing it into electricity, meaning that the signals are all optically amplified.

2. **Features:**
   i) Optical amplifiers can amplify an entire spectral range, so that several channels can be amplified at the same time.
   ii) Reliability
   iii) Flexibility
   iv) Low cost
   v) Match WDM

Classification of Optical Amplifiers

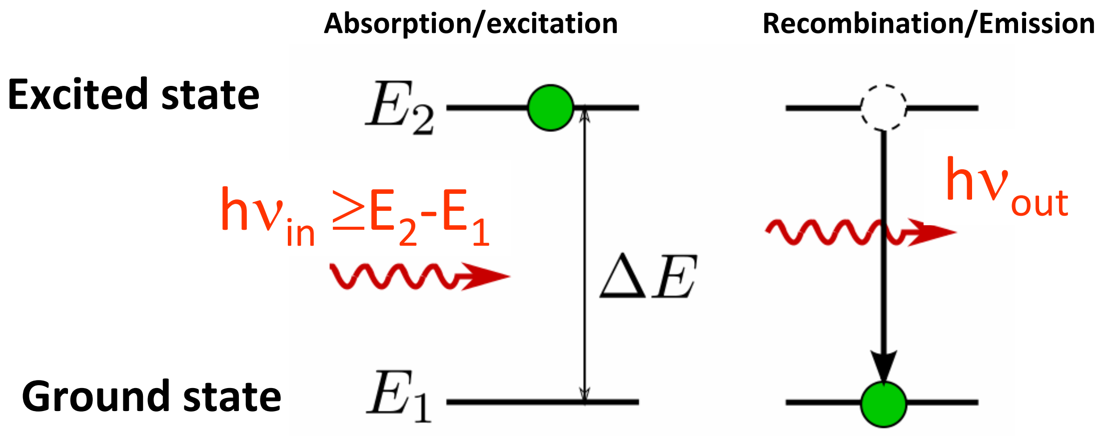
- **Optical fibre amplifiers:**
  (i) Erbium-doped Fibre Amplifiers (EDFA): $\lambda \sim 1.55\ \mu m$
  (ii) Praseodymium-doped Fibre Amplifiers (PDFA): $\lambda \sim 1.31\ \mu m$

- **Semiconductor optical amplifiers (SOA)**

- **Raman amplifiers** (not discussed)
  Based on the effect of Raman scattering

Mechanism for optical amplification:
It is similar to laser, but without feed-back. In order to understand the mechanism, we need to understand **spontaneous and stimulated** emission

Spontaneous Emission



$h\nu_{out} = E_2 - E_1$

- **Spontaneous emission:**

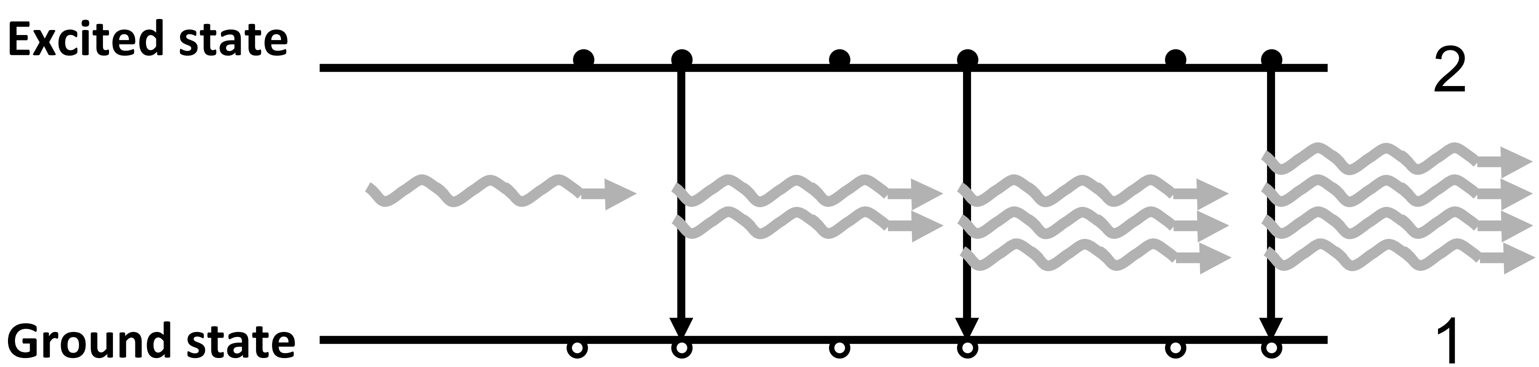
  After an optical or electrical excitation, electrons undergo a transition from an excited state with a high energy level to a ground state with a low energy level and then emits a photon.

- **Conditions for optical absorption**
  (1) $h\nu_{in} \geq E_2 - E_1$; (2) Empty states in excited state

- **Normally, $N_2 < N_1$ (number of atoms in excited state and ground state)**

- **Photons created via Spontaneous emission: random direction and phase**

Stimulated Emission



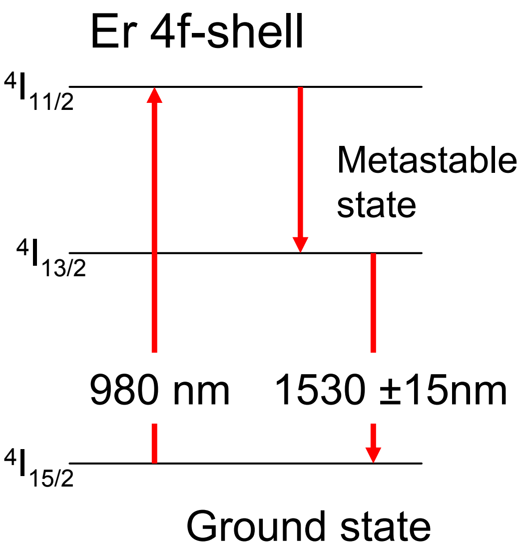
- **Population inversion:**

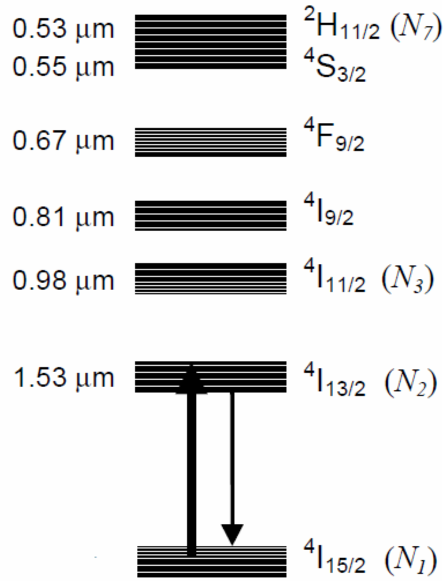
There is no empty states in excited state or
N_2 number of electrons (in excited state) >N1 (in ground state)
The absorption cannot take place, namely, the system becomes transparent.

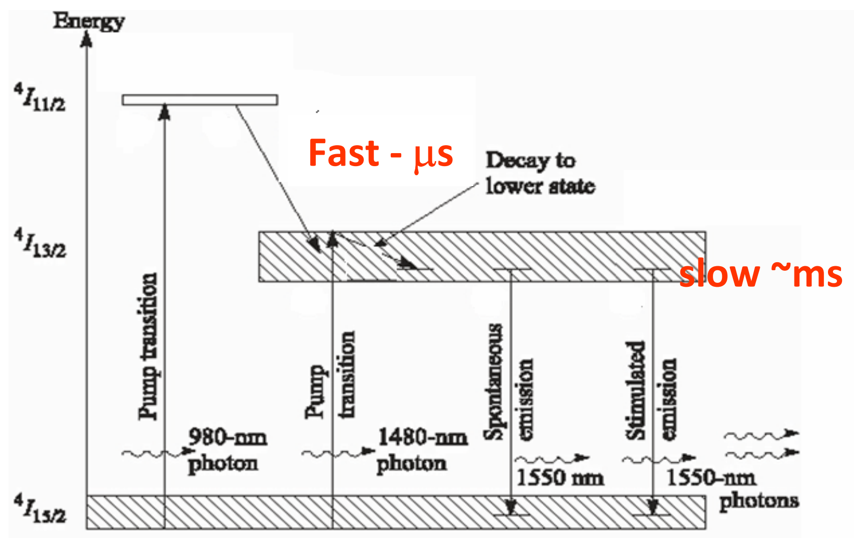
- Incident photon (**same energy**): optical transition takes place from excited state to ground state. The number of photons with the same energy will exponentially increase, which is stimulated emission. **This is optical amplification.**

- Photons created are identical in Energy, Phase, direction

Energy level of erbium doped ions in silica fibers



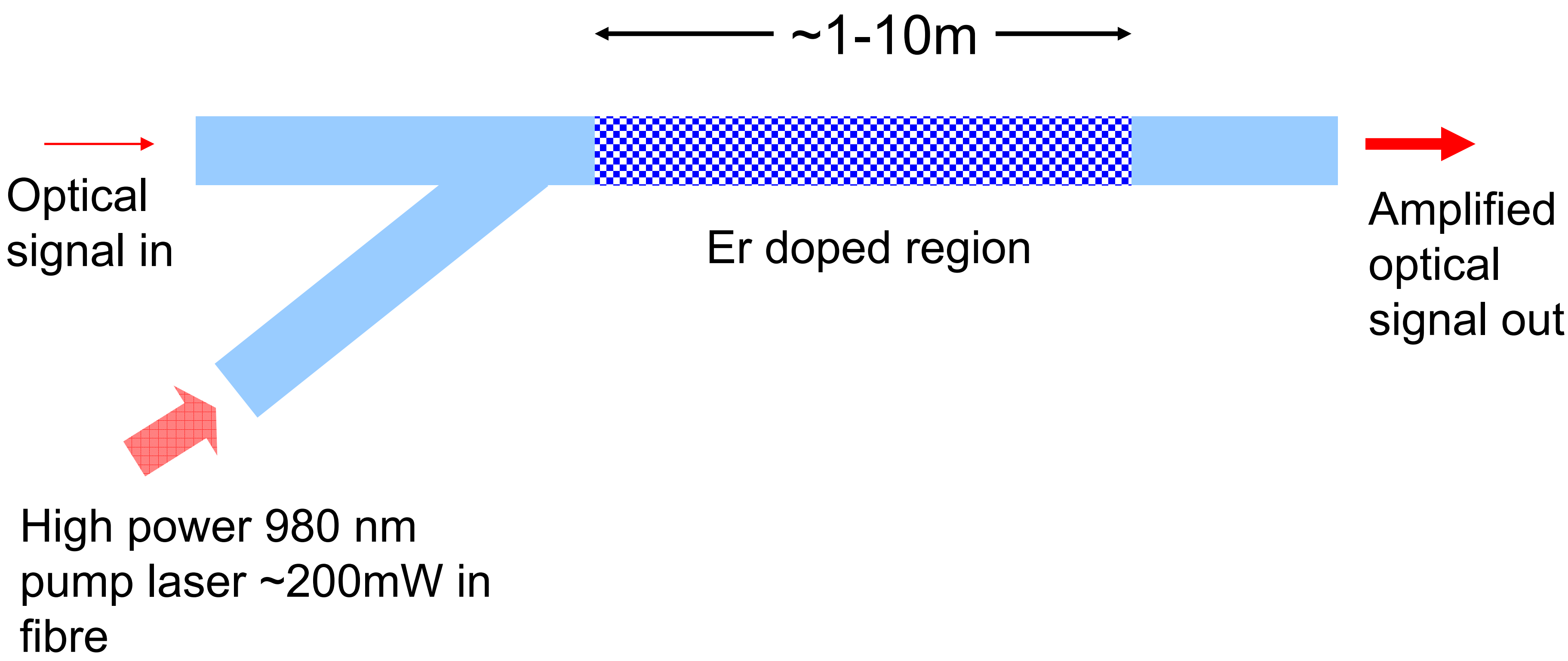




- Doing Erbium ions into silica: a number of energy bands due to the dopant induced electronic state, as described above
- 532nm, 667nm, 800nm and 980nm states are unstable (lifetime: **Fast - μs**).
- 1530 nm state is in a metastable band (lifetime: **slow- ms**)
- 980 nm or 1480 nm light source can excite electrons into a metastable state
- Radiative recombination at ~1.55 um, matching optical communication

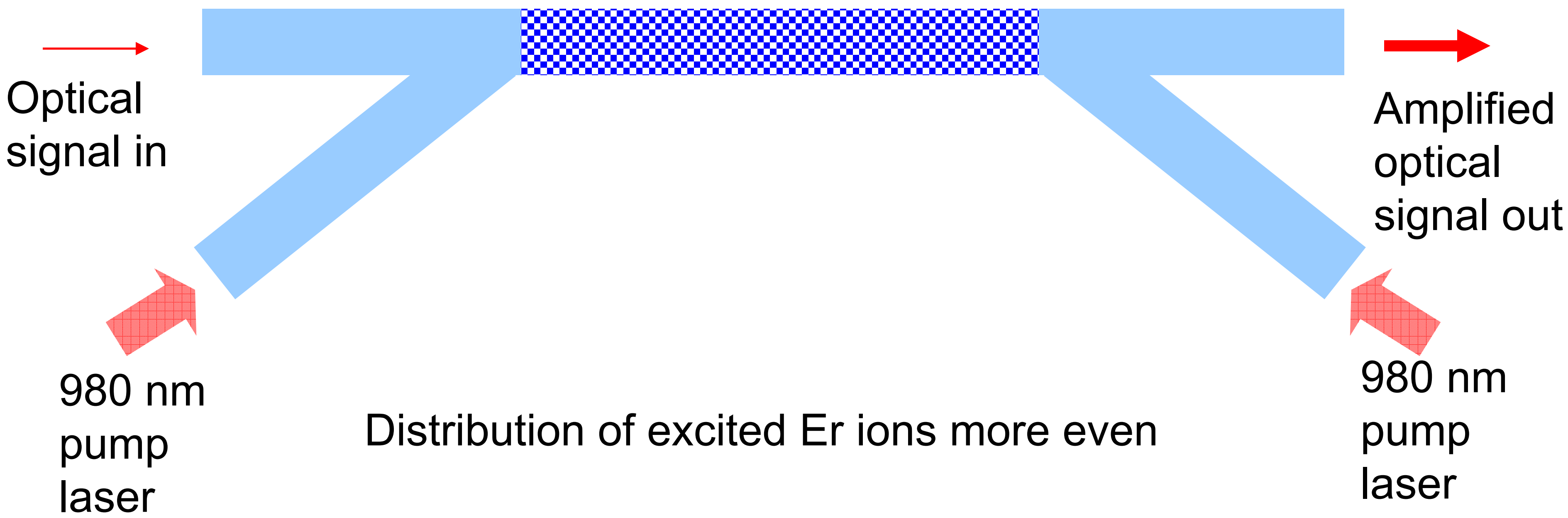
High power excitation source at 980 nm (commercially available) can lead to population inversion, and thus optical amplification.

Erbium Doped Fibre Amplifier (EDFA)



Pump laser can travel in same or opposite direction as pulse to be amplified

Dual pumped EDFA

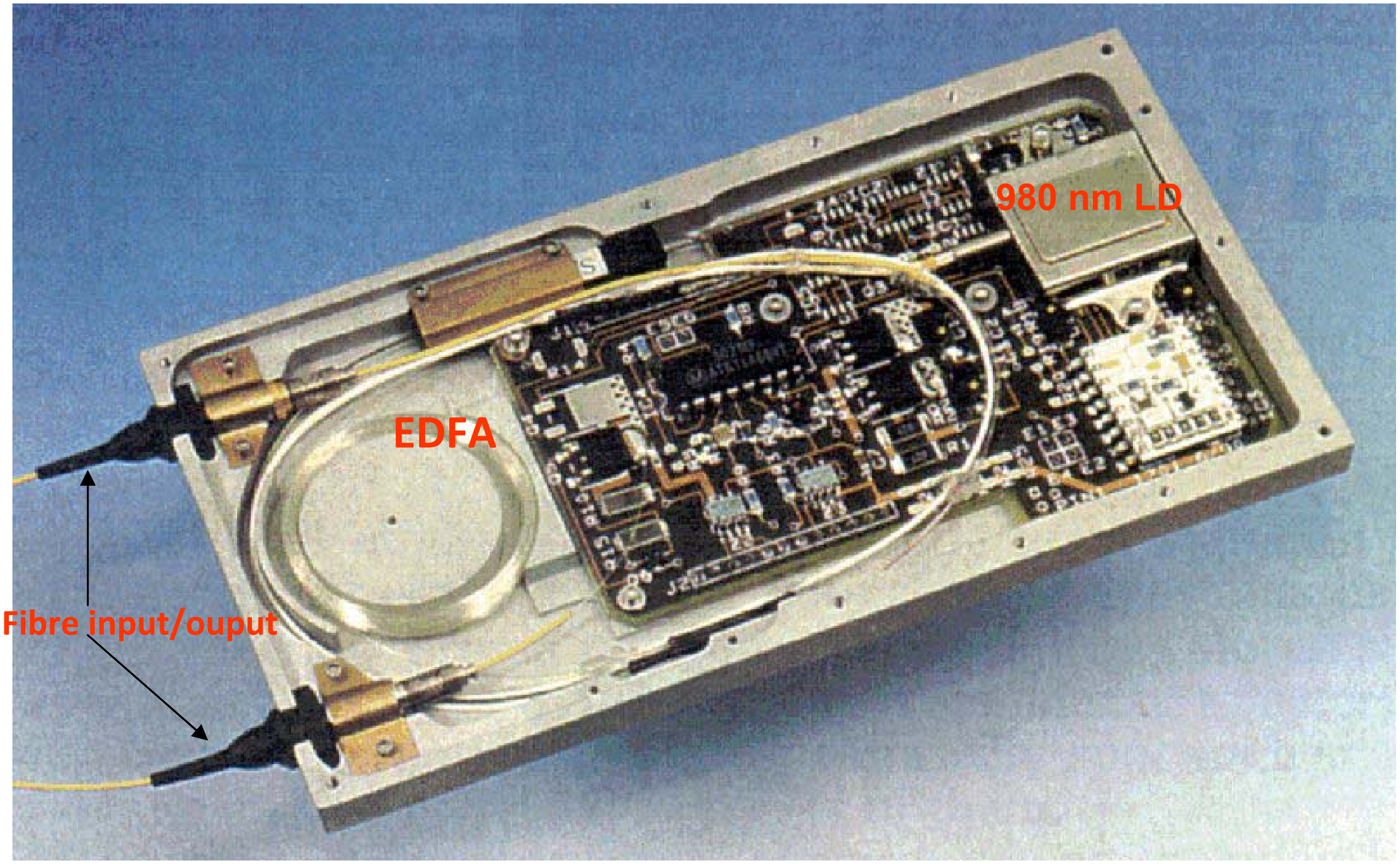


Distribution of excited Er ions more even

Get more gain

If one pump laser fails – still get some gain

Commercial Available EDFA



980 nm semiconductor laser diode:
(1) a long life time; (2) Compact; (3) Robust; (4) High power

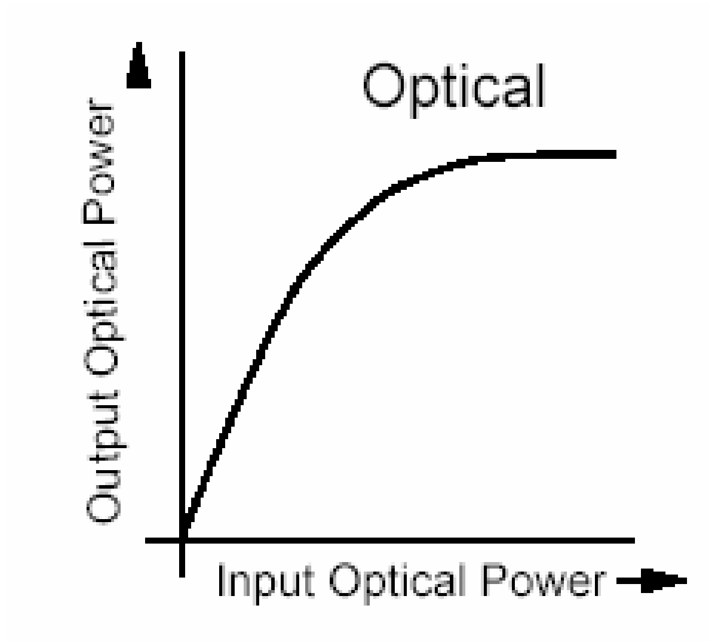
EDFA – Gain saturation

- **Signal gain or amplifier gain** $G = P_{s,out}/P_{s,in}$

- As we increase signal strength, deplete level N_2 and gain saturates as the system cannot keep up – **Gain Saturation**

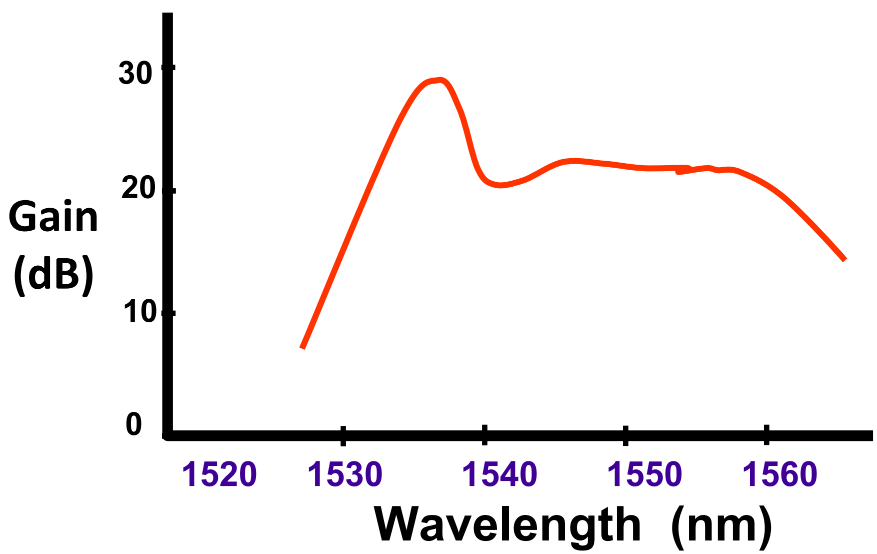
- EDFA is in saturation if almost all Erbium ions are consumed for amplification. Total output power remains almost constant, regardless of input power changes

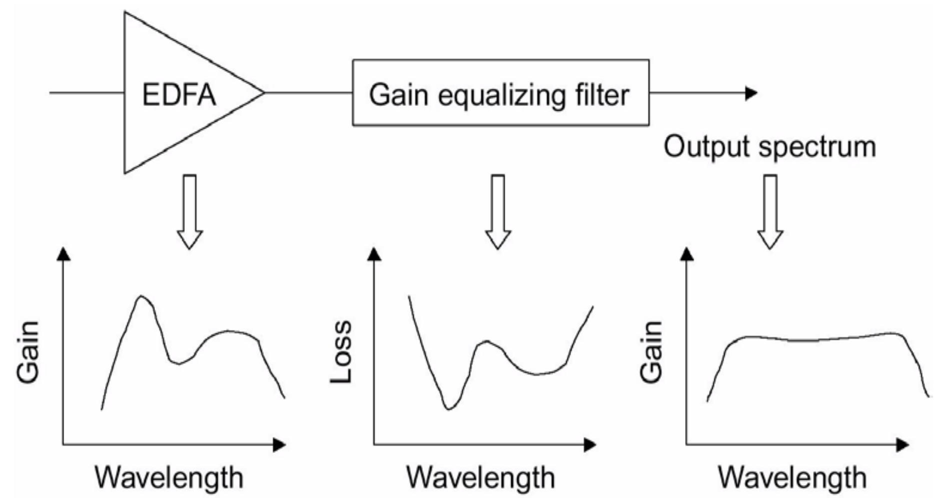
- Max gain ~ 30dB/EDFA

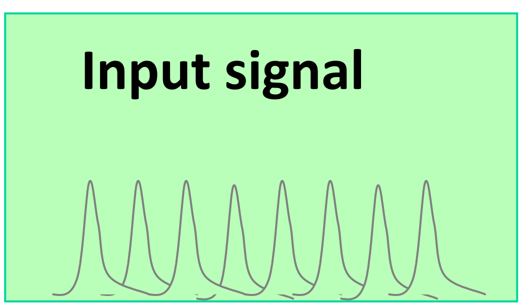


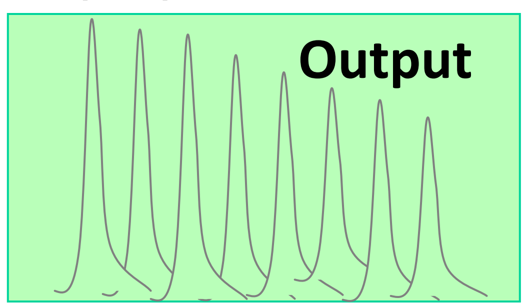
EDFA Gain Spectrum and Gain Flattering

- Optical amplification in 40-50 nm of bandwidth, from 1520 to 1570 nm
- Gain spectrum is not flat, significant gain variations
- Gain equalizing filter is require to flatter gain spectrum



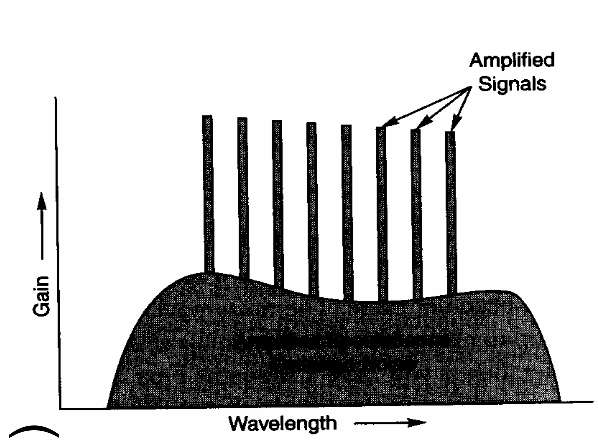






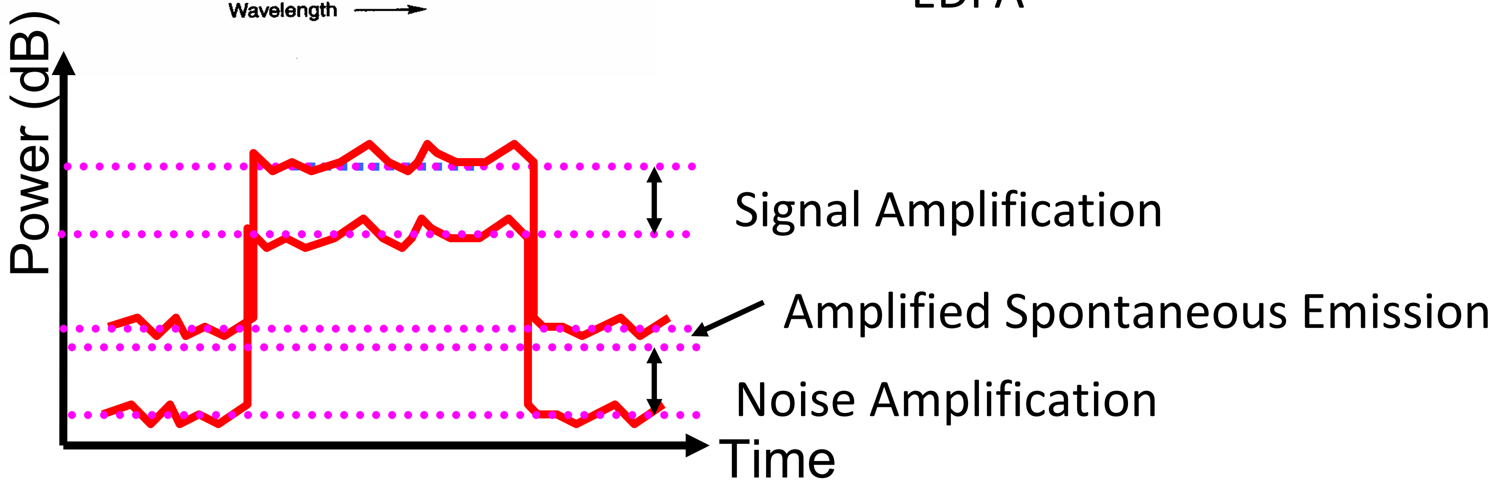
Issues with EDFA

- It is an optical amplifier, and can only compensate for attenuation
- It cannot **compensate for dispersion**
- It also amplifies **noise input with signal**

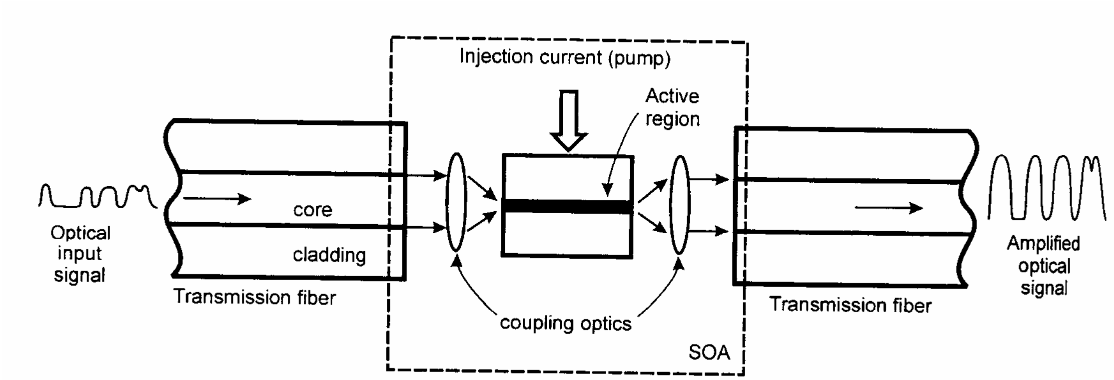


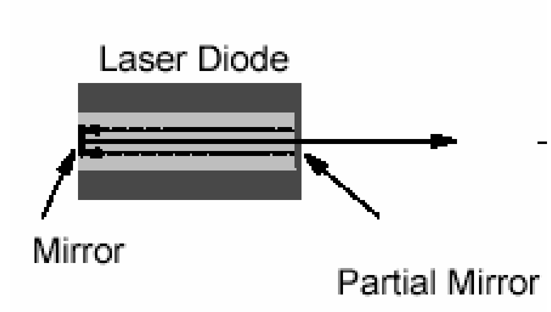
Also generate background noise – amplified spontaneous emission

Spontaneous emission which is waveguided will be amplified in EDFA

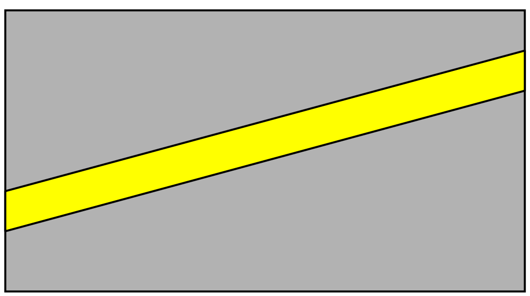


Semiconductor Optical Amplifiers (SOAs)

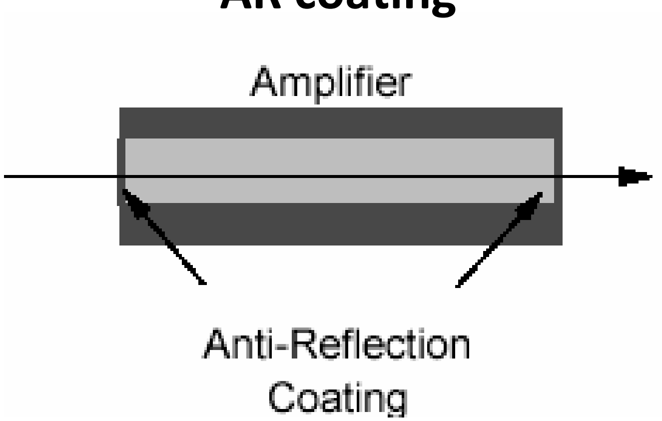




Tilted Active Region



AR coating



- **Need Gain *without* feedback – stop a laser lasing!**

- Laser structure with angled or AR coated facets (R_1R_2<0.001):

- SOAs have a clear disadvantage that they can amplify only at a wavelength channel. In order to amplify several channels several amplifiers are needed.

Advantages & Disadvantages of EDFAs

Good Points

- Simple! Just need high power pump laser with high reliability
- Not tied to a particular data type
- Excellent for WDM applications
- Can be used as pre-amplifiers before a detector, or power booster after a transmitter or amplifier mid-way between transmitter and receiver

Not so good points

- Doesn’t help with dispersion
- Adds noise - ASE
- Crosstalk

T7 Summary

•An amplifier increases the optical signal strength (the signal remains in the time domain) Due to it's atomic shell structure optically pumped erbium doped fibres provide this amplification

•Compared to a regenerator, EDFAs are attractive due to their simple, robust design, that they are not tied to a particular data type, are useful for WDM applications, but the don't help with dispersion, add noise (amplified spontaneous emission), and can suffer from crosstalk

T7 Tutorial Questions

T7.1 Explain the operation of a signal regenerator. What are the advantages and disadvantages of an erbium doped fibre amplifier (EDFA) over such a regenerator.

T7.2 Explain with the aid of diagrams if necessary, the operation of an EDFA. Explain gain saturation, and the sources of noise within the EDFA.