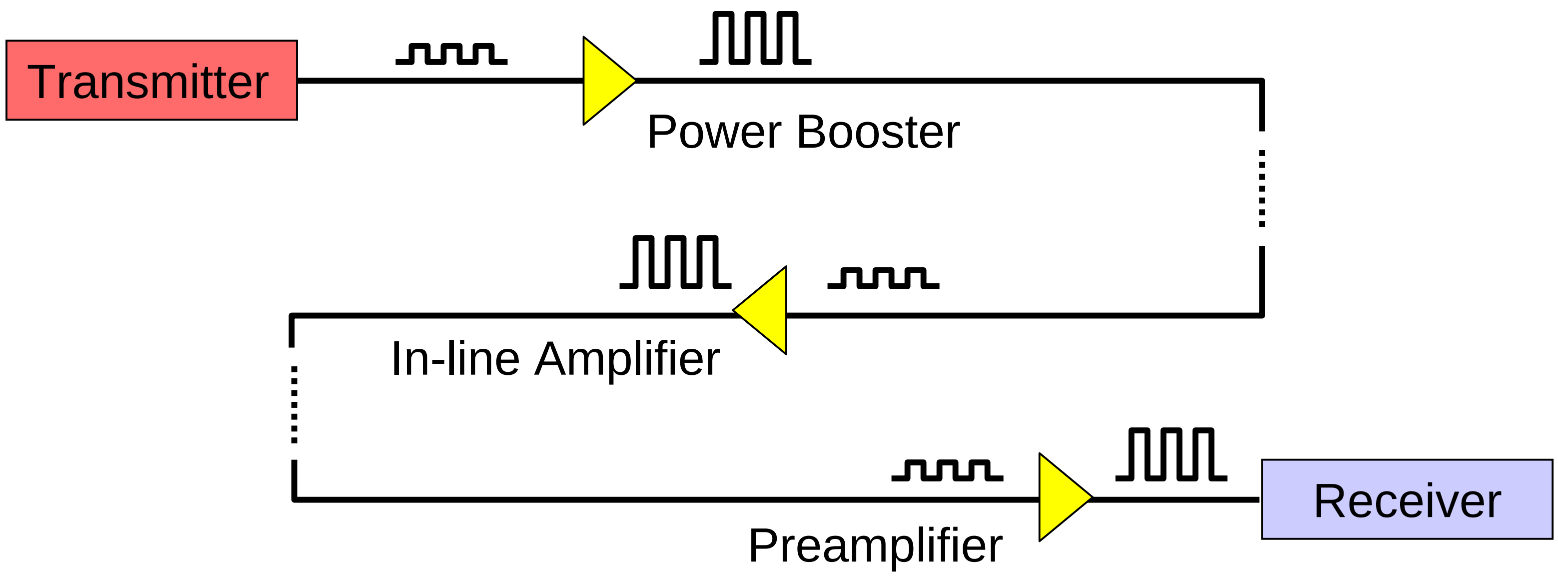
Optical amplifiers

Boosting of an optical signal without any conversion of the light into an electrical signal.

Optical amplifier functions

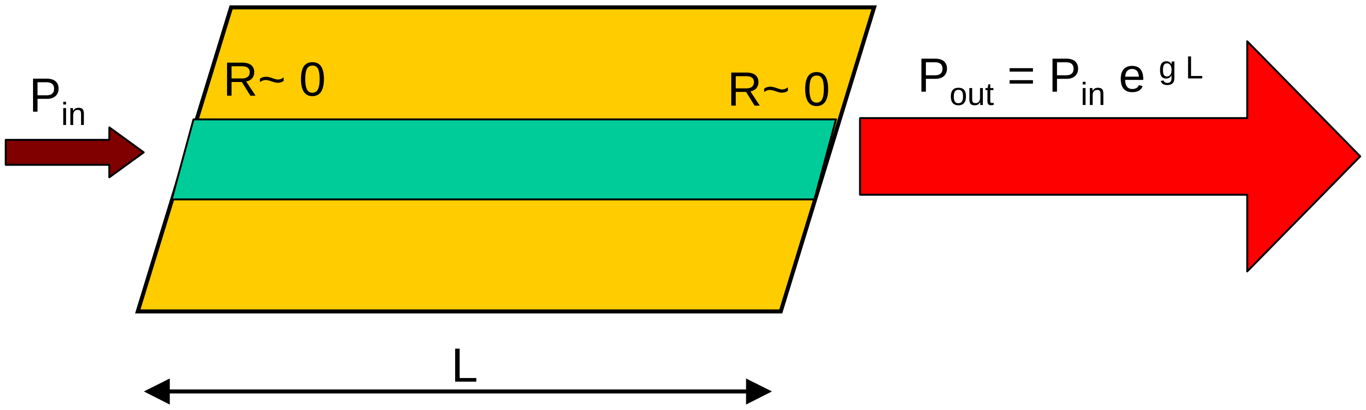
1. In-line amplifier
2. Power booster
3. Detector preamplifier



Optical amplifiers - classification

1. Semiconductor optical amplifiers (SOA, 400 - 2000 nm band)
2. Raman optical amplifiers
3. Brillouin optical amplifiers
4. Erbium doped fiber amplifier (EDFA, 1500-1600 nm band), also PDFFA(1300 nm band)

SOA – principle of operation



An SOA is based on the same technology as a Fabry-Perot diode laser. The amplification function is achieved by externally pumping the energy levels of the material. In order to get only the amplification function, it is necessary to protect the device against self-oscillations generating the laser effect. This is accomplished by blocking cavity reflections using both an antireflection (AR) coating and the technique of angle cleaving the chip facets. SOAs are electrically pumped by injected current

SOA advantages

1. Compactness
2. Integration potential
3. High power output
4. Broad choice of operating wavelength (400-2000 nm)
5. Low price with high volume production

Disadvantages

1. High coupling loss
2. Polarization dependence
3. High noise figure (as compared with EDFA)

SOA applications

1. Amplifier (Power booster – immediately following the LD, in-line amplifier, detector - preamplifier)

2. Optical Switch Element

3. Wavelength Converter

SOA parameters (State-of-the-art)

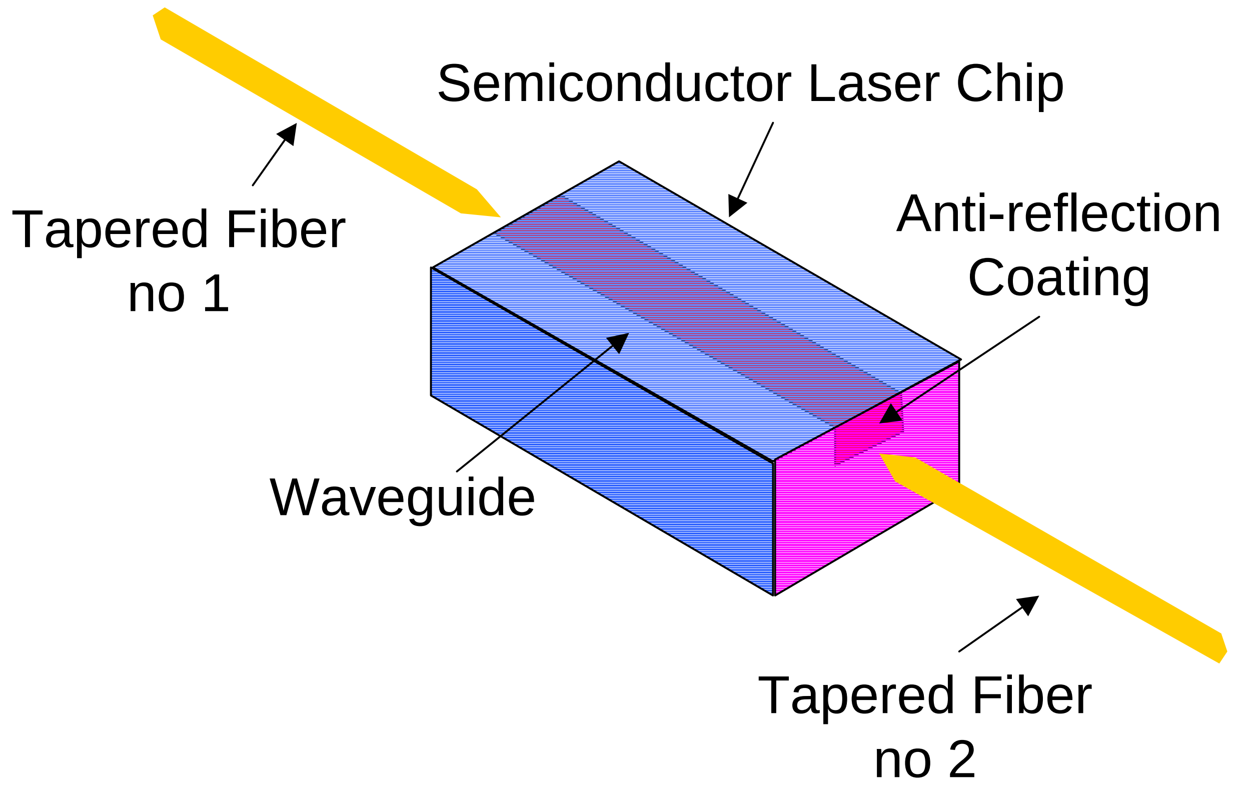
- Wavelength ~1300 nm or ~1550 nm
- residual reflectivity of less than 10^{-4} to ensure a gain ripple below 0.5 dB
- low optical loss to achieve a net gain as high as 30 dB
- high material gain to allow low-drive current operation (20 to 30 dB fiber-to-fiber gain for a 100-mA drive current)
- high output saturation power, defined as the output power for which the gain is reduced by 3 dB
- chip-to-fiber coupling loss of less than 3 dB per facet, which is achieved using integrated mode-expanding tapered waveguides at the output facets.

Polarisation sensitivity of SOA

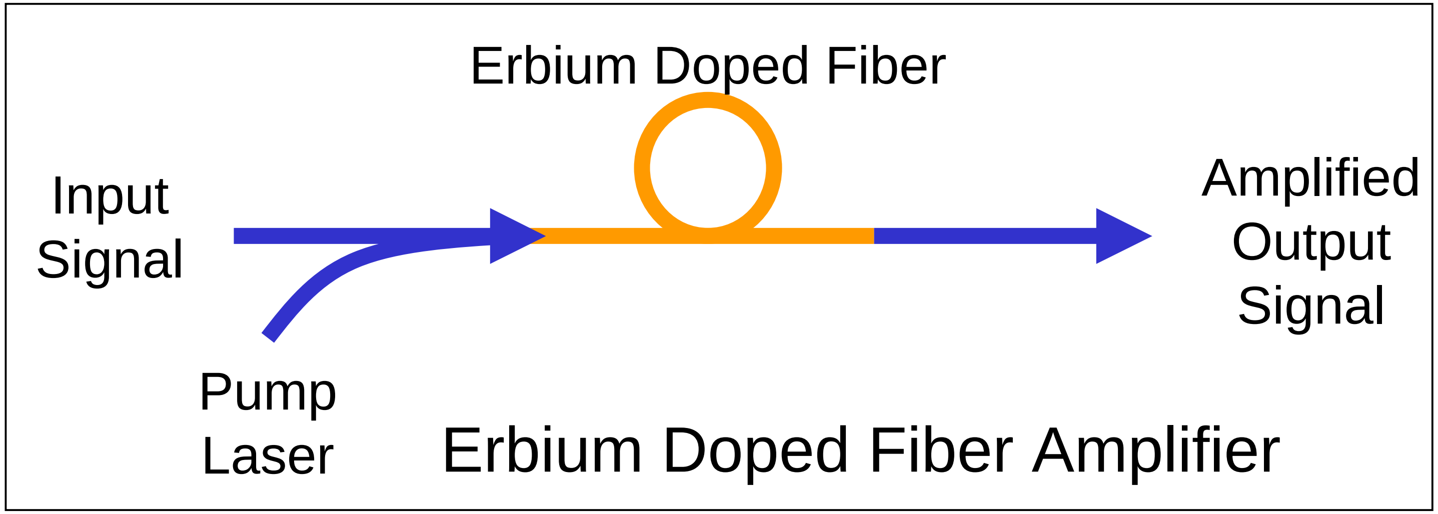
Polarisation sensitivity of SOA is less than 0.5 dB

- The polarization state of the optical signal coming from a link fibre is usually random.
- Material gain is isotropic in bulk material
- The strip waveguide in the SOA active area is polarisation sensitive (differential gain between transverse-electric (TE) and transverse-magnetic (TM) modes)
- Polarization sensitivity as low as 0.3 dB can be achieved with a near square (0.4 µm * 0.6 µm) active waveguide having almost the same confinement factor for both polarization states.

Example of SOA design



Optical amplification - EDFA



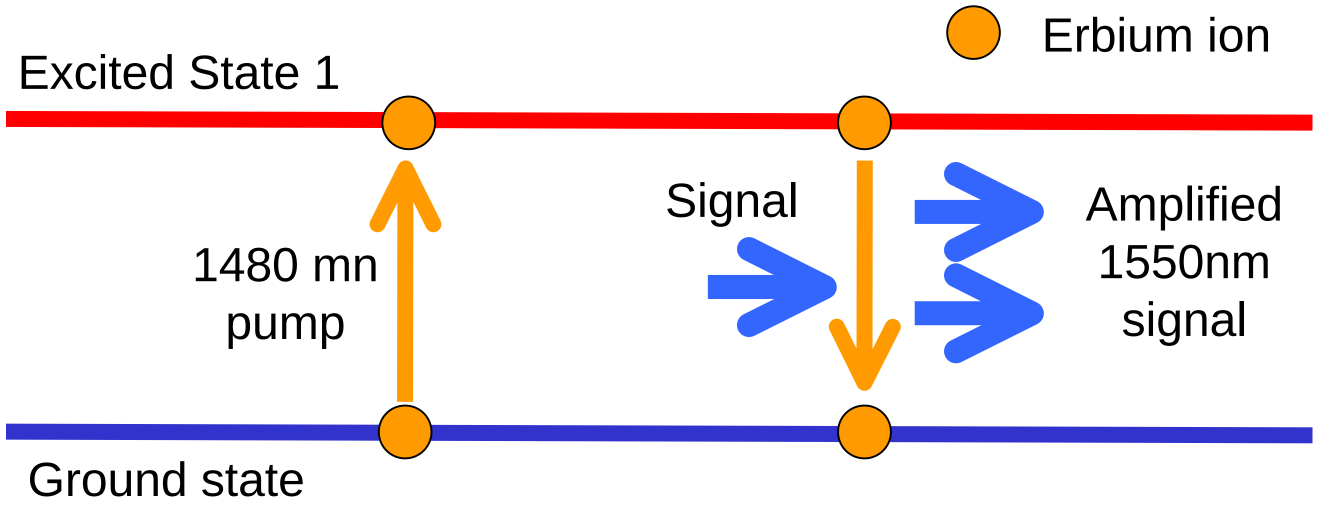
Erbium Doped Fiber Amplifier

EDFA optical amplifiers are made of short lengths (a few meters) of optical fiber doped with the element erbium. A pumping laser excites erbium ions in the fiber, which can then give their energy to the optical signals passing through.

Amplified wavelength: about 1550nm

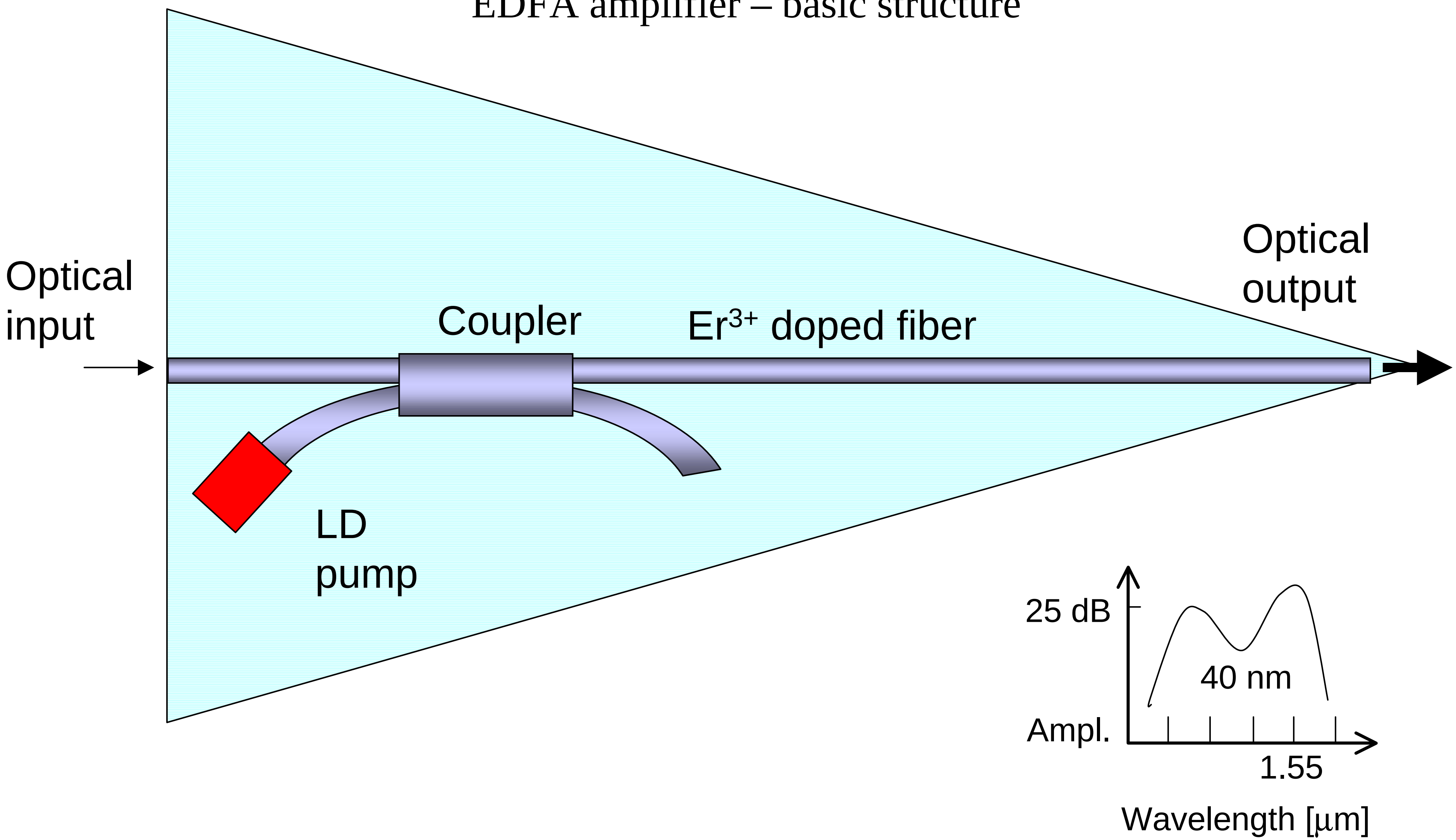
Pump wavelengths: 980 and/or 1480.

Erbium Excitation/Emission



Pump signals - 1480 nm and/or 980 nm. Erbium ions stays in excited state for about 10 ms (time is longer for 980 nm).

EDFA amplifier – basic structure



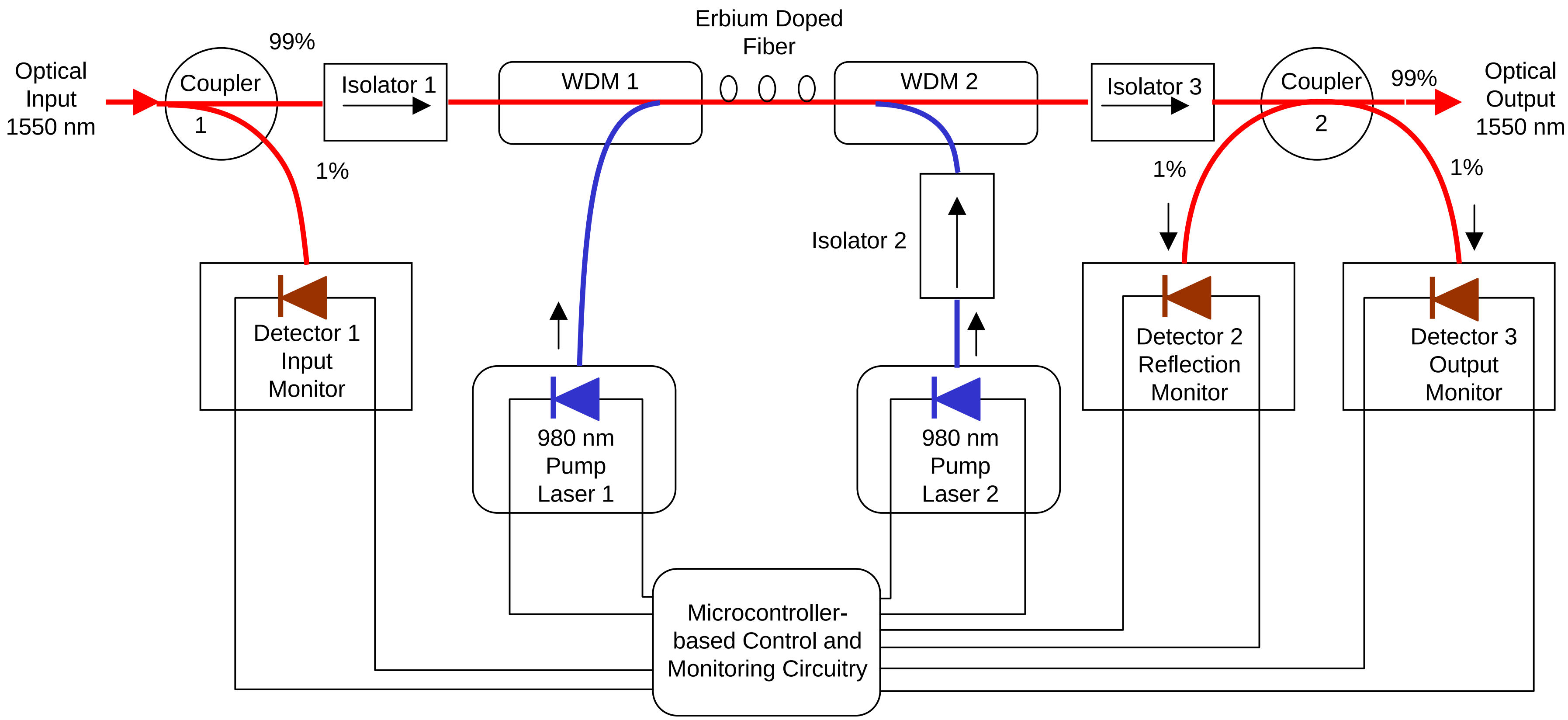
ASE

Amplified Spontaneous Emission (ASE): A background noise mechanism common to all types of erbium-doped fiber amplifiers (EDFAs). It contributes to the noise figure of the EDFA which causes loss of signal-to-noise-ratio (SNR).

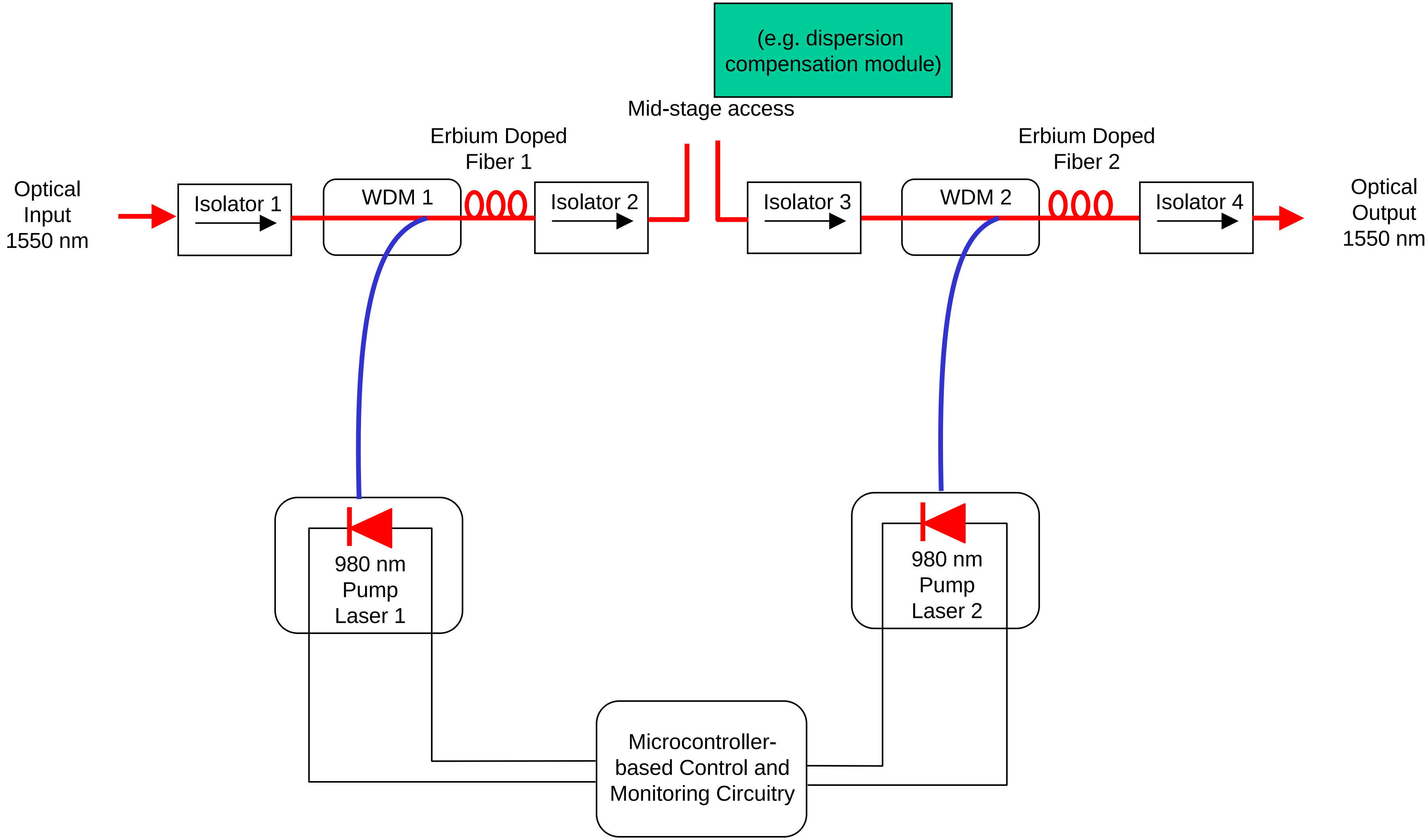
EDFA parameters

- wide bandwidth - 40 nm (5000 GHz)
- high amplification - 30 do 40 dB
- high output power - do +20dBm (100 mW)
- low noise - 4 dB (Noise factor F)
- pump wavelength - 980 or 1480 nm
- no dispersion compensation

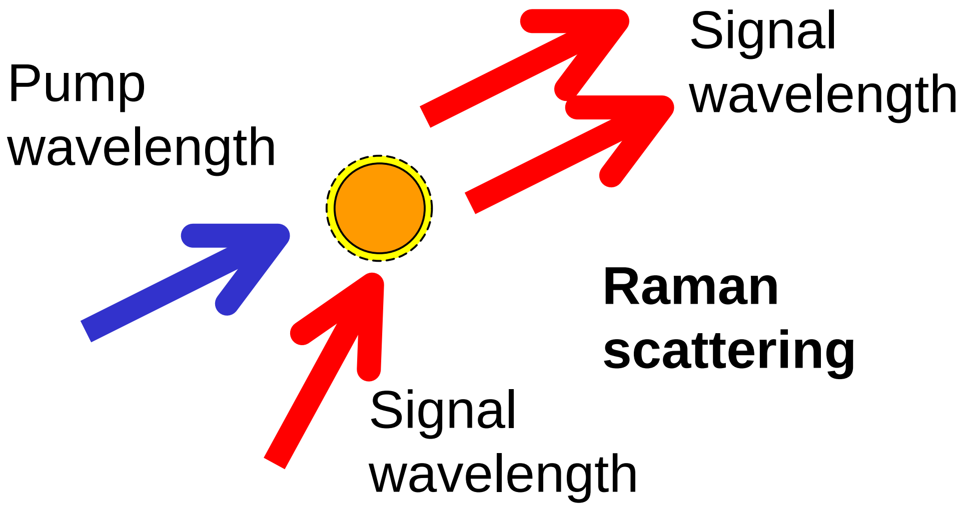
Block diagram of a full-featured EDFA amplifier



Two-stage EDFA with Mid-stage Access

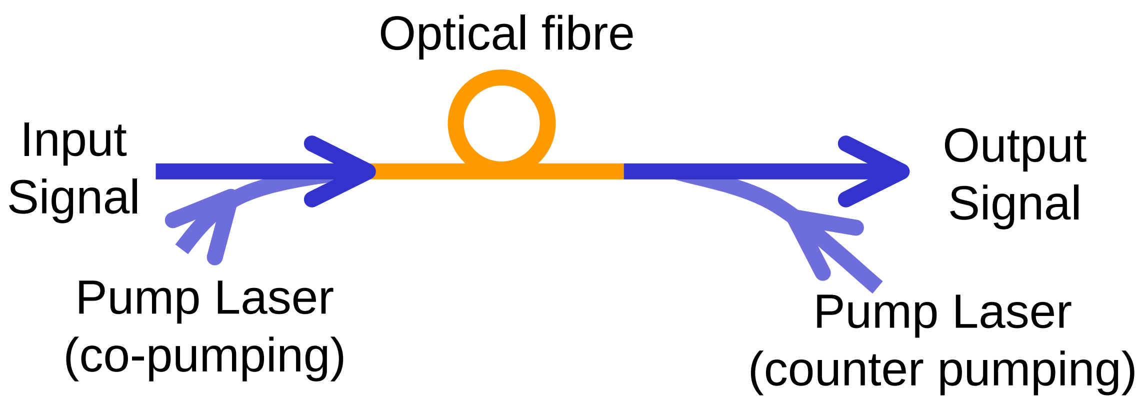


Raman Scattering



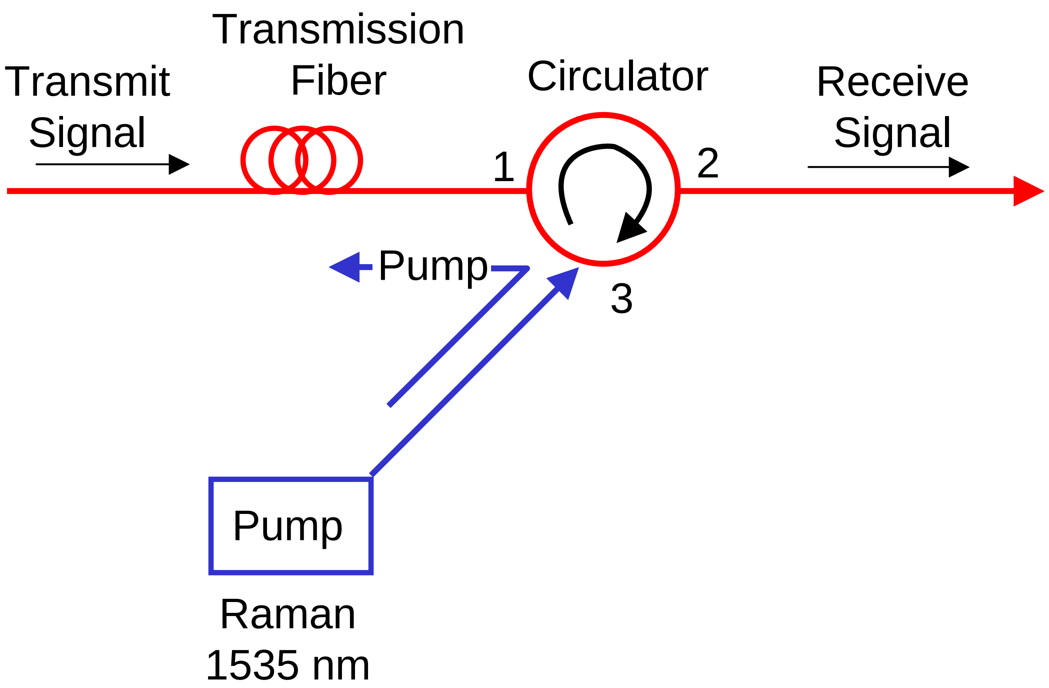
The principle of Raman scattering is that a lower wavelength pump-laser light traveling down an optical fiber along with the signal, scatters off atoms in the fiber, loses some energy to the atoms, and then continues its journey with the same wavelength as the signal.

Raman Amplification

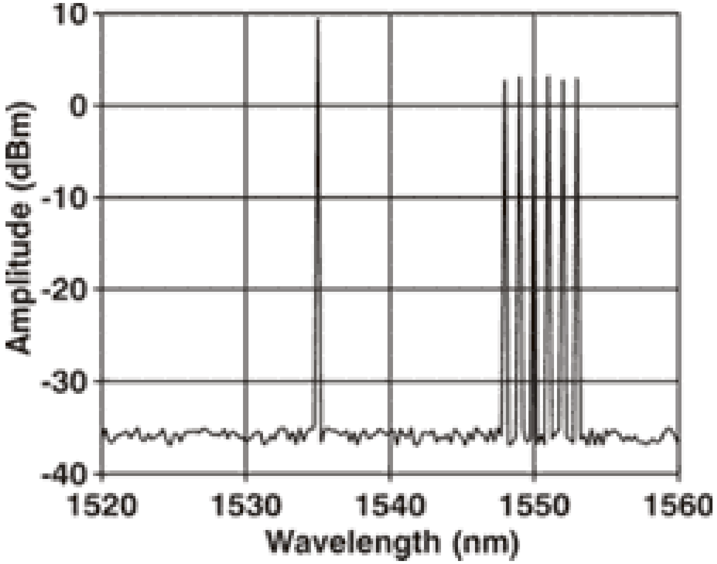


Raman amplification requires no special doping in the optical fiber. It is usually accomplished as “distributed' amplification” — that is, it happens throughout the length of the actual transmission fiber, rather than all in one place in a small box (as is the case with an EDFA).

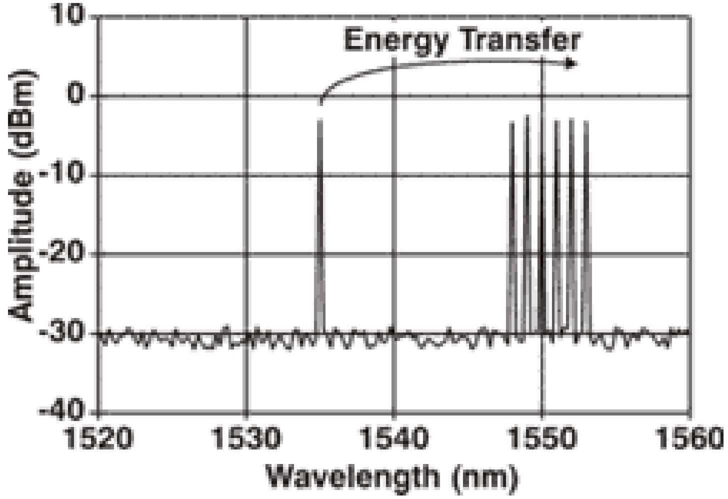
Typical Raman Amplifier Configuration



Raman amplification



Transmitted Spectrum



Received Spectrum

Comparison of EDFA, SOA and EDWA

Technology	Description	Advantage	Disadvantage	Suppliers
Erbium Doped Fiber Amplifier (EDFA)	Standard beyond 2005	Known technology; proven manufacturable	Higher cost	Corning, JDS Uniphase, Agere, Alcatel Optronics, Nortel HPOCS, Avanex, Altamar, Onetta, Keopsys
Semiconductor Optical Amplifier (SOA)	Discrete InP-based component	Potential low cost; ease of integration; small size	Low output power; high noise; immature technology	Alcatel Optronics, Genoa, JDS Uniphase, Nortel HPOCS, Optical Crossing, Kamelian, OptoSpeed
Erbium Doped Waveguide Amplifier (EDWA)	Planar waveguide amplifier	Potential low cost; small size	Immature technology; difficult to manufacture	Teem Photonics, Cisilias, Northstar Photonics, Symmorphix

Christine Mulrooney, Optical Amplifiers--the Metro Story, CIR Whitepaper

Optical amplification, a beverage story

Imagine the scene. You are a “bit” of information traveling through an optical fiber. When you were born at the laser, all those milliseconds ago, you were strong, on top of your game, and ready to take on the world. But then, a few tens of kilometers later, the optical fiber has sapped most of your strength, and you are only a fraction of the optical pulse that you used to be. You need a quick pick-me-up so you enter a mysterious place called the “Amplifier.” This small box that you travel through gives you the vital boost that you so desperately needed, and you exit the amplifier as bold as you were at birth. So what happened in that little box?

You may like to think of an amplifier as one of those drinks tables you see during marathons. A traditional amplifier only has stocks of Electrical Holy Water, and so, as an agnostic pulse of light, you first have to be converted to the religion of electricity before you can take aboard the much-needed boost to your energy. But there is no place for religion within optical fiber, and so you have to be put back into the irreligious optical state again before you leave the amplifier, fresh and boosted after the water has cleansed your soul. As you may imagine, this process is far from ideal. It is lengthy and expensive, involving many stages of conversion, missions to pagan outposts, and many Sunday mornings spent repenting.

To avoid this unnecessary expense and complication, you may wish instead to visit an optical amplifier drinks table. This one is handing out bottles of Optical Energy Juice that requires no religious conversion before consumption. You simply run up to the table as a weakened pulse of light, take a sip of the magical juice as you travel through, and then continue through the fiber refreshed. You must be a little careful however, as your own signal is not the only thing to be boosted. Your breath, a mephitic stench after such a long distance of travel, is made even worse with that isotonic drink aftertaste in your mouth. This amplification of the “noise” within you, although not too serious at the moment, could affect your performance further down the fiber.

The amount of amplification that takes place is known as “gain” and is usually given in units of dB. Just as with runners, there are several positions at which an optical signal may need an energy boost. At the start of the race, the runner may have an energy drink, along with some early morning exercises to get the blood pumping. Optical signals can also get a boost just after they have left the laser, which is known as “power amplification.” An amplifier in the middle of the link (like a drinks table) is known as a “line amplifier.” A final boost may be required as the runner crosses the finishing line and as the optical signals reach the detectors: Such amplification at the end of the system is called “pre-amplification.”

From: www.lightreading.com/document.asp?doc_id=3483

EDFA, a beverage story continued

An erbium doped fiber amplifier (EDFA) consists of a few meters of optical fiber doped with a few parts per million of the rare earth element erbium. The optical signal is injected into this fiber, along with the light from a special “pump” laser that is designed to excite the erbium ions.

Let us think of regular optical fiber as a sensible and studious college student who drinks only mineral water. We can then consider an erbium-doped fiber a beer-swilling frat boy who drinks regularly. He has a slight difference to his composition (erbium doping) that makes him enjoy drinking to the point where he will have repeated bouts of physical sickness. So when you pump this guy with, say, a pint of beer, he is excited into a higher state of drunkenness, just as the erbium ions are excited into higher energy states when pumped by a laser. If you continue the pumping, feeding the student with beer and the fiber with laser light, both become excited to the point where they can be excited no more. An incoming optical signal can now be thought of as a double whisky. The double whisky goes into the student, but instantly comes back out, magnified several times with a flurry of liquid from the earlier pumping. And so the optical signal exits the EDFA having been increased in intensity several times over.

Erbium has several energy levels, but its ions are usually in the ground state (unexcited, alcohol free). The ions can be excited with a 1480-nanometer pump laser into the first excited state. If left there for long enough, they will fall back down to the ground state, just as the effects of alcohol will wear off after a while. When falling back to the ground state, the ions have some extra energy to get rid of, which they each give out as a photon (a single “particle” of light). Think of this as the student relieving himself in a dumpster if you must. This is called spontaneous emission because the ions fall back to the ground state and give out photons without any aid whatsoever. Such spontaneous emission can build up in the amplifier and is known as “amplified spontaneous emission” or ASE. ASE is an undesirable effect and adds “noise” to the amplifier system.

If an optical signal is incoming at around 1550nm however, it can *cause* some of those excited ions to fall down to the ground state and give out a photon each. This is *stimulated* emission because the signal is directly causing the photons to be emitted. The emitted photons are at the exact same wavelength as the signal and so are now a part of the signal. The signal now has more photons representing it than before, so it has been amplified. This process can continue down the few meters of this fiber, until lots of photons have joined the signal photons and the signal has been greatly amplified. This can happen at several wavelengths around 1550nm, and amplification can be achieved via fancy EDFA designs for signals between around 1530nm and 1580nm, which is known as “C-band” (Conventional-band) amplification. EDFAs can also be designed to give amplification between around 1580nm and 1610nm, which is known as the L-band (Long-band). The amount of amplification at different wavelengths can vary, and there is much effort put into EDFA designs to achieve similar levels of amplification at all wavelengths, known as “gain flattening.”

If you think of the 1480nm pump laser as a pint of regular beer, then you can think of a 980nm laser pump as a pint of super-strength lager. The 980nm pump excites the erbium ions into a much higher state than the 1480nm pump. However, the ions only stay in that higher state for a very short period of time (maybe nanoseconds) before moving down to the next state. Once there, they stick around for several milliseconds, which is much longer than ions excited by the 1480nm pump. The longer they remain in the excited state, the more likely it is that the signal will come along and cause stimulated emission. This also reduces the unwanted spontaneous emission that adds to the noise in the system. Therefore 980nm pumps give greater amplification efficiency and are the preferred pump method for EDFAs. Just as super-strength lager is generally the most efficient solution for students.

Books

1. P. C. Becker, N.A. Olsson, J.R. Simpson, Erbium-Doped Fiber Amplifiers: Fundamentals and Technology Academic Pr 1999

2. Emmanuel Desurvire Erbium-Doped Fiber Amplifiers : Principles and Applications, John Wiley & Sons 1994

3. S. Sudo (Editor), Optical Fiber Amplifiers : Materials, Devices, and Applications (Artech House Optoelectronics Library), Artech House 1997

4. Govind P. Agrawal, Nonlinear Fiber Optics, Second Edition, Academic Pr 1995