Optical amplifiers homework solutions

These are the homework questions solutions from Group Best.

Question 1 – Semiconductor optical amplifiers **(3.0 p)**

Write a short essay explaining the following: What is a Semiconductor Optical Amplifier? How does it differ from semiconductor lasers? Additionally, list some of the downsides of using SOAs for general signal amplification.

An example of an answer:

A Semiconductor Optical Amplifier (SOA) is a device that amplifies an optical signal by using the absorption and re-emission of photons in a semiconductor material. The amplification occurs through the process of stimulated emission, where an incoming photon with energy equal to or greater than the semiconductor's bandgap energy causes an electron to transition from the valence band to the conduction band, releasing a photon with the same energy and phase as the incoming photon.

SOAs differ from semiconductor lasers in several ways. First, SOAs do not have a resonant cavity, which is necessary for laser action. On the contrary, the SOAs typically have an anti-reflection coating on them. Second, SOAs are not usually operated in a continuous wave mode, which means that they do not produce a steady output power. Instead, they are operated in a pulsed or a quasi-CW mode, which means that the output power varies with time. If necessary for the application, they can be operated in the continuous wave mode too. This is usually as a pulse form for data amplification in telecommunications.

One of the downsides of using SOAs for general signal amplification is that they have a relatively low gain compared to other types of amplifiers. This means that they require a higher input power to produce a given output power. Additionally, SOAs are sensitive to temperature and bias conditions, which can affect their performance. Furthermore, SOAs have a high noise figure, which means that they add a significant amount of noise to the amplified signal. This noise can be mitigated by using cascaded SOAs, but this increases the complexity and cost of the system. (3.0 p)

Question 2 – Raman amplifiers **(2.5 p)**

2.1 - What is the basic principle behind Raman amplifiers? (0.5 p)

a) Erbium-doping
b) Stimulated Raman Scattering
c) Amplified Spontaneous Emission
d) Four-wave mixing
e) All of the above

2.2 - Which of following aspects affect the Raman gain? (0.5 p)

a) Pump laser power
b) Polarization of pump laser
c) Input signal wavelength
d) Input signal power
e) Fiber used
f) Pump laser signal wavelength
g) Direction of pumping
h) All of the above

2.3 - What is the signal-to-noise ratio of a Raman amplifier mainly dependent on? (0.5 p)

a) The noise characteristics of the pump laser
b) The signal-to-noise ratio (SNR) of the input signal
c) The length of the fiber
d) The gain of the Raman amplifier
e) All of the above

2.4 - How does the fiber length affect the Raman gain when the Pump laser power is constant? (0.5 p)

a) The Raman gain increases with increasing fiber length (partially correct)
b) The Raman gain decreases with increasing fiber length
c) The Raman gain is not affected by the fiber length
d) The Raman gain is affected by the fiber length, but the relationship is complex and nonlinear.

2.5 - There is a maximum Raman gain for a frequency offset of 13.2 THz, causing pump wavelength of 1456 nm to create peak-signal of 1550 nm. The pump of 1066 nm causes 1116 nm peak signal (See page 12 of lecture 4 notes.) Calculate the maximum Raman gain's amplitude (in nm) if the pump wavelength is 1200 nm. Show your calculation. (0.5 p)

Note: The differences, 1550-1456 = 92 nm, and 1116-1066 = 50 nm, are not equal.

1200 nm = 249.827 THz
249.827 THz - 13.2 THz = 236.627 THz
236.627 THz = 1266.94 nm
Any close-by answer is good, as long as calculation is done right.

Question 3 – Erbium-doped fiber amplifiers **(2.5 p)**

a) Draw a block diagram of an EDFA system and name each part in the amplifying system. (0.5 p)

An image representing the one given in lecture materials will suffice for the points. Must be self-made and include at least the isolators, WDM, pump laser, EDF and the signals in and out.

b) Briefly explain the purpose of each part you named. (0.5 p)

The answer should show that everyone understands how each part works on a basic level. Explanations given during lectures will be enough. Examples:

- Isolators: Use of polarization to prevent light going to the wrong direction.
- WDM: To send a laser to EDFA, it must be multiplexed in to the EDF. This is done by the Wavelength Division Multiplexing (WDM) coupler. It joins several optical carrier signals onto a single optical fiber.
- Pump laser: The laser is for pumping the doping wavelength into the system. Usually 980 or 1480 nm laser is used.
- EDF: The EDF itself is the part where the amplifying happens, so new photons are created by stimulated emission.
- Signals: Input and output signals at 1550 nm, output now amplified.

c) Explain how noise is generated in the EDFA? (1.0 p)

Noise in an EDFA is due to the Amplified Spontaneous Emission (ASE). This usually occurs when some of the excited Erbium decays to the ground state before meeting the incoming signal photon, which results in the photon to be emitted with random direction and phase. These emitted photons can occur to be in the same direction as the fiber which cannot be distinguished from the signal by the amplifier and is there by amplified.

d) Explain why EDFAs can only be used for a narrow wavelength spectrum (1.53-1.56 µm)? (0.5 p)

The narrow spectrum is limited by the Erbium energy level that produces the new photon only at this specific wavelength area, thus it cannot amplify any other wavelengths.

Question 4 – The usage and properties of optical amplifiers **(2.0 p)**

What are the most common uses for the following optical amplifiers? (1.0 p)

List one positive and negative aspect of each amplifier (SOAs, Raman amplifiers, EDFAs). (1.0 p)