1.

a:

(i) Spontaneous emission: after electrons are excited from valence band to conduction band, the electrons will fall back to the valence band quickly, and then emit photons with random phases and directions.

(ii) Stimulated emission: photons stimulate recombination between electrons and holes, and then the electrons will fall back to the valence band and thus emit photons with the same phase, direction and energy.

(iii) Population inversion: normally, the number of electrons in a system decreases exponentially with an increase in energy of the electronic states. However, under certain conditions, the number of the electrons at a high energy state can be higher than that at a low energy state.

b:

(i) Laser diode: it requires not only stimulated emission, but also an optical cavity in order to generate optical feedback. Basically, a laser structure consists of a gain medium and an optical cavity.
(ii) Optical amplifier: it is based on stimulated emission in order to obtain optical amplification, which is similar to laser. However, it does not require an optical cavity, which is different from laser.
(iii) Light emitting diodes: it is based on spontaneous emission.

c:

(i) For a 100 μm cavity, the mirror loss $\alpha_m = \frac{1}{2l}\ln\frac{1}{R_1\times R_2}$ (here, $R_1=R_2=R$)

$$R=\left(\frac{n-1}{n+1}\right)^2=\left(\frac{3.6-1}{3.6+1}\right)^2=0.32$$

$$\alpha_m=\frac{1}{2l}\ln\frac{1}{R_1\times R_2}=114cm^{-1}$$

(ii) Optical confinement factor

$$\Gamma=1-\exp(-C\Delta nd)=1-\exp(-8\times10^{7}\times(3.6-3.58)\times1\times10^{-6})=0.8$$

(iii) Gain coefficient $g=\frac{1}{\Gamma}(\alpha_i+\frac{1}{2l}\ln\frac{1}{R_1\times R_2})=\frac{1}{0.8}(100+\frac{1}{0.01}\ln\frac{1}{0.32})=267.5cm^{-1}$

(iv) $g=\frac{1}{\Gamma}(\alpha_i+\frac{1}{2l}\ln\frac{1}{R_1\times R_2})=\frac{1}{0.8}(100+\frac{1}{2L}\ln\frac{1}{0.32\times0.90})=267.5cm^{-1}$

L=54.5 μm

d:

You increase (1) the reflectivity of the coated facet to 100%, such as using DBR, or (2) increase the contrast of refractive index between the active region and cladding region, such as increasing Al composition, or (3) optimise the cavity length.

2

a

(i) Photoconductor: it is the simplest optical detector which exhibits an internal gain mechanism and a band-width limitation. It has a simple structure consisting of a conductor with two opposite contacts. The photo-generated electrons and holes move in opposite directions and are then collected by the contacts under an applied bias.

(ii) PIN photodiodes: it is a junction diode in which a i-region (i.e., undoped region) is sandwiched between p-doped and n-doped regions. It normally works under a high bias, and the transit time can be further reduced by reducing the thickness of the i-region, and thus the response speed can be very high. It leads to a wide bandwidth.

(iii) Avalanche photodiodes: it is a reverse-biased p-n junction operating under a bias which is close to the breakdown voltage. The photo-generated carriers undergo a series of impact ionisation processes during a transit in the depletion region, which leads to carrier multiplication and thus a very large gain. It can detect a very weak signal, but it also generates extra noise due to the avalanche process.

b

(i) Low noise: PIN photodiode

(ii) High gain: photoconductor or avalanche photodiode. An avalanche photodiode has a very large gain, which can detect a very weak signal.

(iii) Large bandwidth: PIN photodiode

c

(i) The quantum efficiency:

$$(1-e^{-\alpha L})(1-R) = (1-e^{-1\times10^{-4}\times 1\times10^{-4}})(1-0.4) = 0.63\times0.6 = 37.9\%$$

(ii) You can increase the thickness of the active region or use anti-coating in order to minimise reflection.

d

Responsivity: $R=\eta e\lambda/(hc)=0.8x1.60x10^{-19}x1.3x10^{-6}/(6.63x10^{-34}x3x10^{8})=83.7\%$

Primary current: $I_p=P_0R=1.0x10^{-6}x0.837=0.837x10^{-6}$

Multiplication factor: $M=I/I_p=20/0.837=23.9$

3

a

(i) There exist a number of mechanisms for optical loss in a silica fibre, mainly due to (1) Intrinsic absorptions including ultraviolet absorption and infrared absorption; (2) Rayleigh scattering; (3) OH^- (moisture) induced absorption; (4) Impurity induced absorption; (4) Fibre bending induced loss; (5) Reflection induced loss due to fibre connection

(ii) The ultraviolet absorption reduces with increasing wavelength to infrared region; the Rayleigh scattering induced loss reduces with increasing wavelength to infrared region; the infrared absorption reduces with reducing wavelength; the OH^- (moisture) induced absorption takes place at 1.4 μm, 1.24 μm, 0.95 μm, etc

(iii) Two best optical windows for optical communication: a region centre at 1.3 μm and a region at 1.55 μm; there exists a severe OH^- (moisture) induced absorption at 1.4 μm between 1.3 μm and 1.55 μm.

b

There exist two kinds of major mechanisms for optical dispersion: (1) Material dispersion: different group velocities of the various spectral components from the optical source; (2) Waveguide Dispersion: there exists a small fraction of the optical power propagating in the cladding layer and this is wavelength dependent, leading to the time difference delay

c

Optical loss: There exists a detection limit for any receiver, and thus the final optical power received by the detector should be higher than the limit, otherwise, it will cause a substantial bit-error rate.

Optical dispersion: There does not exist any purely monochromatical light, and thus optical pulses will broaden as they propagate in an optical fibre due to dispersion. The broadening can be so great that two consecutive pulses can be not clearly identified.

d

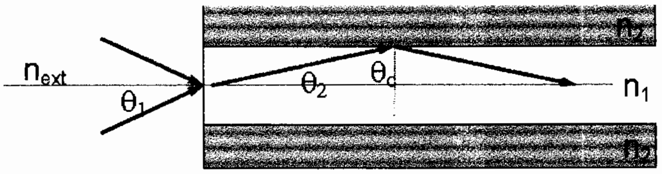
(i) Maximum loss=3dBm-(-35dBm)+10dB-0.3dBx10-0.1dBx2-10dB=34.8dB

(ii) EDFA is Erbium-doped Fibre Amplifier. Erbium doping into silica generates a number of electronic states, among which an optical transition with a transition energy of ~0.8 eV (corresponding to 1.55 um) can be obtained. A high power laser diode with a wavelength of 980 nm (commercially available) as a pumping source can lead to population inversion, and thus optical amplification at 1.55 μm

(iii) L=34.8/0.2=174km

4

a



According to Snell's Law and requirements for total internal reflection, we obtain: $\sin\theta_c = n_2/n_1$

According to Snell's Law, we can obtain $n_{ext}\sin\theta_1 = n_1\sin\theta_2 = n_1\cos\theta_c$

Based on $\sin^2\theta + \cos^2\theta = 1$, $n_{ext}\sin\theta_1 = \sqrt{n_1^2 - n_2^2}$, which is defined as Numerical Aperture

Numerical aperture is a measure of the light gathering ability of an optical fibre. It can be increased by increasing the refractive index contrast between core and cladding layers, or immersing it in a medium with a high refractive index.

b

In order to allow light rays to transmit in a waveguide stable, they need to meet two conditions: (1) The incident angle of light rays in a waveguide need to meet the requirements for total internal; (2) Only light rays with constructive interference can travel in a waveguide stably: same phase or phase difference must be equal to $m(2\pi)$, where m is 0, 1, 2, 3.... Therefore, only a number of certain angles can meet both above conditions, and thus form optical modes. Each incident angle corresponds to an optical mode. m is defined as an optical mode number.

c:

(i) NA= $\sqrt{n_1^2 - n_2^2}$ =0.163

(ii) $$m \le \frac{2d}{\lambda}\sqrt{n_1^2 - n_2^2} = \frac{2\times 100\times 10^{-6}}{1.3\times 10^{-6}}\times 0.163 = 25$$

(iii) You can reduce the thickness of the core layer, i.e., reduce "d".

(iv) Modifying the above equation for m, the thickness of the core layer for a single optical mode

$$d = \frac{\lambda}{2\sqrt{n_1^2 - n_2^2}} = 3.99\mu m$$