21.1 A fiberoptic microwave link has the following characteristics. The overall transmitter efficiency is 10 mW/mA. The overall efficiency of the receiver is 3 mA/mW. The ratio of optical power @ transmit to the optical power @ receive is 2.5. The input resistance of the transmitter and the output resistance of the receiver are both 50 Ω. What is the overall link gain?

Solution.

\[ G_{\text{link}} = 20 \log(\eta_{\text{txrf}} \cdot \eta_{\text{rxrf}}) - 20 \log L_{\text{opt}} + 10 \log\left(\frac{R_{\text{out}}}{R_{\text{in}}}\right) \]

\[ G_{\text{link}} = 20 \log(10 \cdot 3) - 20 \log 2.5 + 10 \log(50/50) \]

\[ = 20 \log(1.477) - 20 \log(0.398) + 10 \cdot 0 \]

\[ = 21.58 \text{ dB} \]

21.4 If the current out of a fiberoptic microwave link is 30 times larger than the input current and the output resistance of the receiver is 1/2 the input resistance of the transmitter, what is the link gain in dB?

Solution.

\[ G_{\text{link}} = \left(\frac{I_{\text{out}}}{I_{\text{in}}}\right)^2 \left(\frac{R_{\text{out}}}{R_{\text{in}}}\right) \]

\[ = (30)^2(1/2) = 450 \]

\[ G_{\text{link dB}} = 10 \log 450 = 26.53 \text{ dB} \]
21.5 Name 4 major improvements in integrated optic technology that have occurred over the past 20 years that have led to modern lightwave telecommunications.

**Solution.** (Any four of the following)
- DFB lasers
- Low-loss, single-mode optical fibers
- Low-loss single-mode couplers
- Optical amplifiers
- Optical modulators with data rates > 10 GHz
- DWDM couplers and switches

21.6 What are the advantages of using a substrate of GaAs or InP in an opto-microwave-monolithic-integrated-circuit (OMMIC)?

**Solution.**
The properties of GaAs and InP are well suited to both optical integrated circuits and microwave integrated circuits. (See Table 21.1a)

<table>
<thead>
<tr>
<th>Table 21.1a–c. Material properties of GaInAsP and GaAlAs desired for OICs and MMICs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Desired in OICs</strong></td>
</tr>
<tr>
<td>• Transparent in visible and near IR</td>
</tr>
<tr>
<td>• Direct bandgap — can make both efficient light emitters and detectors</td>
</tr>
<tr>
<td>• Energy bandgap and index of refraction can be conveniently controlled by changing composition to produce emitters, detectors and waveguides for a given wavelength</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Desired in MMICs</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• High electron mobility for high-gain transistors</td>
</tr>
<tr>
<td>• High scattering-limited velocity for high-frequency transistors</td>
</tr>
<tr>
<td>• Semi-insulating doping possible — can deposit microwave striplines directly on semiconductor surface</td>
</tr>
</tbody>
</table>

21.7 An analog microwave signal is transmitted over an optical fiber link by using the signal to modulate an optical beam and demodulating it at the receiver. The peak input current at the modulator is 10 mA and the peak output current at the demodulator is 15 mA. If the input resistance of the modulator and the output resistance of the demodulator are both 50 • , what is the link gain in dB?

**Solution.**

\[
G(\text{dB}) = 10 \log_{10}(P_2/P_1) = 20 \log_{10}(I_2/I_1) = 20 \log_{10}(15/10) = 3.52 \text{ dB}
\]
22.1 Describe how a photonic crystal guides light. What is the basic principle (mechanism) responsible for the guiding?

Solution.
Photonic crystals guide light by the distributed Bragg Reflection mechanism. Because of the periodic structure of discontinuities in a photonic crystal, plane waves introduced parallel to the rows of discontinuities travel without scattering loss. However, for wavelength $\sim 2a$, where $a$ is the lattice constant (length between discontinuities), no light can propagate and a “photonic bandgap” exists.

22.3 An ideal lens of diameter $= 5$ cm and focal length $= 1$ m is used to focus light of wavelength $= 1.55$ $\mu$m.

(a) What is the size of smallest object that the lens can resolve according to the Rayleigh criterion?

(b) If the same lens is used in a practical lithographic projection exposure system with resist factor $k = 0.80$, what is minimum feature size that can be produced? Hint: Assume $NA = D/2f$

Solution.
(a) 
\[ l = 1.220 f \cdot / D = 1.220 \times 1 \times 1.55 \times 10^{-6} / 5 \times 10^{-2} = 3.782 \times 10^{-5} \text{ m} = 37.82 \mu\text{m} \]

(b) 
\[ NA = D/2f = 5 \times 10^{-2}/2 \times 1 = 2.5 \times 10^{-2} \]

\[ W_{\text{min}} = k \cdot f \cdot / D \cdot k \cdot / NA = 0.80 \times 1.55 \times 10^{-6}/2.5 \times 10^{-2} = 4.96 \times 10^{-5} = 49.6 \mu\text{m} \]

22.4 What is the De Broglie wavelength of an electron traveling on a vacuum with a velocity $= 2 \times 10^7$ $\text{m/s}$?

Solution.
The de Broglie wavelength is given by:
\[ \lambda = h / mv = 6.63 \times 10^{-34} / 2 \times 10^7 \times 9.11 \times 10^{-31} = 3.6 \times 10^{-11} \text{ m} \]

Note: If the velocity were to approach the velocity of light the above equation for $\lambda$ would have to be multiplied by a factor of $(1-v^2/c^2)^{1/2}$.

22.6 A plane wave is traveling in a two-dimensional rectangular photonic crystal lattice with lattice constant $= 660$ nm. What wavelength(s) of light will be blocked and not able to propagate?
Solution.

Wavelengths of $\lambda = 2a = 2(660) = 1320$ nm will be blocked.

22.7 What are the two growth methods used to produce layers in III-V semiconductors like GaAs and InP? Explain the special steps that must be taken in order to grow nanolayers as opposed to microlayers.

Solution.

The two growth methods used to produce nanolayers in III-V semiconductors like GaAs and InP are molecular beam epitaxy (MBE) and metalorganic vapor phase epitaxy (MOVPE). Certain additions and modifications must be made to the basic MBE system shown in Fig. 4.13 to qualify it for nanolayer fabrication. (See Section 22.5.1 for details). A basic horizontal-flow MOVPE reactor is shown in Fig. 22.10. For the growth of nanolayers by MOVPE special efforts must be made to provide the uniformity and control of growth rate that is required. (See Section 22.5.2 for details).