Lectures of optoelectronics

Name of the lecturer: Assist. Prof. Dr. Salah A. Adnan

Branch: Laser Eng.

Class: Fourth Year

References: 1) Optoelectronics An Introduction By John Wilson & John Hawkes

2) Introduction To Laser Technology By Breck Hits , J.J. Ewing

FIRST LECTURE

1. Nature of light

During the seventeenth century two emission theories on the nature of light were developed, the wave theory of Hooke and Huygens and the corpuscular theory of Newton. Subsequent observations by Young, Malus, Euler and others lent support to the wave theory. Then in 1864 Maxwell combined the equations of electromagnetism in a general form and showed that they suggest the existence of transverse electromagnetic waves. The speed of propagation in free space of these waves was given by

$$c = \sqrt{\frac{1}{\mu_0 \epsilon_0}} \tag{1.1}$$

This is called the *wave equation*; it is encountered in many different kinds of physical phenomena such as mechanical vibrations of a string or in a rod. The implication of eq. (1.3) is that *changes* in the fields propagate through space with a speed c, the speed of light. The frequency of oscillation of the fields, ν, and their wavelength in vacuum, λ_0, are related by

$$c = \nu\lambda_0 \tag{1.4}$$

In any other medium the speed of propagation is given by

$$v = \frac{c}{n} = \nu\lambda = \nu\,\frac{\lambda_0}{n} \tag{1.5}$$

where n is the refractive index of the medium and λ is the wavelength in the medium (later in the text we often drop the subscript from the vacuum wavelength λ_0 to simplify the notation). n is given by

$$n = \sqrt{\mu_r \varepsilon_r} \tag{1.5a}$$

where μ_r and ε_r are the relative permeability and relative permittivity of the medium respectively.

The electric and magnetic fields vibrate perpendicularly to one another and perpendicularly to the direction of propagation as illustrated in Fig. 1.1; that is, light waves are transverse waves. In describing optical phenomena we often omit the magnetic field vector. This simplifies diagrams and mathematical descriptions but we should always remember that there is also a magnetic field component which behaves in a similar way to the electric field component.

The simplest waves are sinusoidal waves, which can be expressed mathematically by the equation

$$\mathscr{E}(x, t) = \mathscr{E}_0 \cos(\omega t - kx + \phi) \tag{1.6}$$

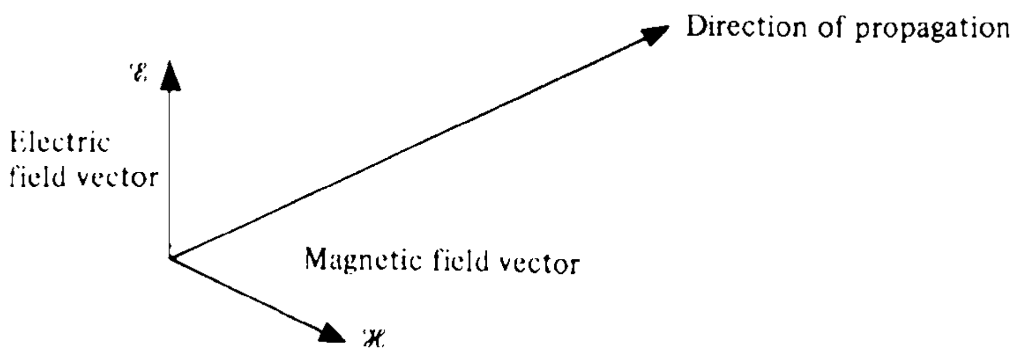


FIG. 1.1 Electromagnetic wave: the electric vector ($\mathscr{E}$) and the magnetic vector ($\mathscr{H}$) vibrate in orthogonal planes and perpendicularly to the direction of propagation.

where $\mathscr{E}$ is the value of the electric field at the point x at time t, $\mathscr{E}_0$ is the amplitude of the wave, ω is the angular frequency ($\omega = 2\pi\nu$), k is the wavenumber ($k = 2\pi/\lambda$) and ϕ is the phase constant. The term ($\omega t - kx + \phi$) is the phase of the wave. Equation (1.6), which describes a perfectly monochromatic plane wave of infinite extent propagating in the positive x direction, is a solution of the wave equation (1.3).

We can represent eq. (1.6) diagrammatically by plotting $\mathscr{E}$ as a function of either x or t as shown in Figs 1.2(a) and (b), where we have taken $\mathscr{E} = \mathscr{E}_0$ at x and t equal to zero so that $\phi = 0$. Figure 1.2(a) shows the variation of the electric field with distance at a given instant of time. If, as a representative time, we take t equal to zero, then the spatial variation of the electric field is given by

$$\mathscr{E} = \mathscr{E}_0 \cos kx \tag{1.6a}$$

Similarly Fig. 1.2(b) shows the variation of the electric field as a function of time at some specific location in space. If we take x equal to zero then the temporal variation of electric field is given by

$$\mathscr{E} = \mathscr{E}_0 \cos \omega t \tag{1.6b}$$

Equations (1.6) can be written in a variety of equivalent forms using the relationships between ν, ω, λ, k and c already given. We note also that the time for one cycle is the period T ($T = 1/\nu$) as shown in Fig. 1.2(b).

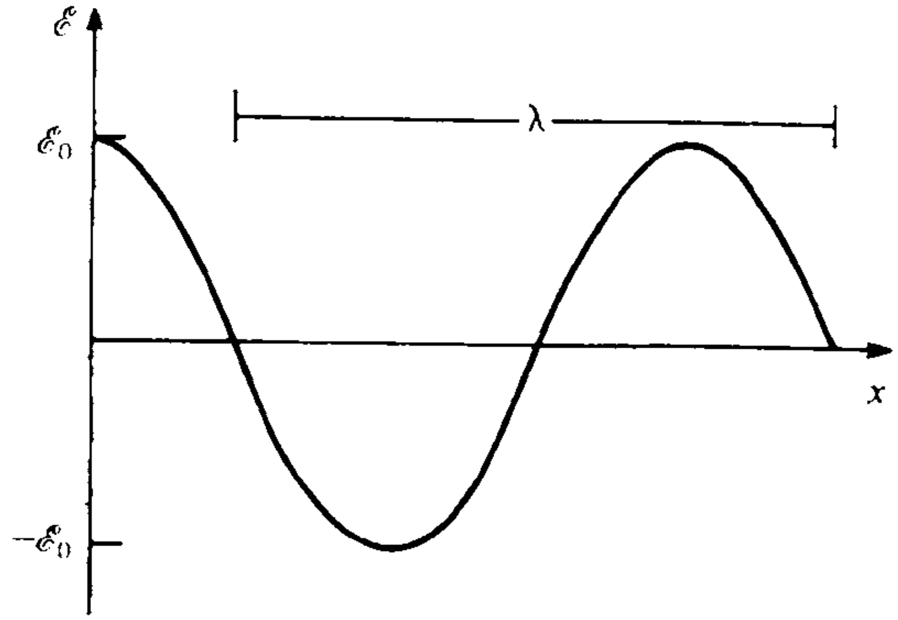
If the value of $\mathscr{E}$ at $x = 0$, $t = 0$ is not $\mathscr{E}_0$ then we must include the arbitrary phase constant ϕ. Equations (1.6) can also be expressed using a sine rather than a cosine function, or alternatively using complex exponentials.

In the plane waves described above and in other forms of wave there are surfaces of constant phase, which are referred to as wave surfaces or wavefronts. As time elapses the wavefronts move through space with a velocity v given by

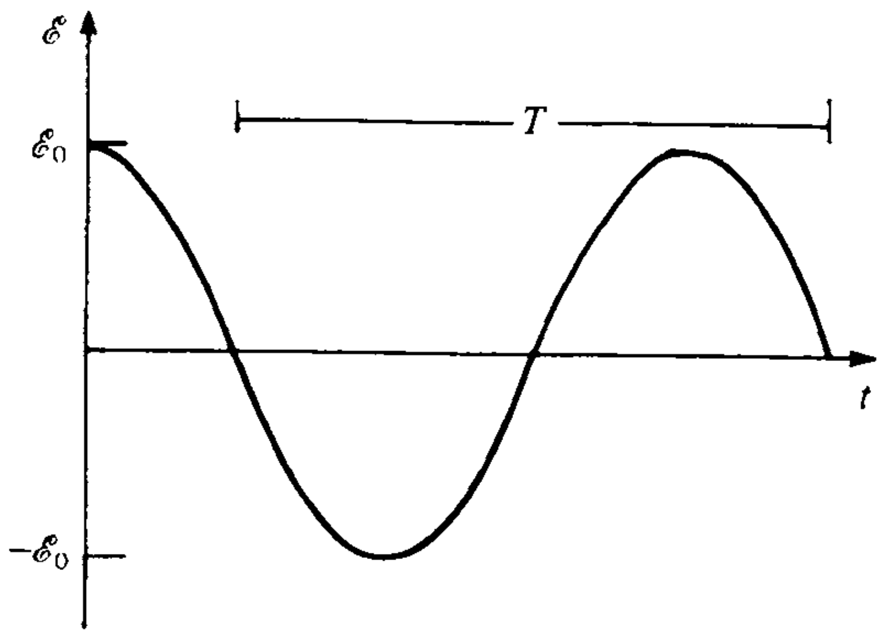
$$v = \omega/k = \nu\lambda \tag{1.7}$$

which is called the *phase* velocity. As it is impossible in practice to produce perfectly monochromatic waves we often have the situation where a group of waves of closely similar wavelength is moving such that their resultant forms a packet. This packet moves with the *group* velocity v_g. A discussion of this phenomenon based on the combination of two waves of slightly different frequencies moving together, which is illustrated in Fig. 1.3, shows that the group velocity is given by (see Problem 1.2)

$$v_g = \frac{\partial \omega}{\partial k} \tag{1.8}$$



(a)



(b)

2. polarization

If the electric field vector of an electromagnetic wave propagating in free space vibrates in a specific plane, the wave is said to be plane polarized. Any real beam of light comprises many individual waves and in general the planes of vibration of their electric fields will be randomly orientated. Such a beam of light is unpolarized and the resultant electric field vector changes orientation randomly in time. It is possible, however, to have light beams characterized by highly orientated electric fields and such light is referred to as being *polarized.* The simplest form of polarization is plane polarized light, which is similar to the single wave shown in Fig. 1.1. Other forms of polarization are discussed in section 3.1.

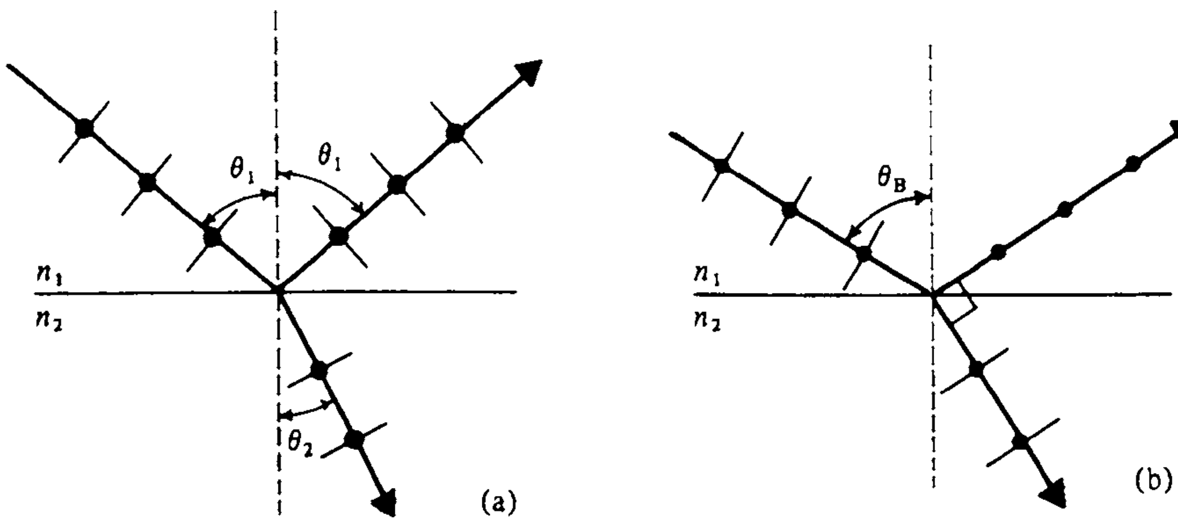


FIG. 1.5 In (a), a light reflected from the interface between two media of refractive index n_1 and n_2 is partially plane polarized (there is less of the parallel component ⟶ than the perpendicular component ⟶), while in (b) for incidence at the Brewster angle θ_B, the reflected light is completely plane polarized.