University of Anbar
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فيزياء المواد

Physics of Materials

المرحلة الثالثة
الكورس الاول

اعداد
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12 Optical Properties of Materials الخواص البصرية للمواد

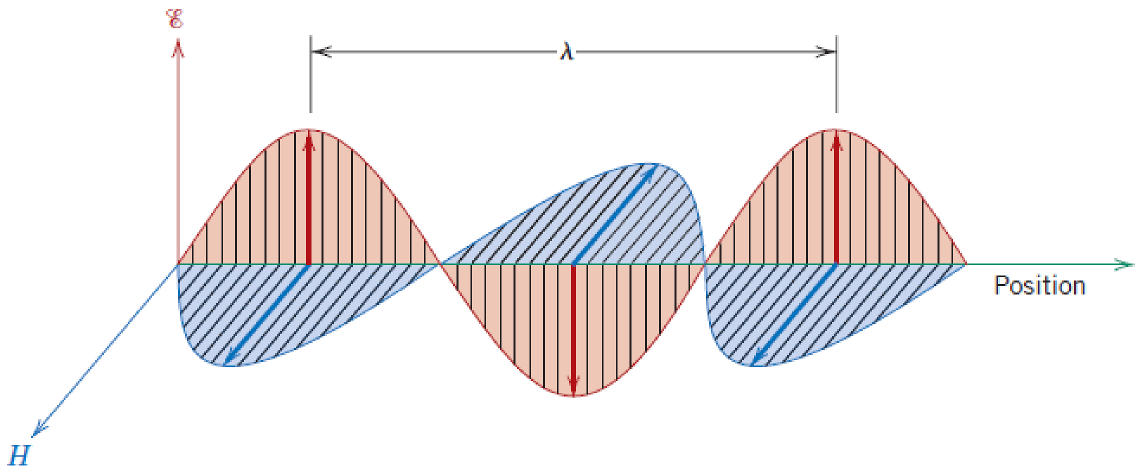
Optical property refers to a material’s response استجابة to exposure التعرض to electromagnetic radiation and, in particular وخصوصا, to visible light الضوء المرئي. The basic principles and concepts relating to the nature of electromagnetic radiation and its possible interactions with solid materials.

12.1 Electromagnetic Radiation

In the classical concept, electromagnetic radiation is considered to be wavelike, consisting of electric and magnetic field components that are perpendicular to each other and also to the direction of propagation Light, heat, radar, radio waves, and x-rays are all forms of electromagnetic radiation. Each is characterized primarily by a specific range of wavelengths, and also according to the technique by which it is generated.

• The optical behavior of a solid material is a function of its interactions with electromagnetic radiation having wavelengths within the visible region of the spectrum (about 0.4 μm to 0.7 μm).

• From a quantum-mechanical perspectiveوجهة نظر , electromagnetic radiation may be considered to be composedتتكون of photons groups or packets حزم of energy that are quantized, that is, they can have only specific values of energy.



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

Furthermore, the frequency ν and the wavelength λ of the electromagnetic radiation are a function of velocity according to

$$c = \lambda \nu$$

Frequency is expressed in terms of hertz (Hz), and 1 Hz = 1 cycle per second.

The energy E of a photon is said to be quantized, or can only have specific values, defined by the relationship

$$E = h\nu = \frac{hc}{\lambda}$$

where h is a Planck's constant, which has a value of 6.63×10^{-34} . Thus, photon energy is proportional to the frequency of the radiation, or inversely proportional to the wavelength.

12.2 Light Interactions With Solids

When light travels from one medium into another (e.g., from air into a solid substance), several things happen. Some of the light radiation may be transmitted through the medium, some will be absorbed, and some will be reflected at the interface between the two media.
The intensity I_0 of the beam incident to the surface of the solid medium must equal the sum of the intensities of the transmitted, absorbed, and reflected beams, denoted as I_T, IA, and I_R, respectively, or

$$I_0 = I_T + I_A + I_R$$

Radiation intensity, expressed in watts per square meter, corresponds to the energy being transmitted per unit of time across a unit area that is perpendicular to the direction of propagation.

$$T + A + R = 1$$

where T, A, and R represent, respectively, the transmissivity (I_T/I_0), absorptivity (I_A/I_0), and reflectivity (I_R/I_0), or the fractions of incident light that are transmitted, absorbed, and reflected by a material; their sum must equal unity, because all the incident light is either transmitted, absorbed, or reflected.

12.3 Atomic And Electronic Interactions

The optical phenomena that occur within solid materials involve interactions between the electromagnetic radiation and atoms, ions, and/or electrons. Two of the most important of these interactions are electronic polarization and electron energy transitions.

12.3.1 Electronic Polarization الاستقطاب الإلكتروني

One component of an electromagnetic wave is simply a rapidly fluctuating electric field . For the visible range of frequencies, this electric field interacts with the electron cloud surrounding each atom within its path in such a way as to induce electronic polarization, or to shift the electron cloud relative to the nucleus of the atom with each change in direction of electric field component. Two consequences of this polarization are as follows: (1) some of the radiation energy may be absorbed, and (2) light waves are retarded يتاخر in velocity as they pass through the medium.

12.3.2 Electron Transitions انتقالات الإلكترون

The absorption and emission of electromagnetic radiation may involve electron transitions from one energy state to another. An electron may be excited يتهيج from an occupied state at energy E_2 to a vacant شاغر and higher one, denoted E_4, by the absorption of a photon of energy. The change in energy that an electron undergoes يمر به, ΔE, depends on the radiation frequency as follows:

$$\Delta E = h\nu$$

12.4 Refraction الانكسار

Light that is transmitted into the interior of transparent شفافة materials experiences a decrease in velocity, and, as a result, is bent ينحني at the interface المنطقة بين وسطين; this phenomenon is termed refraction. The index of refraction n of a material is defined as the ratio of the velocity in a vacuum c to the velocity in the medium or

$$n = \frac{c}{v}$$

the velocity of light in a medium as

$$v = \frac{1}{\sqrt{\epsilon\mu}}$$

where ϵ and μ are, respectively, the permittivity and permeability of the particular substance.

$$n = \frac{c}{v} = \frac{\sqrt{\epsilon\mu}}{\sqrt{\epsilon_0\mu_0}} = \sqrt{\epsilon_r\mu_r}$$

where and are the dielectric constant and the relative magnetic permeability, respectively.

12.5 Reflection

When light radiation passes from one medium into another having a different index of refraction, some of the light is scattered at the interface between the two media even if both are transparent. The reflectivity R represents the fraction of the incident light that is reflected at the interface, or

$$R = \frac{I_R}{I_0}$$

where I_0 and I_R are the intensities of the incident and reflected beams, respectively. If the light is normal (or perpendicular) to the interface, then

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

where n_1 and n_2 are the indices of refraction of the two media. If the incident light is not normal to the interface, R will depend on the angle of incidence. When light is transmitted from a vacuum or air into a solid s, then

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

12.6 Absorption

The intensity of the net absorbed radiation is dependent on the character of the medium as well as the path length within. The intensity of transmitted or non-absorbed radiation continuously decreases with distance x that the light traverses:

$$I'_T = I'_0 e^{-\beta x}$$

where I'_o is the intensity of the non-reflected incident radiation and β , the absorption coefficient (in mm $^{-1}$), is characteristic of the particular material.

EXAMPLE

Computation of the Absorption Coefficient for Glass

The fraction of nonreflected light that is transmitted through a 200-mm thickness of glass is 0.98. Calculate the absorption coefficient of this material.

Solution

This problem calls for us to solve for β We first of all rearrange this expression as

$$\frac{I'_T}{I'_0} = e^{-\beta x}$$

Now taking logarithms of both sides of the preceding equation leads to

$$\ln\left(\frac{I'_T}{I'_0}\right) = -\beta x$$

And, finally, solving for β, realizing that $I'_T/I'_0 = 0.98$ and $x = 200$ mm, yields

$$\beta = -\frac{1}{x}\ln\left(\frac{I'_T}{I'_0}\right)$$

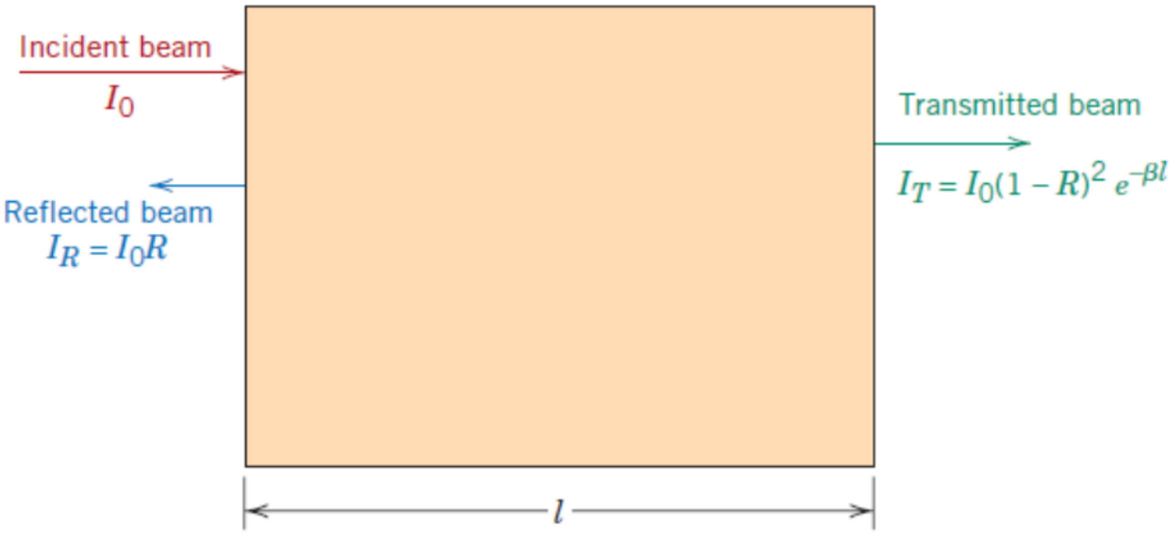
$$= -\frac{1}{200\text{ mm}}\ln(0.98) = 1.01 \times 10^{-4}\text{ mm}^{-1}$$

12.7 Transmission

The phenomena of absorption, reflection, and transmission may be applied to the passage of light through a transparent solid, as shown in Figure. For an incident beam of intensity I_0 that impinges on the front surface of a specimen of thickness l and absorption coefficient, the transmitted intensity at the back face I_T is

$$I_T = I_0(1 - R)^2 e^{-\beta l}$$

where R is the reflectance



12.8 Photoconductivity

The conductivity of semiconducting materials depends on the number of free electrons in the conduction band and also the number of holes in the valence band, additional charge carriers may be generated as a consequence of photon-induced electron transitions in which light is absorbed; the attendant increase in conductivity is called photoconductivity. Thus, when a specimen of a photoconductive material is illuminated, the conductivity increases.

Reference

1- Materials _Science_ and _Engineering_9th .pdf · version 1