

AL- Mustaqpal University
Science College
Dep. Medical physics



Medical physics
Third Stage

Lec 9

Exponential law of absorption

م . م علي سلمان حمادي

Exponential law of absorption

Lambert's law:

The intensity of light decreases exponentially in function of the distance x .

The intensity (I) of the transmitted radiation through a thickness (x) of homogeneous material, is described by the experimental equation of exponential absorption (Lambert Law): $I = I_0 \exp(-ax)$

I_0 = Intensity of incoming radiation.

a = Absorption coefficient of the material

Absorption of electromagnetic Radiation

We saw that the process of **photon absorption** by the atom is a process of raising the atom (electron) from a lower energy level into a higher energy level (excited state), by an amount of energy which is equivalent to the energy of the absorbed photon.

Our discussion involved a **microscopic system** in which one photon interacts with one atom.

In a **macroscopic system**, when electromagnetic radiation passes through matter, part of it is transmitted, and part is absorbed by the atoms.

The **intensity** (I) of the transmitted radiation through a thickness (x) of homogeneous material, is described by the experimental equation of exponential absorption (**Lambert Law**):

$$I = I_0 \exp(-\alpha x)$$

I_0 = Intensity of incoming radiation.

α = Absorption coefficient of the material.

The thicker the material (bigger x), the lower the intensity after the material (the transmitted beam).

The **transmission (T)** of this material is described by the relation between the transmitted intensity (I) to the incident intensity (I_0):

$$T = I/I_0$$

From the last two equations we get the Transmission:

$$T = \exp(-\alpha x)$$

It is common to use units of **centimeter** (10^{-2} [m]), to measure the width of the material (x), so **the units of the absorption coefficient (α) are:**

$$[\text{cm}^{-1}] = [1/\text{cm}].$$

Every material is transparent differently to different wavelengths, so **the absorption coefficient (α) is a function of the wavelength: $\alpha(\lambda)$** . This fact is very important (as we shall see) to understand the interaction of electromagnetic radiation with matter, in the variety of applications of the laser.

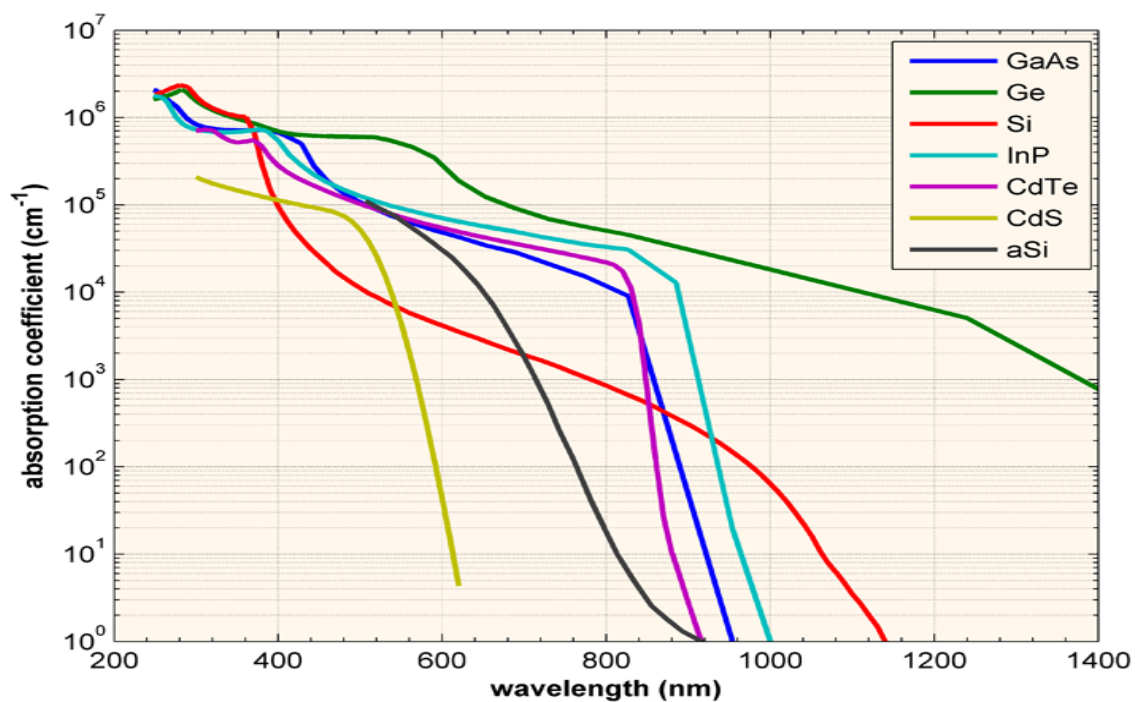
Absorption Coefficient

Overview

1. Different semiconductor materials have different absorption coefficients.
2. Materials with higher absorption coefficients more readily absorb photons, which excite electrons into the conduction band.
3. Knowing the absorption coefficients of materials aids engineers in determining which material to use in their solar cell designs.

The absorption coefficient determines how far into a material light of a particular wavelength can penetrate before it is absorbed. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will

appear transparent to that wavelength. The absorption coefficient depends on the material and also on the wavelength of light which is being absorbed. Semiconductor materials have a sharp edge in their absorption coefficient, since light which has energy below the band gap does not have sufficient energy to excite an electron into the conduction band from the valence band. Consequently, this light is not absorbed. The absorption coefficient for several semiconductor materials is shown below.



The absorption coefficient, α , in a variety of semiconductor materials at 300K as a function of the vacuum wavelength of light.

The above graph shows that even for those photons which have an energy above the band gap, the absorption coefficient is not constant, but still depends strongly on wavelength. The probability of absorbing a photon depends on the likelihood of having a photon and an electron interact in such a way as to move from one energy band to another. For photons which have an energy very close to that of the band gap, the absorption is relatively low since only those electrons directly at the valence band edge can interact with the photon to cause absorption. As the photon energy increases, not

just the electrons already having energy close to that of the band gap can interact with the photon. Therefore, a larger number of electrons can interact with the photon and result in the photon being absorbed.

The absorption coefficient, α , is related to the extinction coefficient, k , by the following formula:

$$\alpha = 4\pi k / \lambda$$

where λ is the wavelength. If λ is in nm, multiply by 10^7 to get the absorption coefficient in the units of cm^{-1} .

Discussion

Question 1:

What does Lambert's law describe?

- A. The reflection of light from surfaces.
- B. The refraction of light in materials.
- C. The exponential decrease of light intensity with distance in a material.
- D. The polarization of light.
- E. The scattering of light in homogeneous media.

Correct Answer: C

Question 2:

In the exponential absorption equation $I = I_0 e^{-\alpha x}$, what does α represent?

- A. Intensity of transmitted light.
- B. Thickness of the material.
- C. Wavelength of the light.
- D. Absorption coefficient of the material.
- E. Frequency of the incident light.

Correct Answer: D

Question 3:

The units of the absorption coefficient (α) are:

- A. cm.
- B. cm^{-1} .
- C. m.
- D. nm.
- E. W/cm^2 .

Correct Answer: B

Question 4:

What is the relation between transmission (T) and the absorption coefficient (α)?

- A. $T = \alpha x$.
- B. $T = \ln(I/I_0)$.
- C. $T = e^{-\alpha x}$.
- D. $T = I_0 / I = I_0 / I$.
- E. $T = \alpha + x$.

Correct Answer: C

Question 5:

How does the absorption coefficient (α) vary with wavelength (λ) in semiconductors?

- A. It is constant for all wavelengths.
- B. It increases for photons with energy below the band gap.
- C. It decreases for photons with energy above the band gap.
- D. It is higher for photons with energy close to the band gap.
- E. It depends on the material and wavelength of light.

Correct Answer: E

Question 6:

Which of the following is **true** about light with energy below the band gap in semiconductors?

- A. It is absorbed strongly.
- B. It does not excite electrons into the conduction band.
- C. It raises atoms to an excited state.
- D. It is fully transmitted without any absorption.
- E. It increases the absorption coefficient.

Correct Answer: B

Question 7:

What happens as the photon energy increases above the band gap in a semiconductor?

- A. Fewer photons are absorbed.
- B. The material becomes transparent.
- C. More electrons can interact with photons and absorption increases.
- D. The absorption coefficient decreases.
- E. The extinction coefficient becomes zero.

Correct Answer: C

Question 8:

The relationship between the absorption coefficient (α) and the extinction coefficient (k) is given by:

- A. $\alpha = \frac{4\pi k}{\lambda}$
- B. $\alpha = 4\pi k \lambda$
- C. $\alpha = \frac{4\pi k}{\lambda^2}$
- D. $\alpha = 4\pi k \lambda^2$
- E. $\alpha = \frac{\pi k}{\lambda}$

Correct Answer: C

Question 9:

Why do semiconductors have a sharp edge in their absorption coefficient?

- A. Due to constant interaction between electrons and photons.
- B. Because photons below the band gap energy do not excite electrons.
- C. Because the band gap energy remains constant for all wavelengths.
- D. Due to uniform absorption across all energy levels.
- E. Because the material is fully opaque to all light.

Correct Answer: B

Question 10:

What determines how far into a material light can penetrate before being absorbed?

- A. The thickness of the material.
- B. The wavelength of light only.
- C. The refractive index of the material.
- D. The absorption coefficient of the material.
- E. The energy of incoming photons.

Correct Answer: D