CH21.光性質

基本概念- electromagnetic radiation

*古典觀點→波

1. electromagnetic radiation:電場.磁場.前進方向相互垂直。

2.光.熱輻射.雷達.無線電波.x 光…等三小的都式電磁波形式

3.波長小至大(能量大至小):

γ 光→X 光→Ultraviolet→Visible→Infrared→Microwave→radio.TV

*用能量想很好想!

4.可見光波長 0.4~0.7μ m 紅光波長高!

5.電磁波在真空中都以光速前進

光速 c 和 electric permittivity 和 magnetic permeability 的關係

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

$$c = \lambda \nu$$

*量子觀點

有時候用量子觀點比較方便討論 the radiation, rather than consisting of waves, is composed of groups or packets of energy, which are called photons.

光子的能量是被量子化的

$$E = h\nu = \frac{hc}{\lambda}$$ (h 為普朗克常數 6.63 乘以 10 的-34 次方)

當討論到輻射和物質交互作用的光學現象，用光子比較好討論，而有些狀況用波較好處理(後面有古典 VS 量子比較)

光子 VS 聲子

21.1 Similarities between photons and phonons are:

1) Both may be described as being wave-like in nature.

2) The energy for both is quantized.

Differences between photons and phonons are:

1) Phonons are elastic waves that exist within solid materials. Photons are electromagnetic energy packets that may exist in solid materials, as well as in other media.

2) There is a considerable disparity between the velocities of photons and phonons. The velocity of a photon is the same as the velocity of light in the particular medium; for a phonon, its velocity is that of sound.

光和固體的交互作用

光由一界質到另一介質，會有傳導.吸收.反射三種現象

$I_0 = I_T + I_A + I_R$ trans.absorb.reflect(總和)

$T + A + R = 1$ other form(分率)

*transparent 主要都是 transmitt 透明!!

*translucent 光線以擴散方式傳導，就是遭遇散射的意思，半透明!!

*opaque 光線不能透過可見光(impervious to the transmittion of visible light)

→不是吸收就是反射

金屬塊→ opaque

電絕緣材料可以做成 transparent

半導體都有可能

固體材料的光學現象包括電磁輻射和原子.離子.電子的交互作用.最重要的是

→電子極化和電子轉移

電子極化

電磁波的電場變動→與繞原子的電子雲交互作用→電子極化→兩個結果

1.輻射能被吸收

2.光波通過介質時被延遲(即折射)

電子轉移(electron transitions) $\Delta E = h\nu$

能量是不連續的，特定的△E→對應特定的頻率的光子才能被電子轉移吸收→每次吸收躍遷(exited)，只要發生了，所有的光子能量都會被吸收。

電子部會永遠在激態，一段時間會回到 ground state，伴隨著電磁輻射的再次放射

金屬的光學性質

1.金屬為啥不透明?

金屬的 Continuously available empty electron states，可見光激發電子進入無填滿的能量狀態(高於 Fermi)→意即被吸收拉，只要薄薄的差不多 0.1μ m 就夠吸收可見光，換句話說，薄到低於 0.1μ m 才會是透明

*事實上，電磁輻射的光譜中，只有γ 光和 X 光能量夠高→透明

2.吸收的輻射會以相同波長的可見光反射，金屬反射率約 0.90~0.95，少部分熱能散失，我們看到的反射光，頻率和數量大約相同於入射光 EX.Al.Ag

而為啥銅和金出現紅橙色和黃色?因為有些短波長高能量的光子沒有已可見光再次放射

非金屬的光學性質

非金屬可以是透明的，所以要考慮反射.吸收.折射.穿透

折射

$$n = \frac{c}{v} = \frac{\sqrt{\epsilon\mu}}{\sqrt{\epsilon_0\mu_0}} = \sqrt{\epsilon_r\mu_r}$$ 大部分物質只有很小的磁性

n 跟入射光的速度有關，意即跟光的波長有關(色散現象即闡述此事實)

$n \cong \sqrt{\epsilon_r}$ n 與介電常數關係!!!

光波通過介質的延遲與折射有關，而延遲就是起因於電子極化

*原子或離子 size 越大→電子極化越大→延遲越大→n 越大(介電長數越大)

*EX.將 BaO 和 PbO 加入玻璃中大大增加 n 值

* cubic crystal structures，n 與方向無關

Noncubic crystals，有非等向 n→離子密度最大方向→延遲最多→n 越大

*n 不可能小於 1，因為速度不可能高過真空中光速

反射

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$ (垂直入射反射率)

$$R = \left(\frac{n_s - 1}{n_s + 1}\right)^2$$ 真空 or 空氣，(空氣折射指數接近於 1)

固體的 n 越高反射率越大!!而 n 是受波長所影響，所以 n 也會直接影響到反射率

*鏡片和光學儀器反射損失可藉由鍍上一層薄介電材料(MgF2)來減少(後面 21.14)原理→薄膜干涉的破壞性干涉!

吸收

二種機構

1. 電子極化: Absorption by electronic polarization is important only at light frequencies in the vicinity of the relaxation frequency of the constituent atoms
2. 電子在價帶-傳導帶間的移轉，與材料的電子能代結構有關
   光子能量必須大於能帶間隙，才能 exited，才能吸收
   $$\frac{hc}{\lambda} > E_g$$
   *考慮可見光最小波長 0.4μ m(最高能量)→Eg(Max)=3.1eV
   意即，沒有可見光被能帶間隙 Eg 超過 3.1eV 得材料吸收→透明無色
   *考慮最大波長 0.7μ m(最小能量)→Eg(Min)=1.8eV
   所有可見光都可以被 Eg<1.8V 的材料吸收→不透明
   *能帶間隙介於 1.8~3.1eV→部分吸收→出現顏色

具有較寬廣能帶間隙的介電材料，除了價帶-傳導帶，若有不純物或或其它電活化缺陷出現，一些 electron level 會出現，比如說 donar 和 acceptor level，會產生一些不同的機制(如圖)

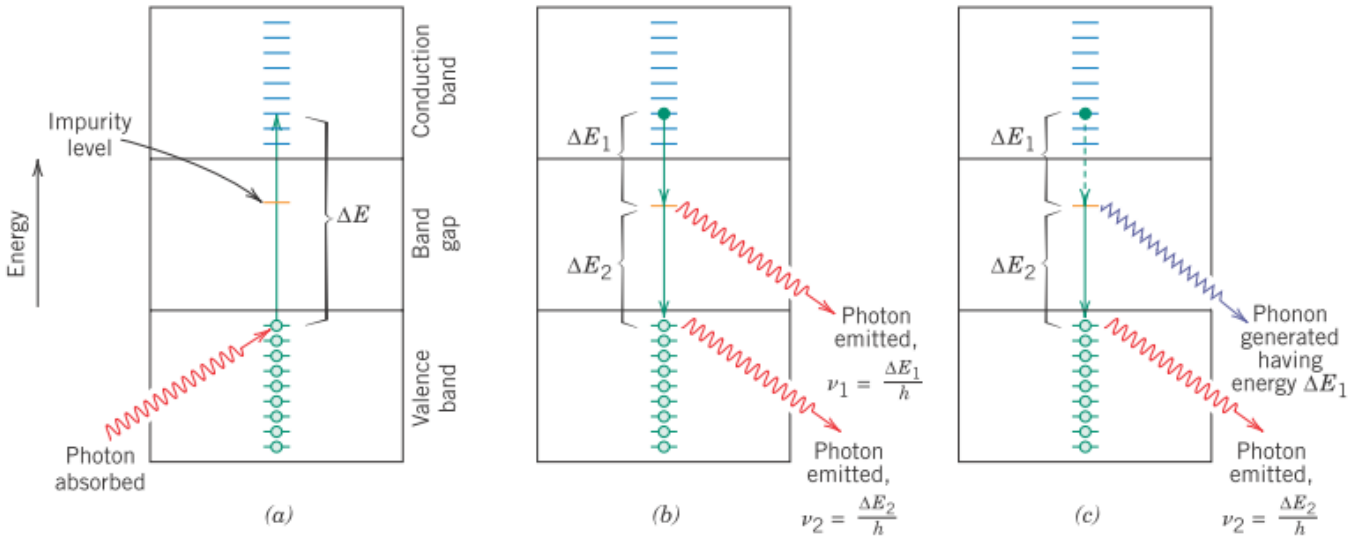


Figure 21.6 (*a*) Photon absorption via a valence band-conduction band electron excitation for a material that has an impurity level that lies within the band gap. (*b*) Emission of two photons involving electron decay first into an impurity state, and finally to the ground state. (*c*) Generation of both a phonon and a photon as an excited electron falls first into an impurity level and finally back to its ground state.

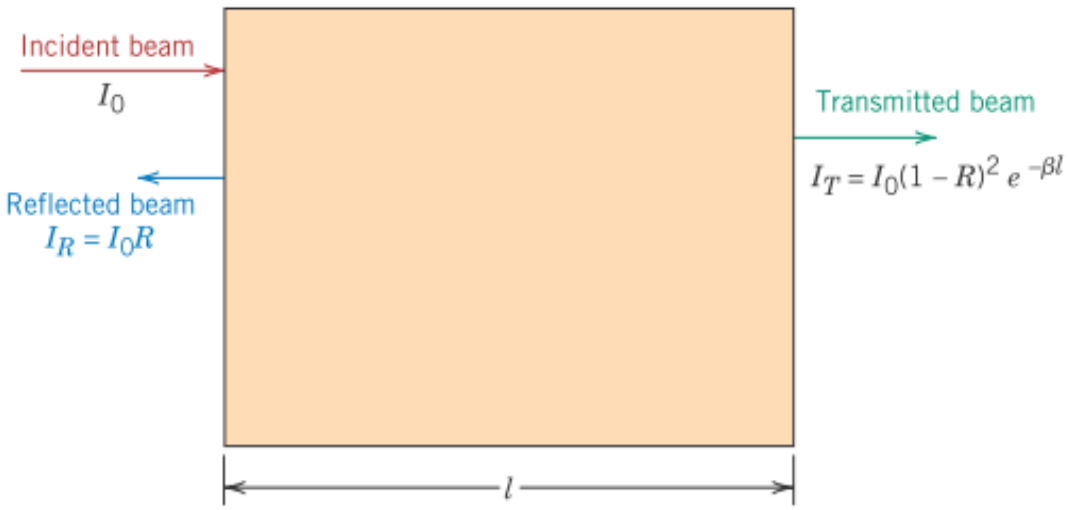
*電子+電洞→能量 *包刮 phonon 的產生→熱能型式散發

Intensity of nonabsorbed radiation—dependence on absorption coefficient and distance light traverses through absorbing medium

$$I_T' = I_0' e^{-\beta x} \tag{21.18}$$

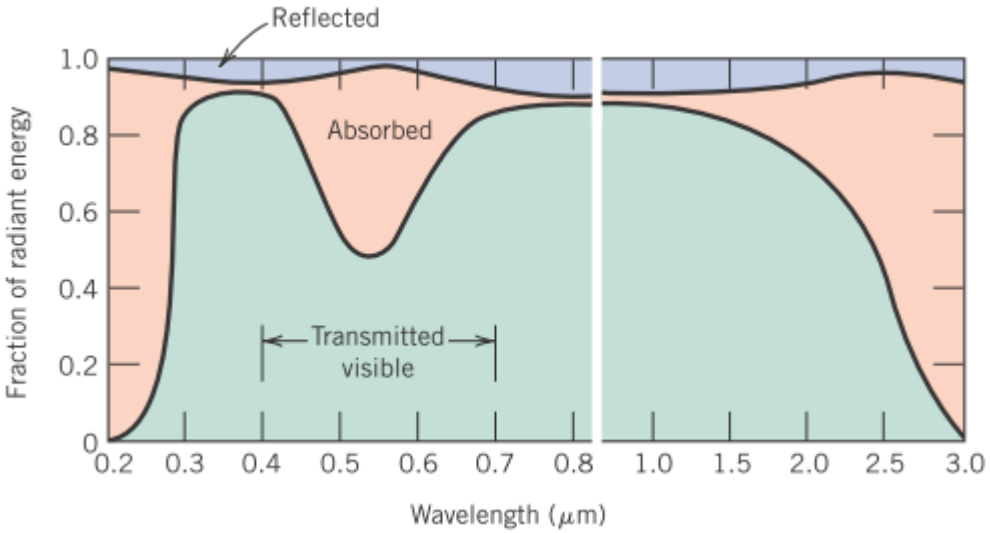
where I_0' is the intensity of the nonreflected incident radiation and β, the *absorption coefficient* (in mm^{-1}), is characteristic of the particular material; furthermore, β varies with wavelength of the incident radiation. The distance parameter x is measured from the incident surface into the material. Materials that have large β values are considered to be highly absorptive.

穿透



2 次反射
加吸收

穿透量受反射和吸收的損失而定



顏色

Transparent materials appear colored as a consequence of specific wavelength ranges of light that are selectively absorbed; the **color** discerned is a result of the combination of wavelengths that are transmitted. If absorption is uniform for all visible wavelengths, the material appears colorless; examples include high-purity inorganic glasses and high-purity and single-crystal diamonds and sapphire.

選擇性吸收是靠電子激發，然而當激態電子回到基態重新放射，不必和吸收實有相同頻率!!!所以顏色會受穿透和重新放射的光率 2 者的頻率而定

*絕緣 ceramic，不純物引進的那些 level 造成能量少於能帶間隙的光子被放射，然後，材料的顏色是穿透光束長的函數!!
*紅寶石為啥紅?是藍寶石加入一點 Cr2O3，Cr 離子置換 Al2O3 中的 Al 離子，引入不純物 level，穿透率是波長的函數!!特定波長的選擇性吸收，使紅寶石產生紅色色彩!

Opacity and translucency in insulators

散射.多孔.第二相散布.多晶→不透明
本質高分子，結晶度→高結晶越會散射，越不透
→高非晶越透明

光學現象

Luminescence:吸收能量，然後再次放射可見光
可依據他吸收和再放射間的 delay time 來分類:
若少於 1 秒→fluorescence

較長時間→phosphorescence

Photoconductivity

光子誘發電子傳輸(光線吸收時)，產生額外電荷載體

EX.照相燈光計.太陽能電池

Laser→light amplification by stimulated emission of radiation

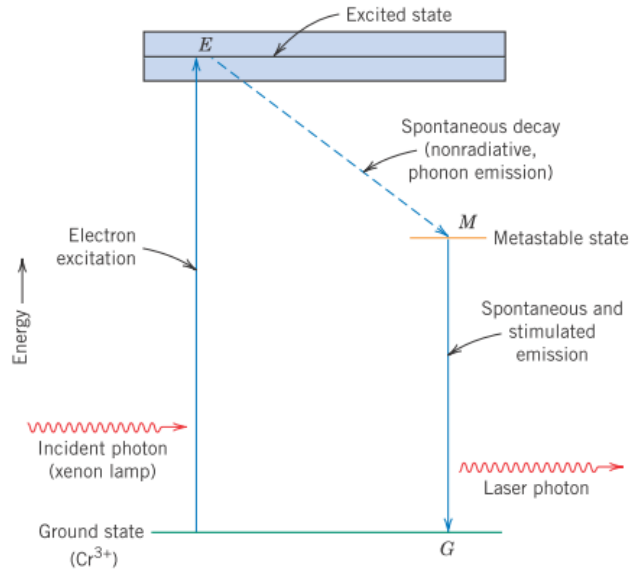


Figure 21.14 Schematic energy diagram for the ruby laser, showing electron excitation and decay paths.

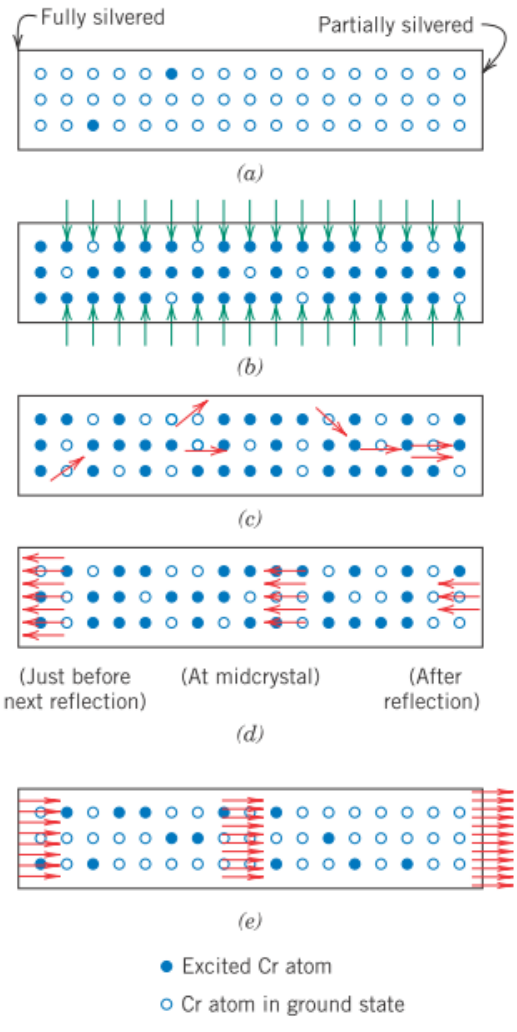


Figure 21.15 Schematic representations of the stimulated emission and light amplification for a ruby laser. (*a*) The chromium ions before excitation. (*b*) Electrons in some chromium ions are excited into higher energy states by the xenon light flash. (*c*) Emission from metastable electron states is initiated or stimulated by photons that are spontaneously emitted. (*d*) Upon reflection from the silvered ends, the photons continue to stimulate emissions as they traverse the rod length. (*e*) The coherent and intense beam is finally emitted through the partially silvered end. (From R. M. Rose, L. A. Shepard, and J. Wulff, *The Structure and Properties of Materials,* Vol. 4, *Electronic Properties.* Copyright © 1966 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

*紅寶石(ruby laser)是 Al2O3 加 Cr 三價離子以 Xe 閃光燈激發

*半導體雷射 such as gallium arsenide

$$\lambda = \frac{hc}{E_g}$$ 波常必須在可見光波段之間，給予 1V 電壓機發電子

光纖→矽土玻璃 silica glass

Digital encoding

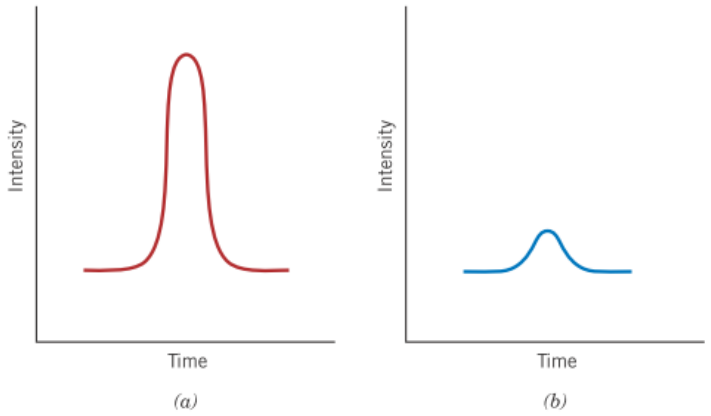


Figure 21.19 Digital encoding scheme for optical communications. (*a*) A high-power pulse of photons corresponds to a "one" in the binary format. (*b*) A low-power photon pulse represents a "zero."

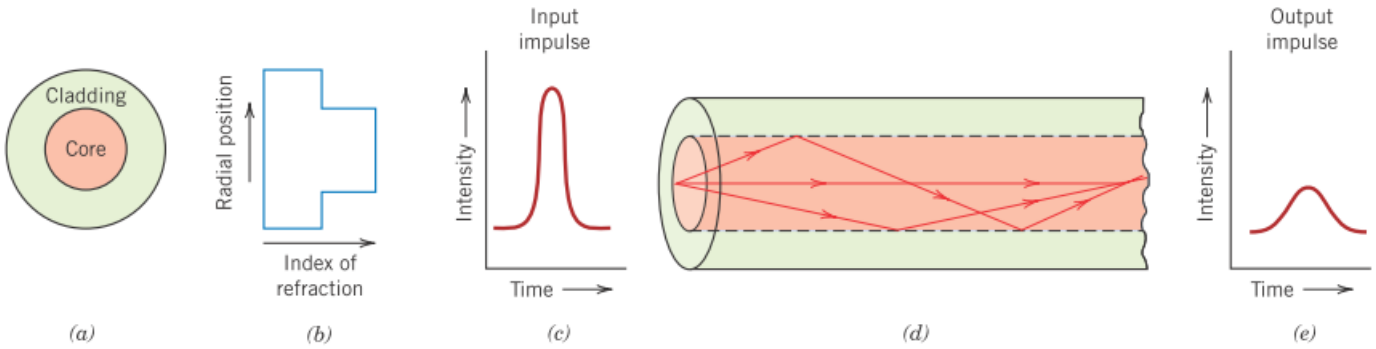


Figure 21.21 Step-index optical fiber design. (*a*) Fiber cross section. (*b*) Fiber radial index of refraction profile. (*c*) Input light pulse. (*d*) Internal reflection of light rays. (*e*) Output light pulse. (Adapted from S. R. Nagel, *IEEE Communications Magazine,* Vol. 25, No. 4, p. 34, 1987.)

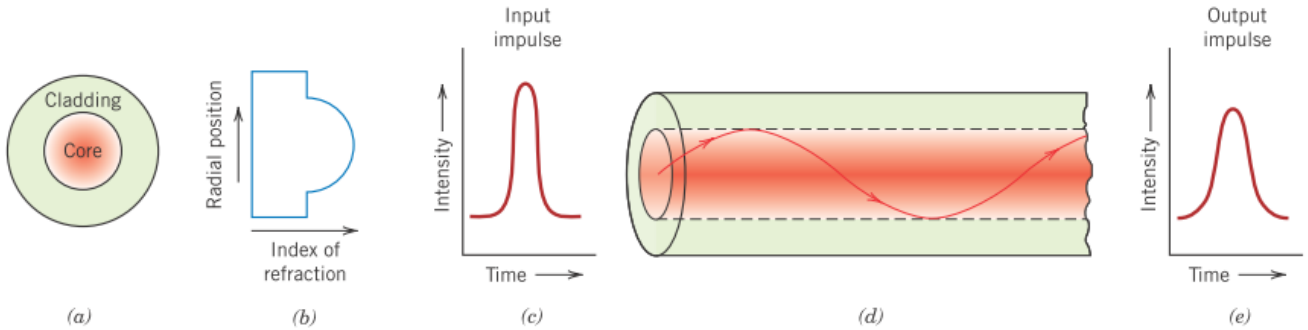


Figure 21.22 Graded-index optical fiber design. (*a*) Fiber cross section. (*b*) Fiber radial index of refraction profile. (*c*) Input light pulse. (*d*) Internal reflection of a light ray. (*e*) Output light pulse. (Adapted from S. R. Nagel, *IEEE Communications Magazine,* Vol. 25, No. 4, p. 34, 1987.)

Step-index 有脈衝擴大現象→不討喜

Pulse broadening results because various light rays, although being injected at approximately the same instant, arrive at the output at different times; they traverse different trajectories and, thus, have a variety of path lengths

改善:

Graded-index→n 隨截面拋物線變化

補述概念

1. 固體材料的光學行為是材料與電磁輻射相互作用的函數，那些相互作用包含折射.反射.吸收.穿透
2. 金屬不透明是因為吸收再放射，可查覺的顏色視反射光光譜組成而定
3. 折射是原子或離子之電子極化的結果，是由光波的電場分量引起
4. 影響反射因素→折射率 n 和入射角度
5. 非金屬材料三種吸收機構:1.電子轉移 2.電子極化 3.scattering
   不透明是因為很窄的能帶間隙，而透明的能帶間隙>3eV，
   有些透明材料還是會吸收，是因為→電子極化
6. 對高能帶間隙的絕緣體來說 decay process 包含了那些不純物 level，他們的顏色由 transmitted beam 的波長範圍決定
7. Opacity and Translucency in Insulators 因為散射，可能發生在→多晶.雙相.小孔.高結晶性高分子

21.2 From the classical perspective, electromagnetic radiation is wave-like in character, and the possible energies of the radiation are continuous. From the quantum-mechanical perspective, electromagnetic radiation is dual-like in character (being both wave-like and particle-like), and not all energies are possible (i.e., energy is quantized).

21.12 Dispersion in a transparent medium is the phenomenon wherein the index of refraction varies slightly with the wavelength of the electromagnetic radiation.

21.22 (a) The characteristic color of a metal is determined by the distribution of wavelengths of the nonabsorbed light radiation that is reflected.

(b) The characteristic color of a transparent nonmetal is determined by the distribution of wavelengths of the nonabsorbed light radiation that is transmitted through the material.

金屬和透明非金屬的特性顏色決定因素不同!!

顯現顏色 VS 無色→選擇吸收 VS 均勻吸收

21.23 For a transparent material that appears colorless, any absorption within its interior is the same for all visible wavelengths. On the other hand, if there is any selective absorption of visible light (usually by electron excitations), the material will appear colored, its color being dependent on the frequency distribution of the transmitted light beam.

21.14 The thickness and dielectric constant of a thin surface coating are selected such that there is destructive interference between the light beam that is reflected from the lens-coating interface and the light beam that is reflected from the coating-air interface; thus, the net intensity of the total reflected beam is very low.

18. A transparent film (n=1.43) is deposited on a glass plate (n=1.52) to form a nonreflective coating. The film has a thickness of 1.07×10^{-7} m. What is the longest possible wavelength of light (in vacuum) for which thin film has been designed?

Ⓐ 612 nm Ⓑ 562 nm Ⓒ 512 nm Ⓓ 462 nm

*利用薄膜干涉的破壞性干涉做，算出來答案 A

Laser	*Type*	*Common Wavelengths (μm)*	*Max. Output Power (W)*[a]	*Applications*
He–Ne	Gas	0.6328, 1.15, 3.39	0.0005,–0.05 (CW)	Line-of sight communications, recording/playback of holograms
CO_2	Gas	9.6, 10.6	500−15,000 (CW)	Heat treating, welding, cutting, scribing, marking
Argon	Gas ion	0.488, 0.5145	0.005−20 (CW)	Surgery, distance measurements, holography
HeCd	Metal vapor	0.441, 0.325	0.05–0.1	Light shows, spectroscopy
Dye	Liquid	0.38−1.0	0.01 (CW) 1×10^6 (P)	Spectroscopy, pollution detection
Ruby	Solid state	0.694	(P)	Pulsed holography, hole piercing
Nd–YAG	Solid state	1.06	1000 (CW) 2×10^8 (P)	Welding, hole piercing, cutting
Nd–Glass	Solid state	1.06	5×10^{14} (P)	Pulse Welding, hole piercing
Diode	Semiconductor	0.33−40	0.6 (CW) 100 (P)	Bar-code reading, CDs and DVDs, optical communications

[a] "CW" denotes continuous; "P" denotes pulsed.

※應用記一下，有時會考