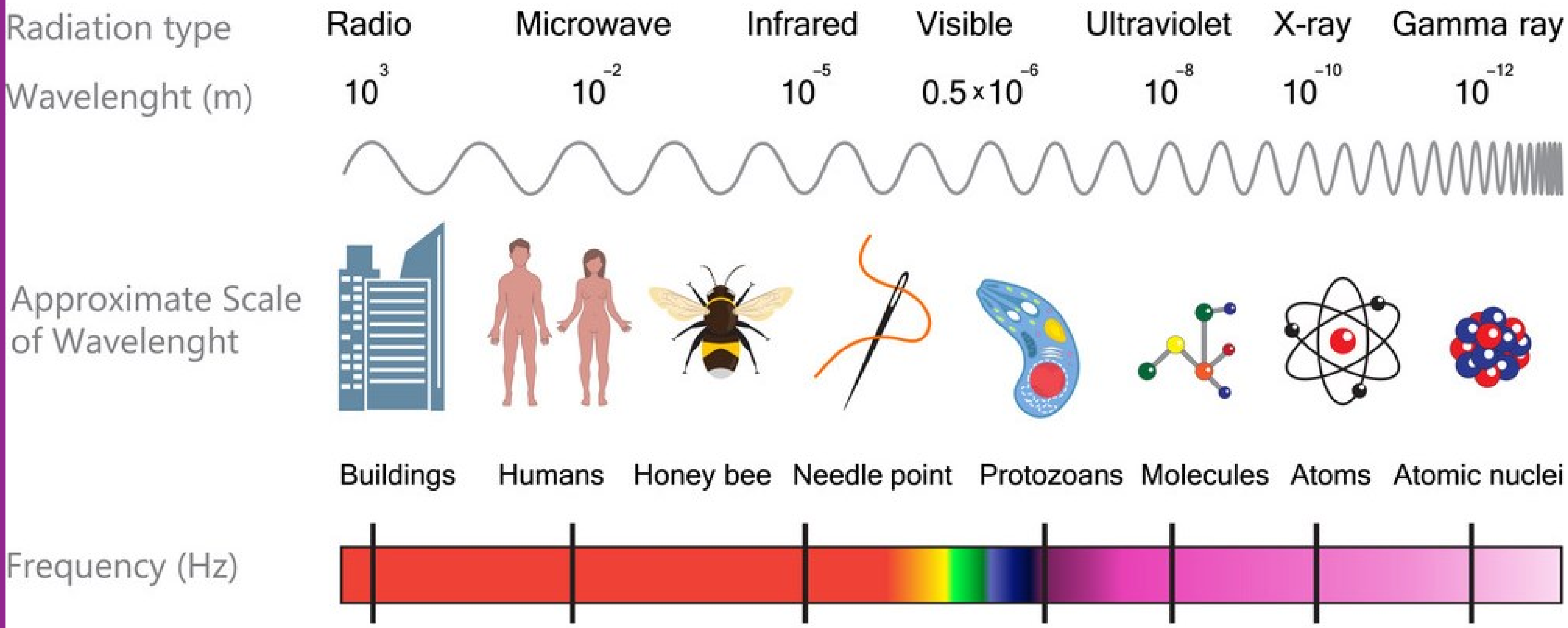
CHAPTER 13

Photonic Materials

Electromagnetic spectrum



$$E = \mathrm{h}v = \frac{\mathrm{h}c}{\lambda}$$

E: Energy of the photon

v : Frequency

λ : Wavelength

c: Speed of light

h: Planck's constant

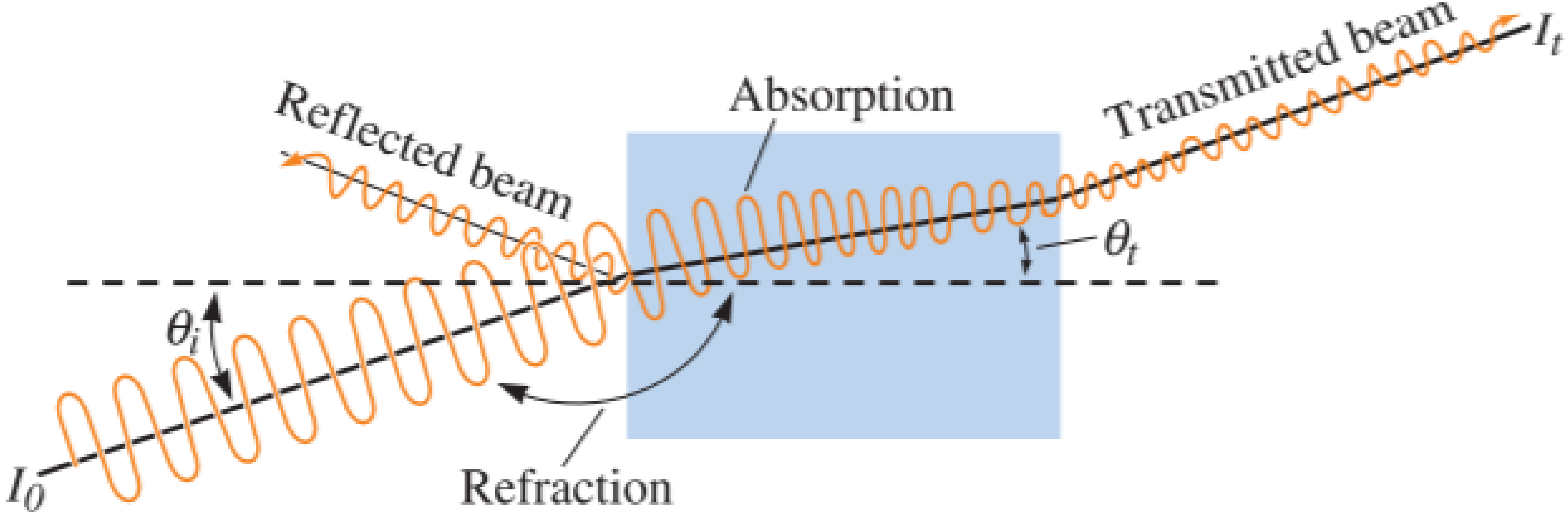
h: $(6.626 \times 10^{-34}\mathrm{J} \cdot s \text{ or } 4.14 \times 10^{-15}\ eV \cdot s)$

c_o: $3 \times 10^{10} cm/s$

Example

How many photons are contained in a burst of yellow light (589 nm) from a sodium lamp that contains 637 kJ of energy?

λ: 589 nm
E_{Beam}: 637 kJ
c_o: $3 \times 10^8 m/s$
h: $6.626 \times 10^{-34} \mathrm{J} \cdot s$



I: Intensity (Watts/m²)

$$I_0 = I_r + I_a + I_t$$

Refraction

This refers to the bending of a light beam as it passes from one material into another.

The index of refraction is therefore a consequence of electrical polarization, especially electronic polarization

n: refraction index
c: Speed of light
c_o: Speed of light in vacuum
λ : Wavelength
θ_i: Incidence angle
θ_t: Transmitted angle

$$n = \frac{c_0}{c} = \frac{\lambda_{vacuum}}{\lambda} = \frac{\sin \theta_i}{\sin \theta_t}$$

$$I_0 = I_r + I_a + I_t$$

Refraction

n: refraction index
c: Speed of light
c_o: Speed of light in vacuum
λ : Wavelength
θ_i: Incidence angle
θ_t: Transmitted angle
μ: magnetic permeability
ε: Electrical permittivity
k: dielectric constant

$$n = \frac{c_0}{c} = \frac{\lambda_{vacuum}}{\lambda} = \frac{\sin\theta_i}{\sin\theta_t}$$

$$c = \frac{1}{\sqrt{\mu\varepsilon}} \quad ; \quad n = \frac{\sqrt{\mu\varepsilon}}{\sqrt{\mu_0\varepsilon_0}} = \sqrt{k}$$

Snell's law

$$\frac{c_1}{c_2} = \frac{n_2}{n_1} = \frac{\sin\theta_i}{\sin\theta_t}$$

Example

A laser beam passing through air strikes a 5-cm-thick polystyrene block at a 20° angle to the normal of the block. By what distance is the beam displaced from its original path when the beam reaches the opposite side of the block?

The refractive index of polystyrene is 1.6

x= 5cm
θ_i= 20°
n= 1.6

CD?

x= 5cm
θ_i= 20°
n= 1.6

CD?

Example

A beam of photons in air strikes a composite material consisting of a 1.5-cm-thick sheet of polyethylene and a 2-cm-thick sheet of soda-lime glass. The incident beam is 10° from the normal of the composite.

Determine the angle of the beam with respect to the normal of the composite as it

(a) passes through the polyethylene
(b) passes through the glass

By what distance is the beam displaced from its original path when it emerges from the composite?

$n_{Polyethylene}$:1.52
n_{Glass}:1.46

θ_i= 10°

Polyethylene

x_1= 1.5cm

n1= 1.52

Glass

x_2= 2cm

n2= 1.46

θ_i= 10°

Polyethylene

x_1= 1.5cm

n1= 1.52

θ_{t1}= 6.56°

Glass

x_2= 2cm

n2= 1.46

θ_{t2}=6.83 °

GH?

θ_i= 10°

Polyethylene

x_1= 1.5cm

n1= 1.52

θ_{t1}= 6.56°

Glass

x_2= 2cm

n2= 1.46

θ_{t2}= 6.83 °

GH?

θ_i= 10°

Polyethylene

x_1= 1.5cm

n1= 1.52

θ_{t1}= 6.56°

Glass

x_2= 2cm

n2= 1.46

θ_{t2}= 6.83 °

GH?

Composite
EH: 0.62 cm
Polyethylene
EF: 0.172 cm
Glass
FG: 0.24 cm

GH?

$$I_0 = I_r + I_a + I_t$$

Reflection

Reflection occurs at the interface between two materials and is therefore related to index of refraction.

After the e- interact with photons, the energy released from the electron will have the same frequency of the initial photon.

In vacuum or air

Other materials

R: Reflectivity
n: refraction index

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

$$R_i = \left(\frac{n-n_i}{n+n_i}\right)^2$$

$$I_r = RI_0$$

$$I_0 = I_r + I_a + I_t$$

Absorption

The beam that is not reflected can be either absorbed or transmitted.

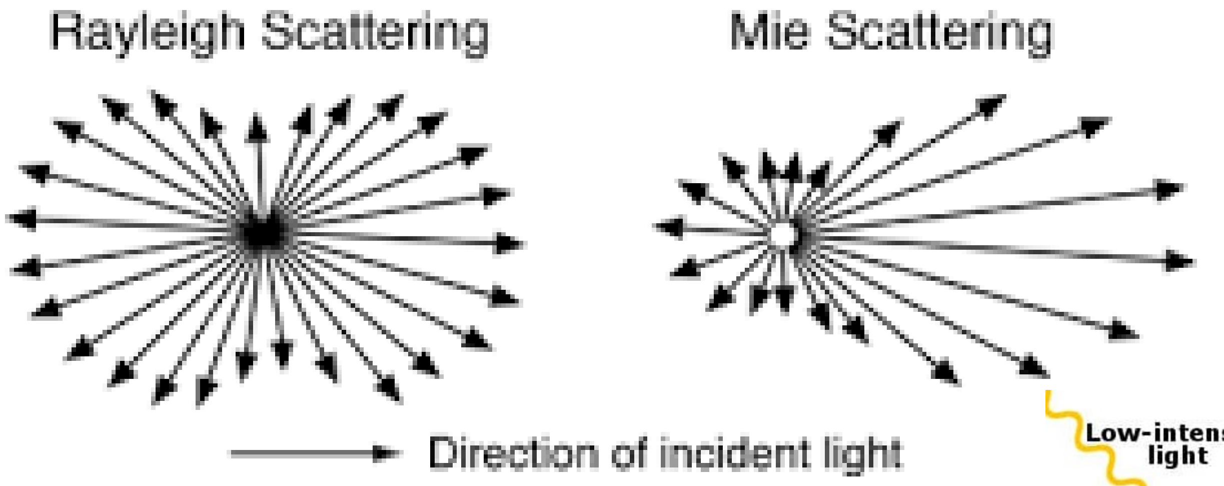
Depends on the thickness and the specific material.

$$I = I_0 e^{-\alpha x}$$

I: intensity of the beam at the end of the material.
I_o: intensity of beam after reflection
α:linear absorption coefficient
x: photon's path

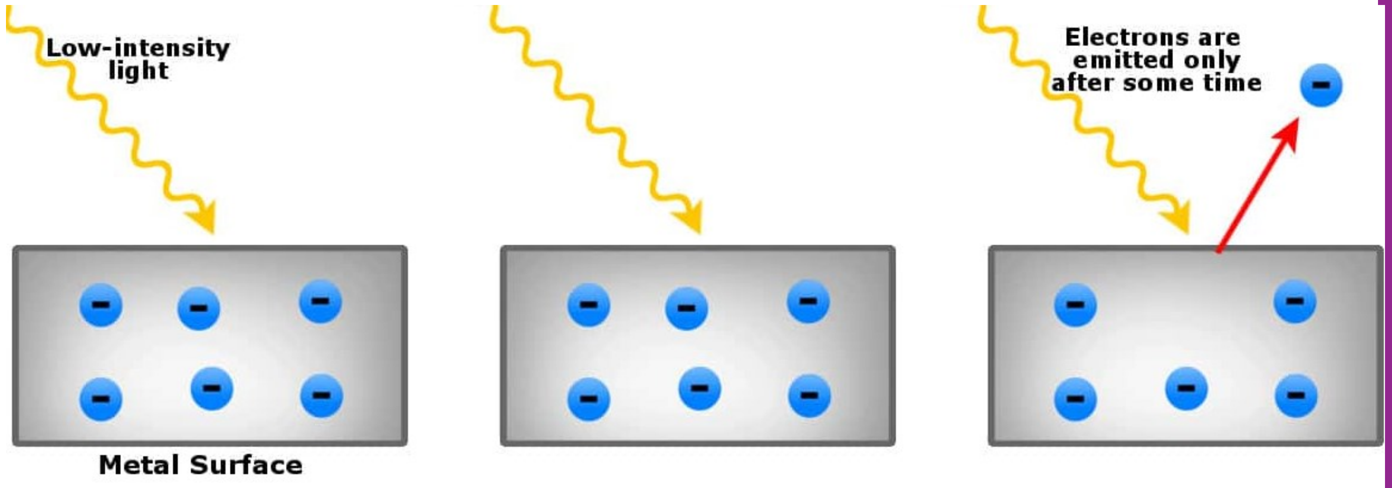
$$I_0 = I_r + I_a + I_t$$

Absorption



Scattering

Photoelectric effect



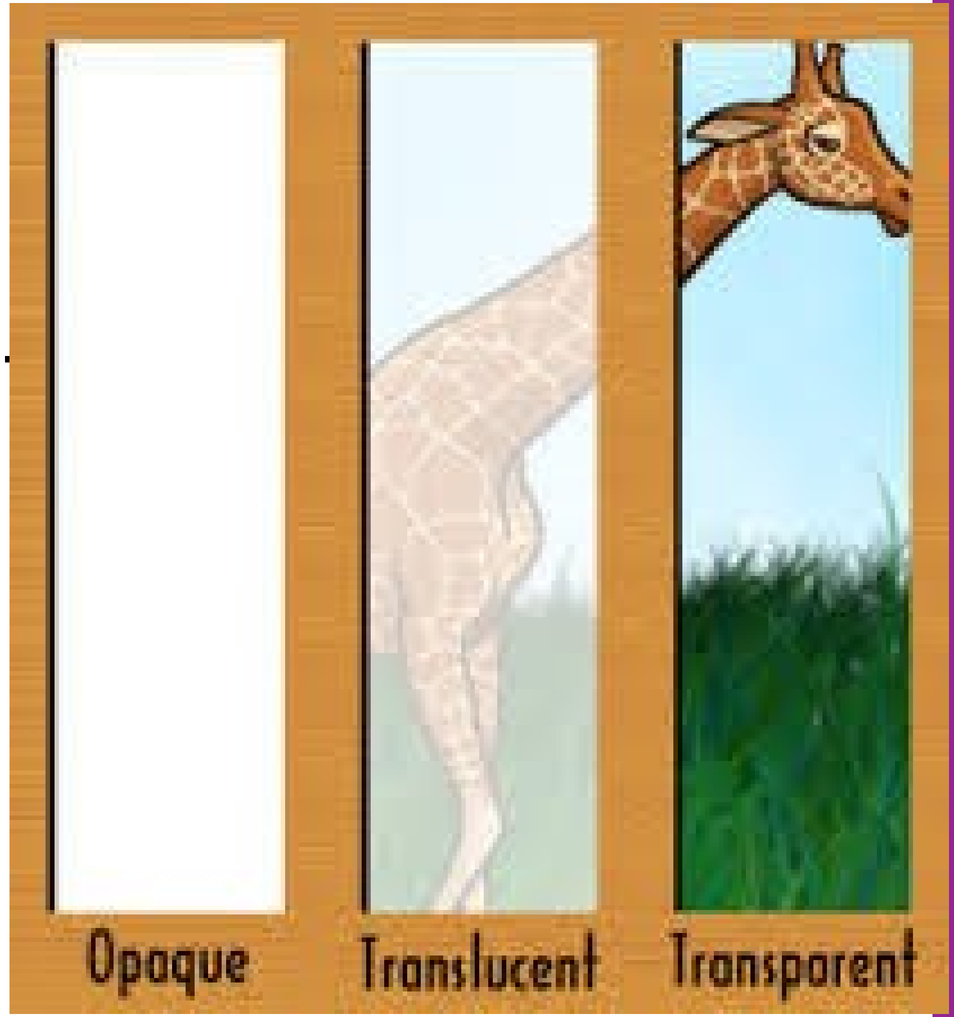
$$I_0 = I_r + I_a + I_t$$

Absorption

Transparent: relatively little absorption and reflection.

Translucent: light scattered within the material.

Opaque: relatively little transmission.



$$I_0 = I_r + I_a + I_t$$

Transmission

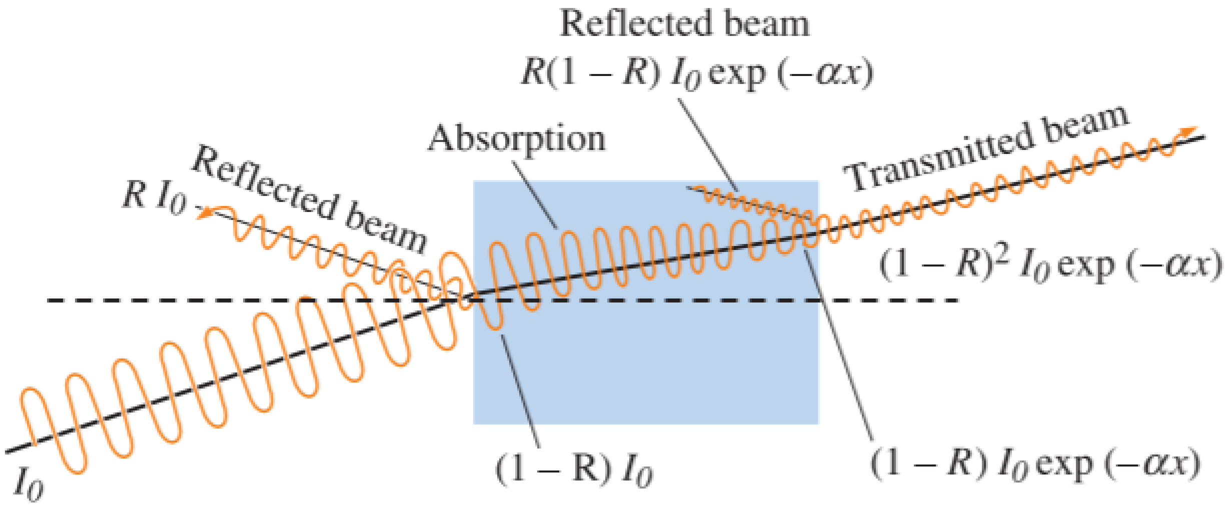
The beam that comes through at the end of the material.

Depends on the properties of the material and the photon's wavelength:

1. Microstructure
2. Presence of different phases
3. Porosity
4. Band gap

$$I_0 = I_r + I_a + I_t$$

Transmission

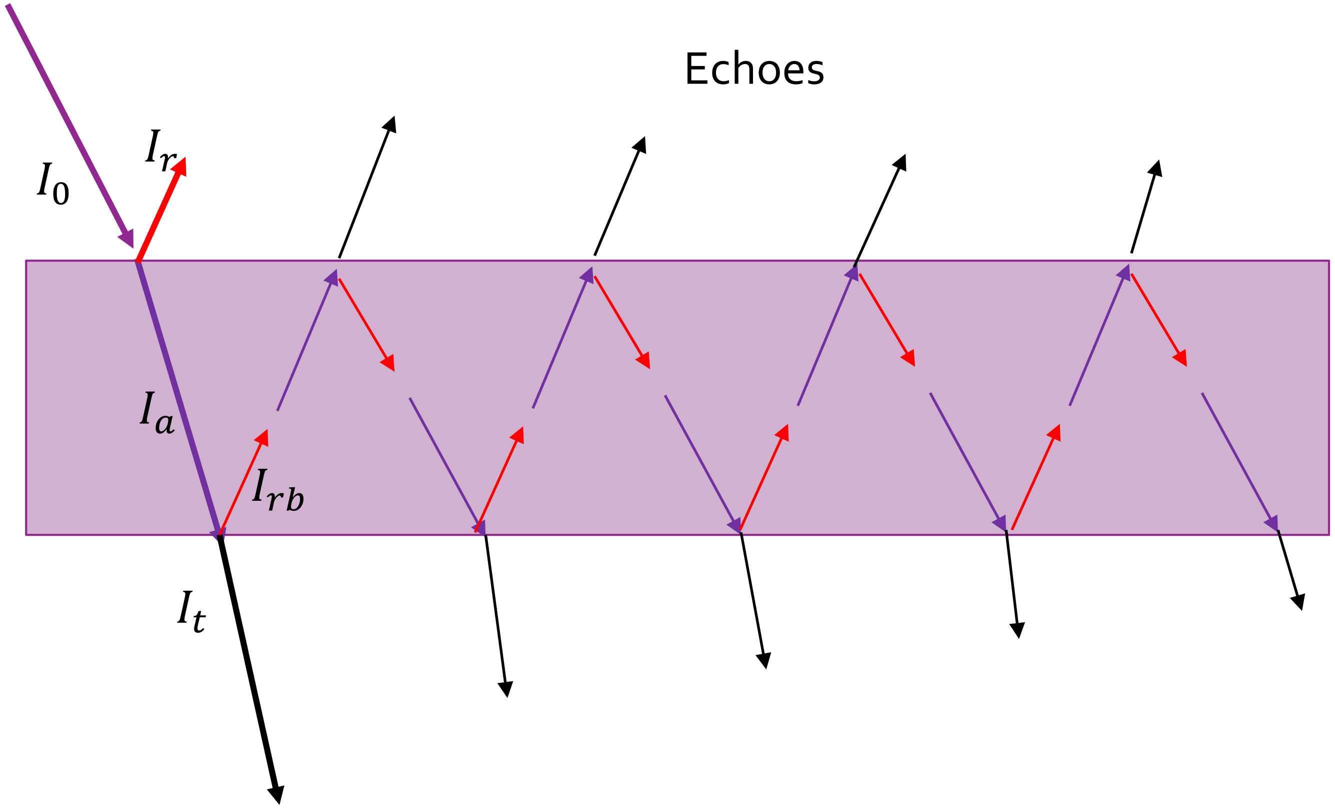


1. After reflection $\mathrm{I}_1 = (1-R)I_0$
2. After absorption $I_2 = I_1 e^{-\alpha x} = (1-R)I_0 e^{-\alpha x}$
3. Tacking into account the reflected beam $I_{rb} = RI_2 = R(1-R)I_0\, e^{-\alpha x}$
4. The difference between the absorbed and the reflected back

$$I_t = (1-R)I_0 e^{-\alpha x} - R(1-R)I_0\, e^{-\alpha x}$$

$$I_t = (1-R)^2\, I_0\, e^{-\alpha x}$$

$$I_0 = I_r + I_a + I_t$$



$$I_0 = I_r + I_a + I_t$$

$$1 = R + A + T$$

$$R = \frac{I_r}{I_0} = \left(\frac{n-1}{n+1}\right)^2$$

$$A = 1 - (1 - R)e^{-\alpha x}$$

$$T = (1 - R)^2 e^{-\alpha x}$$

$$T = 1 - R - A$$

Example

We find that 20% of the original intensity of a beam of photons is transmitted from air through a 0.5-cm-thick material having a dielectric constant of 2.3 and back into air. Determine the a) fraction of the beam that is reflected at the front surface, b) the absorption coefficient and c) the fraction absorbed

$x= 0.5cm$
$k=2.3$
$T=0.2$

$x = 0.5cm$
$k=2.3$
$T=0.2$
$R= 0.0426$

b) α?

x= 0.5cm
k=2.3
T=0.2
R= 0.0426
$\alpha = 3.045\ cm^{-1}$

c) A?

Example

- A material has a linear absorption coefficient of 591 cm^{-1}. Determine the thickness of that material if it absorbs 90% of the photons. What is the expected transmission if there is a beam displacement of 3.622E-4 cm. The beam hits the material at an angle of 17°

$$\alpha = 591\ \text{cm}^{-1}$$
$$\theta_i = 17°$$
$$A = 0.9$$
$$CD = 3.622 \times 10^{-4} cm$$
AB=x

$$\alpha = 591\ \mathrm{cm}^{-1}$$
$$\theta_i = 17°$$
$$A = 0.9$$
$$CD = 3.622 \times 10^{-4} cm$$
AB=x

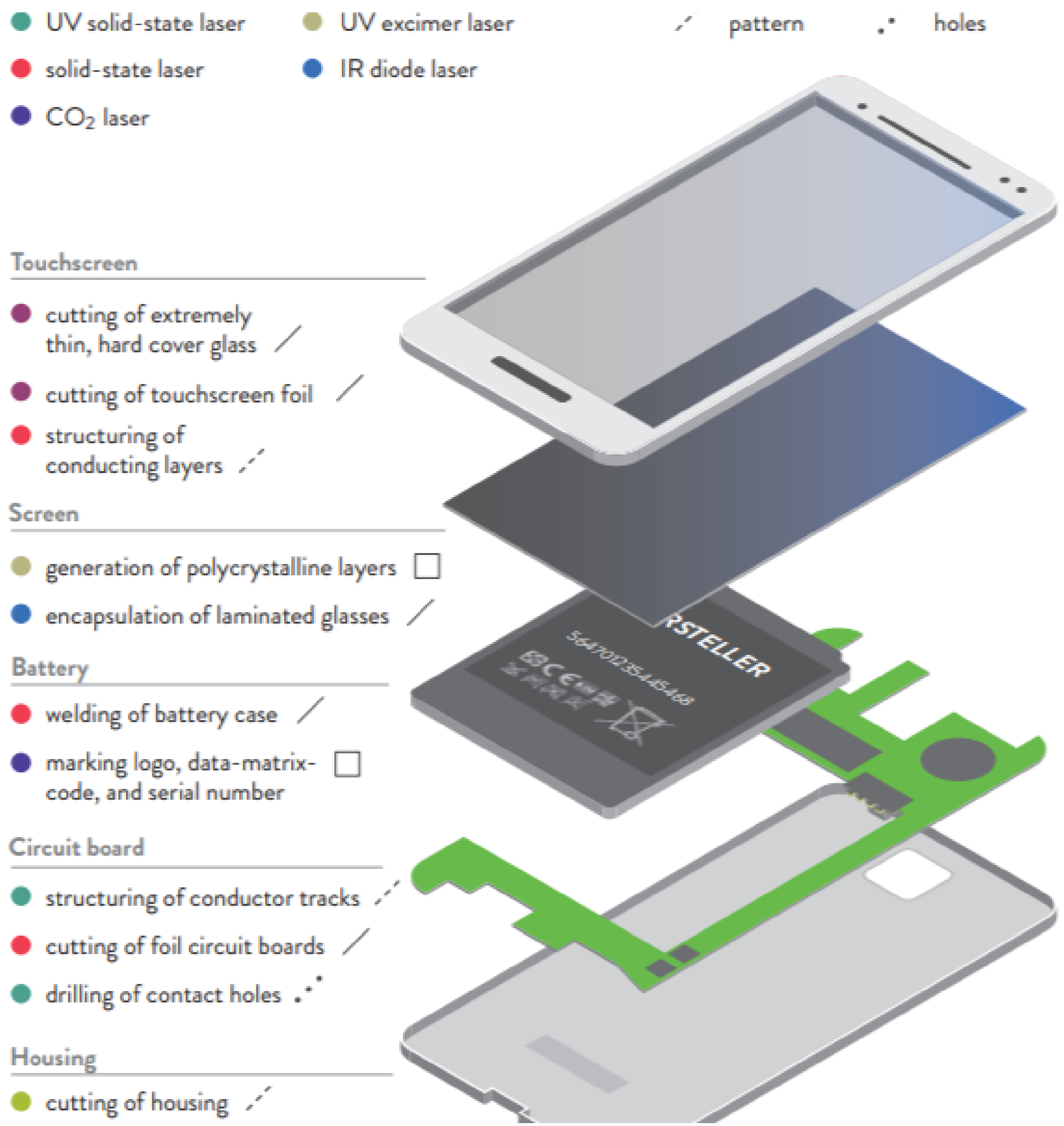
$$\alpha = 591\ \mathrm{cm}^{-1}$$
$$\theta_i = 17°$$
$$A = 0.9$$
$$CD = 3.622 \times 10^{-4} cm$$
$$X = 3.85 \times 10^{-3} cm$$
$$n = 1.42$$

Applications

- Production technology
- Data transfer
- Image capture and display
- Medical technology
- Photovoltaics

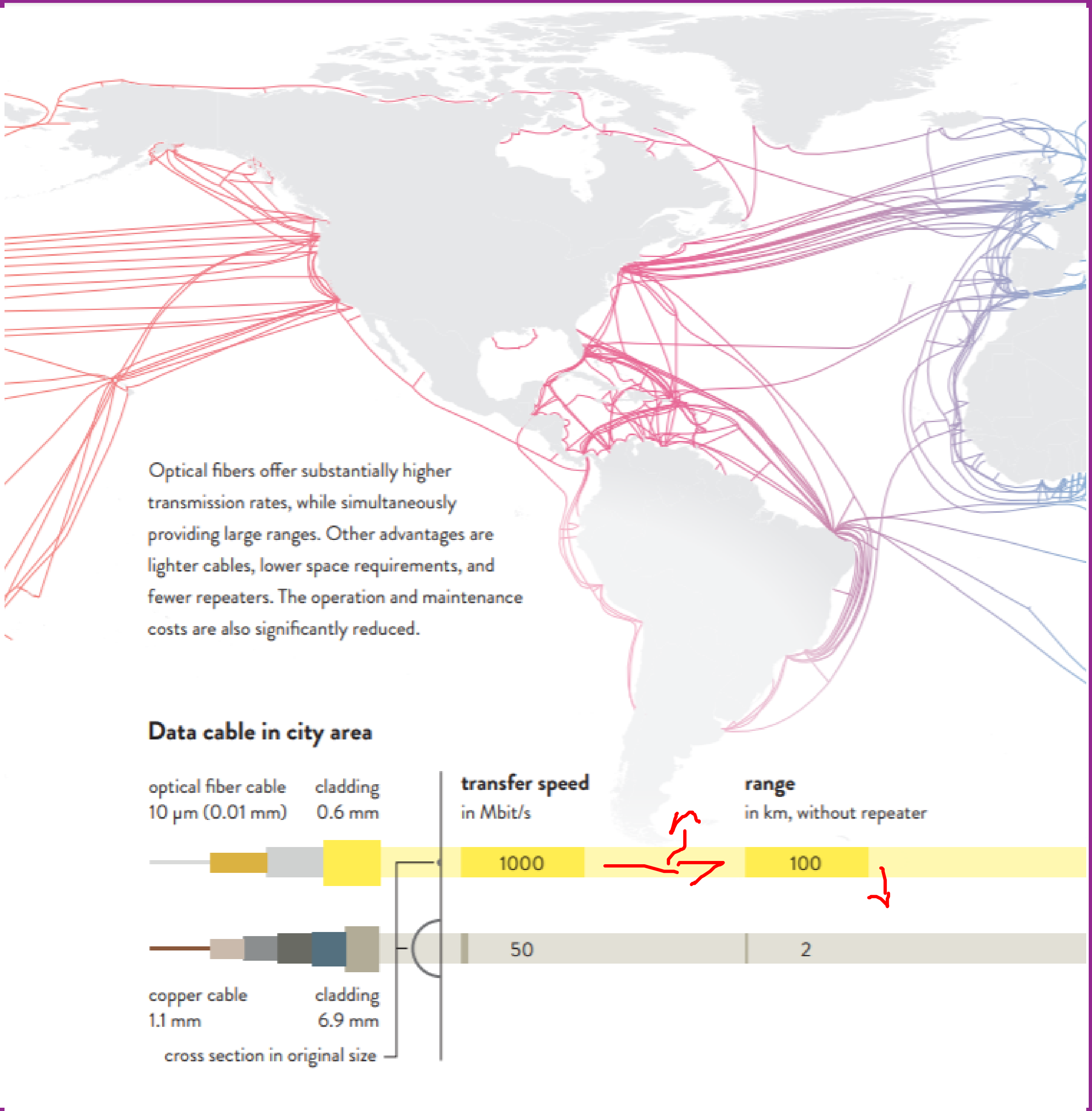
Applications: Production technology

SMARTPHONES THANKS TO THE LASER



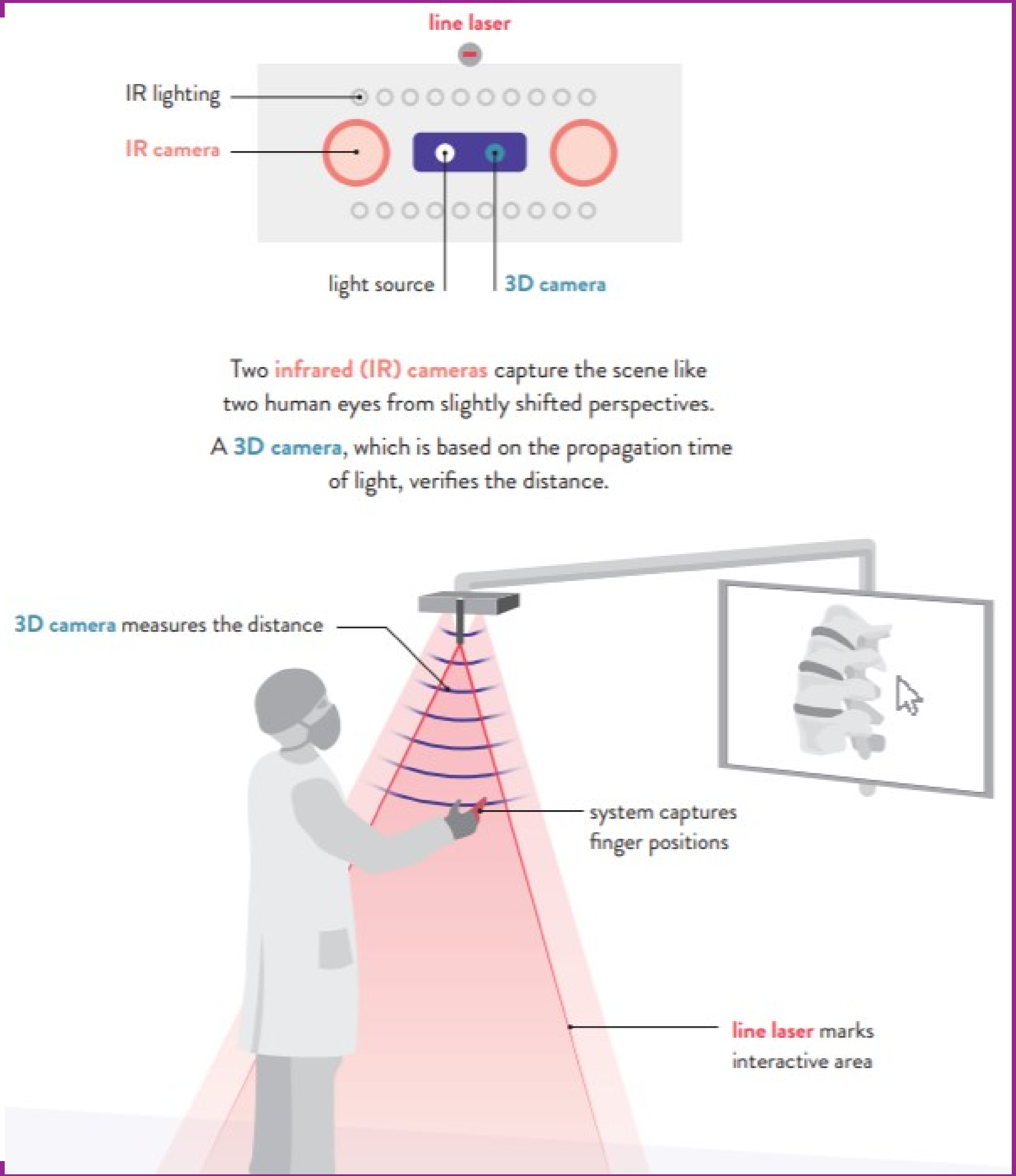
Applications: Data transfer

OPTICAL CABLES



Applications: Image capture and display

GESTURE CAPTURE

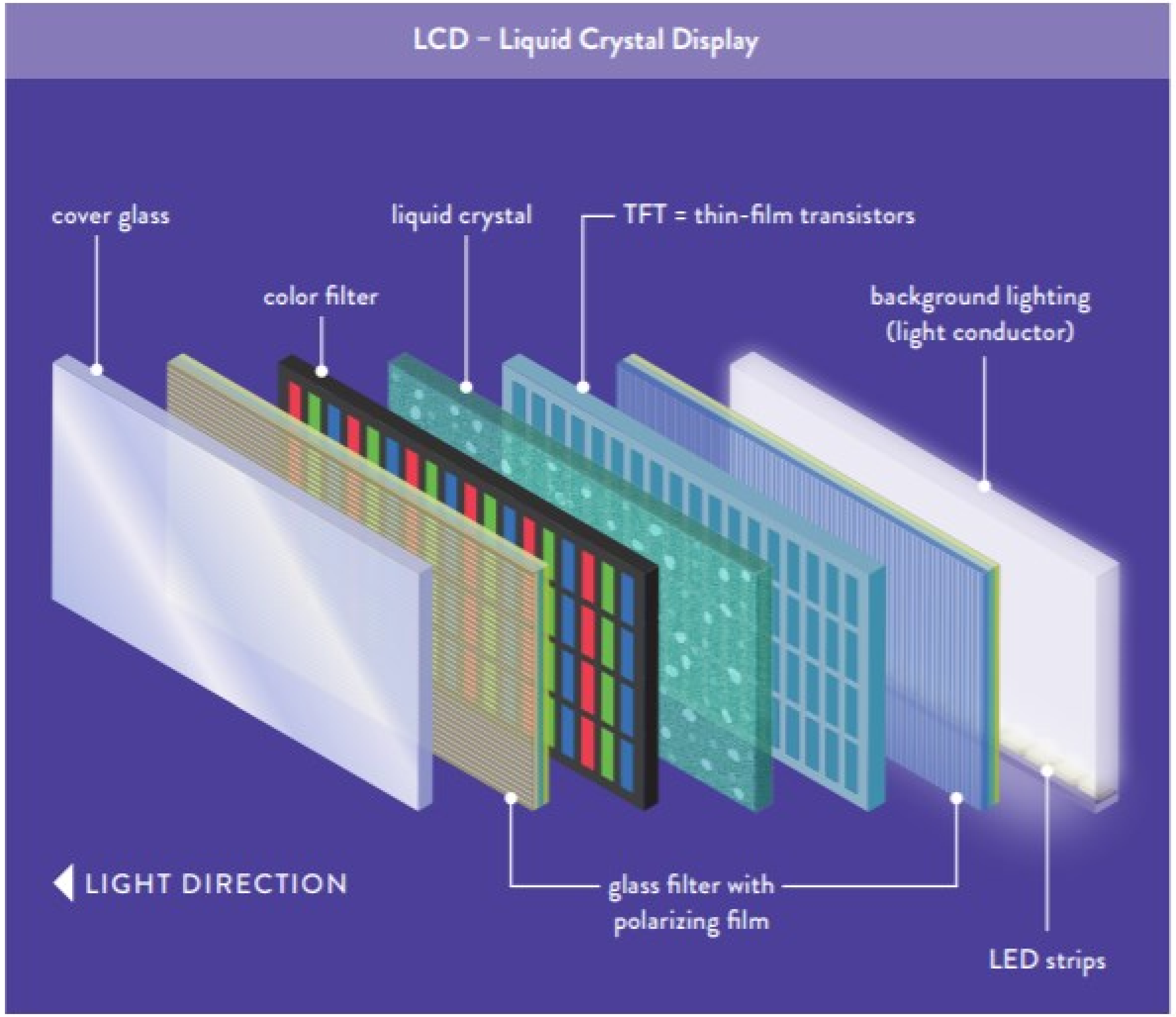


Applications: Image capture and display

LCD Vs O-LED

LCD DISPLAY STRUCTURE

Today's most common type of display creates images by blocking off or letting through white light that LEDs create across the back of the display.

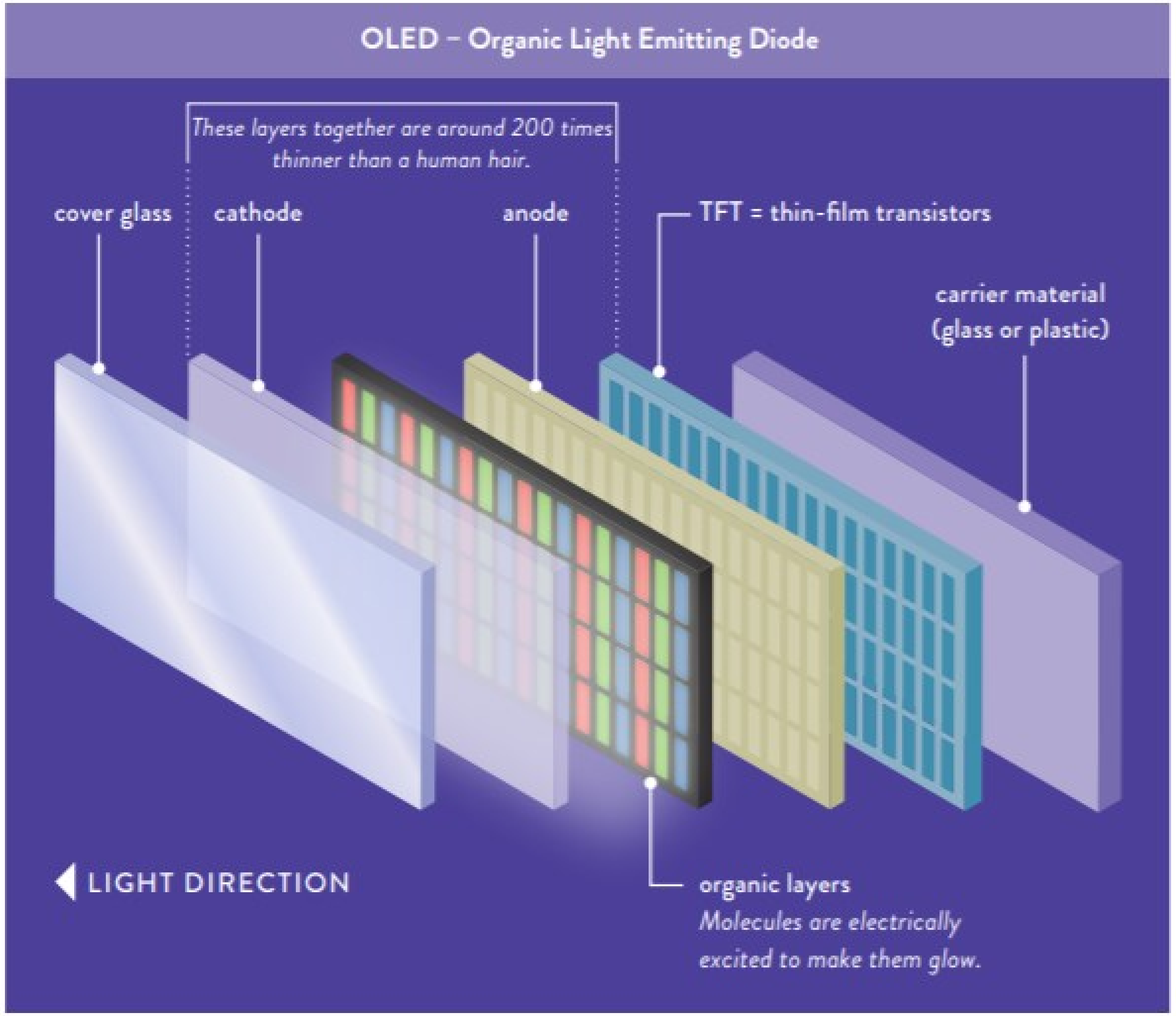


Applications: Image capture and display

LCD Vs O-LED

OLED DISPLAY STRUCTURE

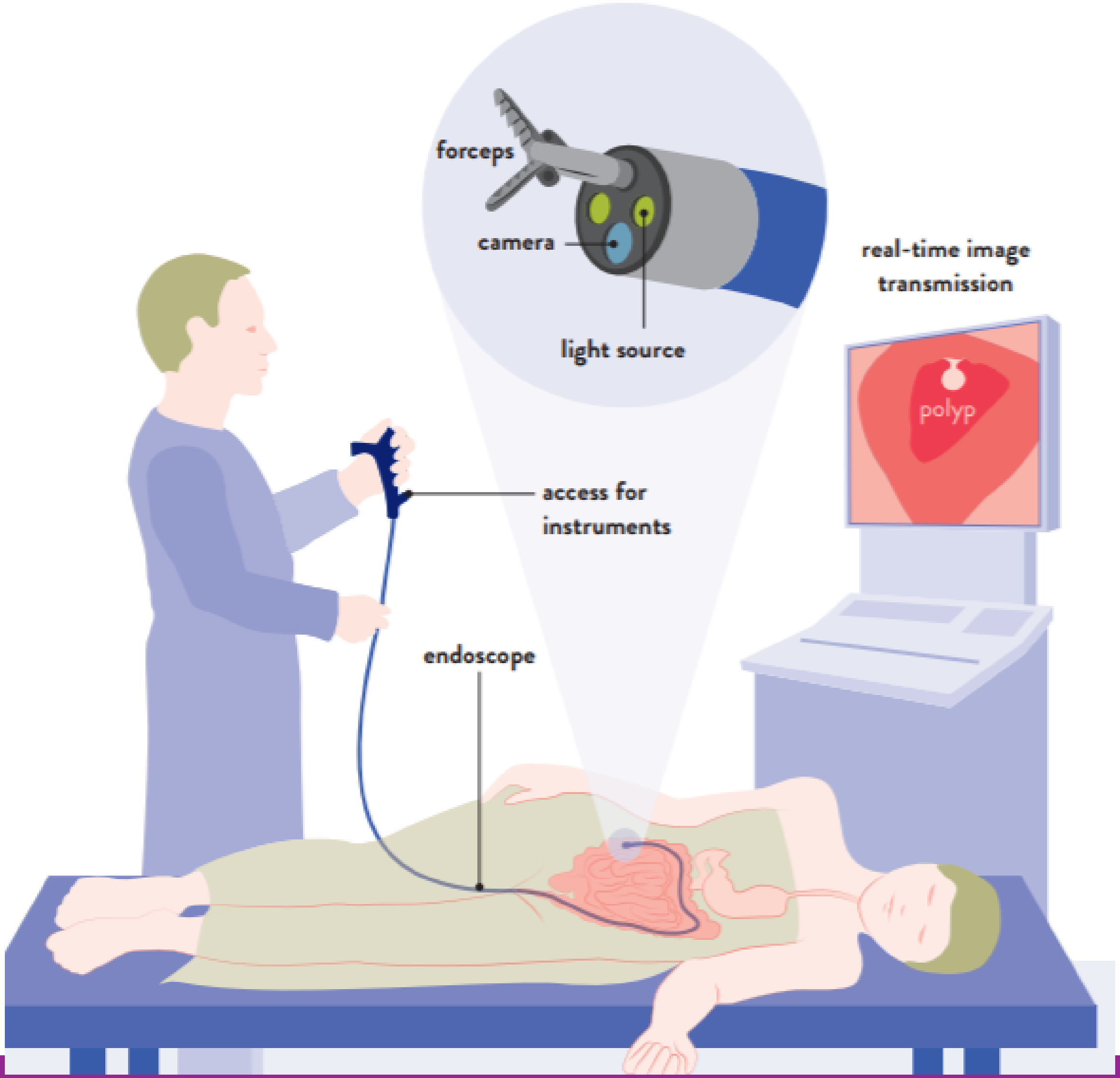
Organically luminous materials in OLED displays do not require a separate light source, which makes their construction depth much thinner.



Applications: Medical technology

ENDOSCOPY

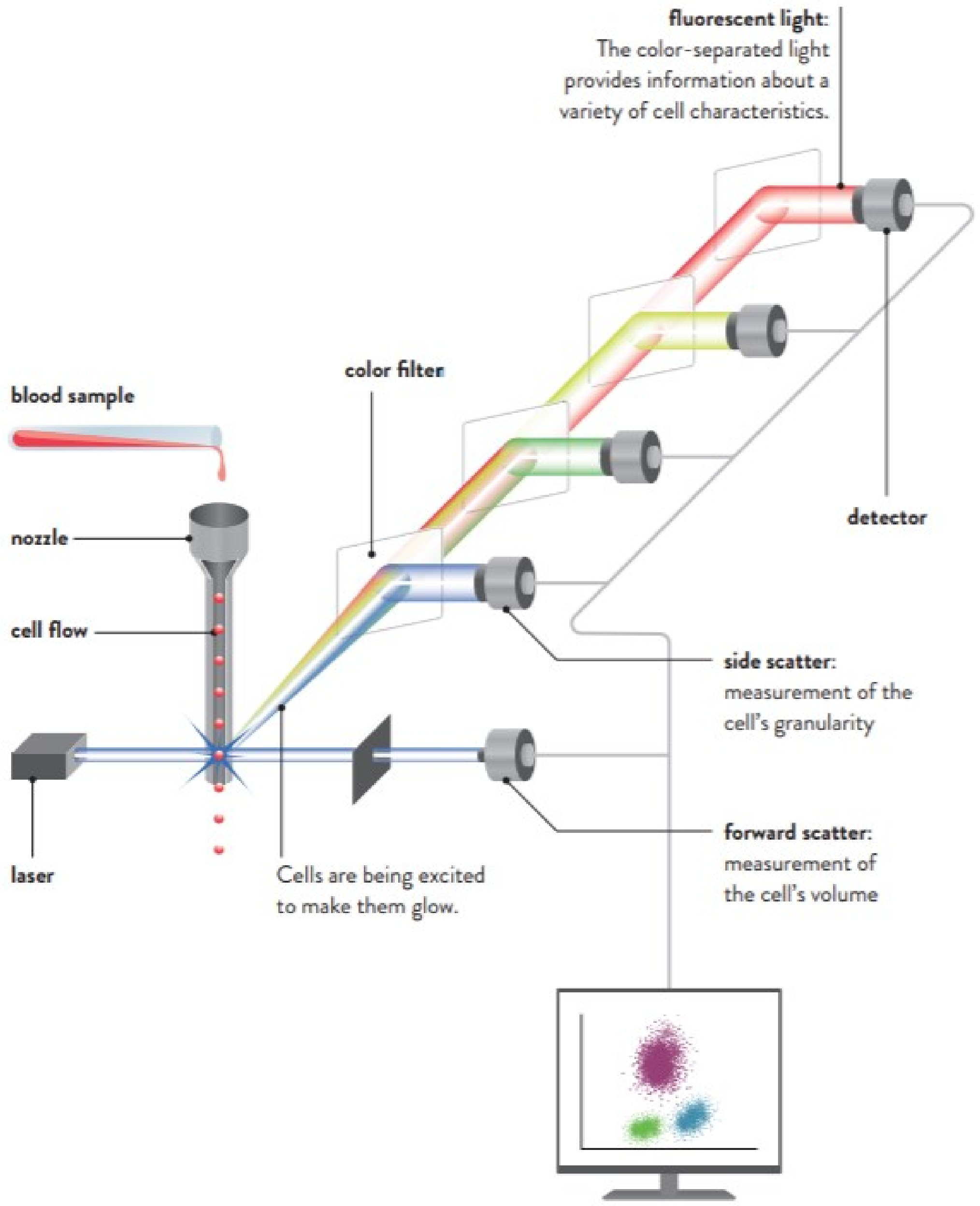
Endoscopes enable doctors to examine body cavities and hollow organs, detect illnesses, and treat them with minimal invasion at the same time, if required. The tubes, which are only a few millimeters thick, transfer illumination in one direction and high-resolution images in real time in the other direction.



Applications: Medical technology

BLOOD CELL COUNTS

Thousands of cells per second are counted and characterized in medical and biotechnical analytics with laser-based flow cytometry. This enables the fast and secure detection of blood anomalies.



Applications: Photovoltaics

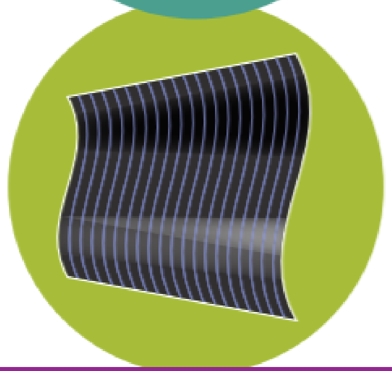
SOLAR CELLS

Solar cells can transform sunlight directly into electricity. An efficiency of around 45% has already been achieved under laboratory conditions. In commercial use, efficiency has to be weighed against acquisition costs.

BASIC COMMERCIAL TYPES

Monocrystalline silicon cells are cut out from a round silicon crystal. The missing corners of the squares are characteristic. This form is created because the round cross section of the raw material is exploited in the best possible way.

Polycrystalline silicon cells feature a characteristic texture that comes from crystal borders that are very close together.



Thin-film cells consist of amorphous silicone or other material compounds. They can be vapor deposited onto carrier materials, even onto flexible material.

In this Class

Molecular analysis

- Crystal structure
- Defects
- Diffusion

Material composition

- Alloys
- Polymers
- Ceramics
- Composites

Application of materials

- Electrical
- Magnetic
- Optical