Exam-04

Q1 (a) High conductivity and high transparency are mutually exclusive.

A highly conductive material has the absorption coefficient $\alpha \approx \sqrt{\frac{1}{2}\mu\omega\sigma}$

Based on this eqn., we conclude that a highly conductive material (high σ) has a large absorption coefficient (high α). A high α means that the material is opaque, i.e. not transparent. Therefore, "high conductivity" and "high transparency" are mutually exclusive.

(b) We showed that the two extremes, together, are not possible. To overcome this problem, we need to make a compromise.

⇒ Moderate conductivity and moderate transparency should be possible.

Q2 (a) Three electrical circuits

1. Only L's and C's
2. L's & C's & one $R=0$ & one $R=\infty$
3. L's & C's & $R=50\Omega$ & $R=8\Omega$

$\Rightarrow$ Only circuit ③ dissipates power.

(b) If $0<\sigma<\infty$, then the material attenuates or absorbs an EM wave.

Why?

For good conductor $\alpha=\sqrt{\frac{1}{2}\mu\omega\sigma}$

For weak conductor $\alpha=\frac{1}{2}\sigma\sqrt{\mu/\varepsilon}$

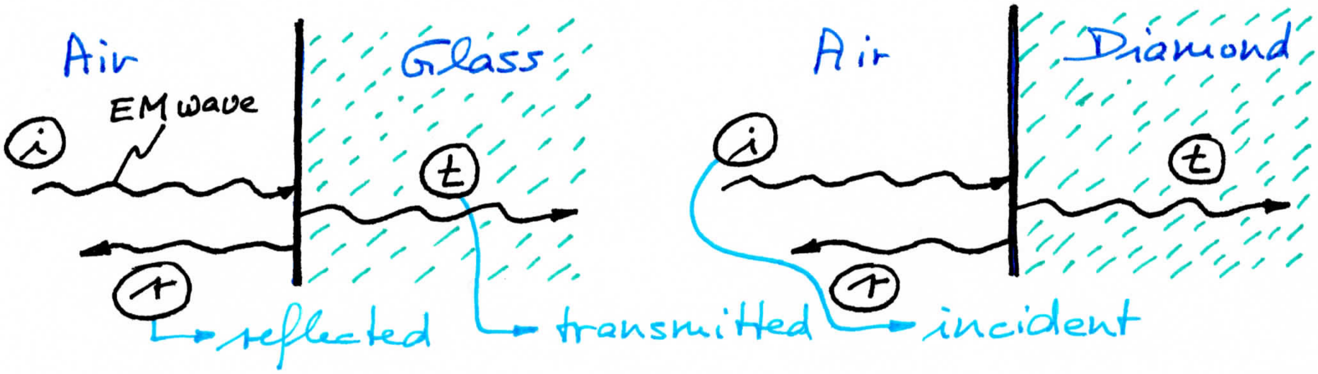
$\Rightarrow$ $\sigma=0$ $\Rightarrow$ $\alpha=0$

Furthermore, we showed for the ideal metal ($\sigma\to\infty$): $R=100\%$. This means that no attenuation (no absorption) occurs.

(c) Correspondence:

Material	Circuit	
ε_r	$\Rightarrow$ C	$\Rightarrow$ ε_r enhances energy stored in $\vec{E}$ by means of polarization
μ_r	$\Rightarrow$ L	$\Rightarrow$ μ_r enhances energy stored in $\vec{H}$ by means of magnetization
σ	$\Rightarrow$ R	$\Rightarrow$ σ enhances dissipation of energy (conversion to heat)

Q3 (a) EM wave in air entering (i) glass or (ii) diamond



Air – Glass:

$$r = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} = \frac{\sqrt{1} - \sqrt{2.1}}{\sqrt{1} + \sqrt{2.1}} = -0.183$$

$$R = r^2 = (-0.183)^2 = 0.0336 = \underline{3.6\%}$$

Air – Diamond:

$$r = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} = \frac{\sqrt{1} - \sqrt{4.8}}{\sqrt{1} + \sqrt{4.8}} = -0.373$$

$$R = r^2 = (-0.373)^2 = 0.139 = \underline{13.9\%}$$

(b) Amplitude reflection coefficient r

① Air-to-diamond

$$r = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} = \frac{\sqrt{1} - \sqrt{4.8}}{\sqrt{1} + \sqrt{4.8}} = -0.373$$

② Diamond-to-air

$$r = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}} = \frac{\sqrt{4.8} - \sqrt{1}}{\sqrt{4.8} + \sqrt{1}} = +0.373$$

⇒ Magnitude of r is the same

⇒ Sign is different

$r_{\text{Air-to-Dia}}$ ⇒ negative

$r_{\text{Dia-to-Air}}$ ⇒ positive

What does this mean?

$$r = |r| e^{j\Delta\phi}$$

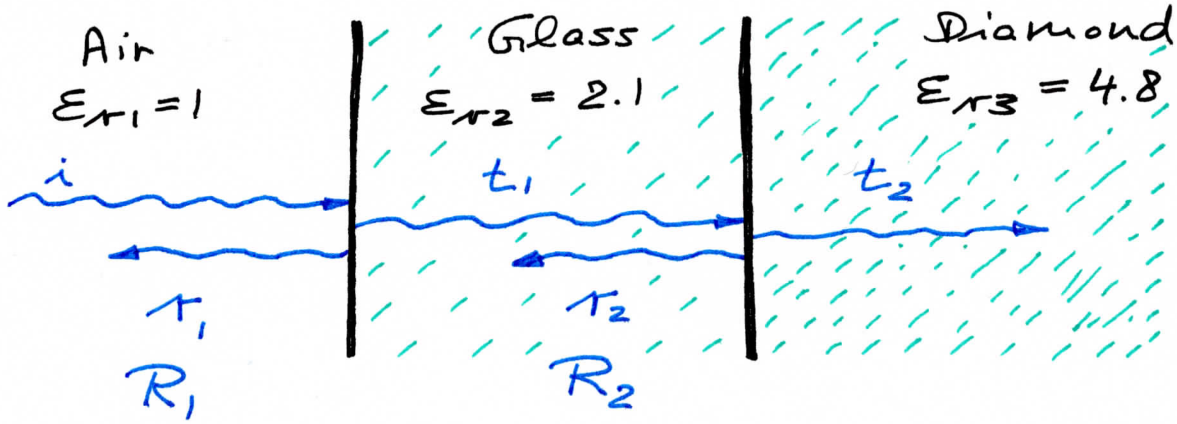
$\Delta\phi$ → Phase change upon reflection

If r is negative, then $\Delta\phi = \pi$

⇒ Wave incurs phase change of π upon reflection.

If r is positive, then $\Delta\phi = 0$

(c)



$R_1 = 3.36\%$ (see above)

$$R_2 = r_2^{\,2} = \left(\frac{\sqrt{\varepsilon_{r2}} - \sqrt{\varepsilon_{r3}}}{\sqrt{\varepsilon_{r2}} + \sqrt{\varepsilon_{r3}}}\right)^2 = \left(\frac{\sqrt{2.1} - \sqrt{4.8}}{\sqrt{2.1} + \sqrt{4.8}}\right)^2$$

$$= 0.0415 = 4.15\%$$

The powers of the reflected waves add up.

⇒ Total reflection $= R = R_1 + R_2 = 7.51\%$

(d) This means:

R of Air | Glass | Diamond $= 7.51\%$

R of Air | Diamond $= 13.9\%$
↳ (see above)

⇒ The glass reduces the reflectivity and thus acts as an anti-reflection (AR) coating.

Q4 (a) <u>True</u>

Sea water absorbs an EM wave due to its non-zero conductivity ($\sigma \neq 0$) and thus $\alpha > 0$. As a result, <u>sea water heats up</u>.

(b) <u>False</u>

The statement concerns a plane wave propagating along the <u>z-direction</u>. Plane waves are waves whose $\vec{E}$ and $\vec{H}$ <u>do not depend on x & y</u>.

This means:

$$\vec{E} = \vec{E}(z)$$

$$\vec{H} = \vec{H}(z)$$