P-M E-S   P-M S-E

전자기파와 광학 과제3   전기과 2018-12432 박정헌

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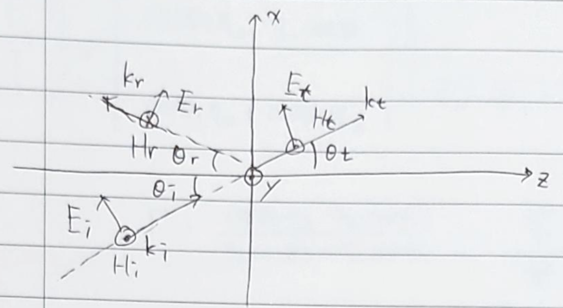


$= j\vec{k}\times\vec{E}$

$= \epsilon_{ijk} E_{0j}\, j k_i e^{j(\vec{k}\cdot\vec{r}-\omega t)}$

i) TM case

$e^{j(\vec{k}\cdot\vec{r}-\omega t)}$ → $\epsilon_{ijk}(E_{0j}\partial_i e^{j(\vec{k}\cdot\vec{r}-\omega t)})$

$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} = -\mu\frac{\partial\vec{H}}{\partial t} = j\mu\omega\cdot\vec{H} = \vec{\nabla}\times(\vec{E}_0 e^{j(\vec{k}\cdot\vec{r}-\omega t)}) = j\vec{k}\times\vec{E}$$

$$\Rightarrow \hat{n}\times\vec{E} = \frac{\mu\omega}{k}\cdot\vec{H} \quad \Rightarrow \frac{\omega}{k} = \frac{2\pi f\lambda}{2\pi} = v = \frac{c}{n} = \eta$$

$$= \frac{c\mu}{n}\cdot\vec{H}$$

$$= \eta\vec{H} \quad , \quad \vec{H} = \frac{1}{\eta}\hat{n}\times\vec{E} \quad , \quad H = \frac{1}{\eta}\cdot E$$

$$\cancel{\vec{\nabla}\times\vec{H} = \vec{J}_f + \frac{\partial\vec{D}}{\partial t} \rightarrow H_i - H_r = H_t \Rightarrow \frac{1}{\eta_1}(E_i - E_r) = \frac{1}{\eta_2}E_t}$$

$$\cancel{\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} \rightarrow E_i\cdot\cos\theta_i + E_r\cos\theta_r = E_t\cdot\cos\theta_t}$$

$$\cancel{\Rightarrow \eta_1 H_i\cos\theta_i + \eta_1 H_r\cos\theta_r = \eta_2 H_t\cos\theta_t}$$

$$\Rightarrow \cancel{\eta_1 H_i\cos\theta_i - \eta_1 H_r\cos\theta_i}$$

$\cancel{E_I} =$

$$\cancel{\text{let, } E_r = \Gamma\cdot E_i}$$

$$\cancel{\Rightarrow H_i - H_r = H_t = \frac{1}{\eta_1}(1-\Gamma)E_i = \frac{1}{\eta_2}\cdot E_t}$$

$$\cancel{E_i\cos\theta_i + \Gamma\cdot\cos\theta_r\cdot E_i = E_t\cos\theta_t}$$

$$\cancel{\Rightarrow \frac{\eta_2(1-\Gamma)\cos\theta_t}{\cos\theta_i + \Gamma\cdot\cos\theta_r} =}$$

$$\vec{E}_i = (\cos\theta_i\hat{x} - \sin\theta_i\hat{z})E_0 e^{j(\vec{k}_i\cdot\vec{r}-\omega t)} \qquad \vec{E}_r = (\cos\theta_r\hat{x} + \sin\theta_r\hat{z})\Gamma\cdot E_0 e^{j(\vec{k}_r\cdot\vec{r}-\omega t)}$$

$$\vec{H}_i = \frac{E_0}{\eta_1}e^{j(\vec{k}_i\cdot\vec{r}-\omega t)}\hat{y} \qquad \vec{H}_r = -\frac{\Gamma E_0}{\eta_1}e^{j(\vec{k}_r\cdot\vec{r}-\omega t)}\hat{y}$$

$$\vec{E}_t = (\cos\theta_t\hat{x} - \sin\theta_t\hat{z})T\cdot E_0 e^{j(\vec{k}_t\cdot\vec{r}-\omega t)} \qquad \Rightarrow \theta_i = \theta_r$$

$$\vec{H}_t = \frac{E_0}{\eta_2}T e^{j(\vec{k}_t\cdot\vec{r}-\omega t)}\hat{y} \qquad k_1\sin\theta_i = k_2\sin\theta_t = k_1\sin\theta_r$$

$$\Rightarrow \text{at } z=0 \quad e^{j(\vec{k}_i\cdot\vec{r})}\cos\theta_i E_0 + \cos\theta_r\cdot E_0\Gamma e^{j(\vec{k}_r\cdot\vec{r})} = T\cdot E_0\cos\theta_t e^{j(\vec{k}_t\cdot\vec{r})}$$

$$\Rightarrow \frac{1}{\eta_1}(1-\Gamma) = \frac{1}{\eta_2}\cdot T \quad \Rightarrow \begin{bmatrix}\eta_2\\ \cos\theta_i\end{bmatrix} = \begin{bmatrix}\eta_2 & \eta_1\\ -\cos\theta_i & \cos\theta_t\end{bmatrix}\begin{bmatrix}\Gamma\\ T\end{bmatrix}$$

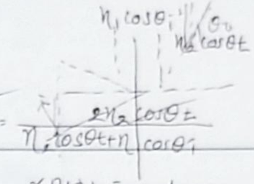
$$\Rightarrow \cos\theta_i + (\cos\theta_i)\Gamma = T\cos\theta_t$$

$$\Rightarrow \frac{1}{\eta_2\cos\theta_t + \eta_1\cos\theta_i}\begin{bmatrix}\cos\theta_t & -\eta_1\\ \cos\theta_i & \eta_2\end{bmatrix}\begin{bmatrix}\eta_2\\ \cos\theta_i\end{bmatrix} = \begin{bmatrix}\Gamma\\ T\end{bmatrix}$$

PM
SE
계

$$\eta = \frac{\mu\omega}{k} = \frac{\mu c}{n}$$

$$\frac{E_t \cos\theta_t}{E_i \cos\theta_i} = \frac{2\eta_2 \cos\theta_t}{\eta_2\cos\theta_t + \eta_1\cos\theta_i}$$



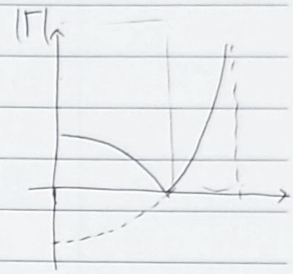
×θ당하는 impedance
$\underbrace{\eta\cos\theta}$

$$\Rightarrow \begin{bmatrix}\Gamma \\ T\end{bmatrix} = \begin{bmatrix}\cos\theta_t\eta_2 - \eta_1\cos\theta_i \\ \\ \cos\theta_i\eta_2 + \cos\theta_i\eta_2\end{bmatrix} \frac{1}{\eta_2\cos\theta_t + \eta_1\cos\theta_i}$$

$$\eta = \cancel{\mu\omega}\ \frac{\mu c}{n}$$

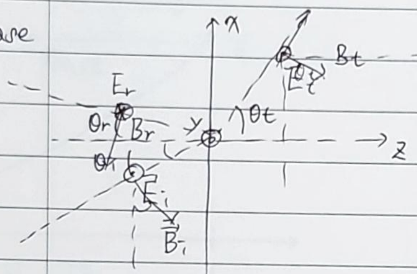
$$\therefore\ \Gamma = \frac{\cos\theta_t\cdot\eta_2 - \eta_1\cos\theta_i}{\eta_2\cos\theta_t + \eta_1\cos\theta_i} = \underbrace{\frac{\frac{\mu_2}{n_2}\cdot\cos\theta_t - \frac{\mu_1}{n_1}\cos\theta_i}{\frac{\mu_2}{n_2}\cos\theta_t + \frac{\mu_1}{n_1}\cos\theta_i}}$$

$$T = \frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_t + \eta_1\cos\theta_i} = \underbrace{\frac{2\frac{\mu_2}{n_2}\cos\theta_i}{\frac{\mu_2}{n_2}\cos\theta_t + \frac{\mu_1}{n_1}\cos\theta_i}}$$



ii). TE case

$$J \sim \vec{B} = \frac{1}{\eta}\hat{n}\times\vec{E}, \quad \eta = \frac{\mu\omega}{k}$$



$$\cancel{\vec{E}_i = (}$$

$$\vec{E}_i = E_0\hat{y}e^{j(\vec{k}_i\cdot\vec{r}-\omega t)}$$

$$\vec{H}_i = \frac{E_0}{\eta_1}\cdot(-\cos\theta_i\hat{x} + \sin\theta_i\hat{z})e^{j(\vec{k}_i\cdot\vec{r}-\omega t)}$$

$$\vec{E}_r = -\Gamma\cdot E_0\hat{y}e^{j(\vec{k}_r\cdot\vec{r}-\omega t)}$$

$$\vec{H}_r = \frac{\Gamma E_0}{\eta_1}\cdot(-\cos\theta_r\hat{x} - \sin\theta_r\hat{z})e^{j(\vec{k}_r\cdot\vec{r}-\omega t)}$$

$$\vec{E}_t = T\cdot E_0 e^{j(\vec{k}_t\cdot\vec{r}-\omega t)}$$

$$\vec{H}_t = \frac{T\cdot E_0}{\eta_2}\cdot(-\cos\theta_t\hat{x} + \sin\theta_t\hat{z})e^{j(\vec{k}_t\cdot\vec{r}-\omega t)}$$

$$\Rightarrow\ e^{j(\vec{k}_i\cdot\vec{r})} - \Gamma e^{j(\vec{k}_r\cdot\vec{r})} = T e^{j(\vec{k}_t\cdot\vec{r})} \quad @\ z=0 \ \Rightarrow k_1\sin\theta_i = k_2\sin\theta_t = k_1\sin\theta_r$$

$$\Rightarrow \theta_i = \theta_r$$

$$\Rightarrow\ 1 - \Gamma = T$$

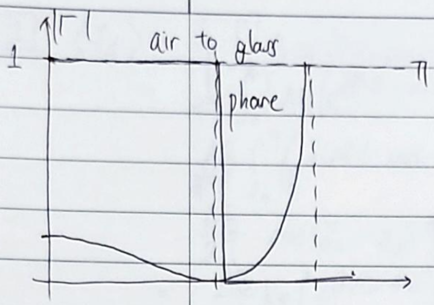
$$\frac{1}{\eta_1}\cdot(+\cos\theta_i + \cos\theta_r\Gamma) = \frac{1}{\eta_2}\cdot(+T\cos\theta_t)$$

$$\Rightarrow \cancel{\begin{bmatrix}1 \\ \eta_2\cos\theta_i\end{bmatrix}} \begin{bmatrix}1 \\ \frac{\cos\theta_i}{\eta_1}\end{bmatrix} = \begin{bmatrix}1 & 1 \\ -\frac{\cos\theta_i}{\eta_1} & \frac{\cos\theta_t}{\eta_2}\end{bmatrix}\begin{bmatrix}\Gamma \\ T\end{bmatrix}$$

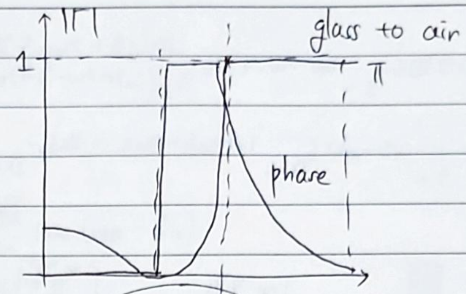
$$\Rightarrow \begin{bmatrix}\Gamma \\ T\end{bmatrix} = \frac{1}{\frac{\cos\theta_t}{\eta_2} + \frac{\cos\theta_i}{\eta_1}}\begin{bmatrix}\frac{\cos\theta_t}{\eta_2} & -1 \\ \frac{\cos\theta_i}{\eta_1} & 1\end{bmatrix}\begin{bmatrix}1 \\ \frac{\cos\theta_i}{\eta_1}\end{bmatrix}$$

$$\Rightarrow \Gamma = \frac{\frac{\cos\theta_t}{\eta_2} - \frac{\cos\theta_i}{\eta_1}}{\frac{\cos\theta_t}{\eta_2} + \frac{\cos\theta_i}{\eta_1}} = \underbrace{\frac{\frac{\mu_1}{n_1}\cos\theta_t - \frac{\mu_2}{n_2}\cos\theta_i}{\frac{\mu_1}{n_1}\cos\theta_t + \frac{\mu_2}{n_2}\cos\theta_i}}$$

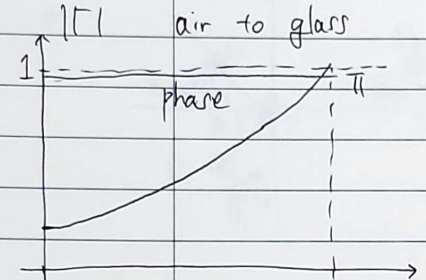
$$T = \frac{\frac{2\cos\theta_i}{\eta_1}}{\frac{\cos\theta_t}{\eta_2} + \frac{\cos\theta_i}{\eta_1}} = \underbrace{\frac{\frac{2\mu_2}{n_2}\cos\theta_i}{\frac{\mu_1}{n_1}\cos\theta_t + \frac{\mu_2}{n_2}\cos\theta_i}}$$



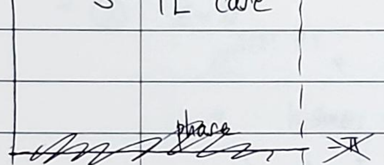
P-TM case

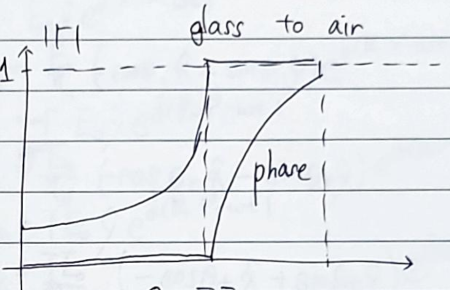


P-TM case



S-TE case





S-TE case

P-TM $\perp$

S-TE $//$

$\boxed{2}$ $\langle fg \rangle = \frac{1}{T}\int_0^T A\cos(\vec{k}\cdot\vec{r}-\omega t+\delta_a)\,B\cos(\vec{k}\cdot\vec{r}-\omega t+\delta_b)\,dt$

$= \frac{1}{4T}\int_0^T AB\left(e^{j(\vec{k}\cdot\vec{r}-\omega t+\delta_a)}+e^{-j(\vec{k}\cdot\vec{r}-\omega t+\delta_a)}\right)\left(e^{+j(\vec{k}\cdot\vec{r}-\omega t+\delta_b)}+e^{-j(\vec{k}\cdot\vec{r}-\omega t+\delta_b)}\right)dt$

$= \frac{AB}{4T}\int_0^T \left(e^{j(2\vec{k}\cdot\vec{r}-2\omega t+\delta_a+\delta_b)}+e^{-j(2\vec{k}\cdot\vec{r}-2\omega t+\delta_a+\delta_b)}+e^{j(\delta_a-\delta_b)}+e^{-j(\delta_a-\delta_b)}\right)dt$

$= \frac{AB}{2T}\cos(\delta_a-\delta_b)\,T = \frac{AB}{2}\cos(\delta_a-\delta_b)$

$= \frac{AB}{2}\mathrm{Re}\left(e^{j(\delta_a-\delta_b)}\right) = \frac{1}{2}\mathrm{Re}(\tilde{f}\tilde{g}^*)$

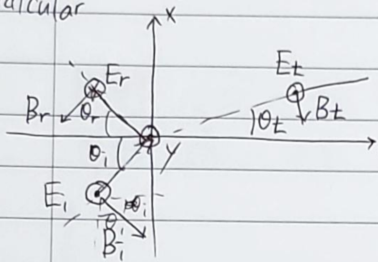
$e^{j(\vec{k}\cdot\vec{r}-\omega t)}$　　V　J

$\Rightarrow \hat{n}\times\vec{E} = \frac{\mu\omega}{k}\vec{H}$

$\nabla\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} = -\mu\frac{\partial\vec{H}}{\partial t} = j\vec{k}\times\vec{E} = +j\mu\omega\vec{H}$

$\boxed{3}$ Perpendicular : TE

$\Rightarrow$



$\vec{E}_i = E_0\hat{y}\,e^{j(\vec{k}_i\cdot\vec{r}-\omega t)}$

$\vec{H}_i = \frac{E_0}{\eta_1}(-\cos\theta_i\hat{x}+\sin\theta_i\hat{y})e^{j(\vec{k}_i\cdot\vec{r}-\omega t)}$

$\vec{E}_r = -\Gamma E_0\hat{y}\,e^{j(\vec{k}_r\cdot\vec{r}-\omega t)}$

$\vec{H}_r = \frac{E_0}{\eta_1}(-\cos\theta_r\hat{x}-\sin\theta_r\hat{y})e^{j(\vec{k}_r\cdot\vec{r}-\omega t)}$

$\vec{E}_t = TE_0\hat{y}\,e^{j(\vec{k}_t\cdot\vec{r}-\omega t)}$

$\vec{H}_t = \frac{TE_0}{\eta_2}(-\cos\theta_t\hat{x}+\sin\theta_t\hat{y})e^{j(\vec{k}_t\cdot\vec{r}-\omega t)}$

$\Rightarrow$ @ $z=0$

$e^{j(\vec{k}_i\cdot\vec{r})} - \Gamma e^{j(\vec{k}_r\cdot\vec{r})} = T\,e^{j\vec{k}_t\cdot\vec{r}}$

$\Rightarrow k_1\sin\theta_i = k_1\sin\theta_r = k_2\sin\theta_t \Rightarrow \theta_i=\theta_r$

$\Rightarrow 1-\Gamma = T \Rightarrow 1=\Gamma+T$

$\frac{\cos\theta_i}{\eta_1}+\Gamma\frac{\cos\theta_r}{\eta_1} = \frac{\cos\theta_t}{\eta_2}T \Rightarrow \frac{\cos\theta_i}{\eta_1} = -\frac{\cos\theta_r}{\eta_1}\Gamma+\frac{\cos\theta_t}{\eta_2}T$

$$\Rightarrow \begin{bmatrix}1\\ \frac{\cos\theta_i}{\eta_1}\end{bmatrix} = \begin{bmatrix}1 & 1\\ -\frac{\cos\theta_r}{\eta_1} & \frac{\cos\theta_t}{\eta_2}\end{bmatrix}\begin{bmatrix}\Gamma\\ T\end{bmatrix}$$

$$\Rightarrow \begin{bmatrix}\Gamma\\ T\end{bmatrix} = \frac{1}{\frac{\cos\theta_t}{\eta_2}+\frac{\cos\theta_r}{\eta_1}}\begin{bmatrix}\frac{\cos\theta_t}{\eta_2} & -1\\ \frac{\cos\theta_r}{\eta_1} & 1\end{bmatrix}\begin{bmatrix}1\\ \frac{\cos\theta_i}{\eta_1}\end{bmatrix}$$

$\eta = \frac{\mu\omega}{k} = \frac{\mu c}{n}$

$$\Rightarrow \Gamma = \frac{\eta_1\cos\theta_t-\eta_2\cos\theta_i}{\eta_1\cos\theta_t+\eta_2\cos\theta_i} \approx \frac{n_2\cos\theta_t-n_1\cos\theta_i}{n_2\cos\theta_t+n_1\cos\theta_i}$$

$$T = \frac{2\eta_2\cos\theta_i}{\eta_1\cos\theta_t+\eta_2\cos\theta_i} \approx \frac{2n_1\cos\theta_i}{n_2\cos\theta_t+n_1\cos\theta_i}$$

$\sin\theta = \frac{1}{1.5}$

$n_1 = n_2 \sin\theta$

$\Rightarrow \Gamma = \frac{1.5\cos\theta_t - \cos\theta_i}{1.5\cos\theta_t + \cos\theta_i}$

$T = \frac{2\cos\theta_i}{1.5\cos\theta_t + \cos\theta_i}$

$n_1 \sin\theta_i = n_2 \sin\theta_t$

$\Rightarrow \cos\theta_t = \sqrt{1-\left(\frac{n_1}{n_2}\right)^2 \sin^2\theta_i}$

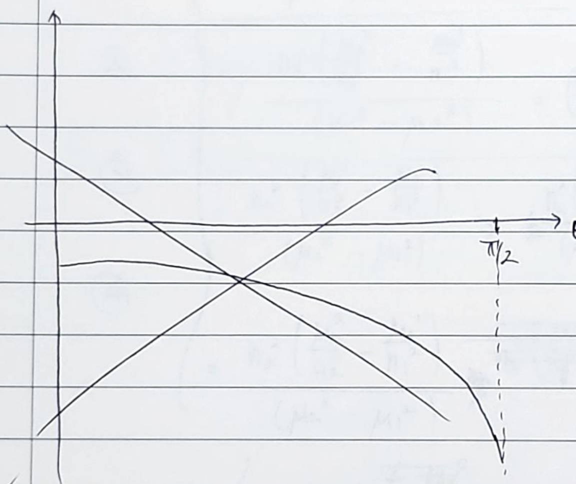
$\cos\theta_t = \sqrt{1-\left(\frac{n_1}{n_2}\right)^2} = \frac{\sqrt{1.25}}{1.5}$

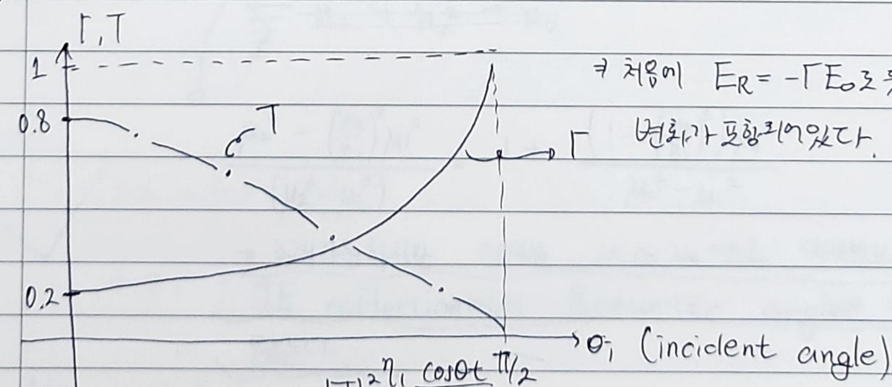
$$\Rightarrow \Gamma(\theta_i) = \frac{1.5\sqrt{1-\frac{1}{(1.5)^2}\sin^2\theta_i} - \cos\theta_i}{1.5\sqrt{1-\frac{1}{(1.5)^2}\sin^2\theta_i} + \cos\theta_i}$$

$$T(\theta_i) = \frac{2\sqrt{1-\left(\frac{1}{1.5}\right)^2\sin^2\theta_i}}{1.5\sqrt{1-\left(\frac{1}{1.5}\right)^2\sin^2\theta_i} + \cos\theta_i}$$

$\Gamma(0) = \frac{1.5-1}{1.5+1} = \frac{0.5}{2.5} = 0.2$ $\quad\Gamma\left(\frac{\pi}{2}\right)$

$T(0) = \frac{2}{2.5} = 0.8$ $\quad T(\pi/2) =$





→ 처음에 $E_R = -\Gamma E_0$로 뒀으므로 이미 π phase 변화가 포함되어있다.

$|T|^2 \frac{\eta_1}{\eta_2}\frac{\cos\theta_t}{\cos\theta_i}$

$$R+T = |\Gamma|^2 + \cancel{\ldots} = \frac{(\eta_1\cos\theta_t)^2 + (\eta_2\cos\theta_i)^2 - 2\eta_1\eta_2\cos\theta_t\cos\theta_i + 4\eta_1\eta_2\cos\theta_i\cos\theta_t}{(\eta_1\cos\theta_t + \eta_2\cos\theta_i)^2} = 1$$

$$\frac{|S_t|^2}{|S_i|^2} = \frac{\frac{1}{\mu_0}|E_0|^2 \cdot \left|\frac{E_0}{\eta_2}\right| |T|^2 \cos\theta_t}{\frac{1}{\mu_0}|E_0|^2 \cdot \left|\frac{E_0}{\eta_1}\right|^2 \cos\theta_i} = \frac{\eta_1}{\eta_2} \cdot |T|^2 \frac{\cos\theta_t}{\cos\theta_i}$$

$$\eta_1 \cos\theta_t = \eta_2 \cos\theta_i \qquad \text{for } \Gamma = 0$$

$$\Rightarrow \frac{\mu_1 \omega}{k_1}\cos\theta_t = \frac{\mu_2 \omega}{k_2}\cos\theta_i$$

$$\Rightarrow \frac{\mu_1}{n_1}\cos\theta_t = \frac{\mu_2}{n_2}\cos\theta_i \qquad \Rightarrow \quad n_1 \sin\theta_i = n_2 \sin\theta_t \Rightarrow$$

$$\rightarrow \cos\theta_t = \sqrt{1-\frac{n_1^2}{n_2^2}\sin^2\theta_i}$$

$$\Rightarrow \frac{\mu_1}{n_1}\sqrt{1-\frac{n_1^2}{n_2^2}\sin^2\theta_i} = \frac{\mu_2}{n_2}\cos\theta_i$$

$$\Rightarrow \mu_1^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\sin^2\theta_i\right) = \frac{\mu_2^2}{n_2^2}\left(1-\sin^2\theta_i\right)$$

$$\Rightarrow \left(\frac{\mu_1^2}{n_1^2} - \frac{\mu_2^2}{n_2^2}\right) = \left(\frac{\mu_1^2}{n_2^2} - \frac{\mu_2^2}{n_2^2}\right)\sin^2\theta_i$$

$$\Rightarrow \sin^2\theta_i = \frac{n_2^2\left(\frac{\mu_1^2}{n_1^2} - \frac{\mu_2^2}{n_2^2}\right)}{(\mu_1^2-\mu_2^2)}$$

① $= \; > \dfrac{n_2^2\left(\frac{\mu_1^2}{n_2^2} - \frac{\mu_2^2}{n_2^2}\right)}{(\mu_1^2-\mu_2^2)} = 1 \qquad (n_2 > n_1 \;,\; \mu_1 > \mu_2)$

② $> \dfrac{n_2^2\left(\frac{\mu_1^2}{n_1^2} - \frac{\mu_2^2}{n_1^2}\right)}{(\mu_1^2-\mu_2^2)} = \left(\frac{n_2}{n_1}\right)^2 > 1 \qquad (n_1 < n_2 \;,\; \mu_1 > \mu_2)$

③ $= \dfrac{n_2^2\left(\frac{\mu_2^2}{n_2^2} - \frac{\mu_1^2}{n_1^2}\right)}{(\mu_2^2-\mu_1^2)} > \dfrac{n_2^2\left(\frac{\mu_2^2}{n_2^2} - \frac{\mu_1^2}{n_2^2}\right)}{(\mu_2^2-\mu_1^2)} = 1 \qquad (n_2 < n_1 \quad \mu_1 < \mu_2 \quad \cancel{\mu_1 > \mu_2})$

④ $= \dfrac{n_2^2\left(\frac{\mu_2^2}{n_2^2} - \frac{\mu_1^2}{n_1^2}\right)}{(\mu_2^2-\mu_1^2)} \quad \cancel{\frac{n_2^2\left(\frac{\mu_2^2}{n_2^2} - \frac{\mu_1^2}{n_1^2}\right)}{}} \qquad (n_1 < n_2 \quad \mu_1 < \mu_2)$

$$= \frac{\mu_2^2 - \left(\frac{n_2}{n_1}\right)^2\mu_1^2}{(\mu_2^2-\mu_1^2)} = 1 + \frac{\left(1-\left(\frac{n_2}{n_1}\right)^2\right)\mu_1^2}{\mu_2^2-\mu_1^2}$$

→ 존재가능하지만 대부분 $\mu_1 \simeq \mu_2$이므로 대부분의 경우 TE reflection에서 Brewster angle은 존재하지 않는다.

$\Rightarrow$ for $\theta_i = 0 \rightarrow \theta_t = 0$

$$\Rightarrow \Gamma = \frac{n_2 - n_1}{n_2 + n_1} \quad \rightarrow \text{수직입사하는 경우와 일치}$$

$$T = \frac{2n_1}{n_2+n_1}$$

$(\nabla^2 + k^2)$

$\vec{H} = e^{j(\vec{k}\cdot\vec{r} - \omega t)}$

$\boxed{4}$ a) $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \rightarrow \vec{\nabla} \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t}$

$\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t} \rightarrow \vec{\nabla} \times \vec{H} = \vec{J}_f + \frac{\partial \vec{D}}{\partial t} = \vec{J}_f + \varepsilon \frac{\partial \vec{E}}{\partial t}$

$\Rightarrow \vec{J}_f \simeq \sigma \vec{E}, \quad \partial_t \vec{H} = -j\omega \vec{H}$

$\Rightarrow \vec{\nabla} \times \vec{E} = +j\omega \vec{H} \mu$

$\vec{\nabla} \times \vec{H} = \sigma \vec{E} - j\omega \varepsilon \vec{E}$

$$\vec{\nabla} \times (\vec{\nabla} \times \vec{E}) = +j\omega\mu \vec{\nabla} \times \vec{H} = -j\omega(\sigma \vec{E} - j\omega\varepsilon \vec{E})$$

$$= +j\omega\sigma\mu \vec{E} + \omega^2 \varepsilon \vec{E} \mu$$

$$= \vec{\nabla}(\underbrace{\cancel{\vec{\nabla} \cdot \vec{E}}}_{0}) - \nabla^2 \vec{E}$$

$$\therefore (\nabla^2 + j\omega\sigma\mu + \omega^2 \mu\varepsilon)\vec{E} = 0$$

$$\vec{E} = \vec{E}_0 \exp(j(\vec{k}\cdot\vec{r} - \omega t))$$

$$\Rightarrow (-k^2 + j\omega\sigma\mu + \omega^2 \mu\varepsilon) = 0$$

$$\therefore k^2 = +\omega^2 \mu\varepsilon + j\omega\sigma\mu$$

$$= \omega^2 \mu\varepsilon \cdot \left(1 + j\frac{\sigma}{\varepsilon\omega}\right)$$

$\rho = \sigma^{-1}$

$$\therefore k = \omega\sqrt{\mu\varepsilon}\left(1 + j\frac{\sigma}{\varepsilon\omega}\right)^{1/2}$$

$$\simeq \omega\sqrt{\mu\varepsilon} \cdot \left(1 + \frac{\sigma}{2\varepsilon\omega} j\right) = \omega\sqrt{\mu\varepsilon} + j\frac{1}{2}\sqrt{\frac{\mu}{\varepsilon}}\,\sigma$$

$$\Rightarrow \vec{E} \sim \exp j\left(j 2\sqrt{\tfrac{\mu}{\varepsilon}}\sigma\right)x = e^{-2\sqrt{\frac{\mu}{\varepsilon}}\cdot \sigma x}$$

$$\Rightarrow \delta = \frac{2}{\sigma}\sqrt{\frac{\varepsilon}{\mu}} = \frac{2}{(8.3 \times 10^3)^{-1}}\left(\frac{8.854 \times 10^{-12} \times 80.1}{4\pi \times 10^{-7}(1 - 9.0 \times 10^{-6})}\right)^{1/2} = 394\text{ m}$$

b) $\sigma \gg \varepsilon\omega$

$$\Rightarrow k \simeq \omega\sqrt{\mu\varepsilon} \cdot \left(j\frac{\sigma}{\varepsilon\omega}\right)^{1/2} = \omega\sqrt{\mu\varepsilon} \cdot \left(\frac{1+j}{\sqrt{2}}\right)\sqrt{\frac{\sigma}{\varepsilon\omega}} \rightarrow \kappa \simeq \sqrt{\frac{\mu\sigma\cdot\omega}{2}}$$

$$\Rightarrow \delta = \sqrt{\frac{2}{\mu\sigma\omega}} = \left(\frac{2}{4\pi \times 10^{-7} \times 10^{7} \times 10^{15}}\right)^{1/2} = 1.26 \times 10^{-8}\text{ m} = 12.6\text{ nm}$$

→ δ 가 너무 작아 전자기파가 투과 불가능하다.

c) $\vec{\nabla} \times \vec{E} = j\omega\mu \vec{H} = j\vec{k} \times \vec{E} \Rightarrow \omega\mu \vec{H} = (\hat{n} \times \vec{E}) \cdot k \Rightarrow$ phase between $\vec{H}, \vec{E} = \angle \vec{k}$

$\Rightarrow k \simeq \omega\sqrt{\mu\varepsilon} \cdot \left(\frac{1+j}{\sqrt{2}}\right) \Rightarrow \angle k = 45° \Rightarrow \angle \vec{H} - \angle \vec{E} = 45° \rightarrow$ 45° 뒤떨어졌다.

$$\Rightarrow \cancel{\frac{|\vec{H}|}{|\vec{E}|} = \left|\frac{k}{\omega\mu}\right| = \frac{\omega\sqrt{\mu\varepsilon}}{\omega\mu} = \sqrt{\frac{\varepsilon}{\mu}} = \frac{10^{-12} \times 8.854}{4\pi \times 10^{-7}}}$$

$$E = cB$$

$$\frac{B}{E} = \frac{1}{c} \qquad \frac{\frac{1}{\mu}B}{E} = \frac{1}{\mu c}$$

$$\frac{|H|}{|E|} = \frac{|k|}{|\omega\mu|} = \frac{\cancel{\omega\sqrt{\mu\epsilon}}}{\omega\mu} \cdot \sqrt{\frac{\sigma}{\cancel{\epsilon}\omega}} = \sqrt{\frac{\sigma}{\mu\omega}} = \sqrt{\frac{10^{7}}{4\pi\times10^{-7}\times10^{15}}}$$

$$= \sqrt{\frac{1}{4\pi\times10}} = 0.0892\ S/m \cdot m/H = \underline{0.0892\ S/H}$$

$$\frac{|B|}{|E|} = \frac{\mu|H|}{|E|} = 0.0892\times4\pi\times10^{-7}\ S/m$$

$$= \underline{1.12\times10^{-7}\ S/m}$$