Comparison of Slit Transmittances between Metal Plates at Terahertz Range and PEC Plate

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***Abstract* - The behavior of power transmission of a normally incidence plane wave with TM polarization through subwavelength slits on Ag and Au plates from 1.2 THz to 200 THz is investigated for various plate thicknesses. The transmission patterns versus plate thickness by using mode matching technique are contrasted to those of a slit on perfectly conducting plate. The transmission physics at low frequency is similar to that of PEC case, while the transmittances at higher frequency do not follow that of PEC.**

***Index Terms* — Slit transmittance, mode matching technique, MIM (Metal-Insulator-Metal) waveguide.**

1. Introduction

Electromagnetic power transmission through perfect electric conductor (PEC) slit is a classical research topic [1]. Besides, the transmission through the slit in optical regime has been dealt with in recent years. However, the transmission phenomena in terahertz (THz) frequencies are not discussed from low to high THz span.

Moreover, power transmission by finite-difference time-domain (FDTD) method or finite elements can be obtained relatively easily but is less suitable to understand the transmission physics. On the other hand, the mode matching technique [2]-[3] is a good alternative way to solve the physical meaning of the transmission.

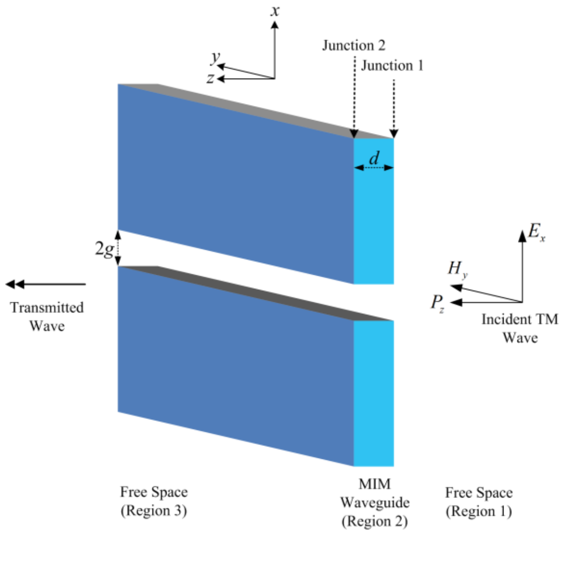

Fig. 1. MIM waveguide geometry for power transmission.

In this presentation, the slit transmittances on real metals at THz frequencies are studied with direct insight by mode matching techniques.

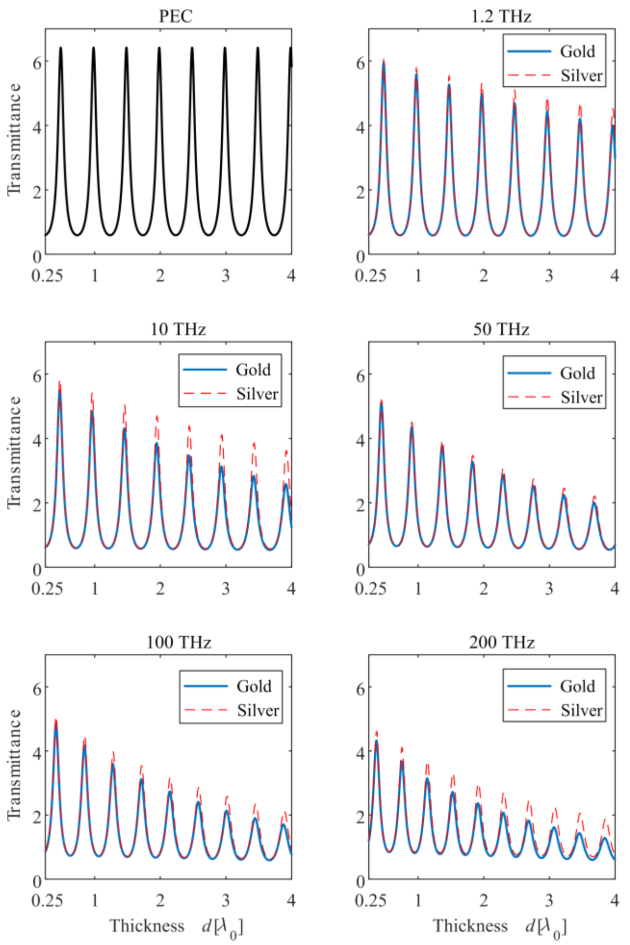

Fig. 2. Transmittance vs. plate thickness d for $2g = 0.05\lambda_0$.

2. Geometry and Permittivities of Metals

Fig. 1 describes the geometry to be solved. Regions 1 and 3 are free-space and Region 2 is composed of Metal-Insulator-Metal (MIM) waveguide [4] with the gap width $2g$ and thickness of metal d. The structure is unchanged along y-axis. Junctions 1 and 2 are defined as boundaries between Regions 1 and 2 and 2 and 3, respectively. A plane-wave is normally incident from Region 1 and

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transmitted to Region 3. A TM mode, as usual, is applied and more informative to investigate resonance of transmission. The transmittance, dimensionless, is defined as follows,

$$\tau = \frac{1}{2g}\frac{P_t}{W_i} = \frac{1}{4gW_i}\int_S \text{Re}\{\vec{E}\times\vec{H}^*\}\cdot\hat{z}\,dS \quad (1)$$

where P_t is transmitted power into Region 3 and W_i is power density of the incident plane-wave.

For reference, the relative permittivities of Ag and Au adopted in THz spectrum are listed in Table I, with $e^{+j\omega t}$ convention. These are obtained from [5] except for the 1.2 THz and 10 THz values. These are not covered by the reference and are extracted instead from [6] in the case of Ag and from [7] in the case of Au.

TABLE I
Relative Permittivities of Ag and Au [5]-[7]

Frequency [THz]	Relative permittivities ε_r	
	Ag	Au
1.2[a]	–192760 – j 731720	–79104 – j 405570
10[a]	–37433 – j 21558	–21962 – j 22118
50	–1470.8 – j 355.65	–1383.2 – j 367.24
100	–380.76 – j 48.957	–361.45 – j 58.599
200	–94.108 – j 7.567	–90.549 – j 10.572

[a]These values are obtained from [6] for Ag and [7] for Au.

3. Transmittance Results

Transmittance results for wide THz frequencies and plate thicknesses are shown in Fig. 2. In all cases, $2g$ is $0.05\lambda_0$. Key characteristics of the transmission shown in Fig. 2 are as follows: (*i*) At lower frequencies, the transmittances are similar to those in the PEC cases; greater discrepancies are visible for higher frequencies. (*ii*) The transmission pattern periodicity with respect to d/λ_0 becomes shorter as the frequency increases. (*iii*) It is also interesting to compare the minimum values for the transmittances among the PEC case and the higher frequency cases. Particularly at 100 THz and 200 THz, the minimum transmittance values for $d/\lambda_0 < 2$ have larger values than the PEC case, indicating that, for those small thicknesses, higher order modes in the lossy MIM waveguide enhance transmission. (*iv*) The loss tangent of Au is larger than that of Ag in the entire frequency range considered, as seen from Table I.

4. Conclusion

This work investigated deep-subwavelength slit transmittances on Ag and Au plates in the THz range for various plate thicknesses and compared the results with those of PEC case. The transmittance results at the lower set of frequencies are similar to the PEC case. Moreover, the results from Au plates show lower transmittances than those of Ag for all frequencies considered due to the higher losses in the former.

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