Analysis of transmission characteristics for periodic perfect and real metal apertures

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***Abstract*—We provide the transmittances through periodic slits for perfect and real conductors as functions of the thickness of plates. In the case of a real metal, resonant transmission effects are observed. At low terahertz frequencies, the electromagnetic transmission properties are very similar to the cases of the perfect conductor, while the properties of high terahertz frequencies are changed compared to those of the perfect conductor.**

Keywords—MIM waveguide; mode matching technique; subwavelength periodic structure;

I. INTRODUCTION

Power transmission through a slit or an aperture [1] has been discussed for several decades. The previous studies usually have investigated transmission characteristics for a perfect electrical conductor (PEC) as a function of polarization, slit width, plate thickness, and shape of aperture. However, these studies cannot provide loss effects from real metals such as gold, silver, and aluminum.

In this paper, we analyze transmission characteristics through PEC and real metal periodic slits. The slit geometry consists of periodic metal-insulator-metal (MIM) waveguides. The transmittances for PEC and real metals of the MMT are examined [2, 3] since the MMT is more effective at obtaining physical insight than other electromagnetic numerical techniques. The results demonstrate that at low terahertz frequencies, the transmittances through a real metal silt are very similar to the transmittances through the PEC, while the transmittances at high terahertz frequencies are similar to those of the lossy dielectric slab waveguide.

II. ANALYSIS OF TRANSMITTANCE PROPERTIES

Fig. 1 shows the geometry of the MIM waveguide consisting of metal, insulator, and metal. The gap width $2g$ and metal plate length $2d$ with the period p are repeatedly located along the x-axis. The plate thickness of metal w is variable, and the structure does not change along the y-axis.

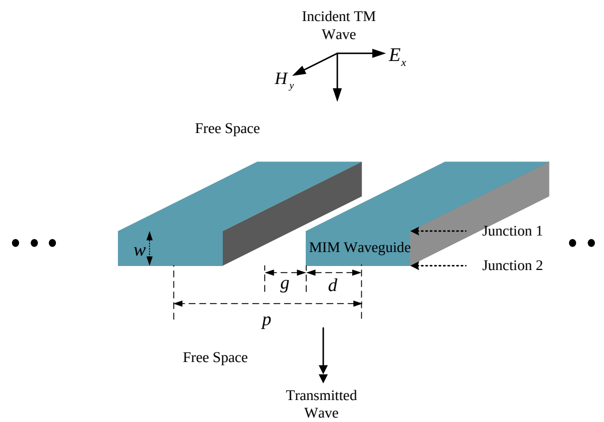


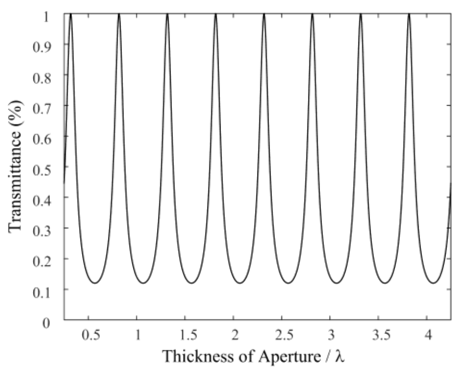
Fig. 1. Geometry of the MIM waveguide.

Figs. 2(a), (b), (c), (d), and (e) show transmittances for PEC plate and real metal plates with $p = 0.8\lambda_0$ and $2g = 0.2\lambda_0$ at four terahertz frequencies. The PEC case in Fig. 2(a), the maximum transmission peaks, which mean the 100% transmission of the incident wave, are achieved near $0.317\lambda_0$ thickness and multiples of free-space half wavelengths, $(0.317 + 0.5n)\lambda_0$, where n is an integer. This phenomenon is widely known as the Fabry-Pérot resonance. On the other hand, in the case of silver, a maximum transmittance peak of 0.92 is observed when w at 30 THz is $0.308\lambda_0$ (See Fig. 2 (b)). For real metals, the Fabry-Pérot resonance is also found, but peaks are attenuated as the thickness w increases. As describe in Figs. 2 (b) to (e), the Fabry-Pérot resonances are still observed, but the maximum peak of less than $0.5\lambda_0$ gradually decreases as the frequency increases. In addition, the peaks appear repeatedly at intervals of less than $0.5n\lambda_0$ thicknesses, which is dissimilar to those of PEC. This means that at higher frequencies, the MIM waveguide allows the relative propagation constant of the dominant propagating mode to be greater than 1.

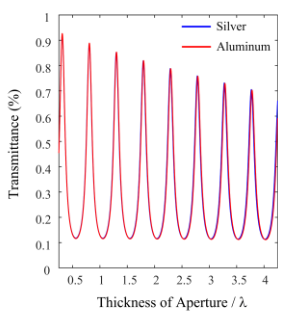
TABLE I. RELATIVE PERMITTIVITIES OF METALS

Frequency (THz)	Silver	Aluminum
30	–3738.3 – j 1487.3	–6361.9 – j 3670.2
50	–1470.8 – j 355.65	–2776.2 – j 1294.0
100	–380.76 – j 48.957	–845.11 – j 245.75
200	–94.108 – j 7.567	–213.96 – j 42.987

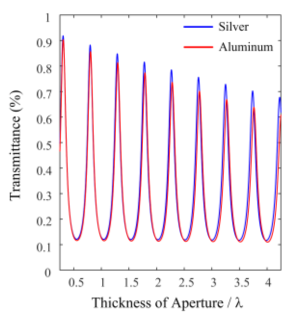
Another interesting point is the comparison of the transmittances between silver and aluminum. Table 1 shows the relative permittivities ε_r of silver and aluminum [4]. In aluminum, $|\mathrm{Re}(\varepsilon_r)|$ is larger than that in silver at all frequencies. On the other hand, the absolute ratios of the imaginary parts to real parts $|\mathrm{Im}(\varepsilon_r)/\mathrm{Re}(\varepsilon_r)|$ in aluminum are greater than the absolute ratios in silver. These two factors make subtle differences in transmission characteristics. (1) Due to the high ratios of $|\mathrm{Im}(\varepsilon_r)/\mathrm{Re}(\varepsilon_r)|$ in aluminum, the transmittances of aluminum are less than the transmittances of sliver at all frequencies. (2) The ratio $|\mathrm{Im}(\varepsilon_r)/\mathrm{Re}(\varepsilon_r)|$ in silver is smaller than that in aluminum at 200 THz. This because the propagation constant of the dominant mode in silver is greater than that in aluminum. Therefore, the period of transmission peaks in silver becomes shorter than aluminum.



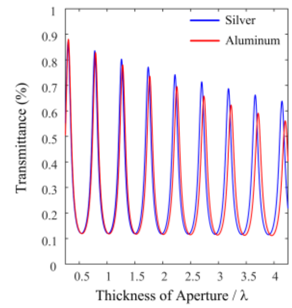
(a) PEC



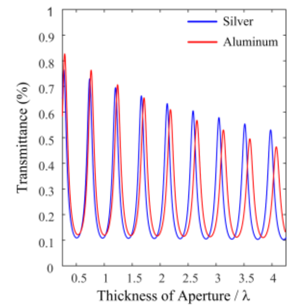
(b) 30 THz



(c) 50 THz



(d) 100 THz



(e) 200 THz

Fig. 2. Transmittances through a slit for PEC and real metals (4 frequencies) vs. the thickness of plate. ($2g = 0.2\lambda_0$)

III. Conclusion

We analyzed the transmission characteristics through PEC and real metal slits with periodic geometry. The transmissions through slits of real metals such as silver and aluminum at low terahertz frequencies were similar to those of PEC, but the properties at higher terahertz frequencies were significantly different from those of PEC. In addition, the loss effects at high terahertz frequencies were observed from the transmittances and relative permittivities.

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References

[1] F. J. Garcia-Vidal, L. Martin-Moreno, T. W. Ebbesen, and L. Kuipers, “Light passing through subwavelength apertures,” Rev. Mod. Phys., vol. 82, pp. 729-787, 2010.

[2] J. –E. Park, F. L. Teixeira, and B. –H. Borges, “Analysis of deep-subwavelength Au and Ag slit transmittances at terahertz frequencies,” J. Opt. Soc. Am. B, vol. 33, no. 7, pp. 1355-1364, Jul. 2016.

[3] Ş. E. Kocabaş, G. Veronis, D. A. B. Miller, and S. Fan, “Modal analysis and coupling in metal-insulator-metal waveguides,” Phys. Rev. B, vol. 79, p. 035120, 2009.

[4] A. D. Rakic, A. B. Djurisic, J. M. Elazar, and M. L. Majewski, “Optical properties of metallic films for vertical-cavity optoelectronic devices,” Appl. Opt., vol. 37, pp. 5271-5283, 1998.