# Compact THz waveguide filter based on periodic dielectric-gold rings

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***Abstract*—A band pass filter based on hollow circular waveguide loaded with axially periodic dielectric and gold rings is demonstrated for THz frequencies. The presence of co-axial gold rings can introduce the single mode operation due to a high rejection values at the both-sides of pass-band, and an acceptable confinement for the proposed structure. The presented numerical results show that the influences of the gold rings on the propagation properties are significant.**

***Keywords—Terahertz filter, hollow circular waveguide, axially periodic dielectric and gold rings, corrugated dielectric.***

## I. Introduction

In recent years, terahertz technology has attracted researchers' attention in many areas, such as security, biomedical, spectroscopy, astronomy, and high speed communications. This recent progress in terahertz technology has fostered the necessity to develop devices capable of manipulating THz waves including switches [1], modulators [2], filters [3-4], polarizer [5], etc., which can reduce the complexity, cost, and dimensions of terahertz systems. Periodic structures play very important roles in microwave and optical filter networks [6]. The special property common to all periodic structures made them so unique is that they can support propagating waves only in the specified frequency bands, commonly known as passband-stopband dispersive characteristics and is of interest in frequency filtering networks. Another property is that the periodic structures support waves with a very low phase velocity that is a crucial characteristic in travelling-wave-tube amplifiers and backward wave oscillators. By inserting the sequential gold rings along the axis of a hollow metal waveguide loaded with axially periodic dielectric, we suggest a metallic-$SiO_2$ filter to realize the control of the propagation waves and bandwidth characteristics. Compared with most existing terahertz filters, the proposed structure demonstrates much better transmittance and suppression properties in pass- and stop-band, respectively.

In a cylindrical metal-only waveguide, the $TE_{11}$ mode, which has the greater practical significance due to its $TEM_{00}$-like mode profile, suffers from higher losses because of a stronger penetration of the electric field into the waveguide walls[7]. The use of $SiO_2$ dielectric coating on the inner surface of metallic hollow THz waveguides significantly reduces the ohmic losses due to reducing the penetration of the electric field into the waveguide walls[8]. However, dielectric losses are introduced, and therefore, the choice of dielectric plays an important role. For large enough diameter waveguides, however, the developed dominant mode is

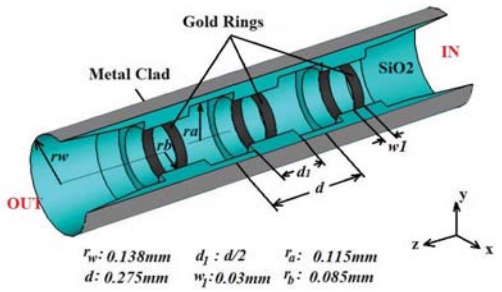


Fig. 1. Schematic of the terahertz filter based on a circular waveguide loaded with axially three-step periodic dielectric-gold rings.

confined into the air core of the dielectric-lined waveguide, whereby dielectric losses are negligible [9-10]. In addition, the use of a periodic dielectric structure instead of a uniform dielectric one, leads to the appearance of space harmonics in the wave field and we can expect having a broadband frequency response. One of the interesting features of using the overall dielectric and sequential gold-rings periodicity is the increment of the frequency separation between the upper edge of the first mode and the lower edge of the second mode (stop-band). Obviously, the regimes with a maximum stop-band are beneficial for providing stable single mode operation. The numerical simulation approaches are utilized to design and to analyze a wide variety of complex electromagnetic structures. The accuracy and feasibility of the proposed structure has been verified by two numerical techniques. The achieved results based on these two approaches has a very good agreement.

## II. Geometry and Materials

Figure 1, shows the sketch of the gold-$SiO_2$ waveguide filter. The gold-rings are periodically located inside a hollow metallic circular waveguide which is coated internally with a corrugated dielectric $SiO_2$ to manipulate the propagation properties. Three corrugations have been chosen because of compactness and the minimum possible transmission loss in THz band. Three and five corrugations have been chosen to keep the device compact and to minimize the device's insertion loss. $SiO_2$ with the refractive index of 1.996 and the loss tangent of 0.0056 is chosen because of its low absorption and low dispersion at THz frequencies [11]. For the metal of the structure, the waveguide wall and the sequential rings, gold has been chosen with the following Drude parameters: $\varepsilon_\infty = 9.1$, $\omega_p = 1.38\times10^{16}$ rad/s, and $\Gamma = 1.075\times10^{14}$ Hz [12].

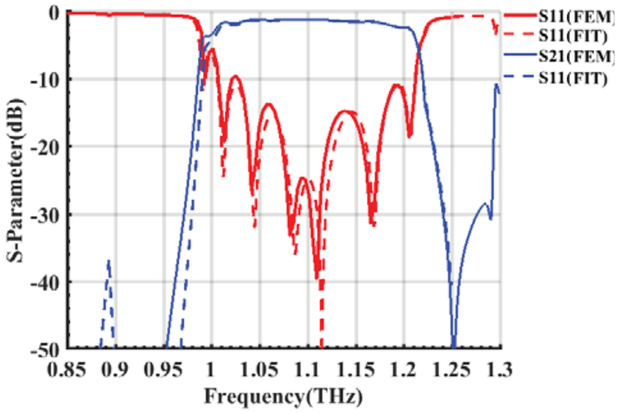


Fig. 2. Simulated frequency responses of the proposed terahertz filter based on five-step periodic dielectric-gold rings circular waveguide using FEM and FIT methods.

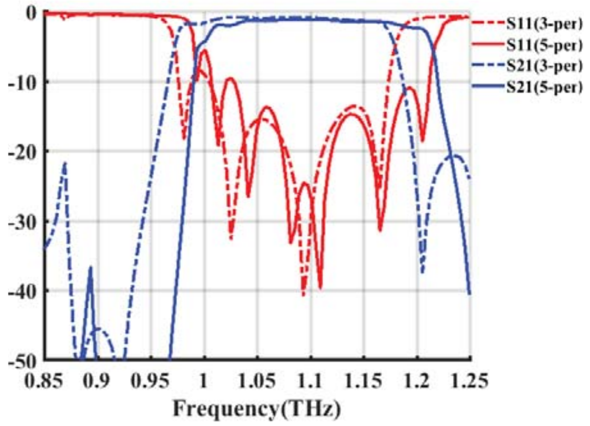


Fig. 3. Simulated frequency responses of the proposed terahertz filter based on five- and three step periodic dielectric-gold rings circular waveguide using FEM method.

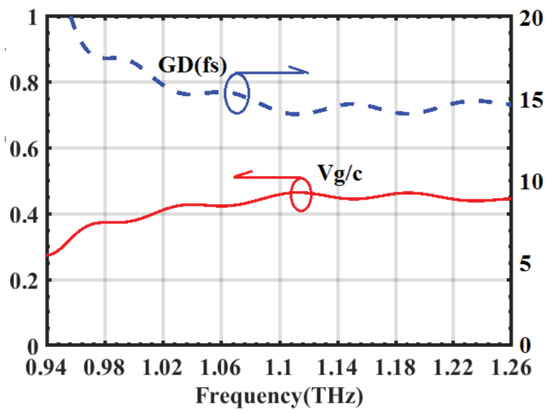


Fig. 4. The normalized group velocity and the group delay of the proposed THz filter with five period.

The field analysis of an infinite air-cored periodically corrugated dielectric waveguides has been presented. Under the assumption that gold rings induce a small perturbation on the overall behavior of the air-cored periodically corrugated dielectric waveguide, we can use the presented rule in [13-14] to determine the period of the corrugation as the primary value for the optimization.

As mentioned in [13], for $\pi < \beta d < 2\pi$, in which d is period of the dielectric corrugation, the group velocity and the phase velocity of the first passband (or $TE_{11}$) are oppositely directed and the backward -wave phenomenon occurs. Hence, an initial guess for the corrugation period can be taken as $\beta d \geq 2\pi$ in size of guiding wavelength($\lambda$). All the geometrical parameters including the cladding radius($r_w$), the period of the corrugated dielectric section($d$), the air-core radius($r_b$), and the dielectric groove radius($r_a$) can be obtained based on the numerical parametric study with the goals of the highest out of band rejection and also the best matching through the entire pass-band regions, respectively . The values of these parameters are shown in Fig 1.

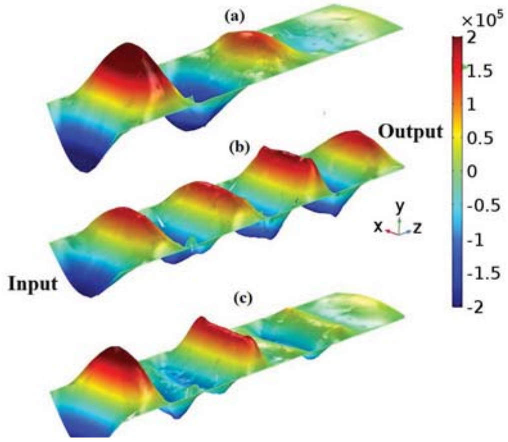


Fig. 5. Magnitude of the y component of the electric field distributions on the xz-plane at different frequencies: (a) 0.94 THz (i.e., in the lower stop band), (b) 1.08 THz (i.e., in the pass-band), and (c) 1.18 THz (i.e., in the upper stop band), for three period.

## III. Results and Discussion

For electromagnetic periodic structures, no physical devices can be made infinitely periodic. Therefore, real devices must be often constructed by the limited number of periods. For terahertz waveguide components, the small length is desirable to minimize insertion loss.

The numerically calculated S-parameters (reflection $|S_{11}|$ and transmission $|S_{21}|$ coefficients) of the proposed filter in cases of five periods using two different numerical methods of finite element method (FEM) and finite integral technique (FIT), are depicted in Fig 2. Figure 3 shows that the structure's passband is almost insensitive to the number of periods. As demonstrated in Figs 2 and 3, the single mode operation in a broad pass-band region of 0.96–1.16 THz has been realized. Moreover, the proposed THz filter exhibits a sharp skirt characteristic at the lower and the upper edges of the pass-band region with the attenuation higher than 50dB. Meanwhile, a smaller insertion loss of 0.6dB/mm has been achieved in the pass-band region for three periods.

As illustrated in Fig 3, the presence of the gold rings, as a dispersive metal at THz frequencies and the periodic dielectric corrugations only show negligible group velocity variations in the bandwidth of 0.2THz. Moreover, the slow wave behavior of the filter has been understood from the group velocity. This low dispersion characteristic can introduce the proposed filter as a potential candidate for terahertz traveling wave tube applications.

The electric field distributions of the y-component on the xz-plane, as the dominant component of $TE_{11}$ mode are shown in Fig 4 at three frequencies of 0.94 THz, 1.08 THz and1.18

THz. The achieved results indicate that the proposed structure prevents from propagating the electromagnetic wave at the stop-band regions and only allows having a confined field pattern in the pass-band region which is required for any single mode application.

## IV. Conclusion

In this paper, a band-pass filter based on a circular waveguide loaded with axially periodic dielectric-gold rings is presented for the application in terahertz regime, which is studied numerically using approach of finite element method(FEM) for two finite number of period of three and five. The filter structure has been proposed for operating at the dominant mode of circular waveguide (TE11), at the center frequency of around 1THz with corresponding bandwidth of 0.2 THz. We have shown that using thin gold rings on the edge of each corrugations, a filter with at least 55dB out-of-band rejections at frequency notches, has been achieved.

## References


[1] M. Yarahmadi, M. K. Moravvej-Farshi and L. Yousefi, "Compact low power graphene-based Y-branch THz switch," *2014 Third Conference on Millimeter-Wave and Terahertz Technologies (MMWATT)*, Tehran, 2014, pp. 1-3.

[2] W. Gao, J. Shu, K. Reichel, D. V. Nickel, X. He, G. Shi, R. Vajtai, P. M. Ajayan, J. Kono, D. M. Mittleman, and Q. Xu, “High-Contrast Terahertz Wave Modulation by Gated Graphene Enhanced by Extraordinary Transmission through Ring Apertures,” *Nano Lett.,* vol. 14, no. 3, pp. 1242-1248, 2014.

[3] K. Yang, S. Liu, S. Arezoomandan, A. Nahata, and B. Sensale-Rodriguez, “Reconfigurable Metamaterial Terahertz Filters based on graphene,” *8th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics – Metamaterials* (2014)

[4] J. Hu, S. Xie and Y. Zhang, "Micromachined Terahertz Rectangular Waveguide Bandpass Filter on Silicon-Substrate," in *IEEE Microwave and Wireless Components Letters*, vol. 22, no. 12, pp. 636-638, Dec. 2012

[5] K. Shiraishi, S. Oyama and C. S. Tsai, "A Polarizer Using Thin Metallic-Film Subwavelength Grating for Infrared to Terahertz Region," in *Journal of Lightwave Technology*, vol. 29, no. 5, pp. 670-676, March1, 2011.

[6] Y. Han, G. S. Nusinovich, T. M. Antonsen, J. Rodgers and O. V. Sinitsyn, "Axially Periodic Dielectric-Loaded Circular Waveguide for Microwave/Millimeter-Wave Devices," in *IEEE Transactions on Plasma Science*, vol. 40, no. 12, pp. 3420-3426, Dec. (2012).

[7] B. Bowden, J. A. Harrington, O. Mitrofanov, *Appl. Phys. Lett.*, vol. 93, pp. 181104, 2008

[8] B. Bowden, J. A. Harrington, O. Mitrofanov, *Opt. Lett.*, vol. 32, pp. 2945, 2007.

[9] M. Navarro-Cía, M.S. Vitiello, C.M. Bledt, J.E. Melzer, J.A. Harrington, and O. Mitrofanov, “Terahertz wave transmission in flexible polystyrene-lined hollow metallic waveguides for the 2.5-5 THz band,” Optics Express, vol. 21, no. 20, pp. 23748-23755, 2013.

[10] M. Navarro-Cía, J.E. Melzer, J.A. Harrington, and O. Mitrofanov, “Silver-coated Teflon Tubes for Waveguiding at 1-2 THz,” Journal of Infrared, Millimeter, and Terahertz Waves, vol. 36, no. 6, pp.542-555, 2015.

[11] D. Y. Smith, E. Shiles, and M. Inokuti, in Handbook of Optical Constants of Solids, edited by E. D. Palik (Academic, Chestnut Hill), vol.1, p763(1997).

[12] M. A. Ordal, L. L. Long, “ Optical properties of the metals Al, Co, Cu, Au, Fe, Pb, Ni, Pd, Pt, Ag, Ti, and W in the infrared and far infrared” *Appl. Opt.*, vol. 22, no. 7, 1099-1119 (1983)

[13] S. W. Chen, X. -P. Liang and K. A. Zaki, "Propagation in periodically loaded corrugated waveguides," in *IEEE Transactions on Magnetics*, vol. 25, no. 4, 3055-3057 (1989)

[14] C. Zhou and H. Y. David Yang “Design Considerations of Miniaturized Least-Dispersive Periodic Slow-Wave Structures,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, no. 2, 467-474 (2008)