IOCM 2025 Conference

The 4th International Online Conference on Materials

03–05 November 2025 | Online

Multilayer THz Metasurface Bandpass Filter with PTFE and HDPE Dielectric Spacers

Karen Simonyan1*, Mkrtich Yeranosyan1,2

[1]ICNT, A.B. Nalbandyan Institute of Chemical Physics, NAS RA, 5/2 P. Sevak Str., Yerevan 0014, Armenia

[2]Institute of Physics, Yerevan State University, 1 A. Manoogian Str., Yerevan 0025, Armenia

INTRODUCTION & AIM

Terahertz (THz) metasurfaces enable subwavelength electromagnetic wave control, offering a path to compact and tunable filters for spectroscopy, sensing, and communications. Here, we present a simulation-driven design for a compact multilayer THz bandpass metasurface filter [1]. The 3D device geometry consists of a silicon substrate supporting a thin gold film perforated with subwavelength annular apertures, a high-transmittance dielectric spacer (PTFE or HDPE), and an aligned array of gold rings on top. This stack can be fabricated by depositing gold through annular masks, eliminating the need for lithographic etching of the substrate presented in our previous model [2].

Full-wave electromagnetic simulations (COMSOL) guided the design process, optimizing spacer thickness and geometric parameters. Simulated transmission spectra show that devices with either PTFE or HDPE spacers yield broad passbands with high transmission. The spectral peak position and shape remain largely invariant under minor geometric deviations, indicating a robust design. The enhanced transmission is attributed to constructive interference between waves reflected at multiple interfaces in the multilayer structure. The combination of a simple mask-defined architecture, material-dependent tunability, and tolerance to fabrication imperfections makes this metasurface filter a promising candidate for THz bandpass filtering, anti-reflection coatings, spectroscopy, and biosensing. This work highlights the effectiveness of computational design in advancing THz metasurface technologies.

METHOD

The operation principle of the THz metasurface can be described using interference theory within a Fabry–Perot resonator model. Transmission enhancement arises from constructive interference of waves transmitted into the silicon substrate after multiple reflections between structural layers, while destructive interference reduces reflection.

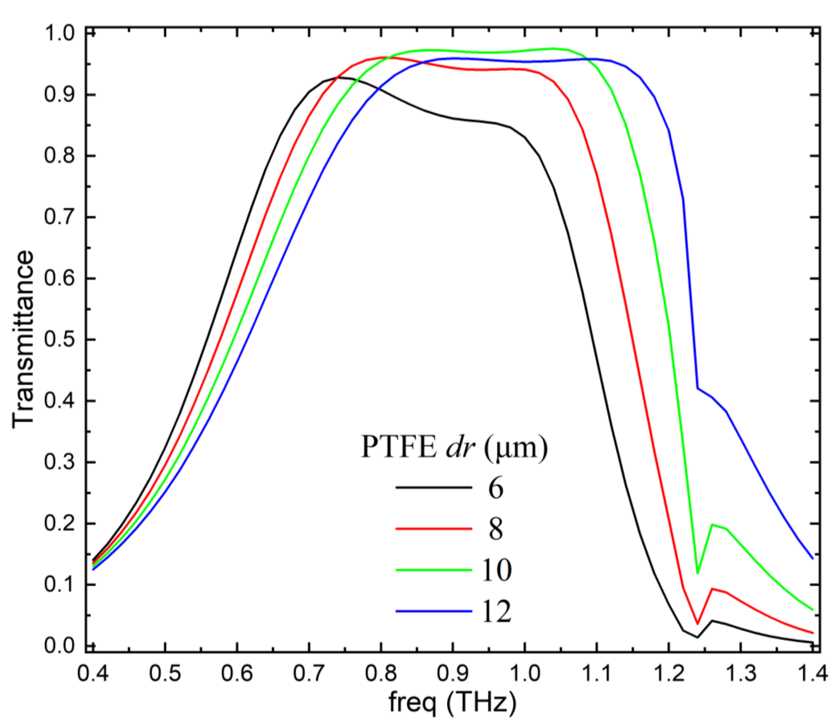
At each interface the incident wave is partly reflected and partly transmitted, undergoing multiple reflections inside the structure. Constructive interference in the forward direction and destructive interference in the backward direction lead to enhanced transmission, reduced reflection, and low absorption.

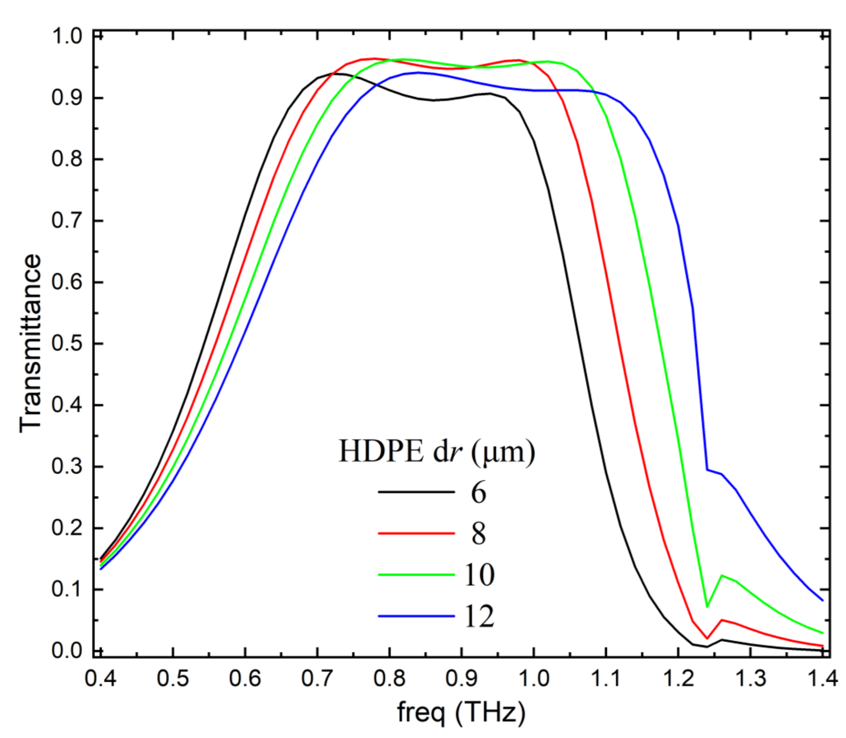
The complex reflection coefficient of a system with lossless material characteristics is defined as:

$$\tilde{r} = \frac{r_{21}\,exp(i\varphi_{12}) - r_{23}\,exp[i(\varphi_{12}+\varphi_{21}+\varphi_{23}+2\beta)]}{1 - r_{21}r_{23}\,exp[i(\varphi_{21}+\varphi_{23}+2\beta)]}$$

Here $\boldsymbol{r_{21}}$ is the reflection coefficient of surface (1*) and $\boldsymbol{r_{23}}$ is the reflection coefficient of surface (2*). $\boldsymbol{\varphi_{12}}$, $\boldsymbol{\varphi_{21}}$ and $\boldsymbol{\varphi_{23}}$ are the reflection phases and $\beta = -\sqrt{\tilde{\varepsilon}_{spacer}}k_0\,h/cos(\alpha_S)$

where $\tilde{\varepsilon}_{spacer}$ is the dielectric permittivity of the spacer, $\boldsymbol{k_0}$ is the wavenumber in free space, $\boldsymbol{h}$ is the thickness of the spacer and $\alpha_s = \arcsin(\sin\alpha_i/\tilde{\varepsilon}_{spacer})$ where $\boldsymbol{\alpha_i}$ is the incidence angle. Transmittance can be expressed via the reflection coefficient $\boldsymbol{r}$ as: $T(f) = 1 - |\tilde{r}(f)|^2$

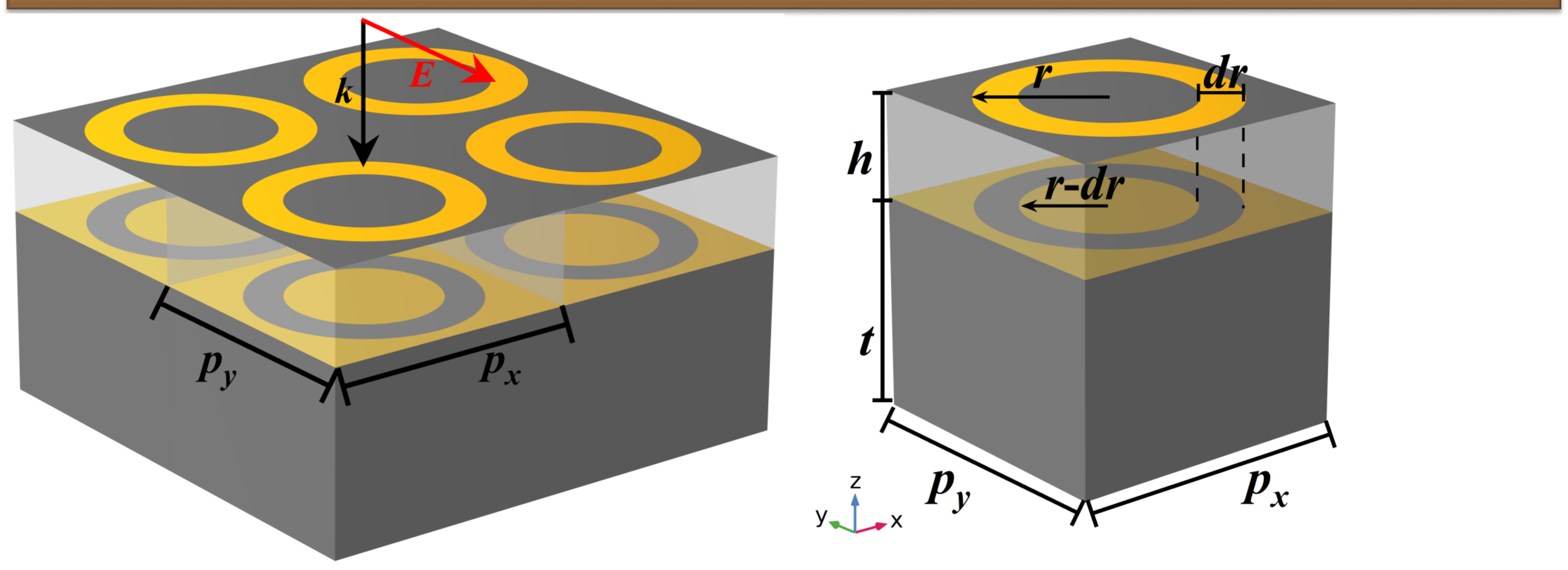




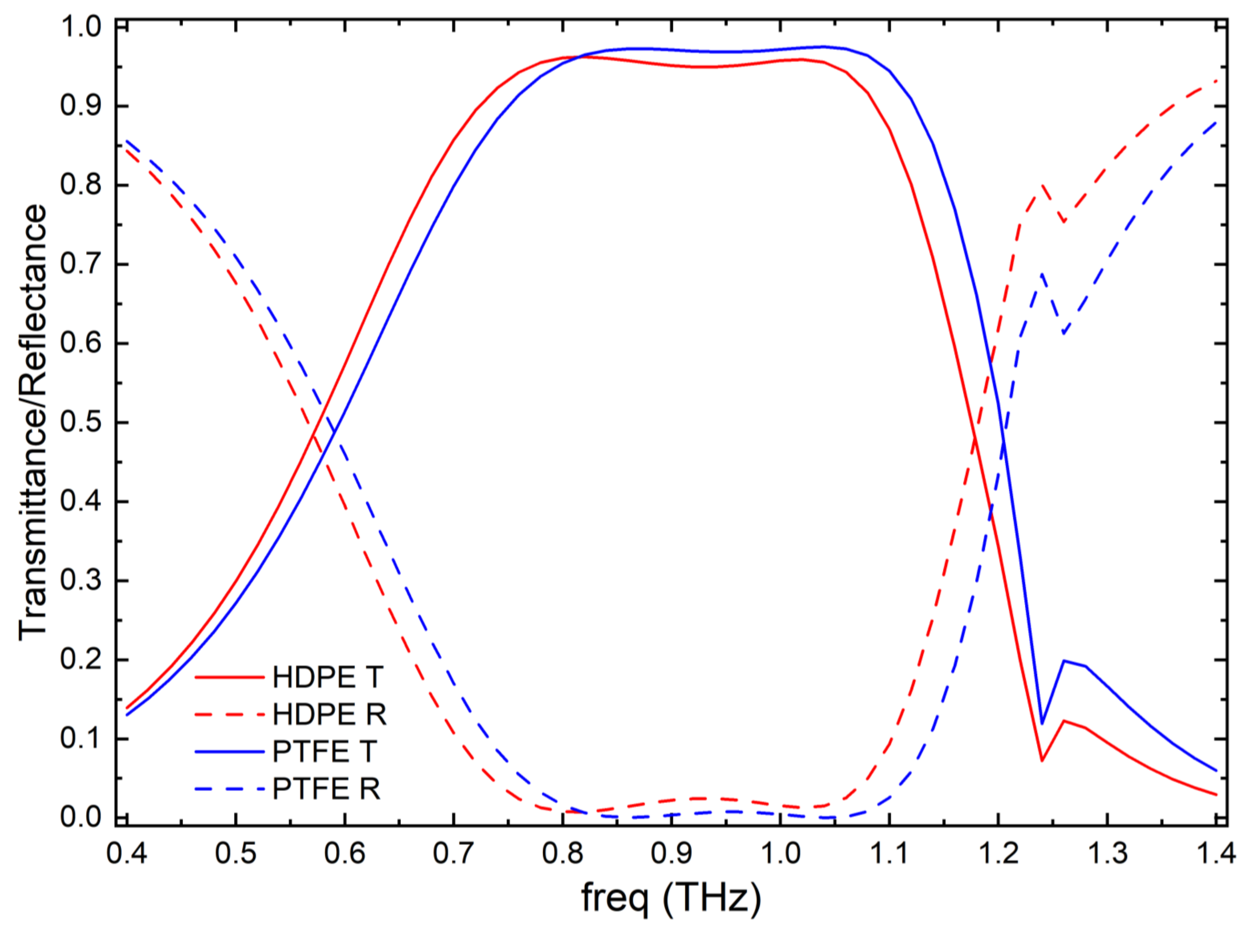
CONCLUSION

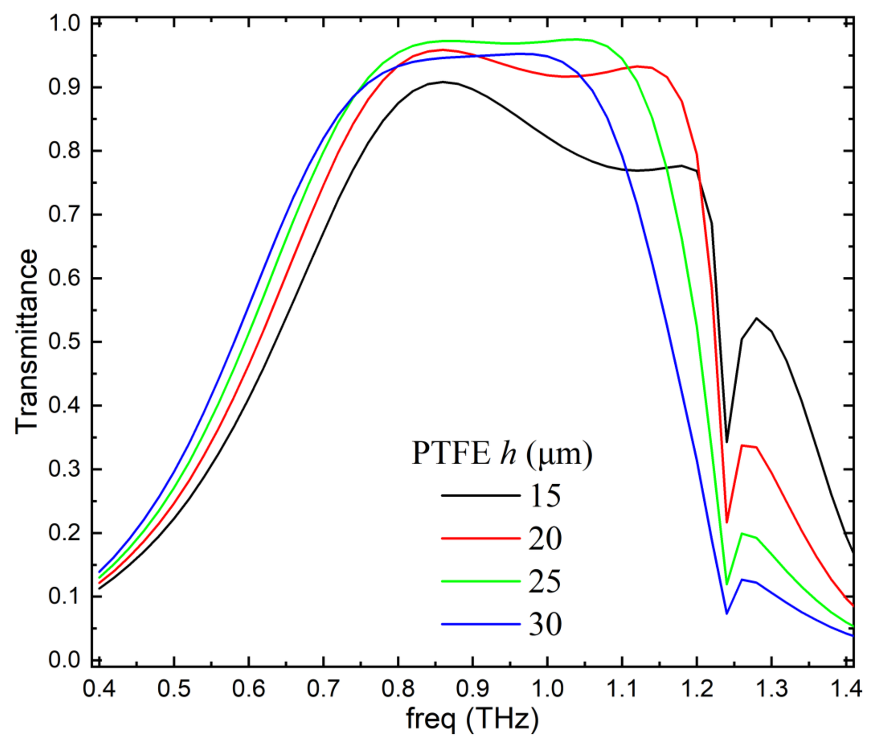
We have proposed a metasurface-based terahertz bandpass filter consisting of two patterned gold layers separated by a dielectric spacer of PTFE or HDPE. Simulations demonstrate broad and stable transmission bands with reduced reflection, explained by constructive interference in the multilayer structure. The spectra are only weakly affected by geometric variations, indicating robustness to fabrication tolerances. Thanks to its simplicity, low-loss materials, and compatibility with lithography, the design offers a promising route for THz filtering, antireflection coatings, spectroscopy, and biosensing.

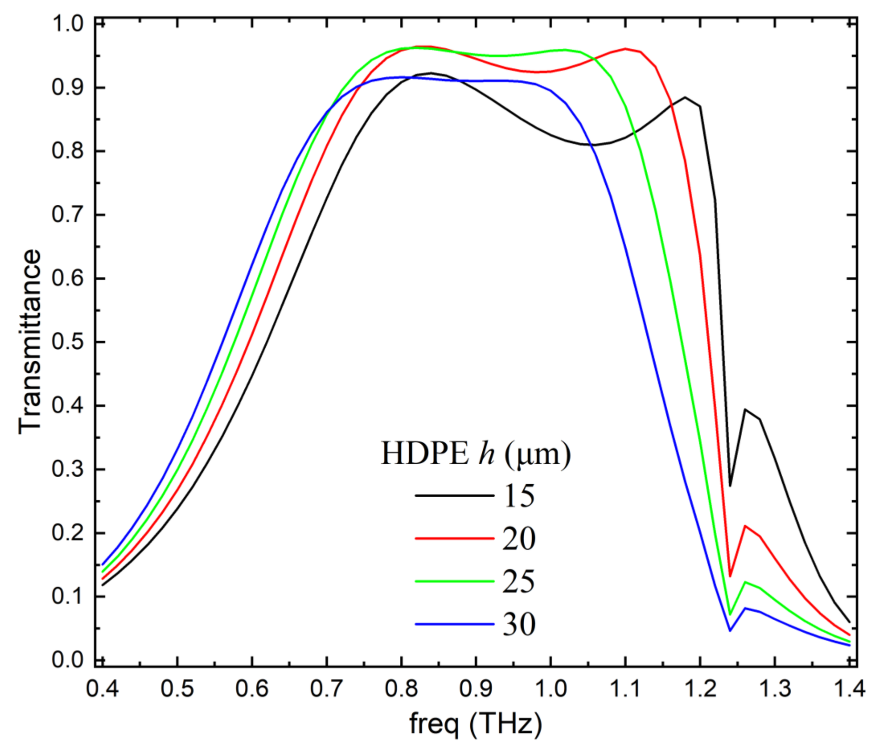
RESULTS & DISCUSSION

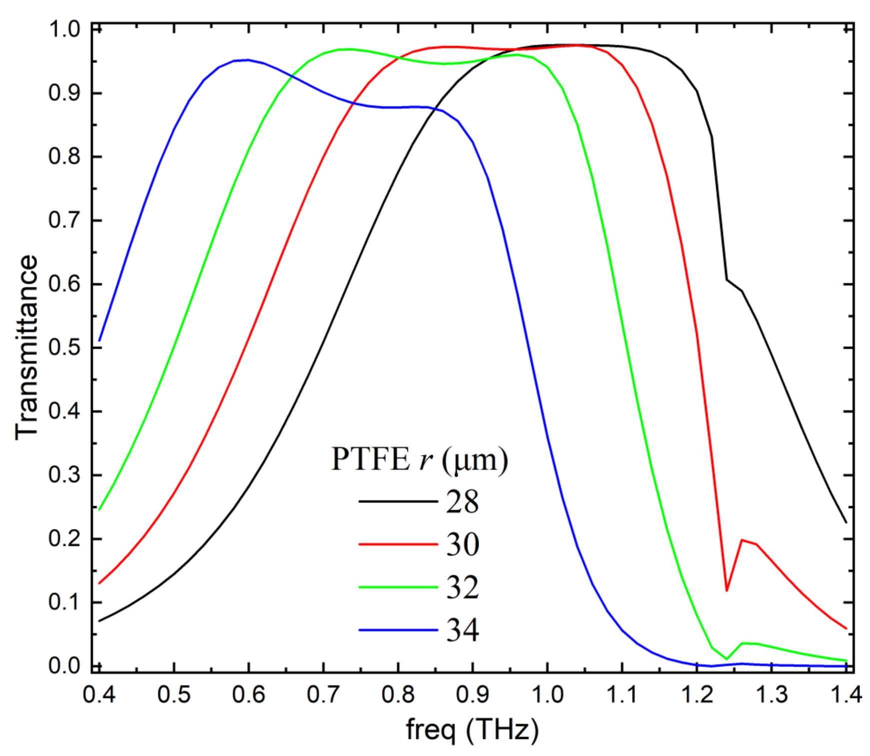


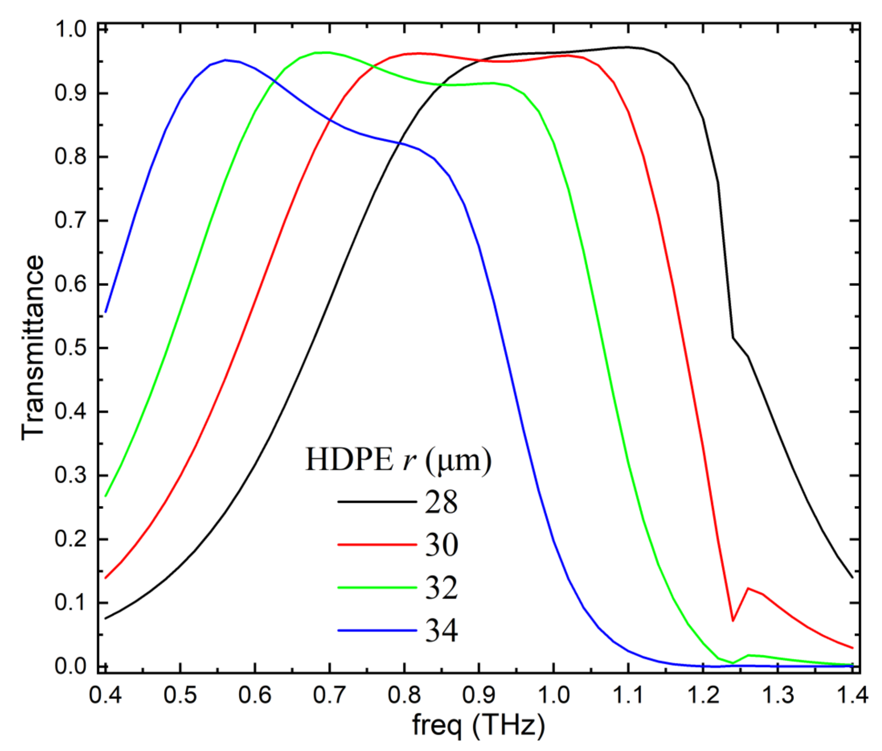
Periodicities of structure $\boldsymbol{p_x = p_y = 70}$ μm, height is $\boldsymbol{h = 25}$ μm, outer radius of ring $\boldsymbol{r = 30}$ μm and its width is $\boldsymbol{dr = 10}$ μm (inner radius is $\boldsymbol{r - dr}$). Plane waves propagate along the z-axis and are linearly polarized along the y-axis. The first graph compares transmission and reflection spectra for PTFE and HDPE at the reference geometry, followed by three pairs of plots showing the effect of varying ***h***, ***r***, and ***dr*** parameters (PTFE left, HDPE right).











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This work was supported by Grants No. 22rl-056 and 24AA-2J068, of Higher Education and Science Committee of the RA MoESCS.