3D Printed Hollow-Core Terahertz Optical Waveguides with Hyperuniform Disordered Dielectric Reflectors

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Abstract: Novel hollow-core THz waveguides featuring hyperuniform disordered reflectors are proposed, fabricated, and characterized. The results confirm that proposed waveguide exhibit sizable photonic band gaps (20%) even when relatively low refractive index contrast used (resin/air).
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1. Introduction

As a new class of photonic crystal (PC) materials, hyperuniform disordered materials have drawn great interest over the years. Up to dates, various planer terahertz waveguide comprising 2D hyperuniform disordered reflectors have been investigated to possess a larger complete photonic band gaps for all polarizations comparing to their counterparts featuring periodic PCs [1-3]. In this paper, we propose a novel hollow core terahertz PBG waveguide which is generalized from the earlier 2D waveguides featuring hyperuniform claddings into 3D waveguides and fibers.

2. Experimental results

The point pattern we used in our design is generated by following the technique shown in [1]. In our case, the hyperuniformity of our point patter is $\chi = 0.5$. The k-space representation of the generated hyperuniform point pattern is shown in Fig. 1(a). Next, the central part of thus generated structure was replaced with a hollow core of 5mm diameter. The fiber is designed and optimized for operation in the vicinity of 0.4 THz, and the optimized PBG features a width of ~80GHz. The resultant band diagram is shown in Fig. 2(a). The color code in Fig. 2 indicates the fraction of the power guided by the individual mode within the hollow core.

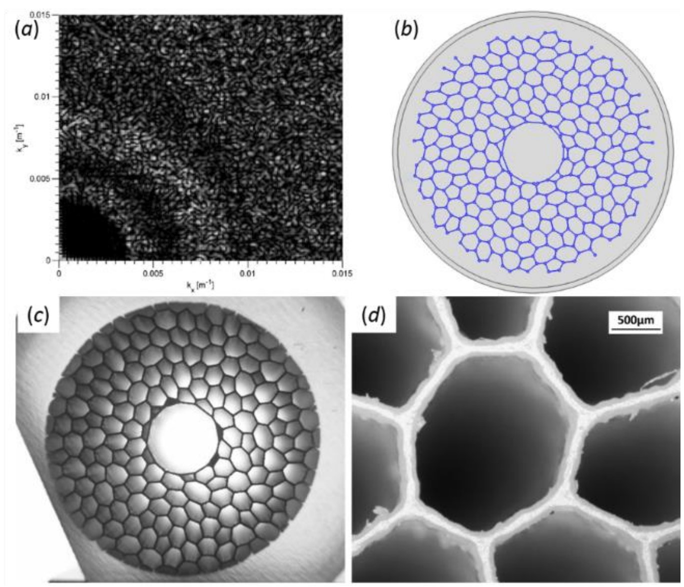

Fig. 1. (a) Hyperuniform point pattern in k-space. (b) Waveguide and a simulation cell used in our numerical calculation. (c) The fabricated waveguide with the bridge thickness of 200µm in the cladding. (d) Zoom of the reflector region shown in (c)

Then, the designed waveguide is fabricated using the stereolithography 3D printing technology. In order to print robust structures, with this printer, the minimum feature size in the lateral directions is required to be at least twice the resolution ~200µm. Instead of the optimized structure, we, therefore, printed a waveguide with bridge thicknesses of 200µm, while keeping the same distribution of cylinders. The cross-section of the fabricated waveguides is illustrated in Fig. 1(c). As the fabricated waveguide features thicker bridge (~200µm), resultant band gaps are smaller and positioned at lower frequencies. As seen in Fig. 2(b), four main band gaps are centered at 0.14THz, 0.24THz, 0.37THz, and 0.45GHz, with the band widths of 13GHz, 12GHz, 40GHz, 14GHz, respectively.

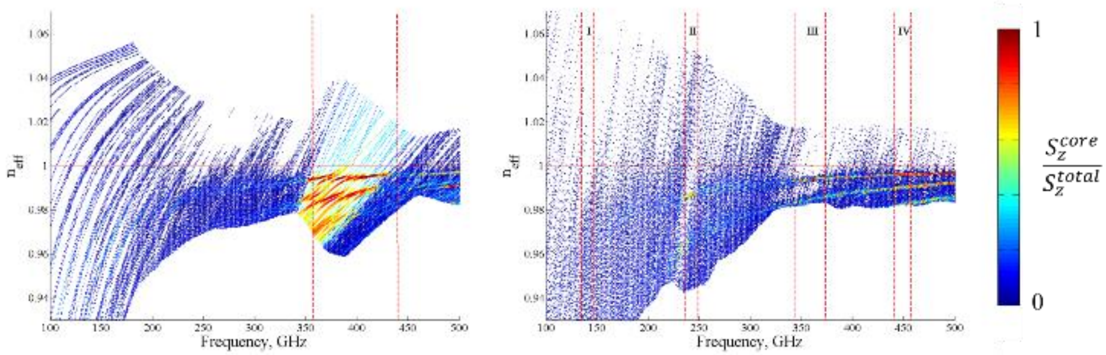

Fig. 2 Band diagrams of (a) the waveguide with numerically optimized reflector structure and (b) the fabricated waveguide with the bridge thickness of ~200μm.

Finally, we characterized THz transmission of the fabricated waveguide using a modified terahertz time-domain spectroscopy (THz-TDS) setup. As shown in Fig. 3. The four PBGs, centered at frequencies of 0.17THz, 0.22THz and 0.29THz and 0.38THz, are characterized by enhanced transmission. The corresponding spectral width are 18GHz, 22GHz, 44GHz and 49GHz, resulting a maximum band gap of ~15.1% at 0.29THz. The location and the widths of the experimentally measured band gaps are in good agreement with the theoretical prediction. Moreover, as the light is guided in the hollow core, transmission losses of the fabricated waveguides can be expected to be significantly lower than those of the reflector material. From Fig. 3, we deduced the waveguide transmission loss in various bandgap regions by comparing transmission through waveguides of different lengths, and estimated the absorption loss of the fabricated waveguide to be $\sim 0.1\text{cm}^{-1}$ at 0.23THz, which is much smaller than the corresponding bulk absorption losses of the reflector material at the corresponding frequency ($\sim 0.55\text{cm}^{-1}$)

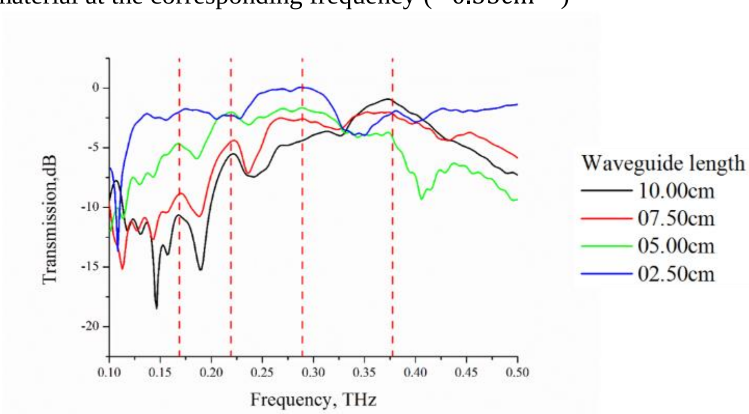

Fig. 3 The transmission spectrum of the fabricated waveguides with bridge thickness of 200μm

Reference

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