Air-core Bandgap Terahertz Fiber with Wider Bandwidth

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***Abstract*—A novel air-core bandgap polymer fiber for terahertz (THz) wave guiding is investigated. The periodic arrangement of square holes with round corners in cladding offers bandgap effect for mode guiding, such THz fiber shows much wider propagation bandwidth.**

Index Terms: Terahertz, Fiber, Bandgap

I. Introduction And Background

With wavelength covering the range of 30μm~~3mm, terahertz (THz) radiation has increasingly wide variety of applications in imaging, spectroscopy and communication technology, especially in bio-medicine, securities[1]. At present, most THz systems are large and difficult to use because they rely on free-space to guide and manipulate the THz pulses. This requires users to be well experienced with optical-alignment techniques and also direct line-of-sight access to the area or sample of interest. Waveguide engineering at THz frequencies is a priority for many THz-based applications.

The principal difficulty has been the lack of materials well suited for guided propagation at THz frequencies. The best suited materials, those that are transparent and relatively dispersionless in the THz regime, are crystalline, which precludes their use for practical waveguides. Materials such as glasses and polymers that work well at optical frequencies exhibit unacceptably high absorptions losses at THz frequencies. Several kinds of THz waveguides have been proposed and demonstrated, such as metallic waveguides [2, 3], metallic wires [4], plastic ribbons [5], dielectric fibers [6], and photonic crystal fibers [7 - 9]. Low attenuation constant less than 0.01 cm^{-1} has been achieved.

The air-core photonic bandgap fibers (PBGFs) have engendered growing interest over the past few years since they have the potential to provide very low-loss transmission in air, along with delivery of high power and low nonlinearity [10]. The main obstacle in designing terahertz waveguides is the fact that almost all materials are highly absorbent in the terahertz region. To overcome this limitation, an efficient waveguide design should maximize the guided power fraction in the air, so the bandgap fiber is an instinctive choice for THz guiding. In addition, due to the limitation of the bandgap guiding mechanism, the THz fiber is well appropriate for narrow band transmission, therefore we have to try to broaden this bandwidth so that it can be used for more applications..

In this paper, we propose an efficient air-core THz fiber. The fiber cladding is consisted with square-latticed subwavelength air holes with round corners, which effectively confine the guided mode in a defect air-core, and produce a much wider propagation bandwidth. Furthermore, the transmission bandwidth of the fiber can be tuned by the geometry parameters of the unit cells in cladding.

II. Design and Results

So far most PBGFs have been fabricated from silica due to their applications in optical domain. However, the material loss of silica is prohibitively high at THz frequencies. Thus, for THz applications, low loss materials such as plastics need to be used. In this paper, three polymers including Poly-tetraflouroethylene (PTFE), Polypropylene (PP) and Polyethylene-high density (HDPE) are considered as the background materials of the air-core THz fiber. For these polymers, the attenuation constants are very weak in 0.2 – 3 THz range. The nearly constant in the refractive indices and the small absorption coefficients of PTFE (n = 1.445), PP (n = 1.51) and HDPE (n = 1.534) in the terahertz region enable them to be good candidates for THz waveguide materials.

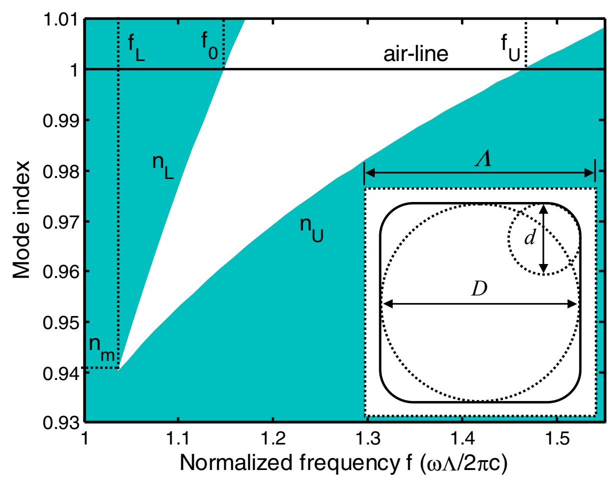

Fig. 1 Bandgap map of square lattice photonic crystal in fiber cladding with parameters: D/Λ=0.96, d/D=0.6 for PTFE polymer. The blank region represents bandgap, in which the fiber modes are guided. The inset shows the unit cell, in which the four corners of a square hole are rounded with circles.

Since the square lattice offers wider bandgap than is achievable with circular/triangular lattice for bandgap fibers [11], the periodic arrangement of subwavelength square holes with round corners is chosen to form the cladding of THz fiber. The inset of Fig. 1 shows the unit cell of the fiber cladding. The unit cells are regularly arranged with square lattice to form fiber cladding. The solid line denotes the boundary between the background material and the air. The lattice spacing is Λ; the size of the hollow part is characterized by a square hole with side D, the four corners of the hole are rounded with circles of diameter d (dash lines). A full-vectorial plane wave method is used to calculate the photonic bandgap of the perfect square lattice. We show in Fig. 1 the bandgap map of the fiber cladding, the blank region represents bandgap, in which the fiber modes are guided. The background material is set as PTFE. The air-line n_{eff}=1 represents the boundary between states that are propagating or evanescent in cladding.

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The bandgap shown in Fig. 1 introduces forbidden area where modes can not propagate along fiber axis. Introducing a defect core will allow a finite number of modes to propagate in the defect core. The bandgap is characterized by several parameters: f_U, where the high frequency band edge (n_U) crosses the air-line (also the highest bandgap frequency); f_0, where the low frequency band edge (n_L) crosses the air-line; f_L, the lowest bandgap frequency. The mode index n_m at the lowest bandgap frequency is related to the maximum equivalent numerical aperture (NA) of the fiber. Since the guided modes are confined in the bandgap region, the transmission bandwidth is then defined as the frequency interval: $\Delta f = f_U - f_L$. The relative bandwidth is $\Delta f / f_c$, where the central frequency of the transmission band is $f_c = (f_U + f_L)/2$.

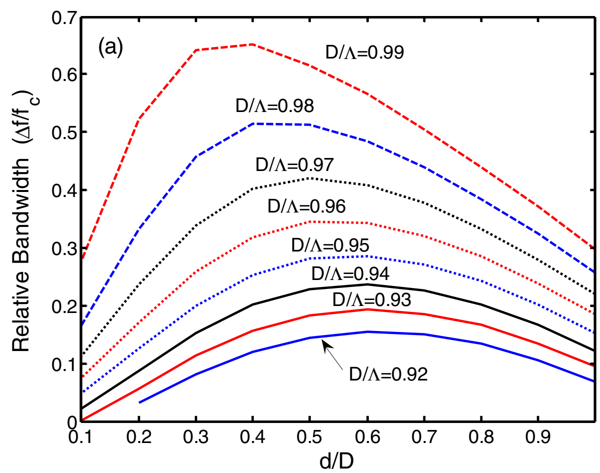

Fig. 2 Relative bandwidth supported by the square lattice photonic crystal cladding versus d/D for different D/Λ, for PTFE.

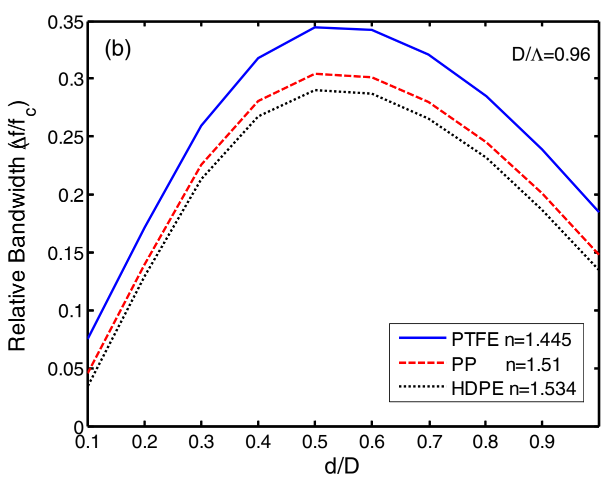

Fig.3 Relative bandwidth evolution with parameter D/Λ = 0.96 for three background material PTFE, PP and HDPE

Since the THz waves cover a broad frequency region (0.1 –10 THz), but due to the guiding mechanism is bandgap effect, the transmission bandwidth of THz bandgap fibers is limited, and it is determined by the bandgap of the photonic crystal cladding. Fig. 2 shows the relative bandwidths supported by the square lattice photonic crystal vary as a function of corner curvature d/D for different hole size D/Λ. We see that as D/Λ increases, the relative bandwidth increases monotonously. For each D/Λ, the relative bandwidth increases, reaches it's maximum and then decreases as d/D increases from 0.1 to 1. But as D/Λ increases from 0.92 to 0.99, the optimized position of d/D, with maximum bandwidth, drops from 0.6 (0.7) to 0.3 (0.4). It is also shown the circular hole (corresponding to d/D = 1) supports a relatively narrow bandwidth; the change of the hole's shape increases the bandwidth effectively. When D/Λ = 0.99, the relative bandwidth is ~0.3 for circular hole. While it reaches ~0.64 for d/D = 0.3, this corresponds to an efficiently widen bandwidth. For example, when the central frequency $f_c = 1THz$, the bandwidth is expected to be 0.68 – 1.32 THz. In Fig. 3, we show the effect of the background materials. For a given D/Λ (0.96), the relative bandwidths as a function of d/D are shown for three polymers PTFE, PP and HDPE. As the index of the background material increases, the bandwidth decreases. The PTFE offers the widest bandwidth compared with the other two polymers

III. Conclusions

A novel air-core bandgap polymer fiber for THz wave guiding is proposed, and a systematical investigation on transmission bandwidth is presented with the different polymer materials of PTFE, PP and HDPE. The periodic arrangement of square holes with round corners in cladding offers bandgap effect for mode guiding. The round corners in unit cell increases the bandwidth effectively compared with circle hole. It is revealed that the relative bandwidth increases monotonously with increasing hole size D/Λ, the optimized corner curvature d/D will offers a wider bandwidth for a given hole size. As the index of the polymer increases, the relative bandwidth reduced accordingly.

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Acknowledgement

This work is supported by grant SBIC RP C-014/2007, Singapore Bioimaging Consortium, A-star.