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High-Order Operating Mode Selection Using Second-Order Bandgap in THz Bragg Fiber

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Abstract—This paper demonstrates a novel design technique for single-TE_{01}-mode Bragg fiber using a second-order bandgap achieving signal propagation loss less than 1.2 dB/m from 0.85 THz to 1.15 THz. The TE_{01} mode intrinsically has a null point in the electric field close to the interface region between the core and the cladding. This makes the TE_{01} mode preferable to other modes since it shows low signal propagation loss and low electromagnetic interference from cladding defects. Bragg fiber can exhibit a strong mode selectivity as a result of modal-filtering effects. A large loss discrimination between the desired TE_{01} mode and competing modes can be designed by appropriately tailoring the photonic bandgap.

Keywords—Bragg fiber, electromagnetic propagation, high-order bandgap, low-loss THz components, modal-filtering effect.

I. INTRODUCTION

Low-loss THz waveguides are of great interest, particularly when the development of compact high-power sources and high-sensitivity detectors has proven challenging [1]. An air-core Bragg fiber is capable of tightly confining THz waves in the lossless air core, consequently reducing propagation loss [2]. In contrast to the fundamental HE_{11} mode, the TE_{01} mode has a null point in the electric field near the interface region between the core and the cladding, making it a strong candidate for low-loss propagation while it also avoids electromagnetic interference effects from cladding defects, such as those caused by support bridges typically used for mechanically maintaining the air gaps.

For lower propagation loss and lower group-velocity dispersion, Bragg fiber typically operates in an asymptotically single-mode pattern [3] – [5]. Therefore, a large propagation loss discrimination between the desired operating mode and other unwanted competing modes is required to ensure the single-mode operation of Bragg fiber. Conventional optical single-TE_{01}-mode Bragg fibers use first-order bandgap as the operating bandgap, which require a large air core (about $7.5\lambda_c$), many cladding layer periods (8 periods) and a long propagation distance (several kilometers) to create a significant loss discrimination [4]. Here, λ_c represents the central wavelength of the operating frequency band. However, it is not preferred for a THz Bragg fiber which otherwise will be very bulky.

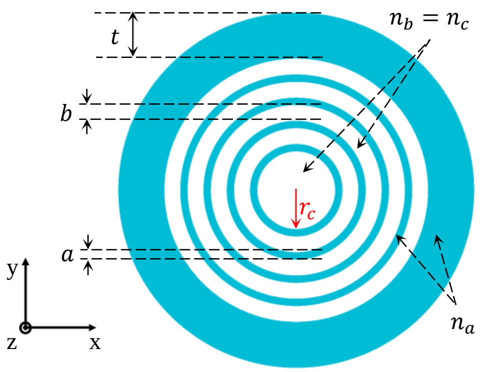


Fig. 1. Schematic of the proposed Bragg fiber. Cyan regions are TOPAS and white region are air. Here, a=77.5 μm, b=1.154 mm, r_c=917.1 μm, and t=2.463 mm.

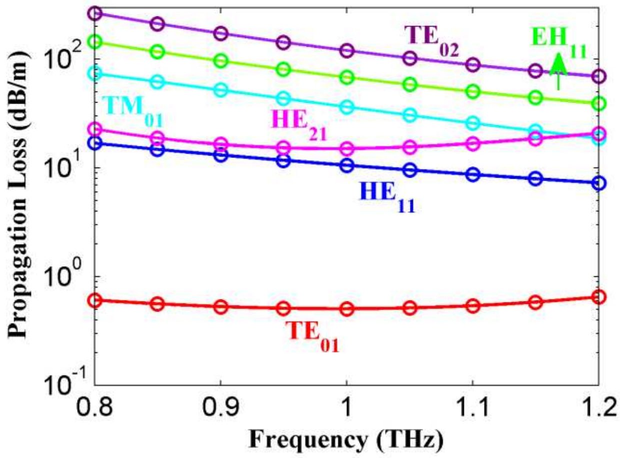


Fig. 2. Propagation loss of the proposed Bragg fiber. The solid lines and discrete circles represents analytical and simulation results, respectively.

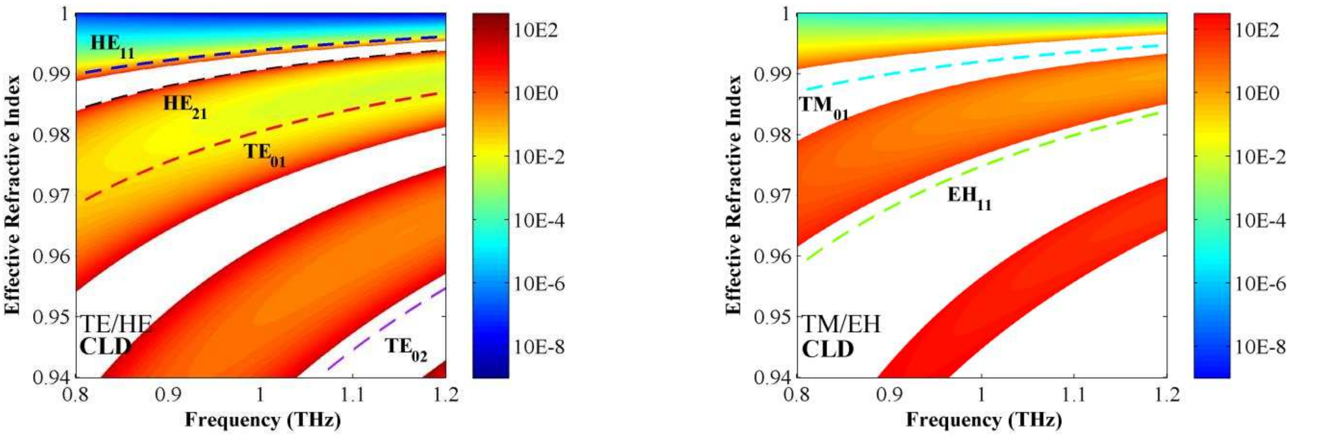
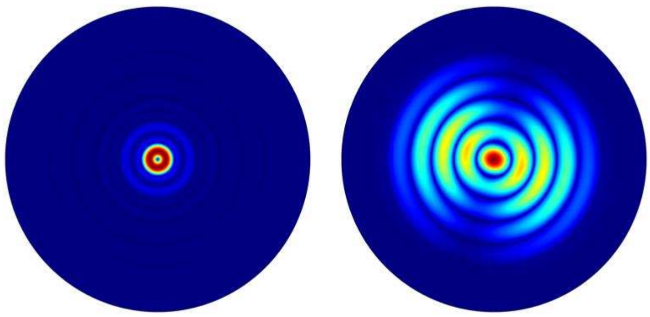


Fig.3. Confinement loss diagram in photonic bandgap for (a) TE/HE or (b) TM/EH modes. The colour map shows the value of confinement loss in unit of dB/m. The white regions are bandpass regions.



TE_{01} HE_{11}

Fig.4.Normalized electrical field of the desired mode TE_{01} and its main competing mode HE_{11}. The field decreases from red to blue.

In this paper, we choose the second-order bandgap as the operating bandgap of the proposed air-core single-TE_{01}-mode THz Bragg fiber. Compared with a conventional optical Bragg fibers using first-order bandgap [4], the proposed THz fiber utilizes a much gsmaller air core (about $3\lambda_c$) and less cladding layer periods (4 periods). Nevertheless, the propagation loss discrimination in the proposed fiber grows about 5 times faster than that in the conventional optical Bragg fiber resulting in a stronger mode selectivity and ensuring a much shorter and more compact device.

II. Design of Bragg Fiber

Fig. 1 shows the cross-section geometry of the Bragg fiber. The frequency-dependent complex refractive index of TOPAS (n_a) is based on the measurement results in the Ref. [6]. At 1 THz, n_a=1.5235+0.0008i. Air is regarded as a lossless medium, therefore, n_b=n_c=1.

The bandgap of the Bragg fiber can be tailored using the generalized half-wavelength condition [3] to make the TE_{01} as the lowest loss mode (<0.6 dB/m) across the frequencies of interest from 0.8 to 1.2 THz, see Fig. 2. A large loss discrimination between the desired TE_{01} mode and other competing modes is thereby created, allowing the fiber to operate effectively as single-mode. The propagation loss of the second lowest loss mode HE11 at the central wavelength is 10.6 dB/m, which is about 20.8 times greater than that of the lowest loss mode TE01 (0.51 dB/m), while as a comparison, the loss discrimination in conventional optical Bragg fiber using first order bandgap is about 4 times [4]. The volume-to-wavelength ratio of the proposed Bragg fiber is much smaller than those of conventional single-TE_{01}-mode Bragg fibers because of the use of the high-order bandgap.

Fig. 3 shows the confinement loss diagram (CLD) overlaid onto the photonic bandgap [3]. The dispersion curve of the desired TE_{01} mode is located near the central region of the second-order bandgap making its confinement loss much smaller than that of other competing modes and, consequently, its overall propagation loss at least 11 times smaller than those of competing modes over the frequency range of interest. Fig. 4 presents the mode patterns of TE_{01} mode and HE_{11} mode. It can be seen that the electrical field of the desired TE_{01} mode is essentially confined within the lossless air core, while that of its main competing mode HE_{11} are leaky, thus experiencing a high signal attenuation introduced by the bulk cladding materials.

III. Conclusion

In summary, we propose a single-TE_{01}-mode Bragg fiber with propagation loss less than 0.6 dB/m over the frequencies from 0.8 to 1.2 THz. Its second-order bandgap is used to select the TE_{01} mode as the propagation mode. The dual properties of low loss and compact volume make the proposed fiber a strong candidate for THz interconnects.

IV. Achnowledgment

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