3D printed hollow core terahertz Bragg waveguide for surface sensing applications

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Abstract: We study the use of 3D-printed hollow-core Terahertz (THz) Bragg waveguides with defect layers operating in an effectively single mode regime for resonant surface sensing applications. The demonstrated sensitivity is found to be 0.12GHz/μm to changes in the defect layer thickness.

OCIS codes: (230.7370) Waveguides; (040.2235) Far infrared or terahertz; (160.5298) Photonic crystals

1. Introduction

To date, most of the investigations of fiber-optic sensors are limited to the visible and near-IR regions [1, 2]. However, since the probing lengths of the evanescent fields in these spectral ranges are deeply sub-wavelength, detection of larger targets (such as bacteria with sizes of 0.5μm-10μm) is found to be problematic. In order to extend the probing depth of the surface wave to longer distance for macromolecular or bacteria detection, in this work, we propose and develop 3D printed Bragg waveguides with defect layers operating at longer wavelengths (i.e., THz) for surface sensing applications. We demonstrate theoretically and confirm experimentally that by introducing a defect in the first layer of the Bragg reflector, thereby causing anticrossing between the dispersion relations of the core-guided mode and the defect mode, we can create a sharp transmission dip inside of the waveguide transmission bandgap. By tracking the changes in the spectral position of the narrow transmission dip, we can build a sensor which is highly sensitive to the optical properties of the defect layer. Unlike many other photonic bandgap waveguide sensors operating on a more common bulk sensing modality, the one proposed here enables a resonant surface sensing modality.

2. Hollow core terahertz Bragg waveguide

Figure 1 shows the cross section of the waveguide, which features a hollow core surrounded by a periodic sequence of high/low refractive index multilayers, namely the printing resin (Plastic clear) and air. The thickness of each layer is designed to be 463μm, with a predicted fundamental bandgap center at 0.2THz according to the basic theory of Bragg fibers [2]. The number of the bilayers in the Bragg reflector is 10. Each Bragg waveguide has a length of 2.5cm. The light blue region represents a defect layer. The defect layer is defined as a supplementary layer deposited on the inner surface of a core, which effectively modifies the thickness of the first layer in the reflector. The waveguide core size of 4.5mm is chosen to ensure an effectively single mode operation within the fundamental bandgap region. In order to maintain the mechanical stability of the Bragg reflector, a set of micro-bridges are introduced into the waveguide cross section, as indicated in Fig. 1. 3D stereolithography is used to fabricate such waveguide sensors operating in the THz range.

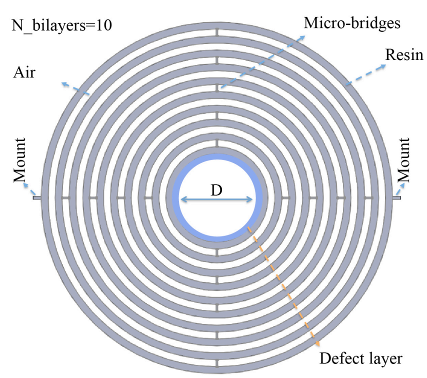

Fig. 1. Cross section of the designed Bragg waveguide.

3. Experimental characterization of the Bragg waveguides with defect layers

In order to introduce a transmission dip with narrow linewidth inside of the original bandgap, we increase the thickness of the first layer in the Bragg reflector, thus introducing anticrossing between the core-guided mode and the lossy modes confined in the vicinity of the defect layer [1]. Then, we characterize the transmission spectra through the fabricated waveguides using a THz time domain spectroscopy (TDS) setup.

As shown in Fig. 2, the introduction of a defect layer results in pronounced anticrossings between the core-guided mode and defect modes localized in the vicinity of a defect layer, which manifest as two sharp transmission dips inside of the Bandgap. When the thickness of the defect layer is increased from 200μm to 400μm, the anticrossing frequency shows a blue frequency shift. In Fig. 2(b), we plot the resonant dip frequency at the right edge of the bandgap as a function of the defect layer thickness, and a linear dependency is well observed. The experimentally obtained surface sensitivity to changes in the thickness of the first reflector layer is found to be 0.12GHZ/μm. The two resonant dips feature narrow linewidths. For example, the linewidth of the transmission dip of the Bragg waveguide with a defect thickness of 300μm is 9GHz, which is five times smaller than that of the bandgap bandwidth (45GHz). By directly tracking the anticrossing frequency between the core-guided mode and the defect mode, which manifests itself as a sharp transmission dip within the relatively broad transmission window, we have significantly improved the detection limit compared to the THz waveguide sensors reported in the literature.

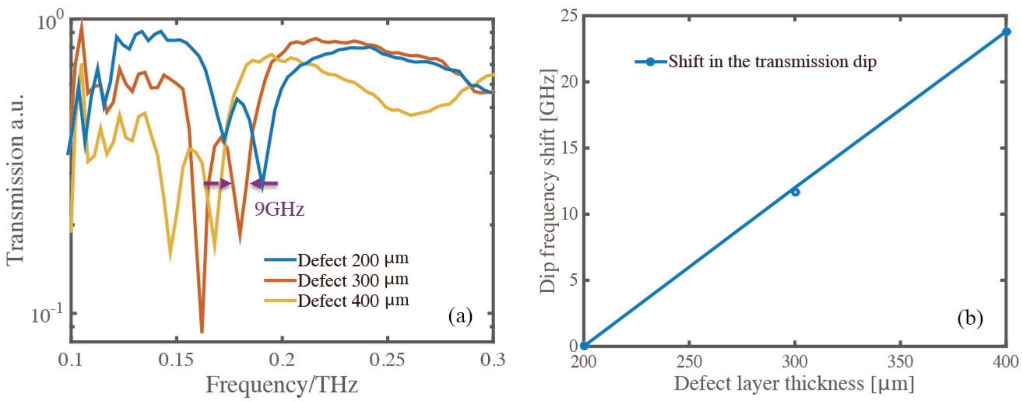

Fig. 2. (a) Experimentally measured transmission spectra of the THz Bragg waveguide featuring a defect layer of different thickness (200μm, 300μm, and 400μm). (b) Transmission dip position at the right edge of the bandgap as a function of the defect layer thickness.

4. Conclusion

In summary, we propose using 3D printed hollow-core THz Bragg waveguides with defect layers for resonant surface sensing applications. It is demonstrated that by introducing a defect into the first layer of the Bragg reflector structure, a strong and spectrally narrow dip appears in the waveguide transmission spectrum. The dip is due to the anticrossing phenomenon between the core-guided mode and a mode localized in the defect of the Bragg reflector. By tracking the anticrossing frequency, which manifests itself as a transmission dip with narrow linewidth in the waveguide transmission spectrum, one can detect changes in the geometrical or optical properties of the defect layer. The experimentally achieved surface sensitivity is found to be 0.12GHz/μm to changes in the defect layer thickness. The ability to tailor the spectral properties of the sensors by properly designing their geometric parameters means that our Bragg waveguides become a viable platform for a wide range of application, such as detection of molecular interaction, study of surface kinetics, and bacteria detection.

5. References

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[2] J. Li, H. Qu, M. Skorobogatiy, "Simultaneous monitoring the real and imaginary parts of the analyte refractive index using liquid-core photonic bandgap Bragg fibers," Optics Express **23,** 22963-22976 (2015).