Comparison of Topological Valley Photonic Crystal and Unclad Silicon Terahertz Waveguides

Nguyen H. Ngo[1], Shota Yamamoto[1], Kei Iyoda[1], Yoshiharu Yamada[2], Yusuke Kondo[2], Shuichi Murakami[2], Masayuki Fujita[1], Tadao Nagatsuma[1]

[1] Graduate School of Engineering Science, Osaka University, Japan
[2] Osaka Research Institute of Industrial Science and Technology, Japan
Email: ngo.h-nguyen.es@osaka-u.ac.jp

High-speed inter-chip communication is required to support for broad bandwidths with low-loss and low-dispersion despite the routing with several sharp bends. Terahertz communications have the potential to achieve very high throughput. Topological valley photonic crystal (VPC) silicon waveguides have shown near-unity transmission in the photonic band gap for sharp bends. We have demonstrated 11 Gbit/s and 60 Gbit/s transmissions over a 10-bend VPC waveguide using on-off keying [1] and 32-QAM [2] modulations at 0.3-THz band, respectively. As the alternative candidate for low-loss terahertz waveguides, unclad silicon wire waveguides where the terahertz wave is confined by strong total internal reflection between silicon and air, have been developed. We have achieved 30 Gbit/s communications using a diplexer with a 90-degree bend based on the unclad waveguide at 0.3-THz band [3]. In this work, we compare VPC and unclad silicon waveguides with the same sharp bending structures.

Both waveguides consist of eight sharp bends (near zero radii of curvature) with 120 degrees as shown in the photograph of Fig. 1. As for the reference, we also fabricated straight waveguides with the length of 2 cm. The VPC is made from high resistivity (>10 kΩcm) silicon with a thickness of 200 µm. The graphene-like periodic structure is composed from the period a = 220 µm as shown in Fig. 1(a). A unit-cell of the lattice consists of an equilateral triangle hole of edge-length l_1 = 0.65a and a similar inverted equilateral triangle of edge-length l_2 = 0.35a. The unclad waveguide comprises a silicon wire and a U-shaped supporting frame separated by the effective medium (EM) composed of silicon and air to suppress the leakage of terahertz wave to the frame at the two ends of the wire. The waveguides were fabricated on the same silicon wafer of VPC, as shown in Fig. 1(b). The width of the unclad silicon wire w is 170 µm. The hole period and diameter of the EM structure are 100 µm and 90 µm, respectively.

The transmittances of waveguides were measured by using a vector network analyzer with WR-2.2 extender modules. Fig. 2 shows the simulation and experiment results of four waveguides from 330 GHz to 380 GHz. Regarding experimental data, the bending VPC waveguide reveals a low loss by retaining a similar bandwidth of the straight waveguide while the bending unclad waveguide shows a significant loss, although the unclad waveguide has a much broader bandwidth than the VPC waveguide in the straight structure. Therefore, the VPC waveguide is better than the unclad waveguide for sharp bending structures. In addition, the simulation results overall depict higher transmittance than the experiment results. The reason is likely due to the imperfect fabrication of samples which causes frequency shifts and narrow bandwidths. However, VPC waveguides also prove its robustness where the maximum transmittances are almost unchanged.

This work was supported in part by CREST, JST (JPMJCR21C4), KAKENHI, Japan (20H00249), and is the commissioned research by the National Institute of Information and Communications Technology (NICT), JAPAN (03001).

Reference

[1] Yang *et al.*, Nat. Photonics 14 (2020) 446, [2] Webber *et al.*, *et al.*, J. Lightwave Technol. 24 (2021) 7609
[3] Headland *et al.*, J. Lightwave Technol. 38 (2020) 6853.

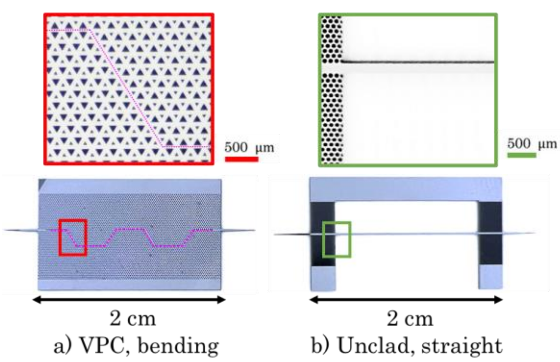

Fig. 1 Fabricated samples of a) bending VPC and b) straight unclad waveguides. Enlarged images are shown on the top.

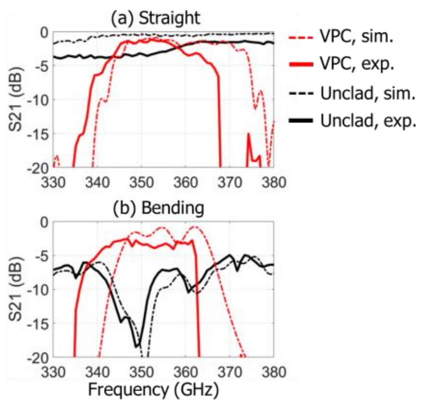

Fig. 2 Measured transmittances of (a) bending and (b) straight waveguides.