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Equal Power Splitting in a 6-Port Valley Photonic Crystal Junction

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Abstract

Topological photonics offer unique opportunities to design robust backscattering suppressed photonic circuits in a small footprint. In this work our recent efforts in realizing a 6-port topological valley mode equal power splitter will be presented. A technique to extract the scattering matrix of the structure will be shown and exploited to design an electromagnetic equal power divider. Its potential for analogue computing will also be discussed.

1. Introduction

Recent advances on the arbitrary manipulation of light has enabled the proposal of ground-breaking applications in many areas including metamaterials and metasurfaces for sensing and antennas [1], [2], time-varying media [3]–[6] and photonic computing[7], [8], among others. In the realm of computing with electromagnetic waves, different analogue processors have been reported with the ability to perform computing tasks including routing of information [9], [10], differentiation and integration [11]–[14], and optical neural networks [15], [16].

In seeking compact and efficient ways to control light, Photonic topological Insulators (PTIs) have demonstrated to provide an opportunity for unconventional light manipulation, allowing for the implementation of photonic circuits with unidirectional waveguides [17]–[19], sharp bends and discontinuities while maintaining low-loss throughput [20], [21]. Recently, PTIs have also be used in applications such as lasing [22], [23], computing [24], [25], protected refraction [26] and quantum entanglement [27] to name a few.

Within the realm of PTIs, Valley Photonic Crystals (VPC) structures inherit their topological protection through a pseudospin, producing a bulk edge correspondence between two opposing pseudospin VPCs [28]. This is without the challenge of requiring magneto-optical materials necessary to break time reversal symmetry, such is the case with Chern PTIs [28]. Instead, inversion symmetry is broken, exploiting a degree of freedom formed in a hexagonal VPC lattice where the angular rotation of electric fields form at high-symmetry K points [28]. Enabling, in this way, a non-zero valley-Chern number [29]. VPCs have been demonstrated for routing [30]–[32], power splitting [33]–[35], sensing [36], logic gates [37], quantum computing [38] and on-chip optical communication[21], to name a few. Furthermore, the recent demonstration of a scattering matrix approach of VPCs provides an inspiring technique to construct complex networks of VPC junctions analytically [32].

Motivated by the opportunities that PTIs offer, here propose and study a 6-port rotationally symmetric equal power splitting junction by exploiting VPCs [39]. The scattering matrix that defines the magnitude and phase of the transmitted/reflected signals are extracted, allowing us to design, for instance, a perfect power divider. It will be shown how the proposed structure can be used for linear analogue computing operations such as routing of information. Our work has the potential to be implemented in scalable $N \times N$ networks of junctions performing analogue computing tasks such as solving partial differential equations [11].

2. Results and Discussion

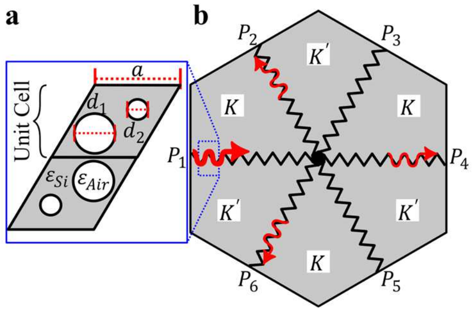

Figure 1. (a) Schematic of two hexagonal unit cells aranged at the VPC-VPC interface, each unit cell has a side length $a = 340$ nm and hole diameters $d_1, d_2 = 0.48a, 0.24a$, respecively [37]. (b) Schematic of the 6-port VPC structure with a single input at port 1, P_1, and equal power splitting between ports $2, 4$ and 6 with zero power reflected to P_1.

Here, we consider the VPCs with a hexagonal unit cells as schematically shown in Fig.1a. The K-type VPC is constructed from a silicon background material, ε_{Si}, and two air filled, ε_{Air}, holes of diameter d_1 and d_2. As observed, and as it will be discussed in detail during the conference, inversion symmetry is broken when $d_2^K \neq d_1^K$. The K'-type VPC is designed by alternating the hole diameters so that $d_1^{K'}, d_2^{K'} = d_2^K, d_1^K$. With this in mind, we designed the 6-port VPC presented in Fig.1b where six VPC waveguides that join at the centre.

The numerical results of the 6-port VPC are presented in Fig. 2. An incident signal is applied at, P_1 with a frequency, f_1. This frequency falls within the bandgap and was chosen such that equal power splitting is achieved to ports P_2, P_4 and P_6. The magnitudes and phases associated with each port have also been extracted as in [32], allowing the formulation of a scattering matrix. During the conference, the full details of the calculation of the scattering matrix for the proposed structure will be presented along with further linear computing operations such as to design wave directors and the possibility to design interferometers.

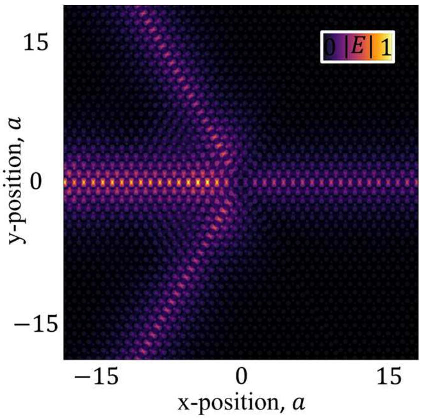

Figure 2. $|\boldsymbol{E}|$ fields for a single input at P_1 at the equal power splititng frequency, $f_1 = 191.85$ THz.

3. Conclusion

In conclusion we have presented our recent efforts in achieving equal power splitting through a rotationally symmetric VPC junction operating at telecom frequencies. An in-depth study of this structure will be presented towards the validity of the equal power splitting, retrieval of the scattering parameters and its implementation for computing operations.

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