Intuitively Designable Power Division based on Substrateless, All-dielectric Waveguides

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***Abstract*—All-dielectric waveguides have emerged as a promising candidate platform for the utilization of the currently untapped terahertz bands. With high efficiency and broad functional bandwidths these waveguides are well suited to the needs of terahertz communications, however a wide range of devices are yet to be realized on this platform. Here we present one such device, a power divider, with intuitive designable division ratio.**

I. INTRODUCTION

BEFOR the widespread adoption of terahertz technologies can be realized, high efficiency integrated platforms must be developed. A critical challenge is the limited available power and as such any potential terahertz platform should emphasize efficiency, alongside broadband operation. To this end, we propose the use of all-dielectric waveguides, monolithically realized from high-resistivity silicon [1,2]. To build upon the capabilities of this platform many devices must be developed; one such device is the power divider. Power dividers are widely useful components with applications in imaging [3] and are critical to the realization of phased arrays for beamforming [4], where often splitting ratios need to be carefully tuned to optimize system performance. Here, we present an intuitive scheme for the realization of arbitrary division ratio power division on an all-dielectric waveguide platform. We contextualize this design in contrast to alternative techniques for realizing power division, notably through inverse-designed multi-mode interferometers [5] and unidirectional couplers [6]. The first of these is not intuitively designable, requiring an opaque and time-consuming optimization process for each unique division ratio. The second, unidirectional coupling, is inherently narrowband owing to the fundamental frequency dependence of evanescent coupling. This necessitates an alternative solution be developed for the terahertz band where fractional bandwidths often exceed 40%.

This report is an adaptation of work previously presented at the 47th Conference on Infrared, Millimeter, and Terahertz Waves [7].

II. DESIGN

The simplest technique for realizing symmetric power division is through the implementation of a Y-junction, simply mirroring a bend along the common input axis. As shown in Fig. 1, to extend this technique to asymmetric power division we introduce an effective-medium barrier consisting of a subwavelength period hexagonal lattice of through-holes which act to partially obstruct one output while guiding the obstructed power to the opposite port. To enhance this effect, while suppressing scattering and cross-coupling we introduce an anisotropic effective medium comprised from silicon microbeams with subwavelength period [8], to clad the waveguide core. The combination of these effects allows for designing of arbitrary division ratios by simply tuning the radius of these obstructions while keeping other design variables constant.

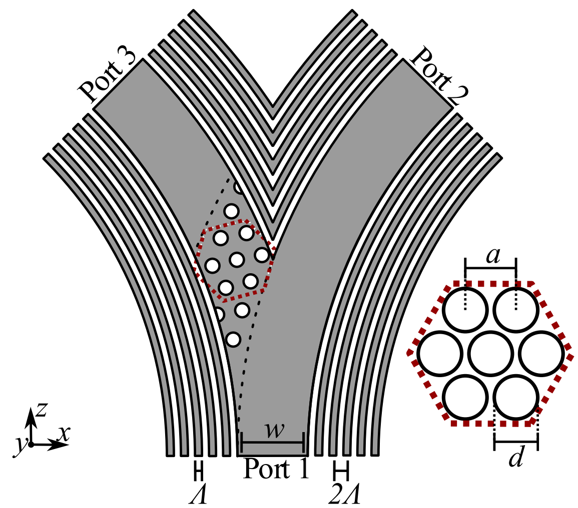

Fig. 1. Schematic for an intuitively designable planar power divider for the substrateless silicon waveguide platform highlighting the design parameters.

III. RESULTS

In Fig. 2, we present simulated results for 3 configurations designed for the frequency range 220 to 330 GHz, with blockage radiuses 0 µm, 25 µm, and 45 µm with a fixed lattice period 100 µm. In this case the waveguide core has width, $w = 225$ µm and is to be etched from a high resistivity silicon wafer with thickness 250 µm. For simulation a realistic permittivity of 11.68 and loss tangent of 3×10^{-5} is adopted for silicon. The anisotropic cladding period is designed with deeply subwavelength period $\Lambda = 20$ µm. Simulation results show power division ratios from 50%/50% up to 95%/5% are achievable by varying the blockage radius between 0 and 45 µm with device average efficiency above 88%. We have begun fabricating these devices with plans to measure them to support these simulated results.

IV. CONCLUSION

Here we present an intuitively designable power designer based upon substrateless all-dielectric waveguides. We utilize silicon microbeams with subwavelength dimensions to realize an anisotropic effective medium, suppressing cross-coupling between the two output waveguides. In this case this technique

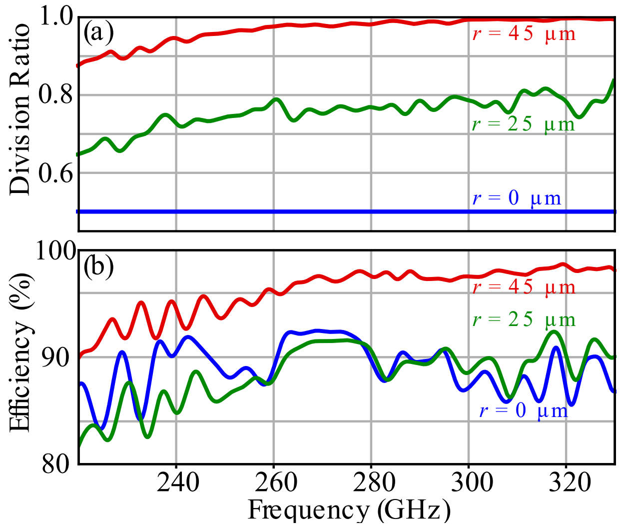

Fig. 2. Simulated results over the frequency band 220—330 GHz, for three configurations, demonstrating the simple designability of this structure. In (a), we define the division ratio as $|S_{21}|^2/(|S_{21}|^2+|S_{31}|^2)$, representing the proportion of power that enters the primary output. In (b), we define the efficiency as $(|S_{21}|^2+|S_{31}|^2)$.

is applied at 220—330 GHz, however, fabrication permitting, this technique could be readily scaled to other frequency ranges.

V. Career Plans and Impact Statement

It has been an honor to be a recipient of the MTT-S Graduate Fellowship in 2022. Through this award I was able to make the most out of my research experience through conference experiences, which inspired me to continue my research journey. The research supported by this fellowship has already supported one conference publication, which was selected as a keynote presentation, and as the project continues, hopefully a future journal publication as well. As I now enter the 3rd year of my PhD candidature I am turning towards future opportunities and would like to actively pursue a career in the terahertz community moving forward.

VI. Acknowledgement

I would like to thank the IEEE MTT-S for this opportunity over the past year, with the support of this award I was able to present my work in person at the 47th International Conference on Infrared, Millimeter, and Terahertz Waves, hosted in Delft, The Netherlands. Alongside this, I would like to express a special thanks to Professor Giovanni Crupi, for coordinating the MTT-S Fellowship program in 2022.

References

[1] W. J. Gao, W. Lee, X. Yu, M. Fujita, T. Nagatsuma, C. Fumeaux, and W. Withayachumnankul, “Characteristics of effective-medium-cladded dielectric waveguides,” IEEE Trans THz Sci. Technol, vol. 11, no. 1, pp. 28–41, 2021.

[2] D. Headland, W. Withayachumnankul, X. Yu, M. Fujita, and T. Nagatsuma, “Unclad microphotonics for terahertz waveguides and systems,” Journal of Lightwave Technology, vol. 38, no. 24, pp. 6853–6862, 2020.

[3]. G. Yurtsever, B. Považay, A. Alex, B. Zabihian, W. Drexler, and R, Baets, "Photonic integrated Mach-Zehnder interferometer with an on-chip reference arm for optical coherence tomography," Biomed. Opt. Express 5, 1050-1061 (2014)

[4]. R. Munson, "Conformal microstrip antennas and microstrip phased arrays," in *IEEE Transactions on Antennas and Propagation*, vol. 22, no. 1, pp. 74-78, (1974).

[5] S. Zhao, W. Liu, J. Chen, Z. Ding, and Y. Shi, “Broadband arbitrary ratio power splitters based on directional couplers with subwavelength structure,” IEEE Photon. Technol. Lett., vol. 33, no. 10, pp. 479–482, 2021.

[6] K. Xu, L. Liu, X. Wen, W. Sun, N. Zhang, N. Yi, S. Sun, S. Xiao, and Q. Song, “Integrated photonic power divider with arbitrary power ratios,” Opt. Lett., vol. 42, no. 4, pp. 855–858, 2017.

[7] H. Lees, D. Headland, and W. Withayachumnankul, “600-GHz-band silicon dielectric waveguide module,” in Proceedings of the 47th Int. Conf. on Infrared, Millimeter and Terahertz Waves, 2022.

[8] S. Jahani, S. Kim, J. Atkinson, J. C. Wirth, F. Kalhor, A. A. Noman, W. D. Newman, P. Shekhar, K. Han, V. Van et al., “Controlling evanescent waves using silicon photonic all-dielectric metamaterials for dense integration,” Nat. Commun., vol. 9, no. 1, pp. 1–9, 2018.