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Design of a 1x4 Optical Power Divider Based on Y-Branch Using III-Nitride Semiconductor

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ABSTRACT

Optical communications are identified as a technology that is able to meet future demands. As a passive component of optical communication, optical power dividers play an essential role. We propose a novel 1x4 optical power divider design, which is a combination of an optical power divider design using a Y-branch and an optical power divider using rectangular waveguides utilizing mode coupling phenomena from our previous researched designs. The 1x4 optical power divider design using three Y-branches and utilizing mode coupling phenomena is described in this work. The design consists of three sections: an input Y-branch, rectangular waveguides, and two output Y-branches. By utilizing mode coupling phenomena with 3 rectangular waveguides, the optical power was transferred from one waveguide to its adjacent, so we obtained a wider splitting angle at the input Y-branch. The design was optimized using the beam propagation method (BPM) at a wavelength for optical communication of $\lambda = 1.55$ µm. We optimized various parameters such as the width and thickness of the waveguide, splitting angles, coupling gaps, and coupling lengths by doing numerous experiments. The result shows that the proposed design was successfully split into four outputs with 0.14 dB power imbalance at four output ports and 0.12 dB excess loss through the design. The excess loss and power imbalance at varied wavelengths were also observed. The distribution of excess loss and power imbalance is almost stable through the C-band range (1530-1565 nm). The proposed design shows the possibility of a new wide-angle optical power divider design and demonstrates the development possibilities of optical interconnections at wavelengths of 1530-1565 nm.

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1. INTRODUCTION

Optical communications are identified as a technology capable of meeting future demands. Optical communications have typically focused on high-speed connections across huge distances. There are many passive components in optical communications. The term “passive” refers to devices that do not require any optical-to-electrical conversion or vice versa to function. The passive components in optical communications include optical connectors, circulators, add/drop multiplexers, switches, and splitters/dividers [1-4]. Optical power dividers play an important role in dividing and combining optical signals in optical communication.

One of the basic parts of integrated photonics is the optical waveguide, which is able to localize light propagation within micron-scale volumes, resulting in increased light intensity within the cavity compared to light intensity within the bulk [5]. An Optical power divider is a waveguide structure that divides and combines optical signals. In recent years, several optical power divider technologies have recently been proposed, such as those using Y-branch [5-7], Y-branch with multimode interference (MMI) structure [8, 9], directional coupler [10, 11], grating [11], microring [12, 13], rectangular waveguides coupling [14, 15], and photonic crystals [16]. Various 1x4 optical power divider designs have been developed, among others are with Y-branch design [17], a photonic crystal resonator [18, 19], a rectangular MMI structure with four tapered waveguides with 0.013 dB excess loss and 0.17 dB power imbalance [20], and rectangular waveguide coupling with 0.18 dB excess loss and 0.23 dB power imbalance [15].

Research on III-nitrides has attracted a great deal of attraction due to their mechanical hardness, large bandgap, and large band offset, which makes them capable of operating at high voltages, high power levels, and high temperatures [21, 22]. These abilities are pursued highly in high-speed computation and communication in a harsh environment [23]. III-nitride semiconductors have been widely developed for laser diodes (LDs) and light-emitting diodes (LEDs) application with huge commercial success [24-27]. Besides being developed as LDs and LEDs, III-nitride has also been developed as waveguide devices. GaN-based structures have developed rapidly in their application on waveguided, such as coupler [28], modulator [29], brag reflection [30], and optical power divider [14]. Sapphire has been recognized for its temperature and mechanical stability, high refractive index, and transparency in a broad spectral range [31, 32].

In our previous works, we investigated the optical power divider using Y-branch only [6] and rectangular waveguides only [14]. The advantages of using a Y-branch are the independence of the wavelength and polarization, and the advantage of the rectangular waveguides is easy to fabricate because a linear rectangular waveguide is easier to fabricate than an S-bend sine waveguide. In this work, we propose a novel 1x4 optical power divider design, which is a combination of Y-branches and rectangular waveguides utilizing mode coupling phenomena from our previous researched designs. By utilizing mode coupling phenomena, the splitter obtained a wider angle than the previous design [6, 14]. A wider splitting angle is required to prevent interference at the output Y-branches. The proposed design shows the possibility of a new wide-angle optical power divider design. The Y-branch loses more of its optical power if the splitting angle is too big, so the combination of the Y-branch and rectangular waveguides is one of the ways to prevent it. The simulation was conducted by running a 3D isotropic simulation with a 1.55 µm propagation step based on the beam propagation method by using OptiBPM software.

2. METHOD

2.1. Beam Propagation Method

BPM is generally formulated as a solution to the Helmholtz equation, and it is expressed for a monochromatic wave as follows:

$$\frac{\partial^2 E}{\partial x^2} + \frac{\partial^2 E}{\partial y^2} + \frac{\partial^2 E}{\partial z^2} + {k_0}^2 n^2(x,y,z)E(x,y,z) = 0 \tag{1}$$

where k_0 is the wave number in free space. The Helmholtz equation for the slowly varying field, which is derived from equation (1), is expressed as follows:

$$2jkn_0 \frac{\partial u}{\partial z} = \frac{\partial^2 u}{\partial x^2}\frac{\partial^2 u}{\partial y^2} + k^2(n^2 - {n_0}^2)v \tag{2}$$

The equation (2) is known as the Fresnel equation, and the solution is known as BPM, and it is used to accurately design the photonic waveguides devices.

2.2. The Proposed Design

In this work, we simulated the continuous wave propagation through the 1x4 optical power divider design using OptiBPM software for λ = 1.55 µm. We designed a 1x4 optical power divider consisting of three sections: the input Y-branch, rectangular waveguides, and two Y-branches as outputs at the end. The design of the input Y-branch consists of a rib waveguide, a parabolic taper, and two S-bend sine taper branching waveguides [6]. The rib waveguide with a width of 4 µm is connected to the parabolic taper, and at the end of the parabolic taper with a width of 8 µm is connected to the two S-bend sine taper waveguides. The S-bend sine taper waveguide was designed with a length of 650 µm.

Two waveguides will exchange power and become coupled if they are close enough to each other. The amount of exchanged powers depends on the direction of the propagation [15], and we connected the input Y-branch to the two output Y-branches by utilizing the mode coupling phenomena to obtain a 1x4 optical power divider. The spatial dependence of one mode in a waveguide will be modified by another near it, and the optical power transfer from one waveguide to another has efficiency expressed by the coupling coefficient κ [33]. The two waveguides propagate independently if they are far apart from each other. The distance over the peak optical power exchanged from one waveguide to the other waveguide is expressed as the coupling length L_c defined by:

$$L_c = \frac{\lambda}{2(n_s - n_a)} \tag{3}$$

$$n_s = n_{eff} + \kappa_{12} \tag{4}$$

$$n_a = n_{eff} + \kappa_{21} \tag{5}$$

$$\kappa_{12} = \kappa_{21} = \kappa \tag{6}$$

where λ is the wavelength; n_s is the refractive index of symmetric and n_a is the refractive index of antisymmetric. Based on mode coupling phenomena, we designed a linear waveguide with a gap of 1 µm to its adjacent, which is the end section of the input Y-branch. The length of the linear waveguide was 400 µm. We designed another linear waveguide with a gap of 1 µm to its adjacent, which is the previous linear waveguide, but it has a length of 600 µm. To prevent the two Y-branches were close to each other, we added another linear waveguide with a gap of 1 µm from the previous linear waveguide, but it has a length of 1200 µm. By utilizing mode coupling phenomena, the input Y-branch has a wider angle and prevents two output Y-branches from becoming close to each other, which will affect the optical power at the four outputs. To improve the performance of the design, the input Y-branch can be further optimized. Fig. 1 shows the design for the 1x4 optical power divider.

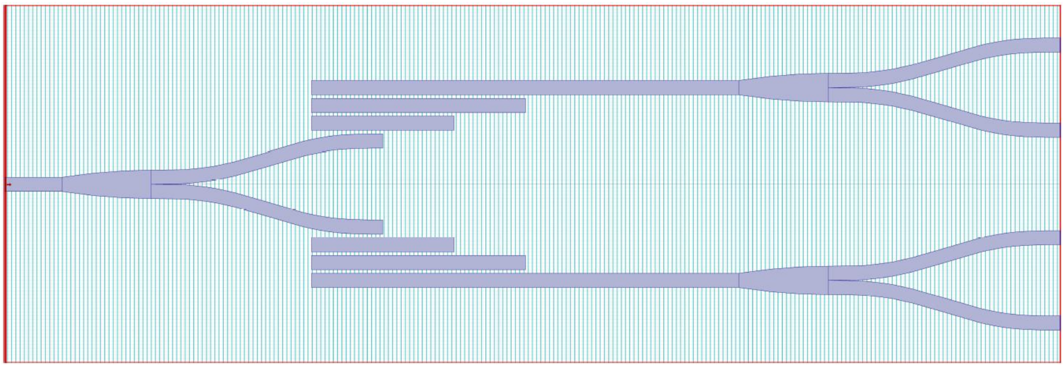

Fig. 1. The proposed 1x4 power divider design

We designed the structure of the waveguide consisting of GaN, buffer layer, and sapphire, as shown in Fig. 2. We used GaN and air as waveguide and cladding material, respectively. As a buffer layer, we used AlN and AlN/GaN and sapphire as a wafer. We optimized the coupling gap, the coupling length, and the waveguide parameters to achieve the desired results at the output ports. The width and the thickness of the cladding material (air) were set to 4 µm and 0.02 µm, respectively, with a refractive index of 1. The waveguide material's (GaN) width and length were set to 4 µm and 4 µm, respectively, with a refractive index of 2.282. The wafer with a refractive index of 1.76 has a width and thickness of 4 µm and 5 µm, respectively.

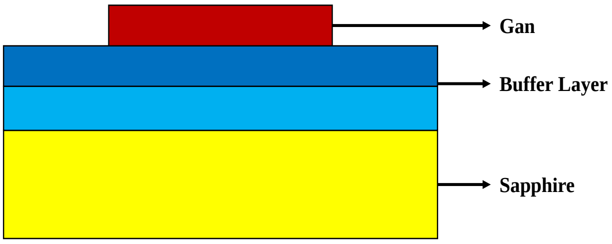

Fig. 2. Illustration of the GaN structure layer

In Fig. 3, the overall design process was described. We started by designing the structure layer. We set material parameters, such as width, thickness, refractive index, and wafer properties. Then we designed the input Y-branch and optimized the required parameter, such as the splitting angle. After obtaining the desired splitting outputs, we designed rectangular waveguides coupling to obtain a wider splitting angle and optimized the required parameter such as coupling length and coupling gap. A wide splitting angle is required so there is no interference at the output caused by the waveguide being close to each other at the center (x = 0 µm). Then we designed another Y-branches as outputs to split into four outputs and optimized the required parameters. The optimum design is a design that gives the lowest power imbalance and excess loss.

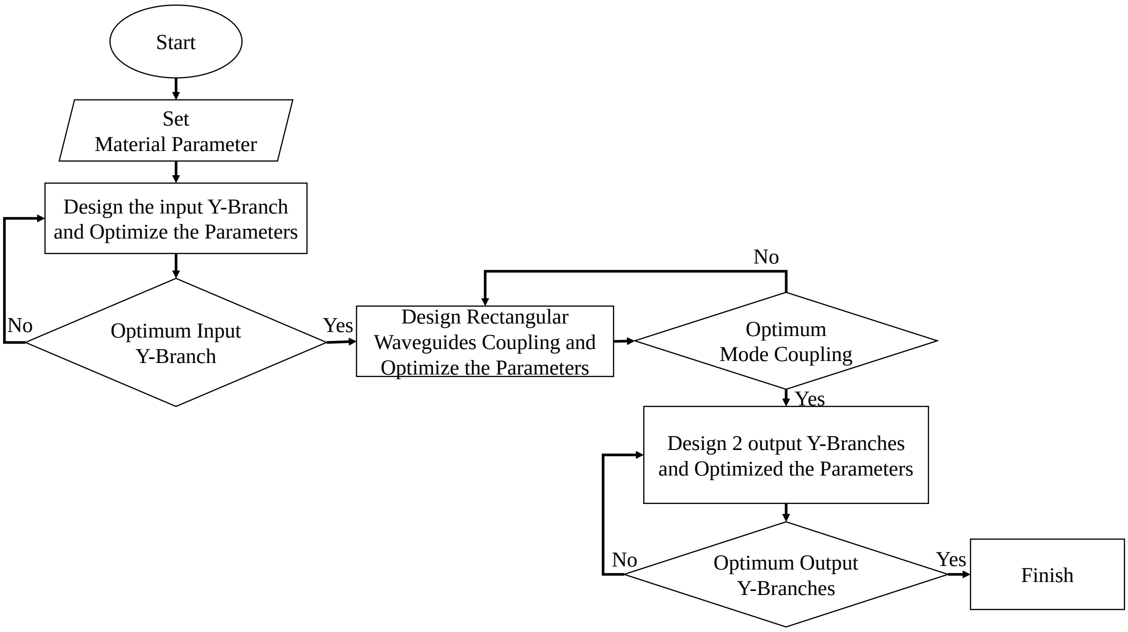

Fig. 3. Flowchart of the design process of 1x4 optical power divider

3. RESULTS AND DISCUSSION

We optimized the parameter values of the proposed design to obtain the lowest excess loss and uniform output distribution. We designed the 1x4 optical power divider based on BPM by running OptiBPM software. The proposed 1x4 optical power divider design is the combination of an optical power divider design using a Y-branch [8] and rectangular waveguides coupling [14]. By performing the 3D isotropic simulation at λ = 1.55 µm, we investigated the proposed design and used the semi-vectorial TE polarized field. We used 1 µm as the coupling gap between adjacent waveguides. The proposed design has a total length of 2960 µm and a total width of 90 µm. Fig. 4 shows the 3D map of optical field propagation through the proposed design. The different colors represent different levels of the optical field. The input Y-branch split the optical power uniformly and it is also split uniformly at the four output branches even though it has weak intensity.

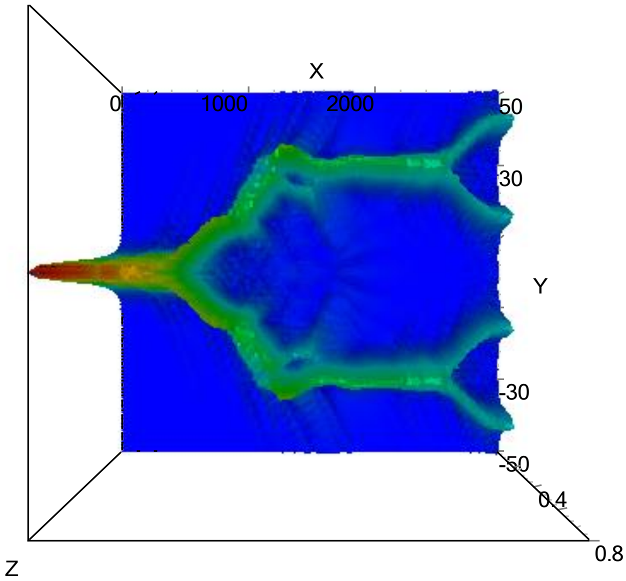

Fig. 4. 3D optical field distribution along the x-z plane

Fig. 5 shows the 3D image of the optical field distribution at propagation distances z = 2960 µm, while Fig. 6 shows the mode propagation for the wavelength of 1.55 µm at propagation distance z = 2960 µm. The optical power reached its peak at x = -39 µm, x = -15 µm, x = 15 µm, and x = 39 µm as shown in Table 1. The optical power is split into four at a propagation distance of z = 2600 µm. The graph of the optical field distribution is shown in Fig. 7, and it shows that the four optical powers at the four outputs were distributed uniformly at a propagation distance of z = 2960 µm.

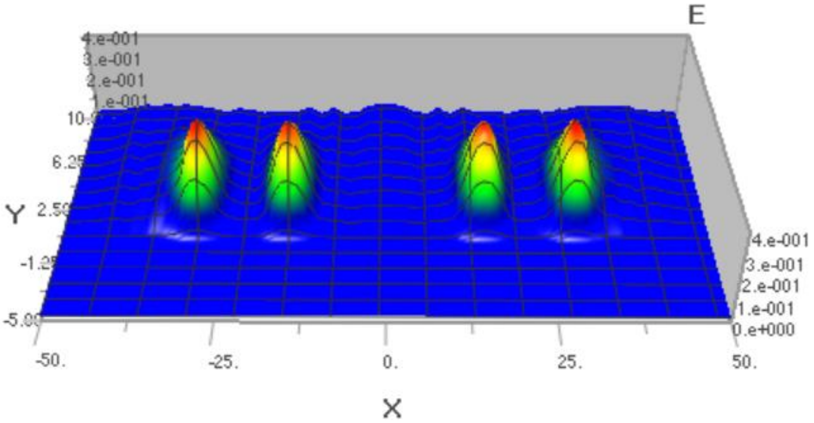

Fig. 5. 3D normalized optical field distribution at propagation distance z = 2960 µm

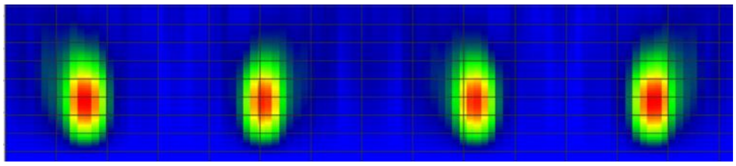

Fig. 6. Mode propagation for propagation step of 1.55 µm at z = 2960 µm

Table 1. Relative peak output

X (mm)	Relative Peak Output
-39	0.198
-15	0.192
15	0.192
39	0.198

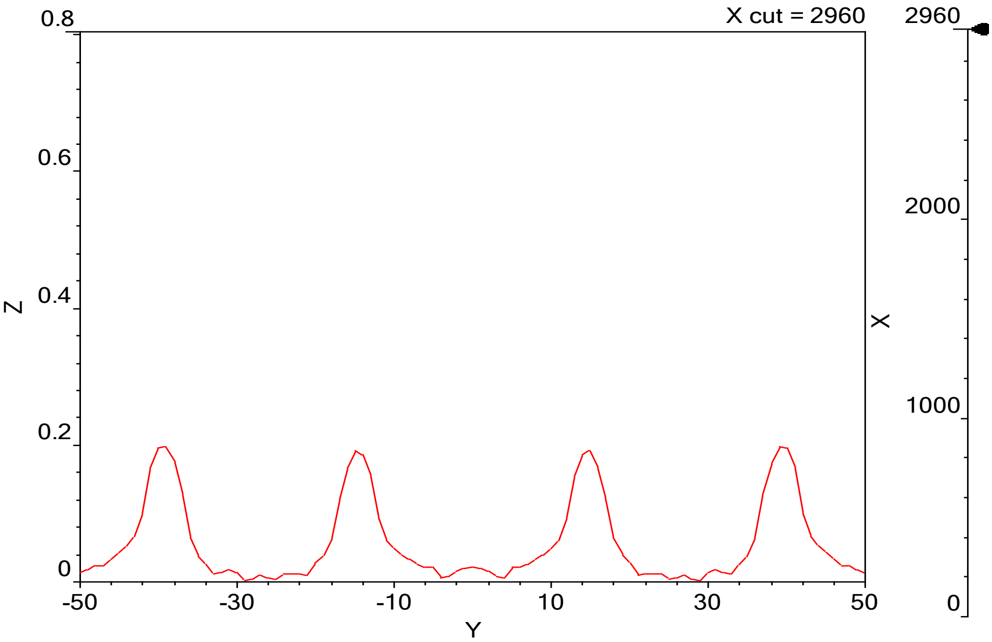

Fig. 7. Optical field distribution at z = 2960 µm

The characteristics of a 1x4 optical power divider are expressed in excess loss of the system and power imbalance at the four outputs. Calculations of excess loss and power imbalance have been performed. The excess loss is the amount of power lost due to the reflective and absorptive properties of the material, and power imbalance is the amount of power imbalance at the four output ports. Both excess loss and imbalance were calculated as follows:

$$\text{Excess Loss} = -10log\left(\frac{P_{out}}{P_{in}}\right) \tag{7}$$

$$\text{Imbalance} = -10log\left(\frac{P_{min}}{P_{max}}\right) \tag{8}$$

where P_{out} and P_{in} are the total optical power at four output ports and the total optical power at the input port, respectively; P_{max} and P_{min} are the highest and the lowest optical power, respectively, at the four output ports [33]. By using equations (7) and (8), we obtained 0.12 dB excess loss with 0.14 dB power imbalance at four output ports for λ = 1.55 µm.

The excess losses and power imbalances for various wavelengths were also calculated, and the results are presented in Table 2. We obtained the lowest excess loss of 0.1 dB at λ = 1.535 µm and the lowest power imbalance of 0.12 dB at λ = 1.565 µm. Based on Table 2, the excess loss and power imbalance distribution are almost stable at various wavelengths, as shown in Fig. 8 and Fig. 9. The proposed design has a wider splitting angle and better performance in light propagation as we obtained a lower excess loss than our previous research using a Y-branch, which has an excess loss of 0.35 Db [6] and better performance in the uniformity of outputs distribution and excess losses through the proposed design than our previous research using rectangular waveguides utilizing mode coupling which has an excess loss 0.18 dB and imbalance of 0.23 [14].

Table 2. Excess loss and power imbalance at various wavelengths

Wavelength (nm)	Excess Loss (dB)	Power Imbalance (dB)
1525	0.107	0.199
1530	0.101	0.184
1535	0.101	0.172
1540	0.107	0.167
1545	0.114	0.155
1550	0.123	0.143
1555	0.134	0.129
1560	0.148	0.118
1565	0.160	0.117

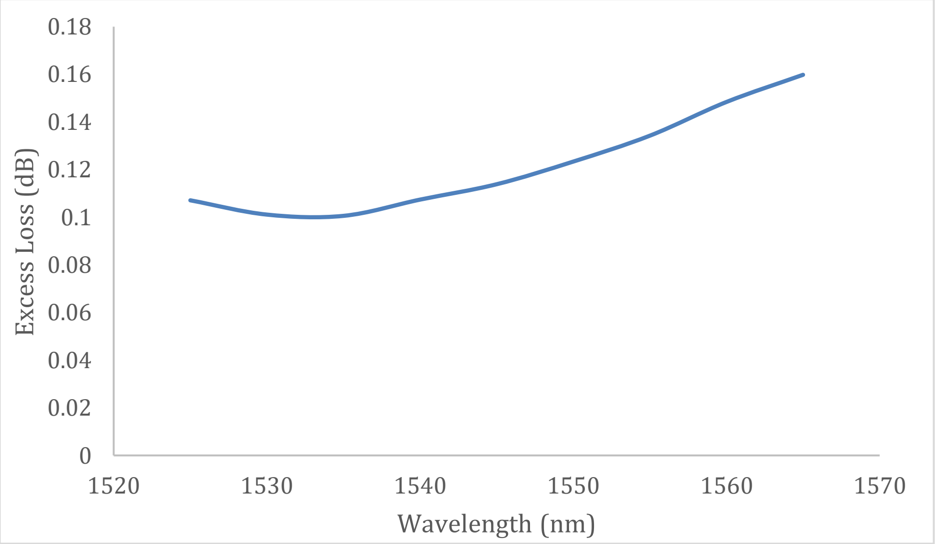

Fig. 8. The excess loss of the proposed design at various wavelengths

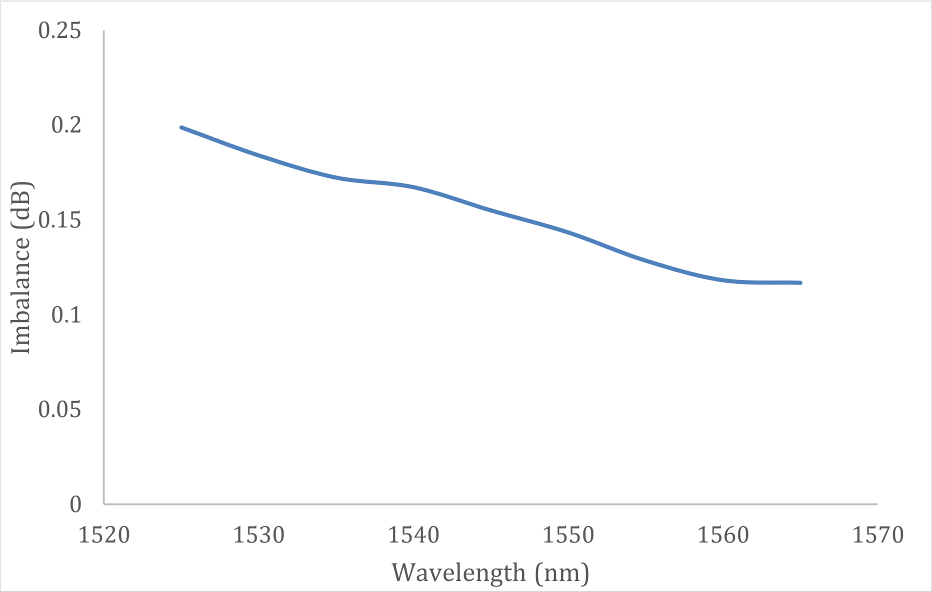

Fig. 9. The power imbalance at the four outputs at various wavelengths

4. CONCLUSION

A design 1x4 optical power divider based on Y-branch and mode coupling using GaN/sapphire was studied. The optical power divider was simulated using OptiBPM at λ = 1.55 µm, and we obtained 0.12 dB excess loss and 0.14 dB power imbalance. At varied wavelengths from 1.525 µm to 1.565 µm, the excess loss varied from 0.1 dB up to 0.16 dB, and the power imbalance varied from 0.12 dB up to 0.2 dB. The study shows the new design possibility of the 1x4 optical power divider using GaN/sapphire.

REFERENCES

[1] M. Kumari, R. Sharma, and A. Sheetal, "A hybrid next-generation passive optical network and visible light communication for future hospital applications," *Optik,* vol. 242, p. 166978, 2021, https://doi.org/10.1016/j.ijleo.2021.166978.

[2] E. Grigoreva, E. Wong, M. Furdek, L. Wosinska, and C. M. Machuca, "Energy consumption and reliability performance of survivable passive optical converged networks: public ITS case study," *Journal of Optical Communications and Networking,* vol. 9, no. 4, pp. C98-C108, 2017, https://doi.org/10.1364/JOCN.9.000C98.

[3] C. Y. Li, C. H. Chang, and D. Y. Lu, "Full-Duplex Self-Recovery Optical Fibre Transport System Based on a Passive Single-Line Bidirectional Optical Add/Drop Multiplexer," *IEEE Photonics Journal,* vol. 12, no. 5, pp. 1-10, 2020, https://doi.org/10.1109/JPHOT.2020.3022703.

[4] J. Zou, S. A. Sasu, M. Lawin, A. Dochhan, J. P. Elbers, and M. Eiselt, "Advanced optical access technologies for next-generation (5G) mobile networks [Invited]," *Journal of Optical Communications and Networking,* vol. 12, no. 10, pp. D86-D98, 2020, https://doi.org/10.1364/JOCN.391033.

[5] C. Chen, S. Akhmadaliev, C. Romero, J. R. V. d. Aldana, S. Zhou, and F. Chen, "Ridge Waveguides and Y-Branch Beam Splitters in KTiOAsO4 Crystal by 15 MeV Oxygen Ion Implantation and Femtosecond Laser Ablation," *Journal of Lightwave Technology,* vol. 35, no. 2, pp. 225-229, 2017, https://doi.org/10.1109/JLT.2016.2636998.

[6] R. W. Purnamaningsih, N. R. Poespawati, T. Abuzairi, S. Rahardjo, M. Hamidah, and E. Dogheche, "The effect of waveguide parameters on gan based S-bend Y-junction optical power divider," in *2017 15th International Conference on Quality in Research (QiR) : International Symposium on Electrical and Computer Engineering*, 2017, pp. 353-356, https://doi.org/10.1109/QIR.2017.8168510.

[7] T. Fujisawa, Y. Yamashita, T. Sakamoto, T. Matsui, K. Tsujikawa, K. Nakajima, K. Saitoh "Scrambling-Type Three-Mode PLC Multiplexer Based on Cascaded Y-Branch Waveguide With Integrated Mode Rotator," *Journal of Lightwave Technology,* vol. 36, no. 10, pp. 1985-1992, 2018, https://doi.org/10.1109/JLT.2018.2798619.

[8] S. Serecunova, D. Seyringer, F. Uherek, and H. Seyringer, "Waveguide shape and waveguide core size optimization of Y-branch optical splitters up to 128 splitting ratio," *Optics Communications,* vol. 501, p. 127362, 2021, https://doi.org/10.1016/j.optcom.2021.127362.

[9] W. Jiang, "Highly uniform and polarization-independent Y-branch with mode filter based on deeply etched silica-on-silicon waveguide," *Optics & Laser Technology,* vol. 111, pp. 20-24, 2019, https://doi.org/10.1016/j.optlastec.2018.09.034.

[10] Y. Liu, H. Li, W. Chen, P. Wang, S. Dai, B. Zhang, J. Li, Y. Li, Q. Fu, T. Dai, H. Yu, and J. Yang, "Direct-binary-search-optimized compact silicon-based polarization beam splitter using a pixelated directional coupler," *Optics Communications,* vol. 484, p. 126670, 2021, https://doi.org/10.1016/j.optcom.2020.126670.

[11] N. Yang and J. Xiao, "A compact silicon-based polarization-independent power splitter using a three-guide directional coupler with subwavelength gratings," *Optics Communications*, vol. 459, p. 125095, 2020, https://doi.org/10.1016/j.optcom.2019.125095.

[12] R. Luo and K. Takahata, "Product-sum photonic integrated circuit based on microring resonators and MMI coupler on SOI," in *2021 International Conference on Numerical Simulation of Optoelectronic Devices (NUSOD)*, 2021, pp. 127-128, https://doi.org/10.1109/NUSOD52207.2021.9541433.

[13] R. Hashida, T. Sasaki, and K. Hane, "GaN microring waveguide bonded to Si substrate by polymer," in *2017 International Conference on Optical MEMS and Nanophotonics (OMN)*, 2017, pp. 1-2, https://doi.org/10.1109/OMN.2017.8051464.

[14] R. W. Purnamaningsih, M. Hamidah, D. Fithriaty, M. R. Gumelar, N. R. Poespawati, and E. Dogheche, "A GaN/sapphire 1 × 4 Optical Power Splitter Using Five Rectangular Waveguide for Underwater Application," in *2018 IEEE 5th International Conference on Engineering Technologies and Applied Sciences (ICETAS)*, 2018, pp. 1-5, https://doi.org/10.1109/ICETAS.2018.8629190.

[15] R. Purnamaningsih, N. Poespawati, and E. Dogheche, "Design of a Four-Branch Optical Power Splitter Based on Gallium-Nitride Using Rectangular Waveguide Coupling for Telecommunication Links," *Journal of Engineering*, vol. 2019, pp. 1-9, 07/22 2019, https://doi.org/10.1155/2019/7285305.

[16] S. Geerthana and S. Syedakbar, "Design and optimization of Y-Junction and T-Junction splitters using photonic crystal," *Materials Today: Proceedings*, vol. 45, pp. 1722-1725, 2021, https://doi.org/10.1016/j.matpr.2020.08.617.

[17] P. Gašo *et al.*, "3D Polymer Based 1x4 Beam Splitter," *Journal of Lightwave Technology*, vol. 39, no. 1, pp. 154-161, 2021, https://doi.org/10.1109/JLT.2020.3026170.

[18] M. Rakshitha, T. Sridarshini, and S. I. G, "Photonic Crystal Ring resonator based 1x4 Optical power splitter," in *2018 International Conference on Recent Trends in Electrical, Control and Communication (RTECC)*, 2018, pp. 71-73, https://doi.org/10.1109/RTECC.2018.8625674.

[19] M. Rakshitha and S. I. Gandhi, "1x4 and 1x8 Photonic crystal ring resonator based Optical Splitters," in *2018 4th International Conference on Devices, Circuits and Systems (ICDCS)*, 2018, pp. 25-27, https://doi.org/10.1109/ICDCSyst.2018.8605126.

[20] R. Purnamaningsih, N. Poespawati, and E. Dogheche, "III-Nitride Semiconductors based Optical Power Splitter Device Design for underwater Application," *International Journal of Electrical and Computer Engineering*, vol. 8, pp. 3866-3874, 2018, http://doi.org/10.11591/ijece.v8i5.pp3866-3874.

[21] B. Chouchen, F. Ducroquet, S. Nasr, A. Y. A. Alzahrani, A. T. Hajjiah, and M. H. Gazzah, "InxGa1-xN/GaN double heterojunction solar cell optimization for high temperature operation," *Solar Energy Materials and Solar Cells*, vol. 234, p. 111446, 2022, https://doi.org/10.1016/j.solmat.2021.111446.

[22] X. Ren, J. Li, D. Gao, L. Wu, and G. Pei, "Analysis of a novel photovoltaic/thermal system using InGaN/GaN MQWs cells in high temperature applications," *Renewable Energy*, vol. 168, pp. 11-20, 2021, https://doi.org/10.1016/j.renene.2020.12.035.

[23] N. Laxmi, S. Routray, and K. P. Pradhan, "Effect of Strain-Modulated Multiple Quantum Wells on Carrier Dynamics and Spectral Sensitivity of III-Nitride Photosensitive Devices," *IEEE Sensors Journal*, vol. 20, no. 10, pp. 5204-5212, 2020, https://doi.org/10.1109/JSEN.2020.2971005.

[24] M. Feng, J. Liu, Q. Sun, and H. Yang, "III-nitride semiconductor lasers grown on Si," *Progress in Quantum Electronics*, vol. 77, p. 100323, 2021, https://doi.org/10.1016/j.pquantelec.2021.100323.

[25] M. Murayama, Y. Nakayama, K. Yamazaki, Y. Hoshina, H. Watanabe, N. Fuutagawa, H. Kawanishi, T. Uemura, and H. Narui, "Watt-Class Green (530 nm) and Blue (465 nm) Laser Diodes," *physica status solidi (a)*, vol. 215, no. 10, p. 1700513, 2018, https://doi.org/10.1002/pssa.201700513.

[26] Z. Li, L. Liu, Y. Huang, Q. Sun, M. Feng, Y. Zhou, H. Zhao, and H. Yang "High-power AlGaN-based near-ultraviolet light-emitting diodes grown on Si(111)," *Applied Physics Express*, Article vol. 10, no. 7, p. 072101, 2017, https://doi.org/10.7567/APEX.10.072101.

[27] Y. Nakatsu, Y. Nagao, T. Hirao, Y. Hara, S. Masui, T. Yanamoto, and S. Nagahama, "Blue and green InGaN semiconductor lasers as light sources for displays," in *Proceedings of SPIE - The International Society for Optical Engineering*, 2020, vol. 11280, https://doi.org/10.1117/12.2541710.

[28] M. Hamidah and R. W. Purnamaningsih, "An S-bend based Optical Directional Coupler Using GaN Semiconductor," in *2019 IEEE International Conference on Innovative Research and Development (ICIRD)*, 2019, pp. 1-4, https://doi.org/10.1109/ICIRD47319.2019.9074743.

[29] M. Feng, J. Wang, R. Zhou, Q. Sun, H. Gao, Y. Zhou, J. Liu, Y. Huang, S. Zhang, M. Ikeda, H. Wang, Y. Zhang, Y. Wang, and H. Yang, "On-Chip Integration of GaN-Based Laser, Modulator, and Photodetector Grown on Si," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 24, no. 6, pp. 1-5, 2018, https://doi.org/10.1109/JSTQE.2018.2815906.

[30] R. Das and K. Thyagarajan, "A High Efficiency Scheme for Phase-Matched Second-Harmonic Generation in GaN-Based Bragg Reflection Waveguide," *IEEE Photonics Technology Letters*, vol. 19, no. 19, pp. 1526-1528, 2007, https://doi.org/10.1109/LPT.2007.903860.

[31] B. Wang, Y. Niu, S. Zheng, Y. Yin, and M. Ding, "A High Temperature Sensor Based on Sapphire Fiber Fabry-Perot Interferometer," *IEEE Photonics Technology Letters*, vol. 32, no. 2, pp. 89-92, 2020, https://doi.org/10.1109/LPT.2019.2957917.

[32] J. Yi, "Sapphire Fabry–Perot Pressure Sensor at High Temperature," *IEEE Sensors Journal*, vol. 21, no. 2, pp. 1596-1602, 2021, https://doi.org/10.1109/JSEN.2020.3021187.

[33] R. Purnamaningsih, Poespawati, T. Abuzairi, and E. Dogheche, "An Optical Power Divider Based on Mode Coupling Using GaN/Al2O3 for Underwater Communication," *Photonics*, vol. 6, p. 63, 2019, https://doi.org/10.3390/photonics6020063.

BIOGRAPHY OF AUTHORS

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