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# Characterisation of optical waveguides for photonic integrated circuits

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**Abstract.** Fast signal processing at the speed of light is the main advantage of photonic integrated circuits. Therefore, these circuits have good prospects for the implementation of mathematical calculations, including matrix to vector multiplication. The purpose of the research was to create and investigate a technique for automatic measurement of brightness distribution along optical waveguides of analogue photonic integrated circuits. Empirical methods (observation, measurement, comparison, experiment) and a complex method (analysis and synthesis) have been used during the research. The proposed technique uses a digital camera that captures images of optical waveguide illuminated by light emitting diodes and image processing software to calculate brightness distribution. This technique determines the best approximation of this distribution, calculates parameters of brightness non-uniformity and losses of optical radiation. Measurements of a set of optical waveguides help to identify the best candidates for photonic integrated circuits. It has been found that optical waveguides with grinded surfaces acting as diffusive scattering have good combination of smooth brightness distribution and small losses of optical radiation. Due to multiple diffuse reflection and scattering within waveguide material, these waveguides are promising candidates for analogue photonic integrated circuits. All other waveguides with non-processed surface, with grooves or grinded with a large grain have sufficient losses of optical radiation. These losses are usually caused by the exit of optical radiation from waveguide surface. The obtained results are necessary for accurate design of circuits that takes into account scattering and losses in optical waveguides. The proposed technique can be applied in automatic technological process of manufacturing a fast and economical photonic matrix to vector multiplication, which does not require expensive electron-beam, optical or laser lithographic equipment

**Keywords:** brightness distribution; automatic measurement; image processing; uniformity evaluation; losses evaluation; photonic matrix to vector multiplication; optoelectronics

## INTRODUCTION

As global data consumption increases and demand for faster networks continues to grow, the world needs to find more sustainable solutions to the energy crisis. Expanding of data networks and data centres, safer autonomous vehicle driving, and more efficient manufacturing cannot be sustained by electronic microchip

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technology alone. However, combining of electrical devices with embedded photonics through heterogeneous integration provides a more energy-efficient way to increase the speed and capacity of data networks, reduce costs, and meet an increasingly diverse range of needs in industries.

Photonic integrated circuits (PICs) are considered as promising devices for telecommunication, signal and image processing, mathematical calculation, hardware neural network implementation for deep learning, and others at the speed of light (Luo *et al.*, 2023). Many PIC applications including signal filtration, integral transform calculations, and neural network implementation require high-speed matrix to vector multiplication (MVM). According to the classification by architecture proposed in the publication of V. Borovytsky *et al.* (2022), they can be divided into three main groups: PICs with Mach-Zehnder interferometres (MZIs), PICs with microring resonator arrays (MRRAs), a combination of two above mentioned groups, and PICs based on the application of non-linear optical effects.

Another approach is proposed by J. Cheng *et al.* (2021) – MVM using two-dimensional MRRA. The entire architecture is based on wavelength division multiplexing and a reconfigurable MRRA, which forms a full 4 × 4 transfer matrix network. Each microring resonator can be adjusted using a miniature electrical heater. Heating changes the transmission spectrum of the microring resonator. It allows to change matrix coefficients for MVM. Researchers C. Huang *et al.* (2020) have demonstrated an experimental MRRA PIC that is able to perform MVM with good accuracy. However, the biggest and scalable MRRA PIC for hardware implementation of large neural networks is described by S. Ohno *et al.* (2022). It is worth noting that MRRA PICs are considered as one of the promising PICs for MVM. This is confirmed by a large number of publications in prestigious scientific journals. Nevertheless, no such MVM PICs are manufactured serially due to high sensitivity of MRRAs to any variations of technological regimes and operating conditions, such as PIC temperature, etc.

PIC technological process that requires electron beam, optical or laser lithographic equipment, equipment for layer deposition and etching, scanning electron microscopes for failure analysis, and specific materials has been described by J. Cheng *et al.* (2022). Economical MVM PIC architecture that can be manufactured without expensive equipment has been proposed by V. Borovytsky & I. Avdieionok (2024). This PIC performs analogue multiplication of input signal to matrix, which is used for signal processing and neural network implementation. However, the accuracy of this multiplication depends on the quality of optical waveguides, mainly on brightness distribution along them.

The purpose of the study was to develop a technique for fully automatic measurement of brightness distribution along optical waveguides for the proposed MVM PIC, which could be used in serial production of such PICs in Ukraine. The list of tasks includes the selection of a technique for measurements of brightness distribution, measurement of brightness distribution in optical waveguides, and analysis of measurement results from the point of view of possible application in MVM PICs.

## MATERIALS AND METHODS

The developed PIC for MVM has three layers (Fig. 1). The layer of input optical waveguides is used to read the input optical signal and form a stable brightness distribution. The second layer with a fixed aperture array provides the transmission of optical radiation from the first layer to the third one. As a result, optical flows that have passed through the apertures become proportional to aperture areas and a layer with output optical waveguides. The third layer has optical waveguides that accumulate optical radiation that has passed through the apertures. The outputs of these waveguides are proportional to the MVM results. This PIC performs analogue multiplication. Therefore, the accuracy of this multiplication depends on the quality of optical waveguides, mainly on brightness distribution along them.

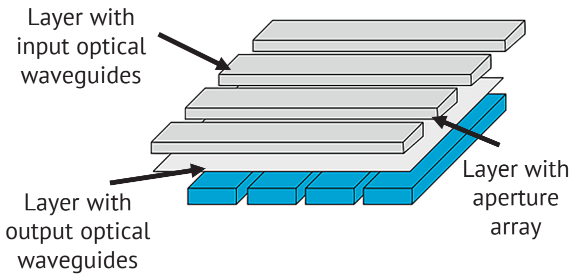



**Figure 1.** Analogue PIC for MVM
**Source:** compiled by the authors

There are several approaches to the measurement of brightness distribution. The first one is two-dimensional mechanical scanning by a photodetector on waveguide surface. This method is very slow and expensive because it requires motorised stages with a controller and a signal capture board. The second method is one-dimensional scanning with a linear photodetector, which is used in wide-spread scanners. It is also slow and expensive due to the use of one motorised stage with a controller, a linear photodetector and a signal capture board. The third method is based on the use of digital cameras without mechanical scanning. Researchers K. Bahali *et al.* (2018) have shown that digital cameras can be successfully used to measure brightness distributions. The work of B. Wojcik & M. Żarski (2021) presents a technique for identifying zones with different optical properties in building construction. These studies have become the starting point for the development of an optical setup for waveguide photometric measurements.

The proposed optical setup contains an optical waveguide illuminated by light emitting diodes (LEDs) at both ends and a digital camera that takes digital photographs of this waveguide (Fig. 2). This camera has a lens with a focal length in the range of 18-55 mm and a 24.1 megapixel image sensor of 22.3 × 14.9 mm. The distance from the camera to the waveguide is 300 mm. At this distance, the field of view of the camera covers the entire surface of the waveguide.

**Figure 2.** Optical setup for measurements of brightness distribution
**Source:** photo by the authors

Captured images have been processed by software written in Python (Dey, 2020). Software has calculated average brightness value along waveguide axis in waveguide surface zone and presented measurement results in the form of diagrams and tables. To evaluate and compare brightness distributions, the following approximation, which takes into account the effect of scattering and loss of optical radiation in optical waveguide, is proposed (1):

$$L(X) = (1 - b) \cdot exp(-p \cdot X) + b, \qquad (1)$$

where $b$ – a coefficient characterising the constant level due to scattering; $p$ – a coefficient characterising optical absorption losses; $L(X)$ – the distribution of normalised brightness as a function of normalised waveguide length $X$ when it is illuminated by a LED from one end.

Then the distribution of normalised brightness when illuminated by two identical LEDs on both sides has the following form (2):

$$L_2(X) = (1 - b) \cdot \{exp(-p \cdot X) + exp(-p \cdot (1 - X))\} + 2 \cdot b, \qquad (2)$$

where $L_2(X)$ – the distribution of normalised brightness when illuminated on both sides as a function of normalised waveguide length $X$.

To find the best approximation, it is necessary to find the $(p, b)$ pair that corresponds to the minimum value of the root-mean-square difference between the result of measuring $L_M(X)$ and the expression $L_2(X)$ (2):

$$e(p,b) = \sqrt{\frac{\sum_{k=0}^{N-1}\left(L_M(X_k) - L_2(X_k,p,b)\right)^2}{N}} \xrightarrow{p,b} min, \qquad (3)$$

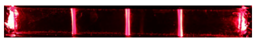
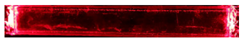
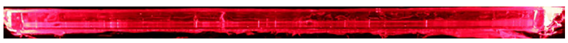
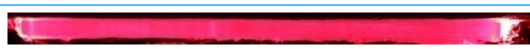
where $e$ – the square root difference as a function of $p$ and $b$ parametres; $L_M(X_k)$ – the measured distribution of normalised brightness when illuminated by two LEDs on both sides as a function of normalised discrete coordinates $X_k$; $N$ – the number of discrete coordinates where brightness has been measured.

The proposed approximations make it possible to choose optical waveguides applicable in analogue PICs, since the $p$ parameter characterises brightness uniformity, and the $b$ parameter reflects optical losses.

## RESULTS AND DISCUSSION

The proposed technique (1)-(3) has been applied for automatic measurements of brightness distribution in nine plastic optical waveguides. These measurements have been performed using the proposed optical setup (Fig. 2) in a dark room. It is necessary to avoid all other illumination sources except optical waveguide. Nine samples have been studied (Table 1).

**Table 1.** Measured optical waveguides

| Sample | Type of surface processing | Photos of the waveguide |
|---|---|---|
| 1 | Grinding with a large grain |  |
| 2 | Grinding and making of two longitudinal grooves |  |
| 3 | No surface processing, only three transverse grooves |  |
| 4 | No surface processing |  |
| 5 | Grinding with a fine grain |  |
| 6 | Matted surface, no grinding applied |  |
| 7 | No surface processing |  |
| 8 | Grinding of all surfaces |  |
| 9 | Grinding of only two sides |  |

**Source:** compiled by the authors

The first six samples have a matte material without additional surface processing. Other waveguides have a transparent material, but with a different surface processing. Sample 4 has a smooth surface without additional processing, sample 5 has a surface grinded with a fine grain, sample 1 is grinded with a large grain. Sample 2 has a grinded surface with two small longitudinal grooves. Sample 3 has a smooth surface with three transverse grooves. Samples 7-9 are rotated to reduce the radiation zone and improve the output parameters. Sample 7 has both surfaces without additional processing. The other waveguide has an unprocessed surface and the other side is grinded in sample 8. In sample 9, both sides are grinded. Waveguide dimensions are presented in Table 2.

The images of waveguide samples are processed and brightness distribution is calculated. Diagrams of these distributions are presented in Figure 3.

**Table 2.** Waveguide parameters

| Parameter name | Parameter value |
|---|---|
| Wavelength | 700 nm |
| Optical waveguides of 1-6 dimensions | 80 × 10 × 3 mm |
| Optical waveguide of 7-9 dimensions | 80 × 3 × 10 mm |

**Source:** compiled by the authors

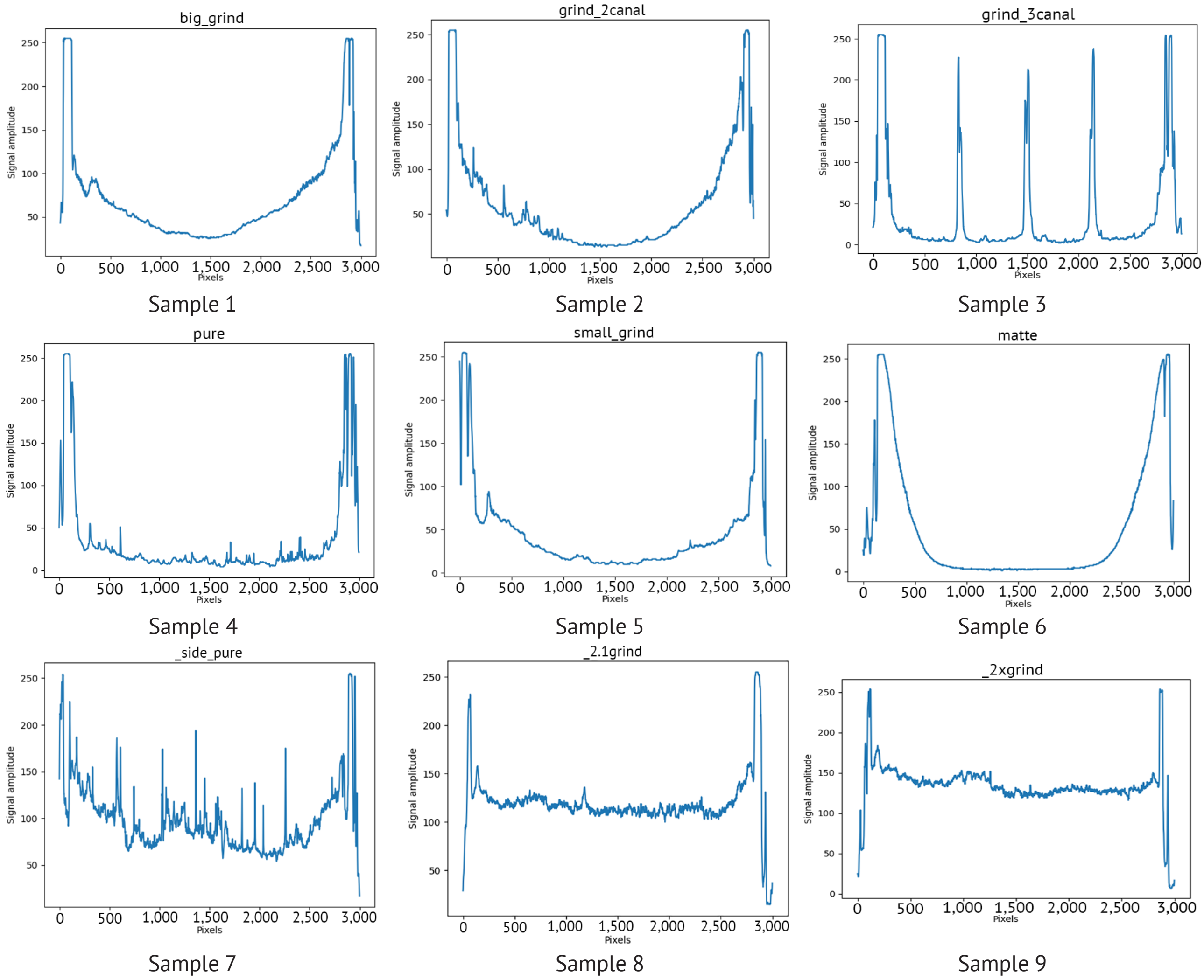



**Figure 3.** Diagrams of the measured brightness distribution

**Source:** compiled by the authors

Based on the obtained diagrams, the worst uniformity has been determined in matte waveguide. The best uniformity options are obtained with waveguides 8-9 with variable spatial placement of the waveguide to reduce the area and increase the signal level. But the waveguide 6 turns out to be the worst option due to high density of waveguide material. It can be seen from the constructed graphs that spatial placement to reduce the area of interaction is the main factor for improvement. By creating periodic grooves on the interaction surface, it will be possible to control more complex mathematical functions of signal transmission, which will allow to expand the functionality of the system.

(*p, b*) parameters have been calculated for all samples according to formulas (1)-(3) and presented in Table 3. It is worth noting that the proposed approximation by exponential functions (1)-(3) gives results close to the measured data for samples with grinded surfaces, such as samples 1, 2, 4, 5, 8, 9 (Fig. 3).

**Table 3.** Calculations of brightness distribution parameters

| Sample | min (e(*p*,*b*) ) | *p* | *b* |
|---|---|---|---|
| 1 | 0.073 | 148.601 | 0.015 |
| 2 | 0.057 | 309.240 | 0.003 |
| 3 | 0.149 | 501.012 | 0.015 |
| 4 | 0.086 | 166.673 | 0.011 |
| 5 | 0.050 | 341.368 | 0.003 |
| 6 | 0.048 | 40.169 | 0.001 |
| 7 | 0.111 | 52.218 | 0.196 |
| 8 | 0.083 | 32.138 | 0.0713 |
| 9 | 0.096 | 32.138 | 0.011 |

**Source:** compiled by the authors

It has been found that optical waveguides (samples 8 and 9) with grinded surfaces can be considered as good candidates for the proposed PIC (Fig. 4). The processed surfaces act as diffusive scattering. Therefore, a good combination of smooth brightness distribution and small losses of optical radiation is achieved (Tables 3, 4). Due to multiple diffuse reflection and scattering within waveguide material, these waveguides are promising candidates for analogue photonic integrated circuits.

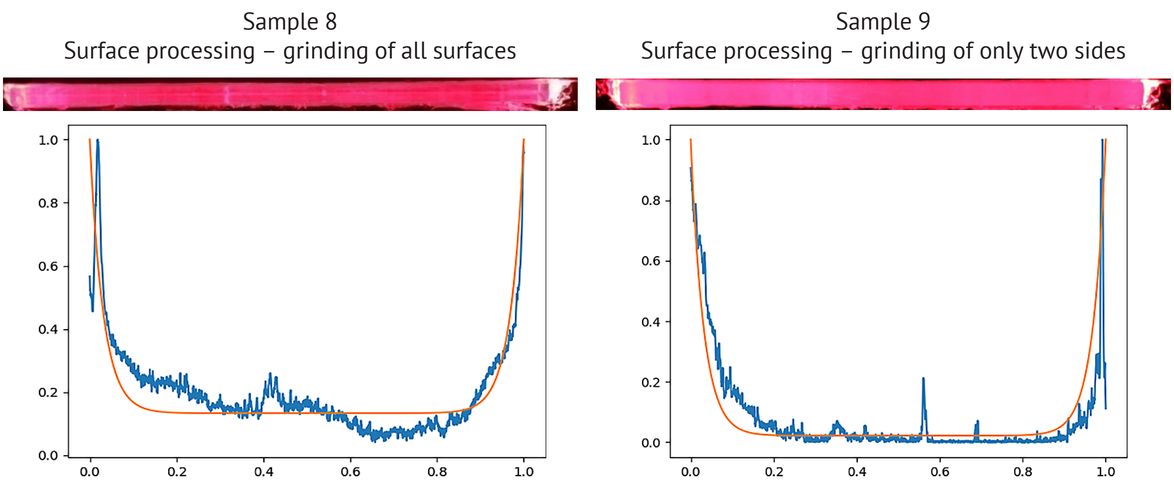



**Figure 4.** Measured data and their approximation

**Source:** compiled by the authors

All other waveguides with non-processed surfaces, with grooves or grinded with a large grain have sufficient losses of optical radiation. These losses, generally caused by the exit of optical radiation from waveguide surface, are so sufficient that in central zone of optical waveguides, the brightness decreases to almost 1% of the values (Fig. 3; Table 3).

The proposed method (1)-(3) makes it possible to obtain measurement results in a short time without expensive equipment. One measurement with image processing takes only several minutes. When optical setup is assembled, it takes one hour to perform measurement and compose the report with diagrams and tables (Fig. 3; Table 3). But routine application of the proposed technique, which is necessary for further research, requires the following improvements. First, it has to apply a monochrome digital camera sensitive in visible and infrared ranges of optical radiation. This helps to investigate optical waveguides in a wide range of optical radiation and capture digital images with a high signal-to-noise ratio. Second, it is necessary to design a cover to protect the measurement zone from external optical radiation, a stable fixed holder for the digital camera to avoid repletion of focusing operation, and a manipulator that moves and fixes one or more optical waveguides in the measurement zone. Third, it has to develop software that can process images of several optical waveguides in the field of view with automatic boundary detection and automatic quality control.

The analysis of the measurement results has shown the following: of nine investigated waveguides, sample 8 is the best candidate for PIC, as it has the largest value of $b \approx 7\%$ with good coincidence with the approximating data (Fig. 4). These results are achieved by grinding the entire waveguide surface. This sample must be considered as a starting point for further search for PIC waveguides. There are three factors that reduce waveguide characteristics: non-uniformity of waveguide material, non-uniformity of surface processing, and losses in waveguide interface of LEDs. The correct choice of plastic and its surface processing can reduce negative impact of the first and second factors. The design of waveguide interface of LEDs can be improved by grinding LED emitting surface and pressing it directly to grinded plane of waveguide side. LED measurements also play an important role. It is worth noting that non-uniformity of brightness distribution can be partially compensated by the design of corresponding layer of aperture array (Strąkowska *et al.*, 2024). This means that after manufacturing the layers with optical waveguides, they must undergo quality control according to the proposed technique, and the measurement data must be taken into account when designing the aperture array.

Many articles describe unique PIC approaches. They highlight the advantages of photonics in the context of speed, efficiency and scalability of computing, but also face challenges of implementation and integration. PICs based on the Mach-Zehnder interferometre (MZI) principle have complex implementations, especially when scaling to larger systems. However, MZI PICs provide fast and efficient solutions to various problems. Thus, in the paper by W. Bogaerts *et al.* (2020) programmable photonic PIC uses waveguides meshed with $2 \times 2$ blocks, or "analogue gates" – crystal-embedded equivalent of free-space optical beam splitters based on MZI. Researchers H. Zhou *et al.* (2020) have developed a nanophotonic processor for MVM that is programmed by setting the voltages on internal and external phase shifters for each MZI. Each MZI performs $2 \times 2$ unitary transformations over input shape state. The kernel, namely the unitary matrix, can be decomposed into sets of turns implemented by cascaded programmable MZIs. Applying this approach, positive real-value matrix computation, optical routing, and low-loss optical power distribution can be achieved.

A PIC using microring resonators requires adaptation to different architectures, but such a system is compact, efficient and scalable for high-performance computing. Mixed systems using nonlinear optics are widespread because they have high speed and recognition accuracy. However, high-speed data processing can require significant energy resources. Designing and customizing of high-speed chips is a technologically challenging task. The most promising approaches include high-speed and energy-efficient computing solutions that can significantly affect the development of artificial intelligence technologies and other advanced industries. A paper by Y. Zhu *et al.* (2024) discusses an architecture based on silicon photonic integrated circuits for accelerating neural networks. The proposed system uses optical frequency combs to achieve high computing speed and energy efficiency. The architecture provides scalability and can be used in high-performance computing applications. W. Wu *et al.* (2024) have presented an optical parallel computing array chip (OPCA chip) for fast image processing, transmission, and reconstruction. Using high-quality resonator channels, the chip provides high speed and efficiency of calculations without frequent optical-electronic and analogue-digital conversions. The obtained measurement results prove that the proposed MVM PIC can be manufactured using grinded optical waveguides. Compared to complex PICs with a waveguide matrix proposed by W. Bogaerts *et al.* (2020) and analogue PICs with microring arrays investigated by C. Huang *et al.* (2020) and V. Bangari *et al.* (2020), the proposed PIC can be produced from plastic waveguides using mechanical processing and without expensive lithographic equipment. The disadvantages of the MVM PIC proposed by V. Borovytsky & I. Avdieionok (2024) consist in sufficient dimensions of centimetre range, limited sense of input vector, and calculation errors caused by analogue multiplications. Nevertheless, the proposed PIC can potentially implement neural networks with a number of neurons up to 20.

For the production of any analogue MVM PIC, characterisation of optical waveguides plays an important role, since the accuracy of analogue multiplication directly depends on brightness distribution. The proposed technique makes this characterisation fast and economical. It can be used by Ukrainian companies, universities and research groups to create and research their own PICs. It is important that this characterisation can be applied in optical education to attract students to optics and photonics.

## CONCLUSIONS

The proposed technique for measuring of brightness distribution helps to characterise optical waveguides quickly, economically and without specialised equipment. It applies only an optical waveguide illuminated by two LEDs on both sides, a digital camera, and a free software package. The application of a monochrome camera sensitive in visible infrared range can expand the types of characterised optical waveguides. This gives good prospects for its implementation into serial PIC production. The proposed approximation parameters ($p$, $b$) allow a clear and objective evaluation of brightness uniformity and optical losses, which can be used to select the best waveguide surface processing. The analysis of the measurement results shows that only waveguides with grinded surfaces, which work as diffusive scatters, can meet the PIC requirements for MVM. Such waveguides have stable scattering characteristics with acceptable losses of optical radiation. In other words, waveguide surfaces must play the role of elements that carry out multiple scattering of optical radiation to achieve maximum brightness uniformity.

Further research on analogue MVM PICs can be focused in three directions. The identification of optimal grinding parameters in the manufacture of optical waveguides, which guarantees the highest value of the $b$ parameter and the stability of the $p$ parameter, is the first one. The design of optical interface between input optical waveguides and LEDs and output optical waveguides and photodetector, which minimises optical losses and maximises the uniformity of brightness distribution, is the second one. Technological control of waveguide layers after their assembling is the third one. In all cases, the proposed technique for characterisation of optical waveguides must play an important role.

## ACKNOWLEDGEMENTS

None.

## CONFLICT OF INTEREST

None.

## REFERENCES

[1] Bahali, K., Samian, A.L., Muslim, N., & Hamid, N.S.A. (2018). Measuring luminance of dawn with a DSLR. *International Journal of Civil Engineering and Technology (IJCIET)*, 9(11), 1269-1278.

[2] Bangari, V., Marquez, B.A., Miller, H., Tait, A.N., Nahmias, M.A., de Lima, T.F., Peng, H.-T., Prucnal, P.R., & Shastri, B.J. (2020). Digital electronics and analog photonics for convolutional neural networks (DEAP-CNNs). *IEEE Journal of Selected Topics in Quantum Electronics*, 26(1), article number 7701213. doi: 10.1109/JSTQE.2019.2945540.

[3] Bogaerts, W., Pérez, D., Capmany, J., Miller, D.A.B., Poon, J., Englund, D., Morichetti, F., & Melloni, A. (2020). Programmable photonic circuits. *Nature*, 586, 207-216. doi: 10.1038/s41586-020-2764-0.

[4] Borovytsky, V., & Avdieionok, I. (2024). Economical optical matrix to vector multiplier. *Proceedings SPIE*, 12938, article number 129381F. doi: 10.1117/12.3013064.

[5] Borovytsky, V., Avdieionok, I., Tuzhanskyi, S., & Lysenko, H. (2022). Photonic integrated circuits for optical matrix-vector multiplication. *Optoelectronic Information-Power Technologies*, 43(1), 11-18. doi: 10.31649/1681-7893-2022-43-1-11-18.

[6] Cheng, J., *et al.* (2022). A small microring array that performs large complex-valued matrix-vector multiplication. *Frontiers of Optoelectronics*, 15, article number 15. doi: 10.1007/s12200-022-00009-4.

[7] Cheng, J., Zhou, H., & Dong, J. (2021). Photonic matrix computing: From fundamentals to applications. *Nanomaterials*, 11(7), article number 1683. doi: 10.3390/nano11071683.

[8] Dey, S. (2020). *Python image processing cookbook: Over 60 recipes to help you perform complex image processing and computer vision tasks with ease*. Birmingham: Packt Publishing.

[9] Huang, C., *et al.* (2020). Demonstration of scalable microring weight bank control for large-scale photonic integrated circuits. *APL Photonics*, 5(4), article number 040803. doi: 10.1063/1.5144121.

[10] Luo, W., *et al.* (2023). Recent progress in quantum photonic chips for quantum communication and internet. *Light: Science & Applications*, 12, article number 175. doi: 10.1038/s41377-023-01173-8.

[11] Ohno, S., Tang, R., Toprasertpong, K., Takagi, S., & Takenaka, M. (2022). Si microring resonator crossbar array for on-chip inference and training of the optical neural network. *ACS Photonics*, 9(8), 2614-2622. doi: 10.1021/acsphotonics.1c01777.

[12] Strąkowska, M., Urbaś, S., Felczak, M., Torzyk, B., Shatarah, I.S.M., Kasikowski, R., Tabaka, P., & Więcek, B. (2024). Modelling and thermographic measurements of LED optical power. *Sensors*, 24(5), article number 1471. doi: 10.3390/s24051471.

[13] Wojcik, B., & Żarski, M. (2021). The measurements of surface defect area with an RGB-D camera for a BIM-backed bridge inspection. *Bulletin of the Polish Academy of Sciences. Technical Sciences*, 69(3), article number e137123. doi: 10.24425/bpasts.2021.137123.

[14] Wu, W., Zhou, T., & Fang, L. (2024). Parallel photonic chip for nanosecond end-to-end image processing, transmission, and reconstruction. *Optica*, 11(6), 831-837. doi: 10.1364/OPTICA.516241.

[15] Zhou, H., Zhao, Y., Wang, X., Gao, D., Dong, J., & Zhang, X. (2020). Self-configuring and reconfigurable silicon photonic signal processor. *ACS Photonics*, 7(3), 792-799. doi: 10.1021/acsphotonics.9b01673.

[16] Zhu, Y., *et al.* (2024). Silicon photonic neuromorphic accelerator using integrated coherent transmit-receive optical sub-assemblies. *Optica*, 11(4), 583-594. doi: 10.1364/OPTICA.514341.

# Характеристика оптичних хвилеводів для фотонних інтегральних схем

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**Анотація.** Швидка обробка сигналів зі швидкістю світла є основною перевагою фотонних інтегральних схем. Тому ці схеми мають гарні перспективи для реалізації математичних обчислень, в тому числі перемноження матриці на вектор. Метою роботи було створення та дослідження методики автоматичного вимірювання розподілу яскравості вздовж оптичних хвилеводів аналогових фотонних інтегральних схем. Під час дослідження використано емпіричні методи (спостереження, вимірювання, порівняння, експеримент) та комплексний метод (аналіз і синтез). Запропонована методика використовує цифрову камеру, яка фіксує зображення оптичного хвилеводу, освітленого світлодіодами, та програмне забезпечення для обробки зображень для розрахунку розподілу яскравості. Ця методика визначає найкращу апроксимацію цього розподілу, обчислює параметри нерівномірності яскравості та втрати оптичного випромінювання. Вимірювання набору оптичних хвилеводів допомагають визначити найкращих кандидатів для фотонних інтегральних схем. Виявлено, що оптичні хвилеводи з шліфованими поверхнями, які виконують функцію дифузного розсіювання, мають гарне поєднання плавного розподілу яскравості та малих втрат оптичного випромінювання. Завдяки багаторазовому дифузному відбиванню і розсіюванню в матеріалі хвилеводу, ці хвилеводи є перспективними кандидатами для аналогових фотонних інтегральних схем. Всі інші хвилеводи з необробленою поверхнею, з канавками або шліфовані з великим зерном мають достатні втрати оптичного випромінювання. Ці втрати, як правило, спричинені виходом оптичного випромінювання з поверхні хвилеводу. Отримані результати необхідні для точного проектування схем, що враховують розсіювання і втрати в оптичних хвилеводах. Запропонована методика може бути застосована в автоматизованому технологічному процесі виготовлення швидкої та економічної фотонної матриці для векторного множення, яка не потребує дорогого електронно-променевого, оптичного або лазерного літографічного обладнання

**Ключові слова:** розподіл яскравості; автоматичне вимірювання; обробка зображень; оцінка однорідності; оцінка втрат; множення фотонної матриці на вектор; оптоелектроніка