The utilization of the Taguchi method on microring resonator design parameters to enhance the value of the quality factor

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Article Info

Article history:

Received Dec 24, 2024
Revised Aug 9, 2025
Accepted Sep 1, 2025

Keywords:

Design of experiments
Finite difference time domain simulation
Microring resonator
Photonic sensors
Quality factor optimization
Refractive index sensing
Taguchi method

ABSTRACT

This study uses the Taguchi method to optimize the quality factor (Q-factor) of microring resonators (MRRs) for sensor applications. The MRRs are compact optical components widely used in biosensors and environmental monitoring due to their sensitivity to refractive index changes. The Q-factor, a key performance metric for MRRs, is significantly influenced by structural parameters such as ring radius (R), gap (g), waveguide width (W), and waveguide height (h). We employed a finite difference time domain (FDTD) simulation to model light propagation within the MRR and compute the corresponding Q-factor to identify the optimal combination of these parameters. An L9 orthogonal array (OA) is used in the Taguchi method to analyze each factor's influence with three levels systematically. The optimization resulted in a Q-factor of 6208.44, significantly higher than the baseline value, indicating a substantial improvement. Compared to previous works, this research highlights the advantages of combining FDTD-based electromagnetic modeling with statistical optimization, offering a structured yet efficient approach to MRR design. The proposed method enhances Q-factor performance and provides scalability for practical applications in biomedical and environmental sensing. These findings underscore the utility of Taguchi-based design in advancing the field of photonic sensor optimization.

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1. INTRODUCTION

Microring resonator (MRR) is a photonic-based device that utilizes light interference within MRR waveguides [1]. In the last decade, MRRs have been developed for sensor applications [2]. Light constructive interference is responsible for producing the resonance of MRR, which can be further examined to analyze the works of MRR-based sensors. The investigated MRR is configured as an add-drop system consisting of two straight waveguides and a single-ring waveguide, as shown in Figure 1. This configuration allows MRR to have better characteristics, such as being more reflective, having a more stable temperature, and having a narrower bandwidth [3]-[5]. The dimensions of MRR are illustrated clearly, including ring radius, gap, waveguide width, and waveguide height, which are denoted as R, g, w, and h, respectively.

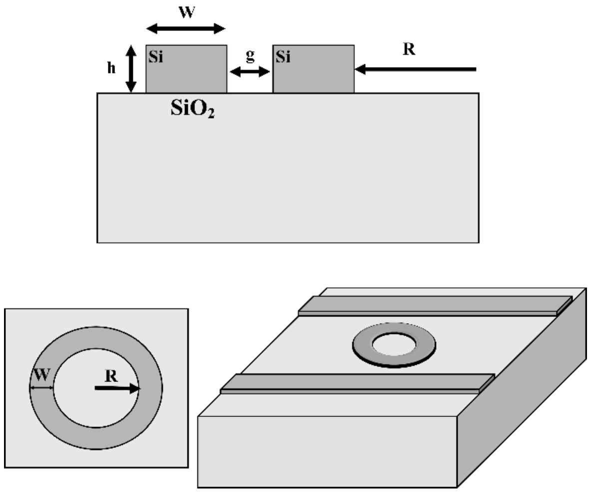

Figure 1. The illustration of a geometric MRR structure with a Si waveguide layer and a SiO_2 buffer layer

The performance of MRR is greatly determined by the size of each dimension and the material used, as light propagation in MRR depends on those parts [6]-[9]. The substrate and waveguide materials used are based on SiO_2 and Si, respectively, due to their outstanding optical properties and excellence as wave-guiding materials [10], [11]. In the case of MRR applications as sensors, quality factors (Q-factor) determine the detection capability of an MRR-based sensor that operates on a shift resonance scheme [12], [13]. A sharper resonance distinguishes a smaller resonance shift from a higher Q-factor [14]. This results in a lower detection limit, making the sensors more sensitive. The Q-factor is mainly described as the ratio between the resonance wavelength λo and the full width at half maximum (FWHM) [15], [16]. The value of the Q-factor greatly depends on the geometrical structure, such as the group index ng and round-trip length L of MRR, as shown in (1).

$$Q = \frac{\lambda_o}{FWHM} = \frac{\pi n_g L}{\lambda \cos^{-1}(\psi)} \tag{1}$$

We employed the Taguchi method for further robust optimization to choose the best possible combination of the geometrical dimensions of MRR. Compared to other robust optimization methods such as stability radius, minimax estimator, stochastic optimization, and info-gap decision theory. The Taguchi method provides excellence, including a specific loss function, the philosophy of off-line quality control, and innovation in the design experiments [17], [18]. On the other hand, the different methods, such as Box-Behnken and Plackett-Burman, have main drawbacks, which only require that factors be varied in three factors, and the two-factor interactions cannot be studied [19], [20]. Consequently, the excellent parameter investigation technique in the experiment led to an improvement in the manufactured quality. Hence, the solution to improve device performance can be obtained through the Taguchi method because the control factors that have the most significant impact on optimization are directly involved in the analysis process of this method.

Theoretical work using the finite difference time domain (FDTD) method was generally used to investigate wave propagation through a medium or space within the time domain framework [21]-[23]. The analysis process with the FDTD method involves discrete light propagation in the waveguide, a continuous physical phenomenon. Discretization is carried out in Maxwell's time-dependent differential equation using a central-difference approach so that the differential equations for $\vec{H}$ and $\vec{E}$ are obtained explicitly, as shown in (2)-(7) [24]. The solution for $\vec{H}$ can be obtained by solving the differential equation component of the electric field vector in a space for a specific time. In contrast, the solution for $\vec{E}$ can be obtained by solving the magnetic field vector differential equation component in a space equal to the electric field vector component for a specific time after that. Hence, by framing these $\vec{H}$ and $\vec{E}$ solutions, the propagating light through the MRR waveguide can be investigated using the FDTD method.

$$\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -\frac{\mu_{xx}}{c_o}\frac{\partial \tilde{H}_x}{\partial t} \quad (2)$$

$$\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -\frac{\mu_{yy}}{c_o}\frac{\partial \tilde{H}_y}{\partial t} \quad (3)$$

$$\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -\frac{\mu_{zz}}{c_o}\frac{\partial \tilde{H}_z}{\partial t} \quad (4)$$

$$\frac{\partial \tilde{H}_z}{\partial y} - \frac{\partial \tilde{H}_y}{\partial z} = -\frac{\varepsilon_{xx}}{c_o}\frac{\partial E_x}{\partial t} \quad (5)$$

$$\frac{\partial \tilde{H}_x}{\partial z} - \frac{\partial \tilde{H}_z}{\partial x} = -\frac{\varepsilon_{yy}}{c_o}\frac{\partial E_y}{\partial t} \quad (6)$$

$$\frac{\partial \tilde{H}_y}{\partial x} - \frac{\partial \tilde{H}_x}{\partial y} = -\frac{\varepsilon_{zz}}{c_o}\frac{\partial E_z}{\partial t} \quad (7)$$

In this work, we combine theoretical work using the FDTD method and a robust optimization process using the Taguchi method for MRR design optimization. This work aims to obtain the highest possible Q-factor by combining the various input parameters. The input parameter variation was chosen based on our literature study from several references, which considered MRR geometry and application for sensors. Further discussion will address how to implement the Taguchi method for optimizing MRR.

2. METHOD

2.1. Microring resonator design and modelling

The simulation of the MRR was conducted using the 3-dimensional FDTD (3D FDTD) method via Lumerical FDTD Solutions®. The FDTD technique solves time-dependent Maxwell's equations—a set of partial differential (2)–(7)—to describe the behavior of electromagnetic fields in space and time. This numerical method is highly effective in simulating the light propagation and field distribution in photonic devices such as MRRs.

An MRR is an integrated optical device consisting of a circular waveguide (the ring) that couples light from straight waveguides positioned nearby. Due to its sensitivity to changes in effective refractive index, it is widely used in optical sensing, filtering, and wavelength multiplexing applications. MRRs detect environmental changes in sensor configurations by observing resonance shifts or variations in their Q-factor.

Figure 2 illustrates the MRR model constructed in Lumerical FDTD Solutions®. The simulation began with creating the base structure, including the buffer layer and the waveguides. The buffer layer was defined using a rectangular geometry from the "structure" menu, while the MRR was formed by selecting the "ring resonator" component under "integrated optics". The design factors studied in this research are the ring's geometric parameters—ring radius, gap between waveguides, waveguide width, and waveguide height, as shown in Figure 2. These parameters directly affect the mode confinement and resonance behavior of the MRR.

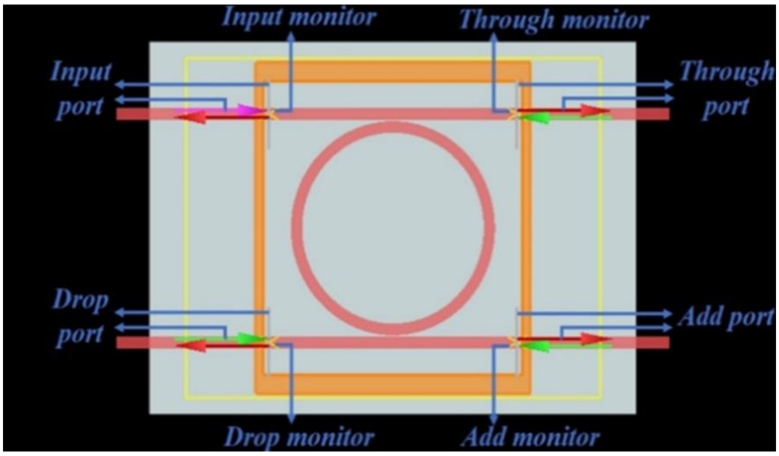

Figure 2. Geometric model of MRRs using FDTD Solutions®

After defining the structure, port objects and time-domain monitors were placed at four locations: the input port, through port, drop port, and add port. Ports define the optical signal's entry and exit points and allow control over the mode, frequency range, and polarization. The time-domain monitors record electromagnetic field data during the simulation, enabling post-processing in both the time and frequency domains.

A Gaussian optical pulse was launched into the input port. The simulation time was set to 50,000 fs, sufficient for the optical signal to traverse the domain completely and interact with the resonator. This duration ensures that resonance and ring-down phenomena are fully captured. The simulation was carried out in an ambient environment at a temperature of 295 K and air refractive index n=1, approximating experimental laboratory conditions.

The simulation engine discretized the spatial region into a Yee cell lattice, calculating the electric and magnetic field components at every point. After completing the simulation, the transmittance at the through port was plotted. Resonance appears as dips in the transmittance spectrum at certain wavelengths. The FWHM was extracted from these data to compute the Q-factor, a dimensionless parameter that describes resonance sharpness and is crucial for sensor sensitivity.

2.2. Taguchi method for microring resonator design

The goal of this research is to enhance the performance of the MRR by maximizing its Q-factor. To achieve this, the Taguchi method was employed. Developed by Genichi Taguchi, this statistical approach improves quality and performance in product design and engineering by minimizing variability and identifying optimal parameter settings [25]-[27]. Figure 3 shows the processes involved in MRR optimization using the Taguchi method.

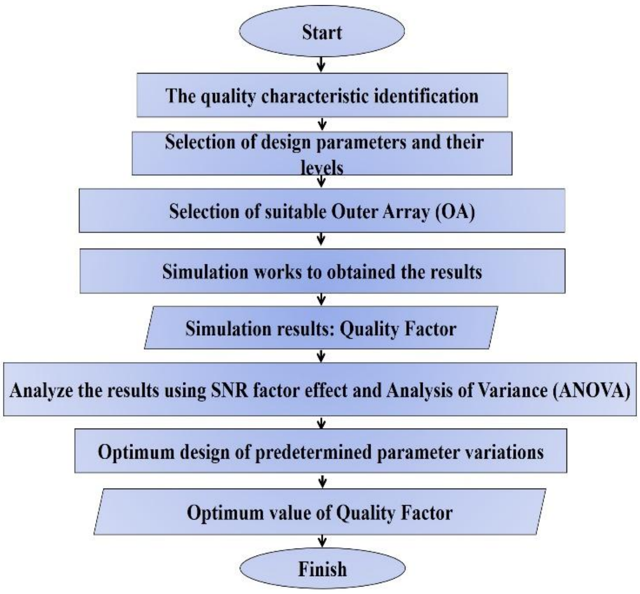

Figure 3. The Taguchi method flow diagram for MRR optimization

The Taguchi method begins with identifying the quality characteristic to be optimized—in this case, the Q-factor, as it directly influences the sensitivity and effectiveness of the MRR in sensing applications [28], [29]. Once the quality target is set, the next step involves selecting design parameters (control factors) and assigning levels to each. These factors significantly influence the resonator's behavior. Based on literature review and sensitivity analysis [30], [31], four control factors were chosen: ring radius, gap, waveguide width, and waveguide height. Each factor was tested at three levels, as shown in Table 1.

Table 1. Control factor for the design and simulation of MRRs

Symbol	Control factor	Unit	Level 1	Level 2	Level 3
R	Ring radius	µm	4.00	4.50	5.00
g	Gap	µm	0.09	0.12	0.15
W	Waveguide width	µm	0.45	0.46	0.47
h	Waveguide height	µm	0.14	0.16	0.18

To efficiently explore the parameter space while minimizing simulation runs, the L9 orthogonal array (OA) was selected. This OA is widely used when dealing with 4 factors at 3 levels, as it reduces the number of experiments from 81 (3^4) to just 9, while still allowing interaction analysis and optimization. Each of the 9 combinations defined by the L9 OA was simulated using the same FDTD setup described in subsection 2.1. The Q-factor obtained from each simulation was then used to compute the signal-to-noise ratio (SNR) using the "larger-the-better" criterion, which is suitable for maximization goals [32].

$$\mathrm{SNR} = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{{y_i}^2} \right) \quad (8)$$

n is the number of simulations performed, and yi is the value of the Q-factor obtained in each simulation. The SNR values help determine which factor levels lead to a more robust and higher Q-factor. After calculating the SNRs, an analysis of variance (ANOVA) was performed to assess the relative impact of each design factor on the Q-factor. The most influential parameters were identified by comparing each control factor's average SNR values at different levels. This process enabled the identification of the optimal combination of MRR design parameters, maximizing the Q-factor and enhancing device performance for practical sensor applications.

3. RESULTS AND DISCUSSION

The L9 OA was the outer array, ideal for evaluating four control factors at three levels. This setup generates nine combinations of the control factors, as presented in Table 2. The Q-factor and SNR values used for optimization in this study were derived from these nine configurations. The SNR calculation follows the "larger-is-better" formulation commonly used in Taguchi optimization for quality improvement.

Table 2. The SNR value of the arrangement is orthogonal L9

Sim.	R	g	W	h	Q	SNR
1	1	1	1	1	644.61	56.19
2	1	2	2	2	2059.64	66.28
3	1	3	3	3	5226.40	74.36
4	2	1	2	3	2556.16	68.15
5	2	2	3	1	1295.65	62.25
6	2	3	1	2	2963.53	69.44
7	3	1	3	2	1556.31	63.84
8	3	2	1	3	2895.35	69.23
9	3	3	2	1	1558.28	63.85

The primary objective of this study is to determine the most influential design parameters for the Q-factor of the MRR. The Taguchi method provides a systematic and statistically efficient approach for optimizing multiple parameters with a minimal number of experiments. By employing the "larger-is-better" SNR criterion, we can quantify the contribution of each control factor variation to the observed of Q-factor performance. Table 2 shows that variations in control factors lead to considerable differences in the resulting Q-factor and SNR values. A preliminary examination suggests that some factors significantly influence the performance, necessitating a quantitative analysis. The ANOVA and SNR response tables are used to identify the magnitude of each factor's impact.

The performance sensitivity of each factor is evaluated by the Δ value, which is the difference between the highest and lowest SNR across the levels. A larger Δ indicates a more influential control factor. Based on Table 3, waveguide height and gap exhibit the most pronounced effects on the Q-factor, with Δ values of 9.82 and 6.49, respectively. These results imply that fine-tuning the vertical geometry of the waveguide and the gap distance between the ring and the bus waveguide significantly improves the resonator's performance. In contrast, the ring radius and waveguide width show relatively modest impact, with Δ values of 1.00 and 1.87, respectively. This finding differs from initial assumptions and highlights the necessity of quantitative evaluation via SNR and ANOVA, rather than relying solely on theoretical intuition.

Table 3. The SNR response for the Q-factor

Symbol	Control factor	SNR			
		Level 1	Level 2	Level 3	Δ
R	Ring radius	65.61	66.61	65.64	1.00
g	Gap	62.73	65.92	69.22	6.49
W	Waveguide width	64.95	66.09	66.82	1.87
h	Waveguide height	60.76	66.52	70.58	9.82

The SNR response analysis results are visualized in Figures 4(a) to (d), graphically illustrating how each control factor level influences the SNR. The optimal levels for each factor can be deduced directly from the highest points in each subfigure of the plot. The optimal value for the ring radius is at level 2, which is R=4.5 µm. The optimal value for the waveguide gap factor is at level 3, namely g=0.15 µm. The optimal value for the waveguide width is at level 3, namely W=0.47 µm. The optimal value for the waveguide height is at level 3, namely h=0.18 µm.

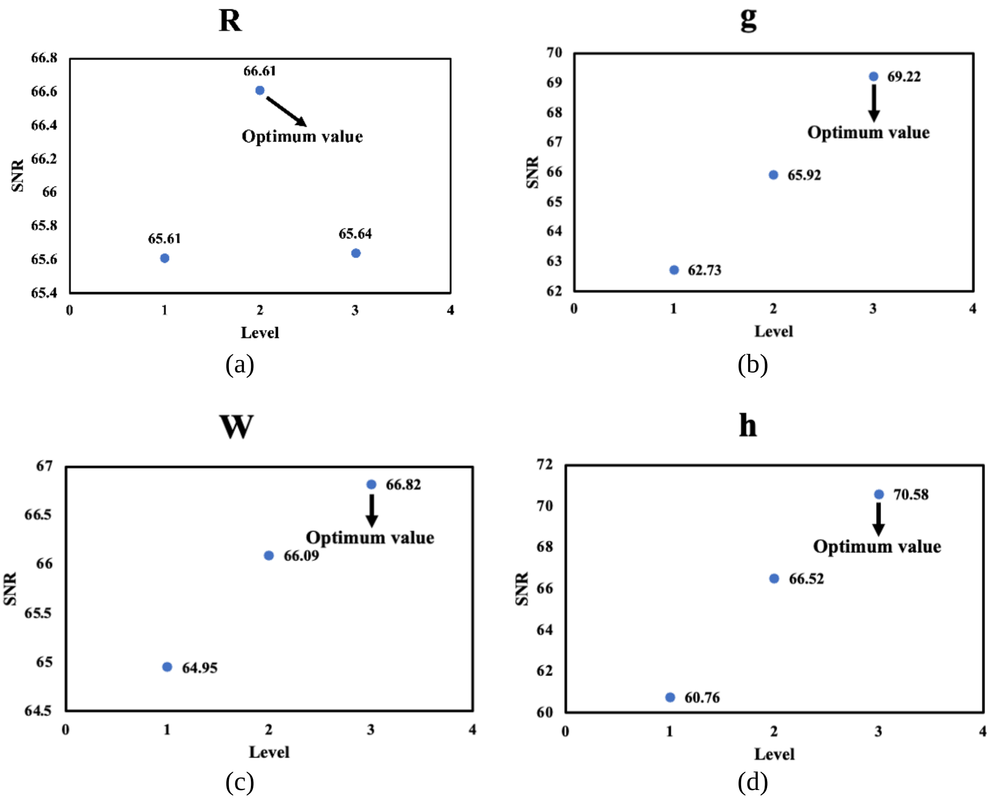

Figure 4. The optimal SNR response for Q-factors according to the four different control factors, namely; (a) ring radius, (b) gap, (c) waveguide width, and (d) waveguide height

While the current study successfully applies the Taguchi method for optimization, future work could validate these optimal settings through additional experiments or simulations and compare results to those reported in existing literature to articulate the contribution and novelty more clearly. Nevertheless, within the constraints of this study, the method effectively isolates the most impactful parameters, particularly waveguide height and gap, in enhancing MRR performance. To improve the discussion of results, a comparison with existing work could be made to highlight the novelty of the obtained results. The optimization result shows a higher Q-factor value than the pre-optimization result in Table 4.

Table 4. Q-factor optimization results using the Taguchi method

Optimum factor control				Optimum Q-factor
R (µm)	g (µm)	W (µm)	h (µm)	
4.50	0.15	0.47	0.18	6208.44

4. CONCLUSION

This study demonstrates the use of the Taguchi method in optimizing the design parameters of an MRR to enhance its Q-factor, which is crucial for sensor performance. The study identified the most influential factors and optimal design configuration by systematically analyzing four geometric parameters—ring radius, gap, waveguide width, and waveguide height—through a 3×4 L9 OA.

The SNR analysis and response table revealed that waveguide height and gap significantly impact the Q-factor, with Δ values of 9.82 and 6.49, respectively. The Taguchi method enabled a data-efficient yet reliable prediction of the optimal parameter combination, achieving an estimated Q-factor of 6208.44 substantially higher than the initial configurations. These findings underscore the value of Taguchi-based statistical design of experiments (DOE) in photonic device optimization.

Although the optimization result is theoretical and not experimentally verified due to simulation constraints, the methodology provides a robust framework for guiding future experimental validation and device fabrication. Compared to traditional trial-and-error or full-factorial methods, the Taguchi approach offers a more structured and resource-efficient route for performance improvement in photonic sensor design. This study contributes to the ongoing development of high-performance optical resonators and supports adopting design optimization techniques in integrated photonics research.

FUNDING INFORMATION

We gratefully acknowledge Lembaga Penelitian Dan Pengabdian Kepada Masyarakat Universitas Pendidikan Indonesia for financial support through the Penelitian Kerjasama Internasional No 337/UN40 grant.LP/PT.01.03/2024.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

There is no ethical approval needed since there is no experiment or data related to human or animal used.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

REFERENCES

[1] X. He *et al.*, "On-chip two-dimensional material-based waveguide-integrated photodetectors," *Journal of Materials Chemistry C*, vol. 12, no. 7, pp. 2279–2316, 2024, doi: 10.1039/D3TC03679K.

[2] N. L. Kazanskiy, S. N. Khonina, and M. A. Butt, "A Review of Photonic Sensors Based on Ring Resonator Structures: Three Widely Used Platforms and Implications of Sensing Applications," *Micromachines (Basel)*, vol. 14, no. 5, pp. 1-25, May 2023, doi: 10.3390/mi14051080.

[3] J. A. Shates, C. Pettersen, T. S. L'Ecuyer, and M. S. Kulie, "Multi-Year Analysis of Rain-Snow Levels at Marquette, Michigan," *Journal of Geophysical Research: Atmospheres*, vol. 128, no. 2, Jan. 2023, doi: 10.1029/2022JD037132.

[4] G.-W. Lu *et al.*, "High Temperature Resistant Silicon-Polymer Hybrid Modulator Operating at up to 200 Gbit s−1 for Energy-Efficient Data Centres and Harsh-Environment Applications," *Nature Communications*, vol. 11, no. 1, pp. 1-9, Aug. 2020, doi: 10.1038/s41467-020-18005-7.

[5] W. Cheng *et al.*, "Tunable Bandpass Microwave Photonic Filter with Largely Reconfigurable Bandwidth And Steep Shape Factor Based on Cascaded Silicon Nitride Micro-Ring Resonators," *Optics Express*, vol. 31, no. 16, pp. 1-14, Jul. 2023, doi: 10.1364/OE.496771.

[6] V. Fallahi, Z. Kordrostami, and M. Hosseini, "Sensitivity and Quality Factor Improvement of Photonic Crystal Sensors by Geometrical Optimization of Waveguides and Micro-Ring Resonators Combination," *Scientific Reports*, vol. 14, no. 1, pp. 1-15, Jan. 2024, doi: 10.1038/s41598-024-52363-2.

[7] Q. Wu, Y. Xiao, G. Zhao, and Q. Song, "Evolutionary Processes and Applications of Microfiber Resonant Rings: A Systematic Exploration for Sensitivity Enhancement," *Optics and Laser Technology*, vol. 174, p. 110567, Jul. 2024, doi: 10.1016/j.optlastec.2024.110567.

[8] Z. Fu, Z. Wang, P. Bienstman, R. Jiang, J. Wang, and C. Wu, "Programmable Low-Power Consumption All-Optical Nonlinear Activation Functions Using A Micro-Ring Resonator with Phase-Change Materials," *Optics Express*, vol. 30, no. 25, pp. 1-11, Dec. 2022, doi: 10.1364/OE.476110.

[9] Y. Lee *et al.*, "Theoretical and experimental study on the detection limit of the micro-ring resonator based ultrasound point detectors," *Photoacoustics*, vol. 34, pp. 1-10, Dec. 2023, doi: 10.1016/j.pacs.2023.100574.

[10] L. Yang, B. Dong, Q. Shao, S. Zhang, and Z. Chen, "Short Carbon Nanotube Nano-Film-Based Polymer/SiO Hybrid Waveguide Micro-Ring Filter," *ACS Applied Materials & Interfaces Journal*, vol. 15, no. 23, pp. 28555–28562, Jun. 2023, doi: 10.1021/acsami.3c04231.

[11] P. Steglich *et al.*, "Silicon Photonic Micro-Ring Resonators for Chemical and Biological Sensing: A Tutorial," *IEEE Sensors Journal*, vol. 22, no. 11, pp. 10089–10105, Jun. 2022, doi: 10.1109/JSEN.2021.3119547.

[12] H. S. Nugroho *et al.*, "The Sensitivity of Sensor Based on Microring Resonator (MRR) and Surface Plasmon Resonance (SPR) for Diabetes Monitoring Application," *IOP Conference Series: Materials Science and Engineering*, vol. 850, no. 1, pp. 1-8, May 2020, doi: 10.1088/1757-899X/850/1/012048.

[13] Q. He, S. Han, W. Chen, H. Hu, T. Liu, and Z. Cheng, "Graphene-Sensitized Microring Gas Sensor Probing With A Single-Wavelength Laser," *Optics Communications*, vol. 537, p. 129447, Jun. 2023, doi: 10.1016/j.optcom.2023.129447.

[14] S. Ohno *et al.*, "Si Microring Resonator Optical Switch Based on Optical Phase Shifter With Ultrathin-Inp/Si Hybrid Metal-Oxide-Semiconductor Capacitor," *Optics Express*, vol. 29, no. 12, pp. 1-10, Jun. 2021, doi: 10.1364/OE.424963.

[15] Y. Zhang, Q. Liu, C. Mei, D. Zeng, Q. Huang, and X. Zhang, "Proposal and Demonstration of a Controllable Q Factor in Directly Coupled Microring Resonators for Optical Buffering Applications," *Photonics Research*, vol. 9, no. 10, pp. 1-10, Oct. 2021, doi: 10.1364/PRJ.434151.

[16] X. Zhang *et al.*, "High Q-Factor, Ultrasensitivity Slot Microring Resonator Sensor Based on Chalcogenide Glasses," *Optics Express*, vol. 30, no. 3, pp. 1-10, Jan. 2022, doi: 10.1364/OE.450092.

[17] P. S. T. Kumar and A. Muniappan, "Experimental Investigation and Modeling of Drilling Process Parameters for Surface Roughness of Al6061/SiC/Gr Hybrid Composite using RSM," *IOP Conference Series: Materials Science and Engineering*, vol. 912, no. 3, pp. 1-9, Aug. 2020, doi: 10.1088/1757-899X/912/3/032067.

[18] S. N. Sawant and S. K. Patil, "Investigation of Effect of Thickness in Micro Drilling of Ti-6Al-4V Alloy Using Tungsten Copper Electrode," *Engineering Research Express*, vol. 6, no. 1, pp. 1-18, Mar. 2024, doi: 10.1088/2631-8695/ad2489.

[19] R. Halima, A. Narula, and V. Sravanthi, "Optimization of process parameters for the green synthesis of silver nanoparticles using Plackett-Burman and 3-level Box–Behnken Design," *Journal of Huazhong University of Science and Technology*, vol. 50, no. 3, pp. 1–17, 2021.

[20] I. D. Boateng *et al.*, "Updating the Status Quo on the Extraction of Bioactive Compounds in Agro-Products Using a Two-Pot Multivariate Design. A Comprehensive Review," *Food and Function*, vol. 14, no. 2, pp. 569–601, 2023, doi: 10.1039/D2FO02520E.

[21] F. L. Teixeira *et al.*, "Finite-Difference Time-Domain Methods," *Nature Reviews Methods Primers*, vol. 3, no. 1, p. 75, Oct. 2023, doi: 10.1038/s43586-023-00257-4.

[22] S. S. Farhat, "Numerical Solutions of Maxwell's Equations to Calculate Waves Propagation in Dielectric Material using Finite Difference Time Domain (FDTD) Technique," *The Libyan Journal of Science*, vol. 27, no. 2, 2024.

[23] C. Zhao, T. Zhang, and G. Hou, "Finite-Difference Time-Domain Modeling for Underwater Acoustic Scattering Applications Based on Immersed Boundary Method," *Applied Acoustics*, vol. 193, pp. 1-13, May 2022, doi: 10.1016/j.apacoust.2022.108764.

[24] J. Xie, D. Liang, and Z. Zhang, "Energy-Preserving Local Mesh-Refined Splitting FDTD Schemes for Two Dimensional Maxwell's Equations," *Journal of Computational Physics*, vol. 425, p. 109896, Jan. 2021, doi: 10.1016/j.jcp.2020.109896.

[25] M. W. Hisam, A. A. Dar, M. O. Elrasheed, M. S. Khan, R. Gera, and I. Azad, "The Versatility of the Taguchi Method: Optimizing Experiments Across Diverse Disciplines," *Journal of Statistical Theory and Applications*, vol. 23, pp. 365–389, Oct. 2024, doi: 10.1007/s44199-024-00093-9.

[26] R. Mahiou, E.-H. Guerrout, and M. E. Sannef, "Taguchi Design for Setting EHO Variants Parameters: Application in Brain Image Segmentation Using HMRF," *SN Computer Science*, vol. 4, no. 6, p. 794, Oct. 2023, doi: 10.1007/s42979-023-02197-y.

[27] P. Li, R. P. A. R. Pereira, and H. Navas, "*Quality Control-Intelligent Manufacturing, Robust Design and Charts*," BoD–Books on Demand, 2020, pp. 1–19.

[28] Y. R. Bawankar and A. Singh, "Microring Resonators Based Applications in Silicon Photonics - A Review," in *2021 5th Conference on Information and Communication Technology (CICT)*, IEEE, Dec. 2021, pp. 1–6, doi: 10.1109/CICT53865.2020.9672427.

[29] W. Lin *et al.*, "High Q-Factor Polymer Microring Resonators Realized by Versatile Damascene Soft Nanoimprinting Lithography," *Advanced Functional Materials*, vol. 34, no. 19, May 2024, doi: 10.1002/adfm.202312229.

[30] D. Kumar, J. K. Rakshit, C. Nayak, and M. Hossain, "Photonic Crystal-Based High Performance Cascaded Micro Ring Resonator using Topological Interface State: Design, Analysis, and Application," *Optical and Quantum Electronics*, vol. 56, no. 8, p. 1378, Aug. 2024, doi: 10.1007/s11082-024-07273-y.

[31] Y. Zhang *et al.*, "Double-Slot Micro-Ring Resonators with Trapezoidal Subwavelength Grating as Ultra-Sensitive Biochemical Sensors," *Optics Communications*, vol. 575, p. 131256, Jan. 2025, doi: 10.1016/j.optcom.2024.131256.

[32] S. N. Zheng *et al.*, "Microring Resonator-Assisted Fourier Transform Spectrometer with Enhanced Resolution and Large Bandwidth in Single Chip Solution," *Nature Communications*, vol. 10, no. 1, pp. 1-8, May 2019, doi: 10.1038/s41467-019-10282-1.

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