Dual wavelength optical duobinary modulation using GaAs–AlGaAs microring resonator

IS Amiri, R Zakaria, T Anwar, M Bahadoran, D Vigneswaran, P Yupapin

PII: S2211-3797(18)32485-9
DOI: https://doi.org/10.1016/j.rinp.2018.11.016
Reference: RINP 1785

To appear in: Results in Physics

Received Date: 12 October 2018
Revised Date: 4 November 2018
Accepted Date: 7 November 2018

Please cite this article as: Amiri, I., Zakaria, R., Anwar, T., Bahadoran, M., Vigneswaran, D., Yupapin, P., Dual wavelength optical duobinary modulation using GaAs–AlGaAs microring resonator, Results in Physics (2018), doi: https://doi.org/10.1016/j.rinp.2018.11.016

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.
Dual wavelength optical duobinary modulation using GaAs–AlGaAs microring resonator

IS Amiri 1,2, R Zakaria 3*, T Anwar 4, M Bahadoran 5, D Vigneswaran 6, P Yupapin 1

1Computational Optics Research Group, Advanced Institute of Materials Science, Ton Duc Thang University, Ho Chi Minh City, Vietnam
2Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Vietnam
Email: irajsadeghamiri@tdtu.edu.vn
3Photonics Research Centre, University of Malaya, 50603 Kuala Lumpur, Malaysia
Corresponding *Email: rozalina@um.edu.my
4Department of Computer and Information Science (DCIS), Faculty of Science and Information Technology (FSIT), Universiti Teknologi Petronas (UTP), 32610 Seri Iskandar
5Department of Physics, Shiraz University of Technology, 31371555, Shiraz, Fars, Iran
6Department of Electronics and Communication Engineering, Sri Krishna College of Technology, Coimbatore, India – 641 042.

ABSTRACT

In this article, optical duobinary modulation technique has been used for modulating the dual-wavelength optical signal generated by the microring resonator system. The optical signals are de-multiplexed to two different optical signals with center wavelength of 1540 and 1545 nm afterward, these are modulated and transmitted over an optical fiber communication system, where the high performance of the transmitted signals is obtained. The NRZ binary signals are used to modulate the optical signals. The high-quality factor and performance of the system has been investigated by applying an optimization through the system parameters, where significant improvement could be obtained and highest quality factor of 32.871 shows the successful transmission. The second wavelength of the dual-wavelength has undergone the same modulation technique and has experienced the optical transmission after the system optimization has been performed, where the quality factor for the received optical signal at 1545 nm center wavelength is 39.282. These results show the introduced modulation technique is suitable to apply for the optical signals generated by the microring resonators.

Keywords: Optical duobinary modulation technique, dual-wavelength, microring resonators

1. Introduction

Optical ring waveguide resonators are emerged in aspects of optical MUX/DEMUX, filtering, the resonance wavelength, pulse switching [1] and splitting efficiency applications [2]. The basic functional parameters such as ring diameter, waveguide thickness are the main...
features of the resonator system [3]. With that significant property, low bending loss is achieved by the interface region among air-semiconductor-air structures [4, 5]. In this low bending analysis, there was a miracle finding in mode propagation and it was thought of 1000 times better than the weakly guiding approximation of ring waveguide having 1-2\(\mu\)m of diameters [6]. The propagation properties have confirmed that the light is enhanced and tuned for the resonant point inside the ring facet which is extended for all optical communication applications [7], optical switching [8], emission of optical energy [9] and nonlinear optics signal processing [10]. Here we present the demonstration of GaAs–AlGaAs waveguide microring resonators for application in optical signal modulation and transmission over an optical fiber communication. We have also shown that such resonators can be used to generate ultra-wide free spectral range (FSR) pulses with THz spacing, providing THz photonics communication signals. In this research we have utilized the microring resonator to generate dual-wavelength at center frequencies of 1540 and 1545 nm. We have applied the optical duobinary modulation technique to the optical signals (dual-wavelength) before undergoing a transmission through an optical fiber transmission link. It is possible to stabilize the spectral property by indirectly monitoring the bandwidth adjustment which tends to reduce the dispersion effect for the better modulation system for data communication [11, 12]. The system can be presented by following building block (Figure 1).

**Fig. 1:** Functional block of duobinary modulation scheme, The MZM is Lithium Niobate (LiNbO3) Mach Zehnder modulator

The line coding configuration of the duobinary code is identical to the RZ line coding format [13]. If the data sequences defined as \(D_m\) and encoded data named as \(P_m\), then the duobinary modulation is performed by comparing the output of precoder with the input to the precoder. The combination of precoder and modulo 2 operation blocks is known as differential precoder where the error possibility during the data propagation is minimized. The reduced symbol interference then is applied as an input into the optical modulator as shown in Figure 1. This modulation format is taken as the unique one as it may be extended in distance to send the data with free propagation loss without regenerator and repeaters [14, 15]. Earlier, this modulation scheme was utilized for the 40 Gbps direct detection method [16]. The another challenge to send the data for long distance without presence of intersymbol interference is crucial [17] which is resolved by providing a delay in the bit slot [18]. The present work also shows that significance of duobinary modulation function with help of ring resonator laser source.

2. Microring Resonator System

The proposed system for dual-wavelength generation is shown in Figure 2. A Gaussian laser beam with power of 1 W is used as input. The two microring resonators have a same radius of 6.36 \(\mu\)m, and coupling coefficients as \(\kappa=0.482\), \(\kappa_1=\kappa_2=\kappa_3=\kappa_4=0.02\).
The structure is modelled of GaAs–AlGaAs with GaAs core whose refractive index is 3.368 surrounded by AlGaAs (refractive index is 3.135). The nonlinear refractive index is $2.7 \times 10^{-16}$ cm$^2$/W for wavelengths around 1550 nm. The other dimension for the given layer is scaled as follows,

- Air cap (0.2 µm)
- AlGaAs cladding (0.3 µm) ($n=3.135$)
- GaAs core (0.5 µm) ($n_0=3.368$)
- AlGaAs buffer (1.5 µm) ($n=3.135$)
- Substrate (5 µm)

This system consists of two coupled microring resonators. Further application of the proposed structures also has been used for optical comb generations with minimum of power consumption [18, 19]. Moreover, the material of III–V material compound for semiconductor is used for many nonlinear optical applications [20-24]. The transmission property and its functional behavior of the proposed structure is detailed in ref [25] and also it is exhibited to reduce inter-channel interference in optical communication networks and on-chip interconnects [26].

### 3. Results and Discussion of The Optical Signals Generated by Microring resonator System

Figure 3 shows the generated results from throughput, drop (1) and drop (2) ports. Dual-wavelength generation is performed within 33 nm range, where the THz free spectral range could be obtained. The drop port (2) output contains a dual-wavelength generated within 33 nm wavelength range, having a linewidth of 1.48 (185.320 GHz) and FSR of 3.95 nm (500 GHz). The simulations are carried over by photonic circuit simulator PICWave, where the PICWave employs flexible Time Domain Travelling Wave (TDTW) model from which the results presented in this paper are derived.
Fig. 3. (a) Throughput outputs, dual-wavelength optical signals with free spectral range (FSR)=3.5 nm and 3.6 nm corresponding to 441.84 GHz and 444.66 GHz respectively, (b) Drop port (1) outputs, dual-wavelength optical signal with FSR=3.46 nm corresponds to 437 GHz, (c) Drop port (2) outputs, dual-wavelength optical signal with FSR=3.95 nm corresponds to 500 GHz

The rectangular waveguide (RWG) is used to describe waveguides or any guide by a modest number of rectangles. Similarly, the SWG (1D-slab waveguide structure) can be designed by the vertical profile of a slice, as like as SWG panel slices. The mode finder panel is located to monitor the intensity mode propagation as well as its corresponding mode profiles. Figure 4 shows the fundamental mode propagation in the cross-sectional view of the waveguide.
4. Proposed optical duobinary modulation technique

The system design is shown in Figure 5. The bit rate of the bit sequence generator is 40Gbps, and the NRZ pulse generator has amplitude of 1(a.u). The NRZ pulse enters the electrical time delay with 1 bit time delay. The optical signal generated by the microring resonator has center wavelength of 1540 nm and 0.24 mW power as indicated in Figure 3(c). Then the optical signal enters the first MZM to be modulated by the binary information signal, where the MZM has an extinction ratio of 100 dB. In the second MZM, the extinction ratio is 50 dB. Afterward the modulated optical signal will propagate through the optical fibers which have a length of 25 km, 0.2 dB/km of loss, 17 ps/nm/km of group velocity dispersion, dispersion group delay of 0.2 ps/km, a nonlinear refractive index of $2.6 \times 10^{-20}$, effective area of 70 µm$^2$, and a nonlinear phase shift of 5 mrad. The DCF is used to cancel out the created dispersion from the optical fibers and it has a length of 10 km, attenuation of 0.5 dB/km, and an ignorable dispersion index. The EDFAs is installed to reshape the pulse propagation along the provide optical link.

![Diagram](image-url)
Fig. 5. System design of the optical duobinary modulation technique applied to modulate and transmit the optical signals (dual-wavelength) generated by the microring resonator shown in Figure 3(c). The signals are generated using the microring resonator. A demultiplexer (de-Mux) is used to separate the two wavelengths from the dual-wavelength to perform two individual transmissions, SMF (single mode fiber), BER (bit error rate), EDFA (Erbium doped fiber amplifier), DCF (dispersion compensating fiber), MZM, NRZ (Non-return-to-zero)

The optical signal generated by the microring resonator which is modulated by duobinary signaling scheme as presented well in [16] and later the modulated data will be detected by the PIN photo detector. Generation of modified duobinary pulses and its system configuration is shown in Figure 1. The error free data modulation is succeeded by the presence of precoder and modulo 2 adder. During the detection process, the reshaping filtering center frequency is assigned as 32 GHz.

5. Results and discussion

The optical signal modulated by the information signals as generated duobinary signals is presented in Figure 6. The optical signal is the first wavelength of the dual-wavelength generated by the microring resonator at wavelength 1540 nm.

Fig. 6. (a) modulated optical signal after the first MZM, (b) after the second MZM

The time domain of the initial and transmitted modulating binary signals is presented in Figure 7. The result show that a very small-time delay occurs due to the fiber and other physical components, where the induced time delay is ignorable, and it does not affect the total performance of the system.
The eye diagram and the quality factor of the first modulated optical signal generated by the microring resonator at wavelength 1540 nm is shown in Figure 8. The optical system has an average quality factor of 6.78 which is acceptable and shows an average performance of the system.

The quality factor of the system can be increased significantly by increasing the power of the optical signal generated by the microring resonator. The enhancement of the quality factor due to increasing the power of the optical signal is presented in the Figure 9 as the BER is almost zero for the higher applied input powers. Figure 10 shows the eye diagrams for the
minimum and maximum input powers. The obtained quality factors are “0” and 32.3 respectively.

![Graph showing optical signal power versus quality factor and BER](image1)

**Fig. 9.** Optical signal power versus quality factor and BER

![Eye diagrams](image2)

**Fig. 10.** Eye diagrams for (a) lowest input power (-11 dBm) and (b) highest input power (7 dBm)

We have calculated the power received at the end of the first MZM, second MZM and the photodetector with respect to the variable input power of the optical signal. The result is shown in Figure 11.

![Graph showing input power versus powers measured after the MZMs and photodetector](image3)

**Fig. 11.** Input power versus powers measured after the first MZM, second MZM and after the photodetector
In the presented design system, the power degrades as the optical signal propagates along the optical fibers. In order to have better performance of the system the losses should be compensated either by the design optimizations or using the different modulation techniques. The used modulation technique as optical duobinary modulation is an efficient technique to perform the modulation especially for the optical systems and optical fiber transmission, therefore we perform further power and quality enhancements by the system optimizations. In the following section we have detailed the step by step optimization applied to the transmission system.

6. System optimizations and transmission of the second optical signal.

Further optimization has been performed through the fiber link by changing the system parameters. The first optimization has been done by reducing the power of the sinusoidal pulse generator to 1(a.u.) from 2(a.u) (shown in Figure 12(a). The input power of the optical signal is fixed to 0.24 mW which is the power presented in the Figure 3(c) for the wavelength center 1540 nm. We perform the optimizations without increasing the power of the optical signal but through the design parameters. We have reduced the noise figure of the amplifiers to 5 dB and could obtained much improved quality factor of 10.209 as shown in Figure 12(b). The loop control has significant contribution to the quality factor performance of the system as we have decreased the number of the loops from 6 to 1 which leads to obtain very high-quality factor of 29.982 as shown in Figure 12(c). The loop control can be utilized in systems which include amplifiers and the number of the loop will determine how many times the power can be amplified. It can be used to control the dispersion and prevents unnecessary usage of many amplifiers for a very long-distance transmission. The quality factor remains the same as the dark current of the photodetector changes. As the nonlinearity of the fiber is $2.6 \times 10^{-20}$ m$^2$/W, we have done the optimization through changing the parameter. If the nonlinearity parameter increases to $3 \times 10^{-20}$ m$^2$/W the quality factor will increase to 30.104 as shown in Figure 12(d). We have further improved the quality factor by increasing the nonlinearity of the second fiber to $7 \times 10^{-20}$ m$^2$/W shown in Figure 12(e). We have found that if we replace the sinusoidal pulse generator with a DC bias pulse generator as electrical signal input into the second MZM the quality factor can be enhanced to 32.871 shown in Figure 12(f).

![Fig. 12. System design optimization through applying different system parameters, (a) by reducing the sinusoidal pulse generator power, (b) by reducing the noise figure of the amplifiers, (c) by reducing the loops of the loop control, (d) by increasing the nonlinearity parameter, (e) by increasing the nonlinearity of the second fiber, (f) by replacing the sinusoidal pulse generator with a DC bias pulse generator as electrical signal input into the second MZM.](image-url)
refractive index of the first fiber link, (e) by increasing the nonlinear refractive index of the second fiber link, (f) replacing the sinusoidal pulse generator with a DC bias pulse generator.

We have examined the second wavelength of the generated dual-wavelength shown in Figure 3(c) which has power of 0.29 mW and a center wavelength of 1545 nm. The eye diagram of the transmitted modulated optical signal is presented in Figure 13. The maximum quality factor obtained for the second wavelength transmission is 39.282 as an advantage, a higher output power has been obtained compared to the first wavelength transmission.

![Eye diagram of the transmitted second wavelength of the generated dual-wavelength shown in Figure 3(c)](image)

**Fig. 13.** Eye diagram of the transmitted second wavelength of the generated dual-wavelength shown in Figure 3(c)

The transmission of the second wavelength has been performed after the optimization has been applied to the optical fiber transmission system. In this case the BER is almost zero which means a very high-quality transmissions of the optical signals generated by the microring resonator has been performed through the optical fiber communications using the optical duobinary modulation scheme.

7. Conclusion:

We have conducted a research to perform the optical duobinary modulation technique to transfer two wavelengths (optical signals) from a generated dual-wavelength in microring resonator systems. The two generated wavelengths have center wavelengths of 1540 and 1545 nm where these have been modulated by the duobinary signals using the Lithium Niobate (LiNbO3) Mach Zehnder modulator (MZM). The received modulated optical signals show a high-quality signal and these have high quality factor and lowest BER which are necessary to evaluate an optical communication system. The modulation can be performed by using differential precoding and electrical or optical filtering. The generated results show a high performance for optical signal transmission in an optical fiber communication. The high-quality factor could be achieved by performing the system optimization, where the highest quality factor of 39.282 has been obtained for the optimized design for the optical signal modulation and transmission at wavelength 1545 nm.

**Acknowledgment**

Dr. Zakaria would like to acknowledge the financial support from FRGS Grant FP034-2017A.
REFERENCES

[1] R. Bruck, B. Mills, D.J. Thomson, B. Troia, V.M. Passaro, G.Z. Mashanovich, G.T. Reed, O.L. Muskens, Picosecond optically reconfigurable filters exploiting full free spectral range tuning of single ring and Vernier effect resonators Optics express 23 (2015), pp. 12468-12477.
[2] J. Yu, S. Jin, Q. Wei, Z. Zang, H. Lu, X. He, Y. Luo, J. Tang, J. Zhang, Z. Chen, Hybrid optical fiber add-drop filter based on wavelength dependent light coupling between micro/nano fiber ring and side-polished fiber Scientific reports 5 (2015), p. 7710.
[3] S. Ranjan, S. Mandal, Performance Analysis of Triple Asymmetrical Optical Micro Ring Resonator with 2× 2 Input-Output Bus Waveguide Brazilian Journal of Physics 48 (2018), pp. 74-84.
[4] G. Sarrigan, K. Matori, I. Amiri, H. Ahmad, F. Fadaeifard, Dual-Wavelength Generation with Terahertz Spacing Using GaAs–AlGaAs Microring Resonator Waveguides Journal of Computational and Theoretical Nanoscience 14 (2017), pp. 330-334.
[5] X. Ji, F.A. Barbosa, S.P. Roberts, A. Dutt, J. Cardenas, Y. Okawachi, A. Bryant, A.L. Gaeta, M. Lipson, Ultra-low-loss on-chip resonators with sub-milliwatt parametric oscillation threshold Optica 4 (2017), pp. 619-624.
[6] I. Amiri, M. Bunruangses, K. Chaiwong, R. Udayakumar, R. Maheswar, M. Hindia, K. Dimyat, P. Yupapin, Dual-wavelength transmission system using double micro-resonator system for EMI healthcare applications Microsystem Technologies (2018), pp. 1-9.
[7] I. Amiri, S. Alavi, M. Soltanian, N. Fisal, A. Supa’at, H. Ahmad, Increment of access points in integrated system of wavelength division multiplexed passive optical network radio over fiber Scientific reports 5 (2015), p. 11897.
[8] J.S. Pelc, K. Rivoire, S. Vo, C. Santori, D.A. Fattal, R.G. Beausoleil, Picosecond all-optical switching in hydrogenated amorphous silicon microring resonators Optics express 22 (2014), pp. 3797-3810.
[9] A. Noury, X. Le Roux, L. Vivien, N. Izard, Enhanced light emission from carbon nanotubes integrated in silicon micro-resonator Nanotechnology 26 (2015), p. 345201.
[10] R. Camacho-Morales, M. Rahmani, S. Kruk, L. Wang, L. Xu, D.A. Smirnova, A.S. Solntsev, A. Miroshnichenko, H.H. Tan, F. Karouta, Nonlinear generation of vector beams from AlGaAs nanoantennas Nano letters 16 (2016), pp. 7191-7197.
[11] R. Kaur, S. Dewra, Duobinary modulation format for optical system-a review Int. J. Adv. Res. Electr. Electron. Instrum. Eng. 3 (2014), p. 11039.
[12] A.N.A. Abbood, H. Al-Raweshidy, Reduction of bandwidth requirement in DRoF systems using optical duobinary modulation, Computer Science and Electronic Engineering (CEEC), 2017, IEEE, 2017, pp. 116-121.
[13] S. Vishwakarma, M. Dutta, Generation of spectral efficient modulation format for fiber transmission by hybridization of duo binary and Manchester, Communication and Computing Systems: Proceedings of the International Conference on Communication and Computing Systems (ICCCS 2016), Gurgaon, India, 9-11 September, 2016, CRC Press, 2017, p. 347.
[14] C. Sun, S.H. Bae, H. Kim, Transmission of 28-Gb/s duobinary and PAM-4 signals using DML for optical access network IEEE Photon. Technol. Lett. 29 (2017), pp. 130-133.
[15] V.R. Krishna, V. Tiwari, Comparison of duobinary and modified duobinary modulation schemes for optimized transmission at 40 Gbps, Wireless and Optical Communications Networks (WOCN), 2015 Twelfth International Conference on, IEEE, 2015, pp. 1-4.
[16] Z. Ye, S. Li, N. Cheng, X. Liu, Demonstration of high-performance cost-effective 100-Gb/s TWDM-PON using 4× 25-Gb/s optical duobinary channels with 16-GHz APD and receiver-side post-equalization, Optical Communication (ECOC), 2015 European Conference on, IEEE, 2015, pp. 1-3.
[17] T. Sabapathi, R. Gayathri, Simultaneous Reduction of Four Wave Mixing and Stimulated Raman Scattering using Duobinary Modulation format in DWDM Fiber Optic Communication System International Journal of Scientific Engineering and Technology 3 (2014), pp. 634-637.
[18] T. Kippenberg, S. Spillane, K. Vahala, Kerr-nonlinearity optical parametric oscillation in an ultrahigh-Q toroid microcavity Physical Review Letters 93 (2004), p. 083904.
[19] P. Del’Haye, A. Schliesser, O. Arcizet, T. Wilken, R. Holzwarth, T. Kippenberg, Optical frequency comb generation from a monolithic microresonator Nature 450 (2007), pp. 1214-1217.
[20] I.S. Amiri, M. Ariannejad, S. Azzuhri, T. Anwar, V. Kouhdaragh, P. Yupapin, Vertical Ge photodetector base on InP taper waveguide Results in Physics 9 (2018), pp. 576-579.
[21] M. Ariannejad, I.S. Amiri, H. Ahmad, P. Yupapin, A large free spectral range of 74.92 GHz in comb peaks generated by SU-8 polymer micro-ring resonators: simulation and experiment Laser Physics 28 (2018), p. 115002.
[22] I.S. Amiri, T. Anwar, R. Zakaria, P. Yupapin, TE-like mode analysis of microsystem InGaAsP/InP semiconductor resonator generating 20 GHz repetition rate pulse trains Results in Physics 10 (2018), pp. 980-986.
[23] I.S. Amiri, F. Alizadeh, M. Ariannejad, R. Amini, P. Yupapin, Computation of Ion Exchange Buried Microring Resonator Waveguide for THz Communication Applications Results in Physics (2018).
[24] I.S. Amiri, M. Ariannejad, S. Daud, P. Yupapin, High sensitive temperature sensor silicon-based microring resonator using the broadband input spectrum Results in Physics 9 (2018), pp. 1578-1584.
[25] G. Lévêque, R. Mathevet, J. Weiner, G.C. des Francs, C. Girard, R. Quidant, J.-C. Weeber, A. Dereux, Modelling resonant coupling between microring resonators addressed by optical evanescent waves Nanotechnology 15 (2004), p. 1200.
[26] I. Amiri, H. Ahmad, M. Ghasemi, M. Ismail, S. Aidit, M. Soltanian, N. Nafarizal, Silicon-based microring resonators for multi-solitons generation for THz communication Optical and Quantum Electronics 48 (2016), p. 415.