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A Novel Variable-Length Header Extraction Scheme Based on Ring Laser for All-Optical Packet Switching Network

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Abstract:

In this paper, a novel header extraction scheme based on semiconductor ring laser is proposed and simulated for proof of principle. This scheme is to be used in all-optical packet switching network which can extract return-to-zero (RZ) format modulation data packet with variable header/payload length and intensive spacing. Simulations and numerical analysis for a 3-byte header and 128-byte payload show that this structure can extract the headers with more than 20 dB contrast ratio. Additionally, the structure simplicity and its small size is proper candida to integration in all-optical circuits.

Keywords: Header extraction, rate equations, Contrast ratio, All-optical devices.

1. Introduction

Today's optical technologies developed in many aspects and branches [1-6]. The rapid growth of the internet, increasing data traffic and all-optical processing and storages in the modern societies force the communication networks to increase the bandwidth and capacity [7-9]. Hence, it is preferred to use optical communication networks that work based on optical packet switching (OPS) instead of current optical packet circuits (OPC) networks [10, 11]. One of the main restrictions of the current networks is electronic-optical-electronic conversion (EOE) which is used for packet identification and processing in the electronic domain. Packets in optical communication networks consist of a header and payload [12]. One of the essential functions in the OPS switch is the separation of the packet header from the optical packet stream [13,14]. Up to now, several different methods have been proposed in order to extract and process of the packet header. These methods depended on labeling techniques. In the serial labeling techniques, the label is placed to the payload in the serial form and in parallel labeling techniques the label is processed parallel with the payload. There are some challenges in the parallel labeling techniques such as the label multiplexing on a separate wavelength or on a subcarrier frequency [14-18]. In the parallel labeling techniques speed of extracting label is high but packet requires more bandwidth so, in this method the bandwidth is occupied [19]. Intensity modulated payload as well as frequency shift keying (FSK) or Binary phase shift keying (BPSK) label or at different label code are serial labeling techniques [20-24]. These methods are amplitude or phase depended and require synchronization pulse and need fixed packet data length hence, these methods not suitable for flexible optical networks.

Since ring laser can be used in the design of various optical gates as well as in data storage [25] and processing [24], it is an appropriate candidate to be used in the design of all-optical integrated circuit [25,26]. In this paper, a structure based on ring laser is proposed which is capable of separating RZ coded headers from the packet, with high speed, and without delay.

The organization of this paper is as follow. The proposed structure is introduced in section 2. Section 3 is devoted to calculations and analysis of the proposed structure. In section 4, simulation results will be discussed and finally, section 5 concludes the paper.

2. Header extraction structure

Figure 1 shows a simple scheme of the proposed header extractor. In this structure, continues wave (CW) laser beam and packet stream signal are applied into port A and B, respectively. Then the separated header signal and its inverse exit from port C and D respectively.

Figure 1. Schematic diagram of optical header extraction

In the first case, assume that the packet signal does not exist, and the laser beam is applied. In this situation, the beam inside the ring propagates clockwise and results the signal at port D and the zero signal at port C and.

In the second case, it is supposed that the header with 15 Gb/s bitrate is applied into port A. Assuming that the power of input header stream is higher than the laser beam, and the length of header's Gaussian pulse is long, these pulses saturate the ring laser and invert the beam propagation direction inside the ring and cause the packets to appear at port C.

Note that if bitrate of the packets that applied into port B increases, the pulse length decreases, hence it cannot change the propagation direction inside the ring, and the packets will not appear at port C.

3. Modeling and numerical analysis

Ring laser is an active device consisting of one ring and two waveguides. Applying current to the active region causes the lasing operation. In the initial state, when the current amplitude is low, the linear characteristic is dominant, and both clockwise (CW) and counter-clockwise (CCW) modes can propagate inside the ring. Increasing the applied current causes the domination of the nonlinear characteristics which leads to the ring laser operate in the unidirectional mode, and only one mode can propagate inside the ring [27-29].

The longitudinal electric fields inside the ring cavity are expressed as:

$$E(x, t) = E_1(t) \exp[-i(\omega_{01}t - kx)] + E_2(t) \exp[-i(\omega_{01}t - kx)] \quad (1)$$

$$E_{ext}(x, t) = E_{ext}(t) \exp[-i((\omega_{02}t + \Delta\omega_{ext}t + \Delta\phi_{ext}) + kx)] \quad (2)$$

Where $E_1(t)$, $E_2(t)$, and $E_{(ext)}$ are mean complex electrical field corresponding to CW, CCW, and external injection amplitude modes, respectively. ω_1 and ω_2 are optical frequencies of ring cavity modes in clockwise and counter-clockwise respectively, and x represents the longitudinal spacing. $\Delta\omega_{ext}$ is detuning angular frequency of external injection and free running mode, and $\Delta\Phi$ is their phase difference. The time evolution of the fields inside the cavity can be described by the following the rate equations [30, 31]:

$$\frac{dE_1}{dt} = \frac{1}{2}(1 - i\alpha) \left(\Gamma v_g g_n (N - N_{tr}) \times (1 - \varepsilon_s |E_1|^2 - \varepsilon_c |E_2|^2) - \frac{1}{\tau_{p1}} \right) E_1 + \quad (3)$$

$$i(\omega_{01} - \omega_{th})E_1 + K_{ext}E_{ecw} \exp[-i(\Delta\omega_{ext}t + \Delta\phi_{ext})]$$

$$\frac{dE_2}{dt} = \frac{1}{2}(1 - i\alpha) \left(\Gamma v_g g_n (N - N_{tr}) \times (1 - \varepsilon_s |E_1|^2 - \varepsilon_c |E_2|^2) - \frac{1}{\tau_{p1}} \right) E_2 \quad (4)$$

$$+ i(\omega_{01} - \omega_{th})E_2 + K_{ext}E_{eccw} \exp[-i(\Delta\omega_{ext}t + \Delta\phi_{ext})]$$

Where spatial overlap between optical mode and active layer gain represent by optical confinement factor Γ . g_n and v_g are differential gain and group velocity in the active layer, respectively. α is the linewidth enhancement factor in the semiconductor medium which is related to phase-amplitude coupling. N is carrier density, while N_{th} and ω_{th} are carrier density and longitudinal resonant frequency at transparency, respectively. τ_1 and τ_2 are photon lifetime in the ring cavity of the two modes. $K_{ext} = \sqrt{(T_r/f_b)}$ is the coupling coefficient in which T_r is the power coupling rate, and f_b is feedback power rate. ε_s and ε_c are self-saturation coefficient and cross gain saturation coefficient, respectively. In these equations, the carrier density in the active region is defined as [33]:

$$\begin{aligned} \frac{dN}{dt} = \frac{j}{eV} - \frac{N}{\tau_e} - & \left(v_g g_n (N - N_{tr}) \times (1 - \varepsilon_s |E_1|^2 - \varepsilon_c |E_2|^2) \right) |E_1|^2 \\ & - \left(v_g g_n (N - N_{tr}) \times (1 - \varepsilon_s |E_2|^2 - \varepsilon_c |E_1|^2) \right) |E_2|^2 \end{aligned} \quad (5)$$

Where V is the volume of the quantum well active region, j is the injection current density, e is the electron charge, and finally, τ_e is the carrier lifetime.

4. Results and Discussions

One of the most important parameters to define the header extractor performance is contrast ratio (CR) as defined by equation 6 in which N and M are the number of payload and header pulse, respectively. Also, P_H and P_P represent header and payload power, respectively [18].

$$CR = 10 \log \frac{\frac{1}{N} \sum_{j=1}^N P_H}{\frac{1}{M} \sum_{j=1}^M P_L} \text{ (dB)} \quad (6)$$

For simulating of the proposed structure, the Gaussian pulse is applied to the ring laser. In order to create the packet sequence, 2-bit header random data was combined with 20-bit payload stream. Also, based on experimental parameters in [27-31], the active region of the ring laser is InGaAs and its radius is assumed 6 μm . The simulation parameters are listed in Table 1.

Table 1. Ring laser simulation parameters.

Symbol	Description	Value
R	Ring Radius	6 μm
Γ	Confinement Factor	0.226
α	Linewidth Enhancement Factor	4
g_n	Group Velocity	$0.857 \times 10^{-8} \text{ m} \cdot \text{s}^{-1}$
τ_{p1}	Photon Lifetime for Mode1	$4.85 \times 10^{-12} \text{ s}$
τ_{p2}	Photon Lifetime for Mode2	$4.85 \times 10^{-12} \text{ s}$
τ_p	Photon Lifetime	$4.85 \times 10^{-12} \text{ s}$
τ_e	Electron Lifetime	$3.14 \times 10^{-9} \text{ m}^2 \cdot \text{s}$
T	Coupler Transmission	0.3
f_b	Power Coupling Back Ratio	0.5
ε_s	Self-nonlinear Coefficient	$3.16 \times 10^{-23} \text{ m}^3$
ε_c	Cross-nonlinear Coefficient	$6.32 \times 10^{-23} \text{ m}^3$
I	Bias Current	3 mA
λ	Lasing Wavelength	1.55 μm
N_{th}	Carrier Density at Transparency	$0.788 \times 10^{23} \text{ m}^{-3}$
P_{cw}	Input laser(CW)power	1mW

Figure 2 shows the output propose scheme with the packet stream contained 2-byte header and 128-byte payload random data stream input. As can be seen, the header stream has been amplified while the payload bits have been attenuated. Additionally, CR of the output header is greater than 18 dB. Also, figure 3 represented the output of header extractor with 3-byte and 128-byte random data stream input. It is clear that the size of data packet and space between header and payload don't effect to the output result of the proposed scheme.

Figure 2. Output power packet extractor with 2-byte header and 128-byte payload input packet.

Figure 3. Output power packet extractor with 3-byte header and 128-byte payload input packet.

Figure 4 demonstrates the output power of the port C with respect to the input data packet frequency. It can be seen that by increasing the bit rate, the output power decreases rapidly.

Figure 4. Output power of the port C with the varies Bit rate of input packet.

As mentioned before, if a packet with header bit rate of less than 20 Gb/s and payload of more than 70 Gb/s is applied to the proposed structure, a high-contrast header signal will appear at the output port.

Figure 5. CR of header extractor vs changes of input packet signal power.

Figure 5 demonstrates the varying of CR vs varying of input power. As can be seen by increasing the input power the CR decrease fast.

Figure 6. CR of header extractor vs packet input frequency detuning.

Figure 6 shows the CR vs header extractor vs packet input frequency detuning. As can be seen by varying of the input frequency detuning the CR doesn't change meaningful hence using of proposed structure it is possible to extract of headers with deferent frequencies.

Conclusion

In this paper, a novel structure based on ring laser was proposed to separate the header data stream. The proposed structure does not require synchronization and does not depend on the length of header. Simulation results show that output header CR can be larger than 20 dB when the input signal power is low as 0.2 mW. On other way, CR increases as the current increases, while the required input power decreases. Also, by varying of the input frequency detuning the CR doesn't change meaningful. The structure is simple and optically integrable and can be used for the OPS networks.

Declarations

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Author contributions: Dariush jafari; Proposed and simulated the structure. Also, analyzed data and co-wrote the paper. Mohammad Danaie , Pejman Rezaeia and Tofiq Nurmohammadi; Supervised the research and co-wrote the paper.

Ethics approval: This material is the authors' own original work, which has not been previously published elsewhere. The paper is not currently being considered for publication elsewhere. The paper reflects the authors' own research and analysis in a truthful and complete manner. This research does NOT involve human participants or Animal.

Consent to Participate: All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

Consent to Publish: All authors have been personally and actively involved in substantial work leading to the paper, and consent to publish of submitted paper.

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Figures

Figure 1

Schematic diagram of optical header extraction

Figure 2

Output power packet extractor with 2-byte header and 128-byte payload input packet.

Figure 3

Output power packet extractor with 3-byte header and 128-byte payload input packet.

Figure 4

Output power of the port C with the varies Bit rate of input packet.

Figure 5

CR of header extractor vs changes of input packet signal power.

Figure 6

CR of header extractor vs packet input frequency detuning.