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Quadrature Amplitude Modulation Discrete Multitone Data Encoded by Si Waveguide Mach-Zehnder Interferometer Modulator Beyond 150 Gbps

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Silicon photonics is the cutting-edge optical interconnect technology with huge market potential toward next-generation chip-level communication solutions for data-center transmitters. For architecting the complete photonic integrated circuit functions, lots of waveguide components including active devices (light source and amplifier), functional elements (switch, modulator and detector), and passive processors (router, multiplexer, coupler, splitter etc.) have successively been realized via electro-optical, optical-optical and optoelectronic effects. Either direct or external modulation of the light source can be considered for encoding data; however, the formal scheme is inherently limited by the size of the emitter due to the gain-bandwidth product, whereas the latter one employs other effects to demonstrate the modulation beyond carrier lifetime limitation. Previously, the external modulation has been implemented via free-carrier absorption, nonlinear Kerr switching, and electro-optic phase/intensity variation. Nonetheless, the last technique realized by the waveguide-type Mach-Zehnder interferometer (MZI) has been comprehensively applied to all data processing blocks owing to its high conversion efficiency and low power consumption [1-3]. Nowadays, numerous literatures have shown that the Si waveguide MZI modulator can easily approach the non-return-to-zero on-off keying (NRZ-OOK) and 4-level pulse amplitude modulation (PAM-4) data streams encoding at 50-Gbps and 50-GBaud, respectively, but its transmission performance with encoding new and complex data such as quadrature amplitude modulation discrete multitone (QAM-DMT) format has yet to be completely realized. In this work, this Si MZI modulator can transmit the NRZ-OOK, PAM-4, and QAM-DMT data beyond 150 Gbps for future low-power consumption and high-speed network applications.

In this work, the $V_\pi L$ product of the MZI modulator can be obtained as 1.18 V-cm lower than 1.7 V-cm for the criterion of Si MZI modulator for inter-data center transmission when the phase shift is measured as 0.65π by varying the reverse bias. This lower $V_\pi L$ product for Si MZI modulator can decrease the whole power consumption to extend the device lifetime. In addition, the operating wavelength changes from 1542.6 nm to 1545.3 nm to enhance the extinction ratio from 13.16 dB to 31.36 dB. Moreover, this Si MZI modulator exhibits its 3- and 6-dB modulation bandwidths of 39 and 41 GHz to allow high-speed data transmission. After optimizing the wavelength and reverse bias of the Si MZI modulator, the maximal data rate of the NRZ-OOK data encoded by the Si MZM is achieved as 57 Gbps with a signal-to-noise ratio (SNR) of 18.3 dB and a bit-error ratio (BER) below 10^{-10}. The data rate of NRZ-OOK data can be enlarged to 60-Gbps with a BER lower than 10^{-9}. As the PAM-4 format requires higher SNR and lower noise than the NRZ-OOK format, its allowable bandwidth is decreased to 45 GBaud (equal to 90 Gbps) for passing the KP4-FEC criterion (BER=2×10^{-4}). In the QAM-DMT case, the allowable bandwidth of the 32-QAM DMT data stream is 30 GHz to maximize the data rate to 150 Gbps with a BER criterion of 3.8×10^{-3} for the forward error correction when the Si MZI modulator is set at only single-arm driven condition.

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