Investigation of high-frequency pulse width modulation of thermo-optic phase shifters using monolithically integrated MOSFET on silicon photonics platform

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Introduction: Thermo-optic (TO) phase shifters play indispensable roles for fine phase tuning in silicon photonic devices. To control these TO modules, an external circuitry is required and this circuitry will get too bulky for devices such as large-scale circuit switches that include a large number of the TO phase shifters [1]. To simplify the control circuits, we have proposed the pulse width modulation (PWM) method using our established monolithic integrated MOSFET on photonic SOI (with a 0.2~0.3-μm thick Si layer on top) platforms [2]. This method has advantages including: (1) since the gate is insulated from the power line, it provides very high input impedance for control circuits and thus satisfies the requirement of digital driving. (2) The extra power loss of the MOSFET is much lower than that driven by continuous-wave voltage signal because the MOSFET can work at fully on and off states in PWM driving. For deploying this method, we should determine the most suitable PWM frequency range for the voltage pulses applied to the gate of MOSFET. Obviously, this frequency should be sufficiently high compared to the TO response to avoid ripples in optical output, as we discussed in Ref. [2] where we recommended >1MHz based on the ripple < -0.4dB. However, it is not clear whether it is better to use frequencies as higher as possible. In this study, we investigated high-frequency PWM characteristics to answer this question.

Experiment: The TO Mach-Zehnder switch with monolithically integrated MOSFET drivers and PWM principle using this device are shown in Fig. 1(a). The details of the device and principle explanation can be referred in Ref. [2]. In usual situation without an integrated MOSFET, the current was directly input into the resistor from the external circuits. However, in our scheme, we control the pulse duration (described as the duty ratio) of the high-frequency voltage pulses that was applied to the gate of the MOSFET. The peak voltage of the pulse was kept at 3.5V. The measurement was done at wavelength of ~1.57μm for TE mode. Fig. 1(b) showed the transmission of the bar port as a function of the duty ratio at gradually enhanced frequencies up to 50MHz. Due to the pulse width limitation, the scanning range was different as the frequency changed. With increasing the driving frequency, the duty ratio which trimmed the bar port to the off state also increases, as seen in Fig. 1(c). In ideal situation, this duty ratio should be constant since the average voltage delivered to the gate is only determined by the duty ratio no matter what frequency is used. However, in real situation, the power loss could be caused by the gate charge effect when increasing the driving frequency. In other words, the condition of large input impedance may not be satisfied because of the capacitance at high frequency. From 5 to 50 MHz, the power loss was almost doubled as seen from the duty ratio in Fig. 1(c). In addition, high frequency requires fine duty ratio step; otherwise, the bit resolution would be not enough. Therefore, in our switch with integrated MOSFET drivers, the frequency of PWM driving should be as small as possible only if the frequency is high enough not to induce any ripples in optical output.

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[1]: K. Tanizawa, et al., OFC2015, M2B.5.
[2]: G. W. Cong, et al., OFC2015, M2B.7.

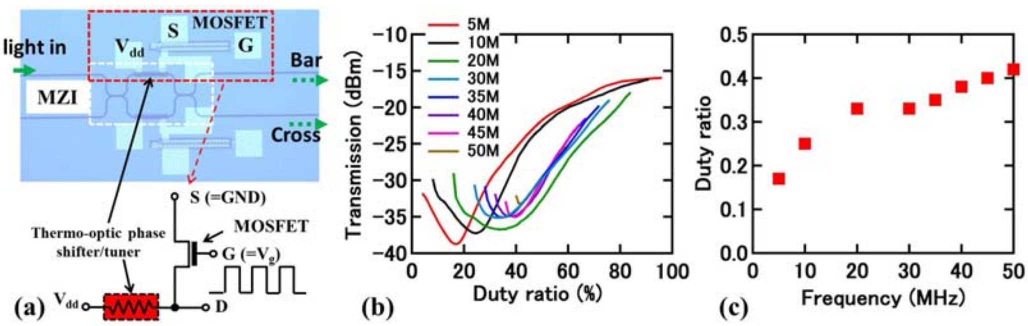

Fig.1 (a) Fabricated device (upper) and the principle schematic of PWM control. Peak voltage applied to the gate was 3.5V. (b) Optical output power at the bar port in relationship to the duty ratio at different frequencies. (c) Frequency dependent duty ratio at which the transmission at the bar port is minimum in (b).