Domain-Inversion-Equivalent EO Polymer based Y-fed Directional Coupler Modulator with High Linearity

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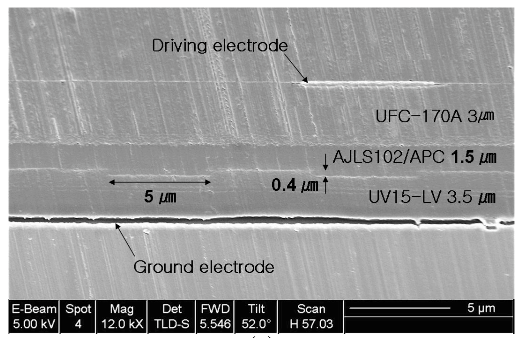
Abstract — A novel Y-branch directional coupler modulator (YDCM) with high linearity based on domain-inverted modulation was fabricated and tested. A two-tone test was performed to demonstrate the improvement of linearity of four-domain YDCM over two-domain YDCM.

I. Introduction

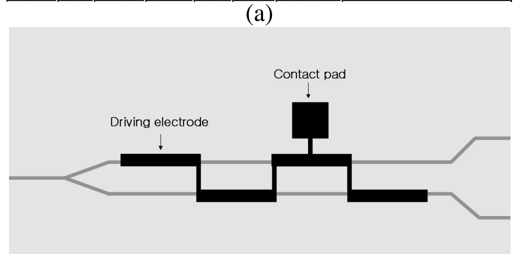
Mach-Zehnder modulators (MZM) made of lithium niobate are the most common type of commercially available EO modulators for RF photonics, but their performances are limited by several issues. MZMs need to be quadrature-biased, which requires a complicated circuitry and precise bias control. Moreover, the linearity of MZM is also limited because of the intrinsic sinusoidal transfer curve. These problems can be overcome by carefully designing a Y-branch directional coupler modulator (YDCM) with inverted domains [1]. Due to the symmetric structure, YDCM is intrinsically set at half-power point, thus it does not require a DC bias. Linearization techniques for YDCM such as domain-inversion and photo bleaching have been proposed by several groups [1-4]. In this work, we demonstrate a four-domain YDCM with a SFDR of 110.22dB/$Hz^{2/3}$, which is 14dB better than a two-domain YDCM.

II. Device Fabrication

The structure of Y-branch directional coupler modulator (YDCM) is shown in Fig. 1. Fig. 1 (a) shows a scanning electron micrograph of device cross-section. The waveguide width is 5μm and the center-to-center separation between waveguides is 10μm. The waveguide structure is vertically inverted. Instead of patterning the core layer, the lower cladding layer is patterned and the core layer is simply spin-coated on top of it. Etching depth is optimized at 0.4μm for single mode condition. Fig. 1 (b) is the schematic illustration of driving electrode in four-domain device where the length of each domain is 8574μm, 9126μm, 4785μm, and 7705μm respectively. In two-domain device, the length of both domains is 10153μm. A lumped electrode structure is designed in order to simplify the poling process while achieving the same effect as inverted domains [5]. The device was fabricated using standard semiconductor processes such as spin-on, photolithography, and RIE. The core layer is 25wt% AJLS102/APC, which is sandwiched between the lower cladding UV15-LV and the upper cladding UFC-170A. Both UV15-LV and UFC-170A were cured by UV lamp with nitrogen flow and were oven-baked to remove residual solvent. AJLS102/APC was cured in vacuum oven at 90°C to remove residual solvent and bubbles. The ground and driving electrodes are aluminum and Cr/gold respectively. These two metal layers were used as poling electrodes and then Cr/gold layer was patterned into driving electrode. Poling of electro-optic polymer was achieved by contact poling where the poling field of 100V/μm was applied across total polymer thickness of 8μm at the temperature of 135°C under nitrogen flow. Measured poling current density ranged 3~11$\mu A/cm^2$. In the last step, the fabricated device was cleaved and polished at both ends for testing.



(a)



(b)

Fig. 1. (a) Scanning electron micrograph of device cross-section and (b) schematic illustration of driving electrode design.

III. Device Testing

The two-domain Y-branch directional coupler waveguide modulator was tested at λ=1.59μm, at which the waveguide supports a single TM mode. The device was placed at the coupling stage of a four-axis Newport auto aligner for precise alignment and light coupling as shown in Fig. 2 (a). A TM-polarized laser beam was launched and coupled to the device with a polarization maintaining fiber. The output beam was coupled out with a bare single mode fiber as is shown Fig. 2 (a). The input optical power used in the testing was 15mW at λ=1.59μm, and the output power coupled out from the device was 15μW. Therefore, the coupling loss and propagation loss sum up to a total of 30dB

Fig. 2 (b) shows the measured output optical signal as a function of the applied voltage of the two-domain YDCM device. As is shown in Fig. 2 (b), the device presents a highly linear transfer curve without applying any DC bias. The measured switching voltage is around 8V.

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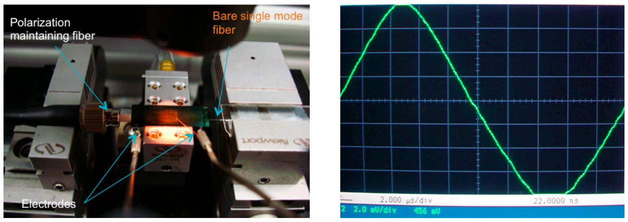

(a) (b)

Fig. 2. (a) Two-domain YDCM device and the picture of coupling setup. (b) Transfer curve of two-domain YDCM, which represents the modulated optical signal. The device was tested at λ=1.59μm when modulated by input RF signal of 100kHz.

The two-tone testing setup is shown schematically in Fig. 3. Test was performed in kHz frequency range to simplify the proof of concept. Two fundamental signals of 50kHz and 55kHz were combined and applied to the YDCM. Modulated optical output signal was coupled out by using a butt single mode fiber and then connected to a photo-detector that convert the optical output signals to RF signals. Then the RF signals from the photo-detector were displayed by an HP8563E microwave spectrum analyzer. Both two-domain and four-domain YDCM were tested by this method. Data points are plotted in Fig. 4 and Fig. 5 and then using linear fit to fit data points. Next, the linear fitting results were extrapolated to show both fundamental signal and third-order inter-modulation distortion (IMD3) as a function of input RF power for two-domain YDCM and four-domain YDCM respectively.

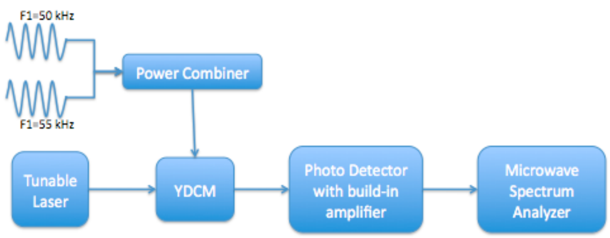

Fig. 3. Block diagram of the testing setup. Two input signals of different frequencies (f1=50kHz, f2=55kHz) were generated by HP8904A multifunction synthesizer and combined to modulate the device. YDCM: Y-branch Directional Coupler Modulator.

From Fig. 4 and 5, four-domain YDCM shows a SFDR of 110.22dB/$Hz^{2/3}$, which is 14dB higher than that of the two-domain YDCM. This could be understood as follow. Because both two and four-domain YDCM linear modulator derive their linearity from the cancellation of nonlinearity in adjacent domains, four domain YDCM could give better cancellation of nonlinear effect therefore better linearity. The design and fabrication process of 4-domain YDCM could be further optimized to deliver even better performance.

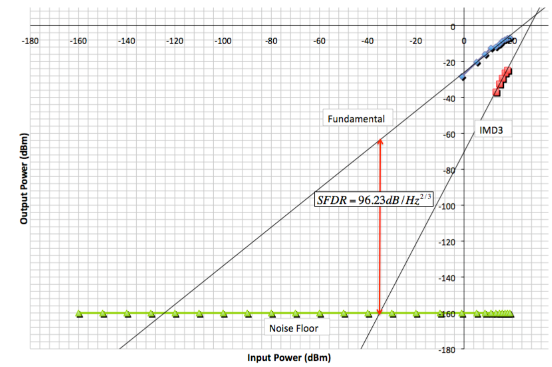

Fig. 4. Fundamental and IMD3 RF output powers versus input RF power for two-domain YDCM. Squares and diamond shapes dots are data points captured from HP8563E microwave spectrum analyzer.

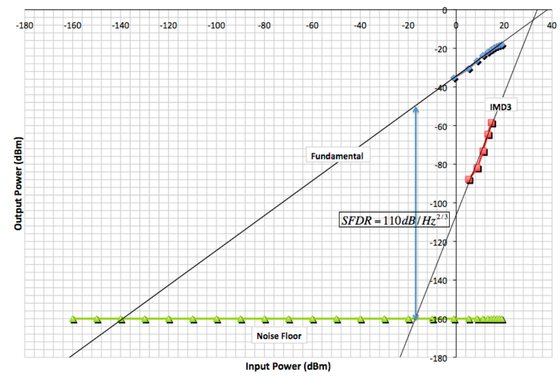

Fig. 5. Fundamental and IMD3 RF output powers as a function of input RF power for four-domain YDCM. Squares and diamond shapes dots are data points captured from microwave spectrum analyzer.

IV. CONCLUSION

In this work, two-domain and four-domain Y-branch directional coupler modulators were fabricated and tested for comparison. Four-domain YDCM with careful design showed 14dB improvement in SFDR compared to two-domain YDCM.

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V. REFERENCES

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