LETTER
IEICE Electronics Express, Vol.10, No.12, 1–6

Precise chirp parameter measurement of asymmetric Mach-Zehnder modulators with active Y-branch

Yuya Yamaguchi[1a)], Yuki Yamada[1], Atsushi Kanno[2], Tetsuya Kawanishi[2], Masayuki Izutsu[1], and Hirochika Nakajima[1]

[1] *Graduate School of Advanced Science and Engineering, Waseda University, 3–4–1 Okubo, Shinjuku, Tokyo 169–8555, Japan*

[2] *National Institute of Information and Communications Technology, 4–2–1 Nukui-Kita, Koganei, Tokyo 184–8795, Japan*

a) *l.yy-sponge-bob@fuji.waseda.jp*

Abstract: For precise chirp parameter control, we investigated x-cut $LiNbO_3$ single-drive asymmetric Mach-Zehnder modulators with extinction-ratio adjustable active Y-branch structures, which can enhance on-off extinction ratio. The chirp parameter of the modulated output was precisely measured by using high extinction ratio operation. Experimental results show that it is possible to fabricate modulators with desired chirp parameters.

Keywords: chirp, asymmetric, modulator, $LiNbO_3$, Mach-Zehnder

Classification: Optoelectronics, Lasers and quantum electronics, Ultrafast optics, Silicon photonics, Planar lightwave circuits

References

[1] F. Koyama and K. Iga: J. Lightwave Tech. **6** [1] (1988) 87.
[2] E. L. Wooten, K. M. Kissa, A. Y. Yan, E. J. Murphy, D. A. Lafaw, P. F. Hallemeier, D. Maack, D. V. Attanasio, D. J. Fritz, G. J. McBrien and D. E. Bossi: IEEE J. Sel. Topics Quantum Electron. **6** [1] (2000) 69.
[3] T. Sakamoto, T. Kawanishi, M. Tsuchiya and M. Izutsu: Proc. Summer Topical Meetings (2007).
[4] T. Kawanishi, K. Kogo, S. Oikawa and M. Izutsu: Opt. Comm. **195** (2001) 399.
[5] T. Kawanishi, T. Sakamoto, A. Chiba, H. Toda, A. Enokihara and H. Murata: IEICE Technical Report, OPE2008-99 (2008).
[6] Y. Ogiso, Y. Tsuchiya, S. Shinada, S. Nakajima, T. Kawanishi and H. Nakajima: IEEE Photon. Technol. Lett. **22** [12] (2010) 941.

1 Introduction

A chirp parameter is one of the most important parameters of optical modulators. In general, the chirp is defined by a ratio of amplitude and phase

DOI: 10.1587/elex.10.20130311
Received April 26, 2013
Accepted May 08, 2013
Publicized May 30, 2013
Copyedited June 25, 2013

IEICE Electronics Express, Vol.10, No.12, 1–6

modulation. Amplitude modulation causes temporal frequency variation of the modulated signal, unavoidable in many cases. The chirp parameter α is given by

$$\alpha = \frac{d\phi}{dt} \Big/ \left(\frac{1}{E} \frac{dE}{dt} \right) \tag{1}$$

where E and ϕ are the amplitude and phase of modulated optical electric field, respectively [1]. Chirp parameters of z-cut $LiNbO_3$ (LN) Mach-Zehnder modulators (MZMs) are typically 0.7 and those of x-cut ones are much smaller (< 0.1) [2].

It is frequently useful to control the chirp parameter. For example, a certain amount of chirp is desirable for long distance transmissions with dispersive fibers, and also for optical comb generations [3]. While, advanced format modulation such as quadrature amplitude modulation (QAM) requires to reduce the chirp parameters as small as possible. It is reported that using z-cut LN dual-drive modulators, we can adjust the chirp parameter to an intended value by tuning mutual amplitudes and phases of two input modulating signals. On the other hand, for x-cut one, control of the chirp is rather difficult since it is usually designed single-drive operation. The introduction of the control method of the chirp parameter is quite important for x-cut modulators, because x-cut single-drive modulators have the smaller effect of DC drift and required simpler operation systems as contrasted with z-cut dual-drive modulators. As shown in Fig. 1, we investigated a modulator structure with asymmetry to obtain a certain chirp parameter with an x-cut single-drive modulator.

A variety of methods has been reported to measure the chirp parameter [4], however, for precise chirp measurement, a use of extinction-ratio

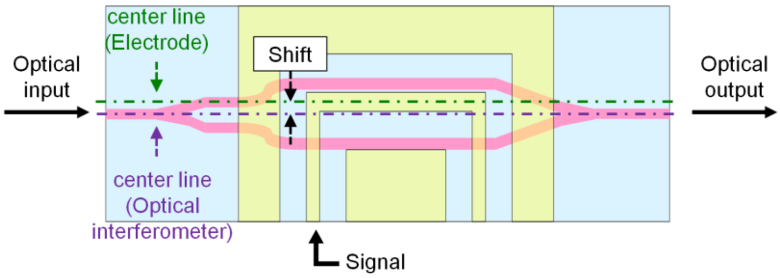

Fig. 1. Asymmetric MZM

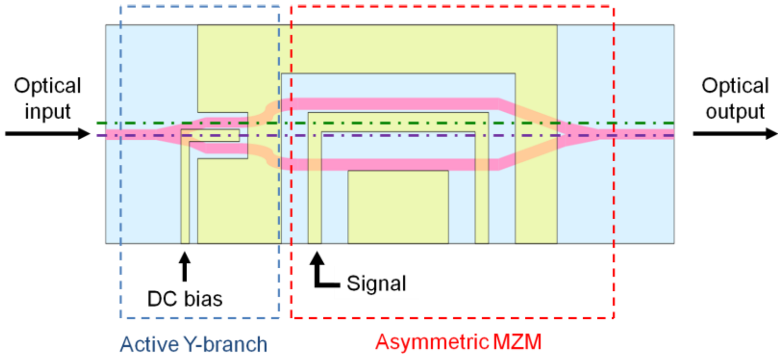

Fig. 2. Active Y-branch asymmetric MZM

DOI: 10.1587/elex.10.20130311
Received April 26, 2013
Accepted May 08, 2013
Publicized May 30, 2013
Copyedited June 25, 2013

IEICE Electronics Express, Vol.10, No.12, 1–6

(ER) adjustable modulator is required [5]. We have already reported an ER adjustable MZM using active Y-branch [6]. For the precise chirp measurement, it is suitable to use a similar structure of the device, as shown in Fig. 2.

2 Principle of chirp parameter measurement

We consider an output lightwave from an MZM driven by a sinusoidal modulating RF signal. The output electric field can be described by

$$E_{out} = \frac{E_{in}e^{j\omega_0 t}}{2} \sum_{n=-\infty}^{\infty} e^{jn\omega_m t}\left[J_n(A_1)e^{j\phi_{B1}}\left(1+\frac{\eta}{2}\right) + J_n(A_2)e^{j\phi_{B2}}\left(1-\frac{\eta}{2}\right)\right] \tag{2}$$

where $E_{in}e^{j\omega_0 t}$ is the input lightwave with a frequency ω_0, ω_m is frequency of the RF signal. ϕ_{B1} and ϕ_{B2} are the phase retardations by DC bias. J_n is the first-kind n-th order Bessel's function, and η indicates the optical amplitude imbalance of the MZ interferometer. After two lightwaves traveled through two different arms of the interferometer, the induced phase changes of the upper and the lower arms are given by $A_1 \sin(\omega_m t) + \phi_{B1}$ and $A_2 \sin(\omega_m t) + \phi_{B2}$, respectively, where A_1 and A_2 are amplitudes of electrooptically induced phase change [5]. Considering the asymmetry of push-pull modulation, we can indicate $A_1 = A + \alpha_A$ and $A_2 = -A + \alpha_A$, where A and α_A are balanced and unbalanced components of the induced phase changes, respectively. From Eq. (1), the chirp parameter α is approximated by α_0 [4].

$$\alpha_0 \equiv \frac{\alpha_A}{A} = \frac{A_1 + A_2}{A_1 - A_2}. \tag{3}$$

For the ideal push-pull modulator, α_A and therefore α_0 will be zero.

When the modulator is driven at a bias condition of the minimum transmission point ($\phi_{B1} - \phi_{B2} = \pi$), the condition to suppress E_0 (amplitude of the zero-th order component in Eq. (3)) to be zero is given by

$$\eta = \frac{2[-J_0(A+\alpha_A) + J_0(A-\alpha_A)]}{J_0(A+\alpha_A) + J_0(A-\alpha_A)} \tag{4}$$

in addition to the trivial case ($\alpha_A = \eta = 0$) [4]. Under the condition, the ratio of amplitudes of the first- and second-order sidebands, E_1 and E_2, respectively, is described by

$$\frac{E_2}{E_1} = \alpha_0 \left[A - 2\frac{J_2(A)}{J_1(A)} + A\frac{J_2(A)}{J_0(A)}\right]. \tag{5}$$

Thus, the ratio of E_1 and E_2 is proportional to the chirp parameter α_0. To derive the chirp parameter, the parameters E_1, E_2 and A under the double sideband suppressed carrier (DSB-SC) operation are necessary to be measured experimentally. The spectrum modulated by the single-drive one is symmetric, i.e., upper and lower sideband components have the same amplitudes, while for the dual-drive modulators, skew between the phases of two driving signals causes asymmetry of the modulated spectrum. The higher

DOI: 10.1587/elex.10.20130311
Received April 26, 2013
Accepted May 08, 2013
Publicized May 30, 2013
Copyedited June 25, 2013

IEICE Electronics Express, Vol.10, No.12, 1–6

order harmonics of electrical signal source also make the spectrum asymmetry, so that we should use a pure modulating signal without harmonics. The induced phase change A can be calculated from

$$\left|\frac{E_1}{E_{00}}\right| \approx |J_1(A)| \tag{6}$$

where E_{00} is an amplitude of a zero-th order component without modulation. By measuring E_1 and E_{00} from the optical spectra with and without modulation, we obtain A from Eq. (6). Thus, by observing the optical spectrum with DSB-SC operation, contrasted with the one of no modulation, under this condition, we can estimate the chirp parameter from Eq. (5).

3 Device fabrications

To produce an asymmetry on the induced amplitude and phase of the device, we give a displacement, or shift s, between center axes of the electrode and the waveguide interferometer. We fabricated three modulators of different s from the same wafer; $s = 0\,\mu$m (as symmetric case), $2\,\mu$m, and $4\,\mu$m (as asymmetric cases).

We used an x-cut LN wafer as substrate and fabricated Ti-diffused optical waveguides. Ti stripes (width: $6\,\mu$m, thickness: 90 nm) with waveguide pattern (separation: $23\,\mu$m) were deposited on the $-x$ surface and diffused at 970°C for 20 hour with a wet-O_2 gas flow. As an optical buffer layer, we deposited SiO_2 (thickness: $1\,\mu$m) on the LN wafer. MZ signal electrodes (coplanar waveguide, width: $7\,\mu$m, gap: $25\,\mu$m, effective length: 26 mm) and active Y-branch electrodes (effective length: 1.3 mm) were fabricated by electroplating gold (thickness: $20\,\mu$m). The half wave voltages of fabricated modulators were around 3.8 V, and electrical 6-dB bandwidths (S_{21}) were around 15 GHz.

4 Precise measurement of chirp parameter

To measure the chirp parameter, we generated optical modulated signals at DSB-SC operation. Figure 3 shows the experimental setup. The input lightwave wavelength was 1550 nm and the output power was 0 dBm. We used polarization controller to adjust the polarization to TE mode to input the modulator. To suppress the polarization crosstalk, we put a polarizer on

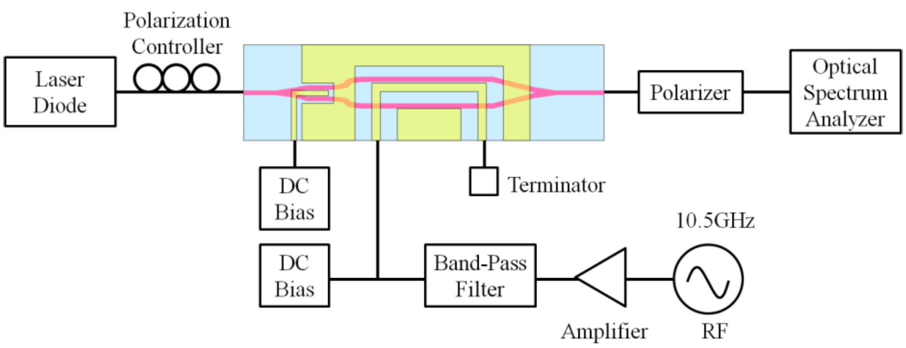

Fig. 3. Experimental setup

DOI: 10.1587/elex.10.20130311
Received April 26, 2013
Accepted May 08, 2013
Publicized May 30, 2013
Copyedited June 25, 2013

output side of the modulator. The modulator was driven by an RF signal (22.8 dBm, 10.5 GHz), and applied DC bias was set at the bottom point of modulation curve. To suppress the higher order harmonics of electrical signal source, we inserted an electrical band-pass filter. By adjusting the applied voltage to the active Y-branch, the carrier component (zero-th order sideband) of the measured optical spectrum was suppressed to the minimum value.

The optical spectra with the three modulators of different s were shown in Fig. 4. In each case, the carrier component was suppressed to less than −65 dBm by applied voltage to the active Y-branch to minimize the ER. On the other hand, the suppressions of second-order sidebands were different with depending on s. We could confirm the electrode shift caused the chirp. Figure 5 summarizes the relation between the electrode shift and the calculated chirp parameters from applying the observed parameters to Eq. (5), compared with the theoretical value from a simulation by the beam propagation method. The measured values were accorded with simulated line, although there was a little error. If we assume 1 μm misalignment in patterning process, two lines show good agreement.

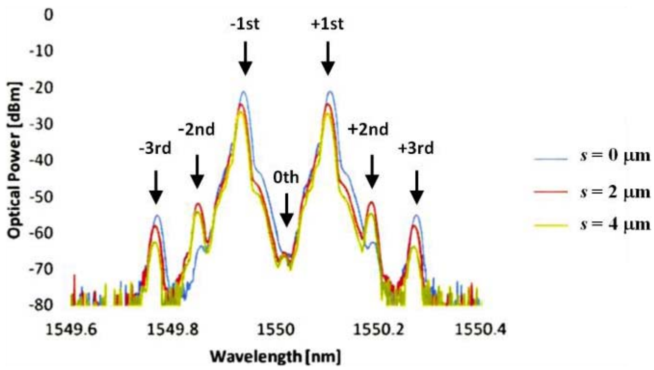

Fig. 4. Measured optical spectra for different shifts

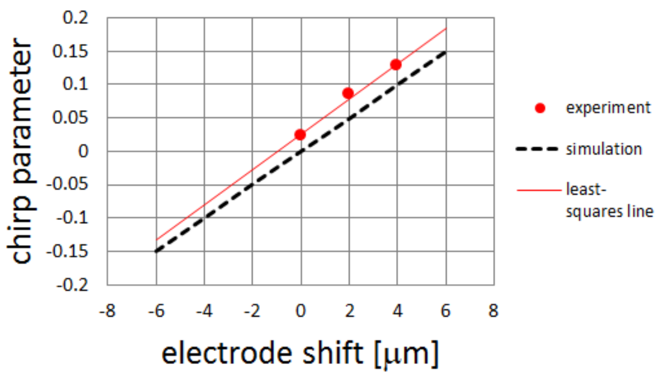

Fig. 5. Measured and calculated chirp parameters. The narrow line is obtained by the least-squares method

© IEICE 2013
DOI: 10.1587/elex.10.20130311
Received April 26, 2013
Accepted May 08, 2013
Publicized May 30, 2013
Copyedited June 25, 2013

5 Conclusion

We proposed x-cut LN asymmetric modulators with an active Y-branch, and precisely measured their chirp parameters. The measured chirp parameters were well accorded with the designed values from the simulation. Although there is small difference between a designed and a measured values attributable to the unavoidable fabrication error, we can conclude that it is possible to build an x-cut LN modulator of intended chirp parameter. In case we need to reproduce a chirp parameter with a tolerance less than 0.02, better processing system will be required. The accurate setting of the chirp parameter with the proposed precise measurement technique is capable for huge capacity optical transmission, microwave signal generation and sensing systems.

6 Acknowledgements

The authors would like to thank J. Ichikawa, S. Oikawa and K. Higuma of Sumitomo Osaka Cement Co., Ltd., Japan, Y. Oikawa of Trimatiz Ltd., Japan, and S. Nakajima of NICT for useful discussions. A part of this research is the result of research commissioned by National Institute of Information and Communications Technology (NICT) entitled "Agile Deployment Capability of Highly Resilient Optical and Radio Seamless Communication Systems."

DOI: 10.1587/elex.10.20130311
Received April 26, 2013
Accepted May 08, 2013
Publicized May 30, 2013
Copyedited June 25, 2013