Monolithically Integrated Coherent Receiver for Highly Linear Microwave Photonic Links

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***Abstract*— A compact monolithically integrated coherent receiver with feedback has been fabricated for linear optical phase demodulation. The photodiodes demonstrate a saturation current greater than 60 mA and an OIP3 of 35 dBm at 40 mA.**

I. Introduction

Phase modulation can be used to improve the signal-to-noise ratio (SNR) and spur-free dynamic range in microwave photonic links as long as the signal phase can be linearly demodulated. Traditional interferometer based demodulators have a sinusoidal response therefore a novel approach is required to build a linear phase demodulator. We have demonstrated a coherent receiver with feedback to a reference phase modulator [1], [2]. For high loop gain the received signal phase is closely tracked and the phase detection falls within the linear regime of the sinusoidal response. In order to operate at high frequency, the delay of the feedback loop must be kept short to prevent instability. A monolithically integrated receiver is therefore required to realize high frequency operation. Here we present a compact monolithic coherent receiver that consists of MQW phase modulators, a 2x2 multimode interference (MMI) coupler, and a high power balanced uni-traveling-carrier photodiode (UTC-PD) as shown in Fig. 1. This photonic integrated circuit is designed for hybrid integration with an electronic integrated circuit that can provide transconducance amplification of the feedback signal.

II. Device Design and Results

The device structure is designed to incorporate the following optical functions: phase modulation, low loss propagation, and photodetection. The structure is grown on a semi-insulating InP substrate by MOCVD. The optical waveguide consists of a MQW stack for efficient phase modulation. The UTC-PD structure is grown directly above the waveguide. The layers of the photodiode (PD) structure are selectively removed prior to the p^+-InP cladding and p^{++}-InGaAs contact layer regrowth in order to form the photodetection regions. The 2x2 MMI coupler is fabricated in a surface ridge and is 350 μm in length. A metal pad is integrated in a section in the center of the MMI for current injection tuning. In order to build a balanced UTC-PD, adjacent PDs are electrically isolated with high energy Helium implantation and then connected in series with a monolithic metal interconnect.

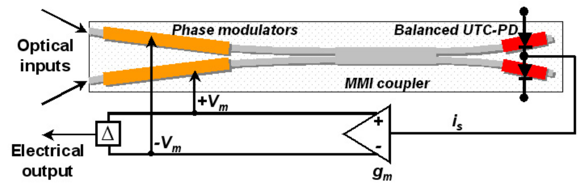

Fig. 1. Integrated coherent receiver device schematic.

Although the feedback loop suppresses nonlinearities in the interferometer, the linearity of the reference phase modulator needs to be addressed. Phase modulation in InP QCSE modulators is dominated by the quadratic electro-optic effect. By incorporating phase modulators into both input arms and driving them differentially, the linear term is doubled while the second order term as well as higher even order terms are canceled. With this push-pull configuration, the efficiency is therefore doubled and the third-order nonlinearities can be suppressed by adjusting the bias. The absorption spectra of the phase modulator structure were measured and from these measurements the efficiency of a single modulator was extracted using a Kramers-Kronig transformation. For a modulator length of 560 μm, V_{pi} is 5.0 V at 1540 nm. The efficiency can be improved simply by increasing the modulator length. With a more efficient modulator, the feedback loop gain requirements are less stringent, however with a longer modulator the loop delay increases. Therefore it is desirable to use very efficient modulator structures so that the modulator length can be kept short.

The design of the MMI is important in that the excess loss should be kept low so that maximum transmission of optical power to the PDs is allowed. The tuning of the splitting in a MMI relies on a refractive index change in one interval where the field is imaged in order to produce new phase relations in the next interval. Fig. 2 shows the splitting properties of the MMI coupler. With low levels of injected current the splitting ratio can be fine tuned. The effect of the tuning section length on the tuning efficiency is shown in Fig. 3. As shown, a 100 μm long tuning section is more efficient than a 300 μm long tuning section.

It is important that the PDs can operate under high current, for high SNR, and that they are linear. UTC-PDs are used

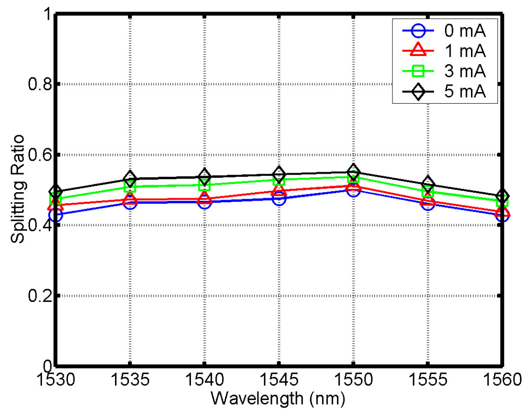

Fig. 2. MMI splitting ratio as a function of wavelength for different levels of tuning current.

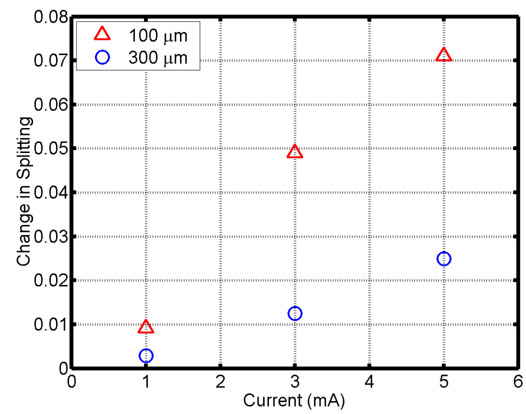

Fig. 3. Change in splitting as a function of injected tuning current for a 100 μm long tuning pad and a 300 μm long tuning pad.

because they are designed for high current operation. We previously reported UTC-PDs with 40 mA saturation current and an OIP3 of 34 dBm at 40 mA [3]. We have since improved the design of the UTC-PD structure to increase the output saturation current. Fig. 4 shows the normalized RF power as a function of DC photocurrent at several frequencies. The saturation current is greater than 60 mA in all cases. This is among the highest reported saturation current for a waveguide PD at comparable frequencies. Fig. 5 shows the results of third-order intermodulation distortion measurements at a DC photocurrent level of 40 mA. The measured OIP3 is 31 dBm for a bias of -5 V and 35 dBm for a bias of -5.8 V.

III. Conclusions

We have demonstrated a monolithic coherent integrated receiver for a novel feedback loop architecture. The performance of the optical phase modulators, the 2x2 MMI coupler, and the balanced UTC-PD as well as their impact on the operation of the feedback system have been discussed.

Acknowledgment

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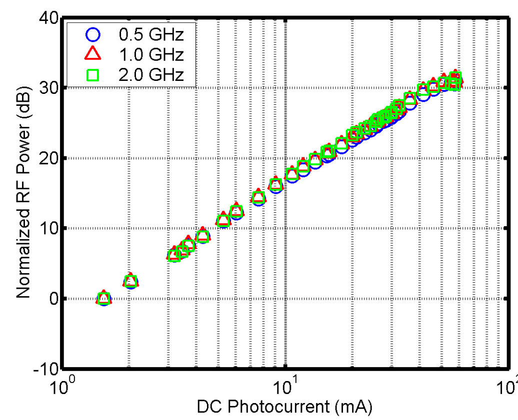

Fig. 4. Normalized RF power as a function of DC photocurrent at 0.5 GHz, 1.0 GHz, and 2.0 GHz. The bias is -3.5 V for all measurements.

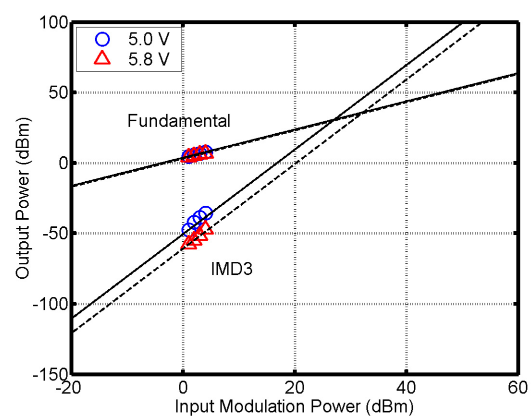

Fig. 5. Two-tone IMD3 measurements at a DC photocurrent level of 40 mA for biases of -5.0 V and -5.8 V.