Monolithic integration of distributed balanced photodetectors for high performance RF photonic links

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ABSTRACT

We report on the microwave performance of a novel velocity-matched distributed balanced photodetector. A 30-dB rejection of the common mode signals and a 17-dB suppression of the laser relative intensity noise have been achieved.

I. INTRODUCTION

Balanced photodetectors play a very important role in high performance RF photonic systems. When used in conjunction with an external modulator with complementary outputs, shot noise-limited system performance can be achieved [1]. Because balanced photodetector can suppress the laser intensity noise and amplified spontaneous emission noise of fiber amplifiers, the noise figure and the spurious-free dynamic range (SFDR) can be further improved by increasing the optical power. To fully exploit the advantages of the balanced systems, balanced photodetectors with high saturation photocurrents and broad bandwidth are required. Monolithically integrated balanced photodetectors offers many advantages, including superior performance (broader bandwidth, better matching of photodiodes) and reduced packaging cost [2]. However, most of the integrated balanced photodetectors reported to date have low saturation photocurrents and are not suitable for analog applications [2-4].

Previously, we have reported a novel distributed balanced photodetector [5]. It integrates two velocity matched distributed photodetectors (VMDP) with a microwave coplanar waveguide (CPW). This new device inherits the basic advantages of the VMDP, namely, broad bandwidth and high saturation photocurrent [6]. In this paper, we reported on the microwave performance of the monolithic balanced distributed photodetector. A 17-dB suppression of the laser relative intensity noise (RIN) has been achieved in the RF photonic links employing the balanced VMDP.

II. DESIGN AND FABRICATION

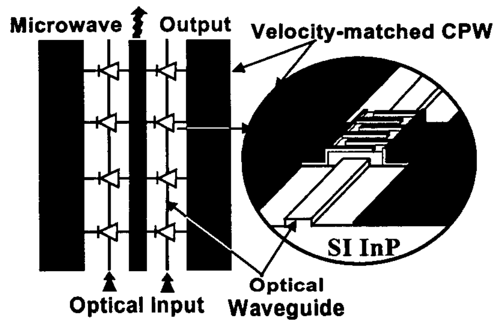

Figure 1. Schematic structure of the distributed balanced photodetector. The inset shows the active region with an MSM photodiode.

Figure 1 shows the schematic of the distributed balanced photodetector. It consists of two input optical waveguides, two arrays of high-speed metal-semiconductor-metal (MSM) photodiodes distributed along the optical waveguides, and a 50Ω coplanar waveguide (CPW) output transmission line. When the top ground electrode of the CPW is biased at a positive voltage, the two photodiodes in the same column form a balanced detector. The DC photocurrent (common mode signal) flows directly to the bottom ground electrode while the difference photocurrent (signal) flows to the center conductor. The signal is then collected by the CPW. The velocity matching between the optical waveguides and the CPW ensures broadband operation of the distributed balanced photodetector. It should be noted that even though only the difference photocurrent is collected, the individual photodiodes still absorb the DC part of the signal. As a result, balanced photodetector requires *high DC saturation photocurrent*. This is accomplished by the distributed absorption, as in the VMDP.

Beam propagation method (BPM) was used to simulate the optical properties of the balanced VMDP. The optical waveguide consists of a 200-nm-thick $In_{0.52}Al_{0.37}Ga_{0.11}As$ lower cladding layer, a 500-nm-thick $In_{0.52}Al_{0.178}Ga_{0.302}As$ core region, a 200-nm-thick $In_{0.52}Al_{0.37}Ga_{0.11}As$ first upper cladding layer, and a thin $In_{0.52}Al_{0.48}As$ second upper cladding layer. The MSM photodiodes with a 150-nm-thick absorption region is placed on top of the waveguide for evanescent coupling. We used a thin $In_{0.52}Al_{0.48}As$ cap layer to increase the Schottky barrier height. A graded layer is incorporated to reduce carrier trapping at the InAlAs-InGaAs band edge discontinuity. The fabrication process will be reported elsewhere.

III. MEASUREMENTS

The balanced VMDP exhibits very good electrical and optical characteristics. The dark current is measured to be 28μA/cm^2 at 10 V bias, the lowest reported for InAlAs/InGaAs MSM photodiodes. The low dark current is attributed to the sidewall passivation and the electric insulation of the MSM tips [7]. Using a lensed fiber, the average DC responsivity was measured to be 0.45A/W at 8 bias. Responsivity as high as 0.6A/W has been observed in some devices. With anti-reflection coating, the average responsivity can be increased to 0.64 A/W. An HP 8510C network analyzer was used to measure the characteristic impedance and the microwave return loss (S_{11}) of the balanced receiver. The characteristic impedance of the receiver is very well matched to 50Ω. The S_{11} is as low as -30 dB from 0.1 GHz to 40 GHz. The CPW also has very low insertion loss. The measured S_{12} shows a drop of only 0.6 dB from 0.1 GHz to 40 GHz.

Using the optical heterodyne technique with two external cavity tunable semiconductor lasers at 1.55 μm, the 3-dB bandwidth was found to be 16 GHz. The bandwidth is currently limited by the carrier transit time of the MSM photodiodes. Since our bandwidth of the capacitance loaded CPW is much greater than 40 GHz, the bandwidth of the balanced VMDP can be increased by scaling down the MSM photodiodes. Theoretical simulation indicates that bandwidth > 100 GHz is achievable.

Figure 2 depicts the experimental setup for balanced detection. A distributed feedback (DFB) laser with 1542-nm wavelength and 0 dBm output power is employed as optical source. It is amplified by an erbium-doped fiber amplifier (EDFA) and then filtered by an optical bandpass filter with 2-nm bandwidth. The microwave signal was modulated onto the optical carrier by an X-coupled Mach-Zehnder modulator, which produces two complimentary outputs for the balanced VMDP. The outputs are coupled to the balanced VMDP by two lensed fibers. To maximize the signal enhancement and noise cancellation, it is important to match the amplitudes and phases of the two detected microwave signals. In our experiment, a variable attenuator and a variable delay line were used to match the amplitudes and phases of the photocurrents. A common mode rejection ratio of -30 dB has been achieved.

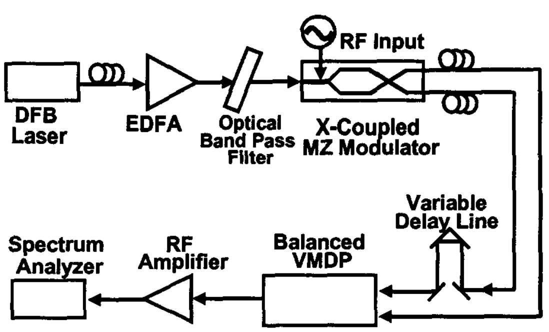

Figure 2. Experimental setup for balanced detection. The complimentary input signals are produced by the X-coupled MZ modulator.

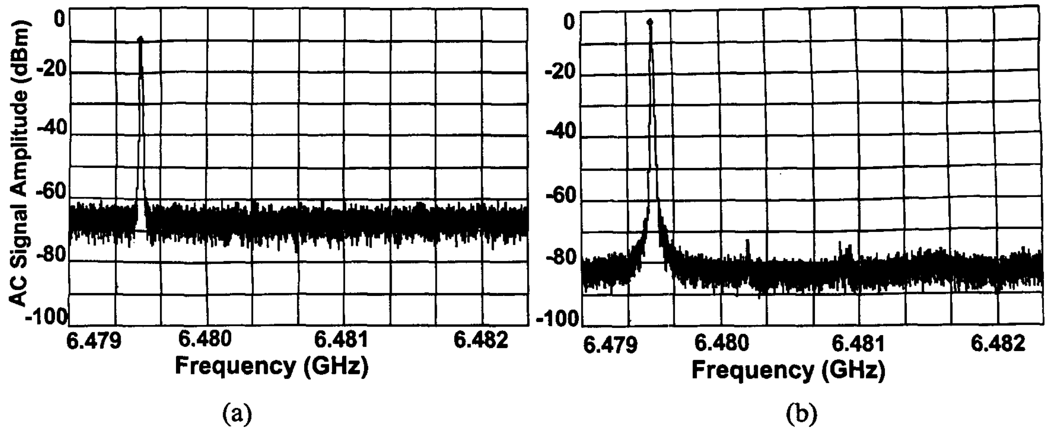

Figure 3. The RF spectra of the received signal in (a) unbalanced and (b) balanced detection modes are plotted. The signal in the balanced mode is 6 dB higher than the unbalanced signal. Noise suppression of greater than 17-dB is achieved.

Figure 3 shows the RF spectra of the outputs from the device in the unbalanced (only one waveguide is illuminated) and the balanced mode. Suppression of the noise floor by 17-dB has been observed in the balanced mode over a wide frequency range from 6 to 15 GHz. This is equivalent to 23-dB improvement of noise if two outputs were considered. The signal is also enhanced by 6-dB. We are currently working on the measurement of the AC responsivity of the device in the balanced mode equalizing the optical path lengths of both the branches of the MZM that goes to the balanced receiver.

IV. CONCLUSION

We have successfully designed, fabricated and experimentally demonstrated a balanced velocity-matched distributed photodetector (VMDP) with both impedance and velocity matching. The device exhibits a very low dark current and an external quantum efficiency of 0.64 A/W. The laser relative intensity noise (RIN) has been suppressed by 17-dB, and the signal has been enhanced by 6-dB. To our knowledge, this is the first monolithic distributed balanced photodetector reported to date. The distributed balanced photodetector will have a broad impact on RF photonic systems.

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