Noise Performance of a Two-Terminal InP/InGaAs Heterojunction Phototransistor Optoelectronic Mixer

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Summary

Introduction

Two-terminal edge-coupled heterojunction phototransistors (HPTs) have shown excellent photoresponsivity [1] which is desirable in optical communications. The authors have recently reported that such an HPT can be used as an optoelectronic mixer [2] with conversion gain greatly exceeding other photodetector-mixer combinations. In this paper we report on the noise performance of the HPT used as a photodetector and as an optoelectronic mixer. To the authors’ knowledge, these are the first published noise measurement results on two-terminal HPT optoelectronic mixers.

Experimental Details

Full details of the two-terminal InP/InGaAs HPT used in the experiment are given in [1]. Light was edge-coupled to the base in parallel with the epi-layer of the device. The collector was grounded.

In the mixing experiment, the RF input, LO and mixed IF output were chosen to be 2.81GHz, 2.92GHz and 110MHz, respectively. In the direct photodetection measurements, the 2.81GHz RF was used. Fig. 1 shows the experimental arrangement. The optical source was a 1550nm wavelength DFB laser. The laser was directly modulated by a -10dBm RF signal for the signal-to-noise ratio (S/N) measurements; during the noise measurements, the RF drive was turned off. Using an HP70800/HP70810B lightwave signal analyzer (LSA) with the internal RIN calculation program, the relative intensity noise (RIN) of the laser was measured to be -135.4dB/Hz at 110MHz and -129.9dB/Hz at 2.81GHz. For the mixing experiments, the emitter was pumped by the 2.92GHz, 10dBm LO via a microstrip coupled-line diplexer. The output IF signal was extracted from the other port of the diplexer. A broadband amplifier with a nominal gain of 18dB and noise figure of 8dB was employed to improve the sensitivity of the spectrum analyzer used for measuring detected RF and IF signal.

Signal Gain and Conversion Gain definitions

The HPT input is optical while the output is electrical. To characterize device performance, it is convenient to convert the input to the equivalent electrical power that would be generated by an ideal 100% quantum efficient photodetector operated at the laser modulation frequency and terminated in the 50Ω system impedance. The modulated optical beam can be described by

\[ P_{\text{opt}} = P_{\text{avg}} + P_{\text{mod}} \cos \left( 2\pi f_m t \right) \]

\[ = P_{\text{avg}} \left[ 1 + m \cos \left( 2\pi f_m t \right) \right] \]

where \( P_{\text{avg}} \) is the average optical power, \( P_{\text{mod}} = m P_{\text{avg}} \) is the peak modulated optical power, \( m \) is the modulation index and \( f_m \) is the modulation frequency of the laser beam. \( m \) was measured using the LSA. The peak

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Fig. 2: HPT signal gain, measured and calculated noise PSDs for direct photodetection at 2.81GHz (RF). Average incident optical power=0.8mW.

Fig. 3: HPT signal gain at 110MHz when pumped by LO and mixer conversion gain. Incident optical power=0.8mW. For mixing measurements the input was the 2.81GHz RF modulated laser beam and the output was the mixed IF at 110MHz.

alternating current due to $P_{\text{mod}}$ generated in an ideal photodetector is

$$i = \frac{qP_{\text{mod}}}{hv}$$

where $q$ is the electron charge, $h$ is Planck’s constant and $v$ is the optical frequency. Therefore the electrical power generated by the ideal photodetector terminated in system impedance $R_L$ is

$$P_{\text{elec}} = \left( \frac{qP_{\text{mod}}}{hv} \right)^2 \frac{R_L}{2}$$

The equivalent electrical noise power spectral density (PSD) of the laser beam is equal to the laser RIN multiplied by the equivalent average electrical power generated in an ideal photodetector terminated in $R_L$.

In this paper the signal gain is defined as the ratio of the output power to the equivalent electrical input power at the same frequency and the conversion gain the ratio of the mixed output at IF to the equivalent electrical RF input power as if the HPT had an electrical input.

Results and analysis

The results here have been de-embedded so that they refer to signal levels at the HPT emitter. Fig. 2 shows the HPT signal gain and the measured and calculated noise PSDs at 2.81GHz for direct photodetection. For $V_{\text{ce}}>0.3V$, the measured and calculated noise PSDs were virtually identical and followed the same shape as the signal gain of the HPT. For smaller $V_{\text{ce}}$, the measured PSD was greater than the calculated PSD because of the noise floor of the spectrum analyzer. It is clear that at this input optical power level the noise level was RIN limited.

Fig. 3 shows the HPT conversion gain and the signal gain. The signal gain in Fig. 3 was measured at 110MHz when the HPT was being pumped simultaneously. Since the signal gain of the HPT at 110MHz was much greater (>10dB) than at 2.81GHz (Fig. 2), the measured noise PSD was mainly due to the laser intensity noise at 110MHz amplified by the HPT signal gain at the same frequency, as shown in Fig. 4.

Fig. 5 shows the S/N for direct photodetection, mixing and the difference in S/N between these two processes. Since the measured noise for direct photodetection was mainly due to that of the optical input (Fig. 2), it is plausible to take the noise PSD and the S/N of the
optical input as those of the HPT in this process, minimizing the error caused by the spectrum analyzer's noise floor. It is seen that the maximum S/N in mixing occurred at the lowest Vce while the maximum conversion gain occurred when Vce=0.6V (Fig. 3).

Conclusion

We have shown that the noise penalty arising from the two-terminal HPT was very small for the operating conditions used here. The measured noise for direct photodetection and optoelectronic mixing was mainly due to the laser noise being amplified by the HPT signal gain. This is because the shot noise due to photogenerated bias current was smaller than the laser RIN. The noise penalty for mixing varied between 12dB and 22dB depending on HPT bias. This penalty was almost entirely due to direct detection of IF RIN by the optoelectronic mixer. Thus it is important to use optical sources having low IF RIN in deployed systems, requiring careful attention to optical back-reflection control.

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References
