Spur-Free Dynamic Range Measurements of the Hybrid Light Emitting Transistor

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ABSTRACT

This letter reports the spur free dynamic range (SFDR) of hybrid light emitting transistors operating in the common-emitter configuration. Two tone signals at 0.995 GHz and 1.005 GHz are used to modulate the base of the hybrid Light-Emitting Transistor (LET) at a base current (I_B) of 3 mA. The second-order intermodulation distortion (IM2) and third-order intermodulation distortion (IM3) are determined to be 70.6 dB-Hz$^{1/2}$ and 86.3 dB-Hz$^{2/3}$ respectively. An optical bandwidth measurement f_{3dB} for the hybrid LET of 5 GHz is also demonstrated.

INTRODUCTION

Photonic devices are commonly used in digital transmission over fiber optic cables, but the ability to transmit analog signals is also of fundamental importance. The market for analog optical links has experienced steady growth over the past 15 years for many application such as RF-over-fiber, analog links for cable television (CATV) signals, and military markets. The need to expand network capacity has also led to the exploration of advanced modulation formats that put further demands on device performance. Among the criteria for good analog links are low relative intensity noise (RIN) and high spur-free dynamic range (SFDR). This abstract provides the first report of the Spur Free Dynamic Range (SFDR) of Light Emitting Transistors (LETs). The LET, invented in 2003 by Holonyak and Feng, came from recognition that transistor base recombination in a direct-gap material generates light related to the applied signal.[1,2] The transistor laser (TL), a laser version of the LET, has shown superior low relative intensity noise (-151 dB/Hz) at frequency 8.6 GHz.[3] The goal of this work is to investigate hybrid-LET spur free dynamic range for potential use in microwave analog optical links.

The hybrid-LET is a LET with integrated passive components (RLC) for AC and DC voltage regulation. We have performed hybrid-LET SFDR measurements as a function of base current to study the optimum bias condition for achieving the highest dynamic range. The highest reported SFDR (IM3) for an edge-emitting distributed feedback (DFB) laser emitting at 1300 nm is 100 dBHz$^{2/3}$ for frequencies below 1 GHz[4] and for a vertical cavity surface emitting (VCSEL) laser emitting at 850 nm is 113 dB-Hz$^{2/3}$.[5] For 1550 nm VSCELs, the highest IM3 SFDR reported is 81dB-Hz$^{2/3}$.[6] The highest SFDR of a Light-Emitting Diode (LED) reported to date is 39 dB at 100 MHz using single tone measurement.[7] This work shows that hybrid-LETs have significantly better SFDR performance than LEDs, and similar performance to 1550 nm VCSELs.

EPITAXIAL LAYER STRUCTURE AND PROCESS

The hybrid-LETs are grown on a (100) semi-insulating GaAs substrate with an epitaxial layer structure consisting of a 5500 Å *n*-type heavily doped GaAs collector contact layer, a 120 Å *n*-type $In_{0.49}G_{0.51}P$ etch stop layer, a 3000 Å undoped GaAs collector layer followed by a 1600 Å *p*-type GaAs base layer containing two 120 Å undoped InGaAs quantum well QWs designed for emission at λ=1000 nm, and a 120 Å *n*-type $In_{0.49}Ga_{0.51}P$ emitter layer capped with a total thickness of 2200 Å of GaAs and a graded heavily n-type $In_{0.5}Ga_{0.5}As$ contact layer.

The crystal is processed using standard photolithographic masking, patterning and etching processes. The wafer is then thinned and polished to 100 um. Lastly, a micro-lens is fabricated on at the back of the LET active area to maximize coupling of the light output into multimode fiber. The hybrid-LET wafer is singulated into die, and then flip-chip attached onto a ceramic substrate and printed circuit board (PCB).

A scanning electron microscope (SEM) photomicrograph showing a cross section of the hybrid-LET device used in the SFDR measurements is shown in Fig.1. The device used in this test has an emitter length of 15 um and an emitter width from emitter mesa edge to emitter contact of 1um for each side. An optical photomicrograph showing the micro-lenses fabricated on the bottom-side of the hybrid-LET to enhance optical extraction is presented in Fig. 2.

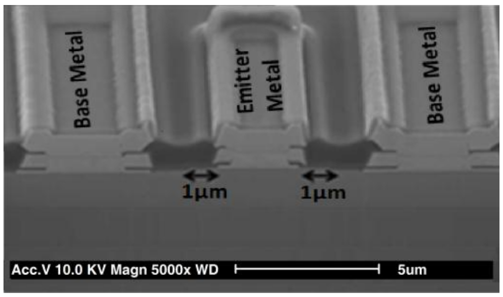

FIG. 1. Scanning electron microscope photomicrograph showing the cross section of the hybrid-LET.

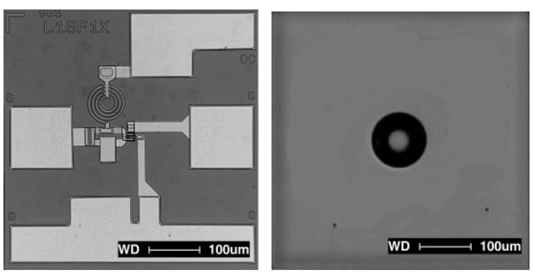

FIG. 2. Optical photomicrographs showing the top view of the LET and the bottom view of the hybrid-LET micro-lens.

The SFDR is defined as the dynamic range difference in dB between the minimum discernible signal and the signal that causes a specified amount of harmonic distortion. In our measurement, we use an Agilent PNA-X to generate the two-tone signal at 0.995 GHz and 1.005 GHz and modulate the base of the hybrid-LET. The modulated optical output from the hybrid-LET is coupled into multimode fiber and brought to a high-speed photodetector to convert the optical signal into an electrical signal driving the PNA. The second-order intermodulation (IM2) and third-order intermodulation (IM3) harmonics on the optical output are characterized. At a base current (I_B) of 3 mA, we measured a SFDR (IM2) of 70.6 dB-$Hz^{1/2}$ and a SFDR (IM3) of 86.3 dB-$Hz^{2/3}$ as shown in Fig. 3. The 2^{nd} order intercept point (IP2) and 3^{rd} order intercept point (IP3) correspond to the extrapolated input power level or output power level at which the 2^{nd} and the 3^{rd} order intermodulation products would exhibit the same power level as the fundamental tone power.[8] In our hybrid-LET SFDR measurement, the corresponding 2^{nd} order input intercept point (IIP2) and 3^{rd} order input intercept point (IIP3) are 36.4 dB and 24.5 dB. The 2^{nd} order output intercept point (OIP2) and 3^{rd} order output intercept point (OIP3) are found to be 39.5 dB and 30.2 dB. We also observed that the spur free dynamic range of the hybrid-LET increases with bias as shown in Fig.4 and tabulated in Table 1. At low bias, the hybrid LET intermodulation is higher because it is dominated by the non-linearity of the I-V characteristic near the device's turn on voltage. As the bias increases, the modulation is further away from the non-linear turn-on voltage and the dynamic range increases. However, the dynamic range does not continue to increase with increasing current. At high current, electron rethermalization from the quantum wells increases and contributes to the L-I rollover. [6]

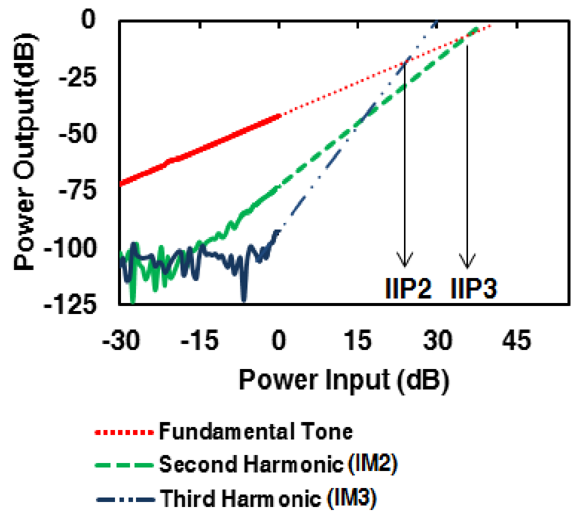

FIG. 3. (a) Two tone 0.995 and 1.005 GHz spur free dynamic (SFDR) measurement of a hybrid-LET at a base current bias (I_B) of 3 mA.

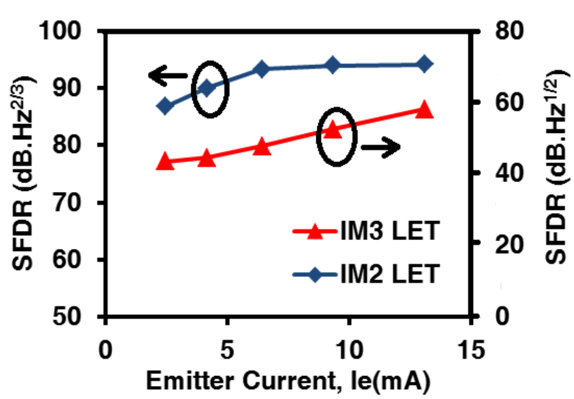

FIG. 4. SFDR for IM3 and IM2 of a hybrid-LET at different base current bias (I_B) values.

We further compare the hybrid-LET optical bandwidth and SFDR performance with edge-emitting LEDs designed for telecommunications applications. The optical bandwidth of the hybrid-LET is 5 GHz as compare to the LED which is 70 MHz as shown in Fig. 5. Using the same measurement apparatus we analyze the SFDR of the hybrid-LET and LED at different emitter bias level at two tone frequencies of 60 MHz and 61 MHz as shown in Fig. 6. The two-tone frequencies are chosen to be close to the f_{3dB} of the LED. At an emitter current 7 mA, the hybrid-LET IM2 and IM3 SFDR is higher than the LED by 20 dB-Hz$^{1/2}$ and 19 dB-Hz$^{2/3}$ respectively.

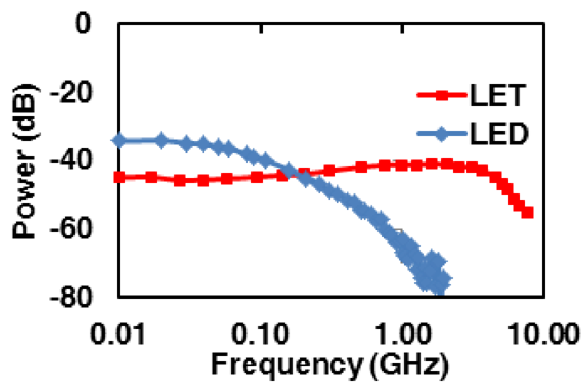

FIG. 5: Measured optical microwave response of the light emitting transistor (hybrid-LET) and light emitting diode (LED) at a current of 13 mA.

TABLE 1: Summary of light emitting transistor (Hybrid-LET) dynamic range characteristics

Ib (mA)	IM2 (dB-Hz$^{1/2}$)	IM3 (dB-Hz$^{2/3}$)	IIP3 (dB)	IIP2 (dB)	OIP3 (dB)	OIP2 (dB)
0.5	60.3	79.4	14.2	15.7	23.6	28.5
1.0	58.8	77.1	10.7	12.5	20.9	25.9
1.5	64.0	77.8	11.7	22.9	20.2	31.9
2.0	69.3	79.8	14.7	33.5	22.3	37.4
2.5	70.3	82.7	19.1	35.6	25.9	38.7
3.0	70.7	86.3	24.5	36.4	30.2	39.5

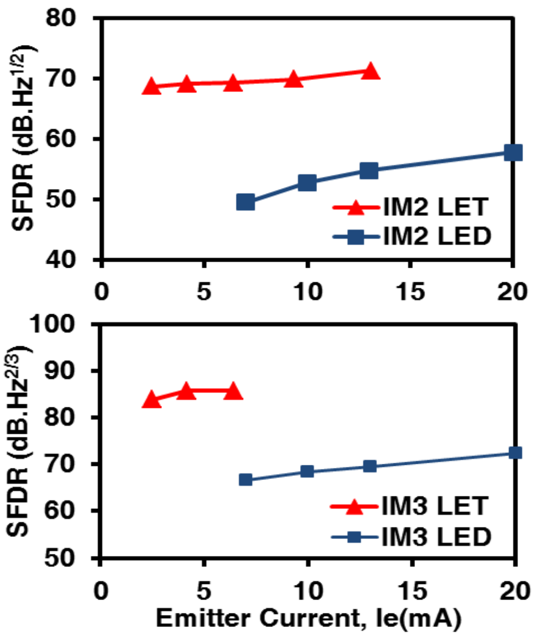

FIG. 6. Spur free dynamic range dependency of the hybrid-LET and LED at different emitter bias using two tone frequencies of 60 MHz and 61 MHz. (a) Measured IM2 of light emitting transistor (hybrid-LET) and light emitting diode (LED) (b) IM3 of light emitting transistor (Hybrid-LET) and light emitting diode (LED).

We conclude that the SFDR of the hybrid-LET shows ~20 dB improvement in performance relative to a conventional light-emitting diode. This is significant, as both devices utilize spontaneous emission. The hybrid-LET has low power consumption compared to laser-based links, even those based upon VCSELs. Additionally, the hybrid-LET can be directly driven – further reducing power dissipation. The hybrid-LET does not require complex driver circuitry and yet is able to achieve high dynamic range. It is potentially suitable for low cost short haul analog fiber links.

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ACRONYMS

Hybrid-LET: Hybrid Light-Emitting Transistor
SFDR: Spur Free Dynamic Range
LED: Light-Emitting Diode
IM2: Second-order intermodulation distortion
IM3: Third-order intermodulation distortion
IIP2: 2^{nd} order Input Intercept Point
OIP2: 2^{nd} order Output Intercept Point
IIP3: 3^{rd} order Input Intercept Point
OIP3: 3^{rd} order Output Intercept Point