International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 5 Issue 1, November-December 2020 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Review on High Gain and High Performance N-Polar GaN MIS-HEMT at 30 GHz

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ABSTRACT

The GaN HEMTs are well suited for receiver applications. But non-linearities, such as third-order inter modulation products can lead to signal distortion. Such non linearities are dominated by transconductance and its derivatives. A modified device structure of N-polar GaN MIS-HEMTs designed for high gain, have excellent linearity performance for low-power receiver applications at 30 GHz. An OIP3/PDC of up to 15dB is demonstrated at 30 GHz using a vector receiver load pull system.

KEYWORD: *GaN, N-polar, linearity, inter modulation distortion, Transconductance*

How to cite this paper: Padmam Gopinath Kaimal "Review on High Gain and High Performance N-Polar GaN MIS-HEMT at 30 GHz" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-5 | Issue-1, December 2020, pp.1166-1168, URL: www.ijtsrd.com/papers/ijtsrd38158.pdf

IJTSRD38158

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INTRODUCTION

As a semiconductor material, Galium Nitride (GaN) has higher electron mobility and higher electron saturation velocity compared to Si .This makes GaN excellent choice for high frequency operation .This material has bandgap of 3.4eV which is several times greater than that of Si[5]. GaN high electron mobility transistor (HEMT) have low on-state resistance and superior high-speed switching performance as well as high breakdown voltage. Technologies and research in GaN in scaling the gate length into deep submicron region have extended usable frequency range to millimeter waves. GaN HEMTs are mainly used for power amplification and for low power receiver applications.

The linearization technique in device level is discussed for receiver application. The parameters such as transconductance g_m and its derivatives(such as g_{m2} and g_{m3}) are the main factors that govern linearity of the device and intermodulation distortion [10].The intermodulation distortion are spurious frequency components[11] that can lead to signal distortion in front end receivers.

Under two-tone stimulus, the linearity metrics are IM3, C/IM3, OIP3 and $OIP3/P_{DC}$. The power in third-order intermodulation products is indicated by IM3.Ratio of carrier power to IM3 is shortly termed as C/IM3. Output-referred third order intercept point (OIP3) mentioned in [1], [10] is the deduced output power at which the carrier power equals IM3. OIP3 normalized over dissipated DC power ($OIP3/P_{DC}$), is a figure of merit for comparing the linearity among different devices and bias conditions, giving importance to power dissipation. This is the best metric for comparison of linearity among devices.

The device is designed for high transconductance .In order to decrease g_{m3} the biasing condition is selected for two-tone load-pull measurement. High transconductance indicates high gain .Low g_{m3} indicates high OIP3. For achieving linearity in device, some modifications in design structure in Ga polar GaN MIS HEMT in [6], [7], [8] as well as in N polar GaN MIS HEMT in [2], [3], [11] were reported .The device structure in [2] showed $OIP3/P_{DC}$of up to 11.4 dB at 30 GHz .

DEVICE STRUCTURE

The device structure from the N-polar GaN MIS-HEMT mentioned in [2] are modified using thin AlGaN/GaN cap which is used to improve gain and scaled gate-length for higher transconductance and low drain bias voltage [1] .

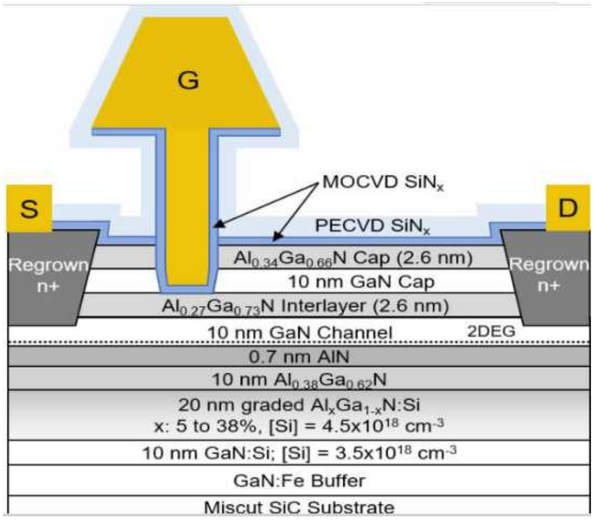

Fig 1 Cross sectional schematic of N-polar GaN MIS-HEMT [1]

Using metal organic chemical vapour decomposition (MOCVD), the sample is grown on a miscut SiC substrate. The techniques of epitaxial growth [12] is mostly same for planar N-polar devices [13] and GaN cap was added for better millimeter-wave performance [3]. The 2-dimensional electron gas (2DEG) within the GaN channel is formed at its bottom interface with the AlGaN back-barrier. Then the 2DEG is bordered by AlGaN. The source and ohmic drain contacts are realized by molecular beam epitaxy regrown n^+GaN, and electron beam deposited Ti/Au metal stack. The gate trench was accomplished by removing the AlGaN cap layer with non-selective etch and then utilizing BCl_3/SF_6 selective dry etch for removing the GaN cap and stop on the AlGaN interlayer. 7 nm of SiN_x gate dielectric is deposited by MOCVD in the gate trench, followed by a Cr/Au T-gate metal stack. Information on device fabrication can be referred in [3]. At last, the device is passivated with 20 nm of plasma-enhanced chemical vapor deposition (PECVD) SiN_x. The selection of thin passivation is done to regulate radio frequency dispersion while reducing additional parasitic capacitances. The device have 60 nm gate length, 85 nm gate-source spacing, 315 nm gate-drain spacing[1] and a T-feed layout [11] with a 2×25μm gate width, and coplanar waveguide probe pads.

IJTSRD International Journal of Trend in Scientific Research and Development ISSN: 2456-6470

RESULTS AND DISCUSSIONS

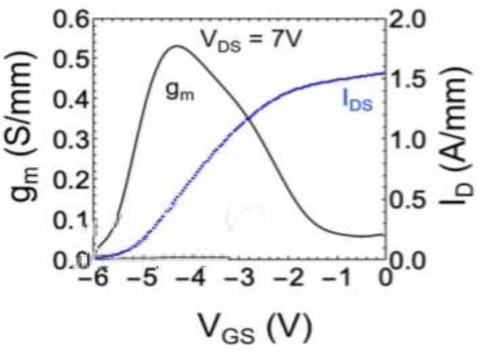

Fig 2 Tansfer characteristics at a quiescent gate and drain bias [1]

The output and transfer characteristics was observed with 800 ns of drain pulse width and 1μs of gate pulse width. The measurements in Fig. 2 and Fig .3 are taken at quiescent gate and drain bias ($V_{GS,Q}$;$V_{DS,Q}$)of (−6V;+7V) to observe the relevant I-V characteristics for RF measurements. Within the transfer curve (Fig. 2), the pulsed gate voltage ($V_{GS,P}$) has been swept from−6V to 0V, whereas pulsed drain voltage ($V_{DS,P}$) is maintained at +7V. Threshold voltage of −5.24V and maximum transconductance (gm) of 0.53 S/mm peaking at V_{GS}=−4.3V was observed.

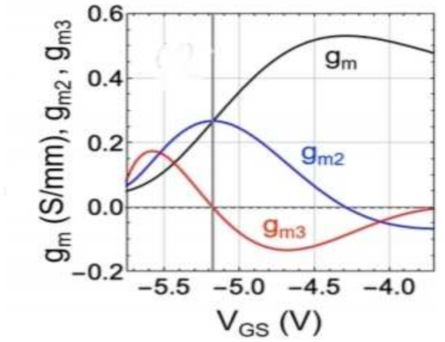

Fig 3 Transconductance and its derivatives crossing zero at device turn-on (V_{GS}=−5.18V)[1]

The transconductance and its derivatives such as g_{m2} and g_{m3} is shown in Fig 3 .Beyond peak of g_m, there will be sharp decrease in g_m when gate voltage is increased. This usually happens in GaN HEMT devices. One of the bias conditions for high OIP3 is using g_{m3} zero crossing point where device turns on and at a limited range of gate bias, $OIP3/P_{DC}$ will be at peak value. In this graph, g_{m3} crosses zero at V_{GS}=−5.18V, a good linear response and a peak in the OIP3 and $OIP3/P_{DC}$ is expected.

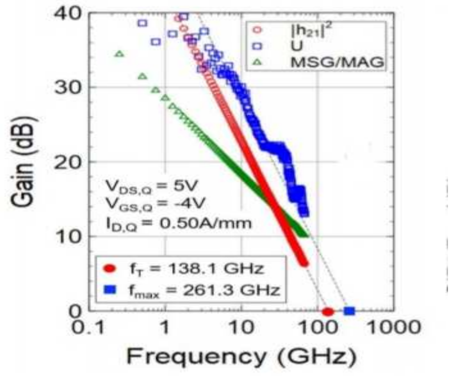

Fig 4 Graph for Small signal Analysis [1]

For observing small signal performance S-parameters, that are bias-dependent up to 67 GHz, were acquired. Using the line-reflect-reflect-match (LRRM) method, The network analyzer was calibrated at the probe tips. In Fig 4, at quiescent gate bias ($V_{GS,Q}$)of -4V and quiescent drain bias of 5V ($V_{DS,Q}$), there is peak f_T of 138 GHz. At ($V_{GS,Q}$, $V_{DS,Q}$) of (−4.25V, 9V) there is peak f_{max} of 287 GHz. At 30 GHz, the maximum stable gain is 13.6 dB at the bias condition for peak f_T and 14.8 dB for peak f_{max} condition.

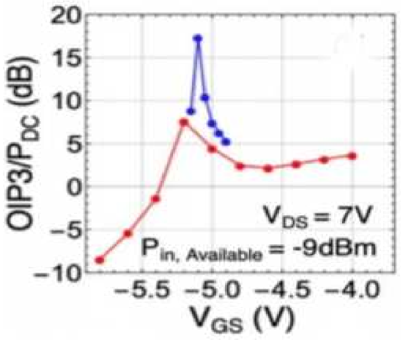

Fig 5 Two-tone load-pull input-bias sweep at 30 GHz with a tone- spacing of 1MHz [1]

The linearity performance in Fig 5 was observed using two tone load pull input bias sweep. The red curve indicates coarse sweep and blue curve finer $V_{GS}$to capture peak $OIP3/P_{DC}$.At V_{GS}= -5.1 V there is sharp peak $OIP3/P_{DC}$that is adhering with Fig 3 at zero crossing point. Over limited range of gate bias there is peak $OIP3/P_{DC}$ .This means that linearity is sensitive to gate bias.

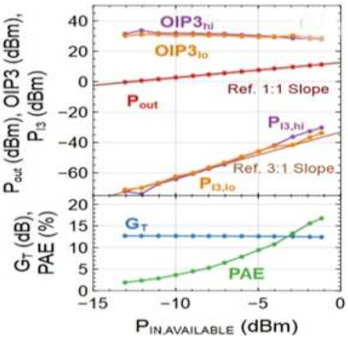

Fig 6 Total output power in the fundamental tones and corresponding OIP3

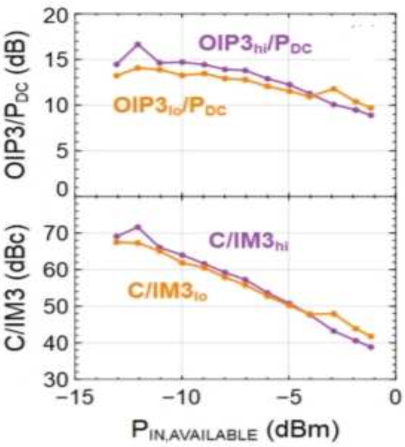

Fig.7 Graph for to studying linearity

In Fig.6 and Fig.7, two-tone load-pull input-power sweep at 30 GHz with tone spacing of 1MHz are represented. The biasing is done at $V_{GS,Q}$ of −5.125 V, $I_{D,Q}$ of 135 mA /mm and $V_{DS,Q}$ of 7V. In Fig 6, there is generation of low IM3, with C/IM3 better than 50 dBc for input powers less than−5dBm (Fig.7). The device exhibits a maximum OIP3 of 32 dBm and a transducer gain (G_T) of 12.7 dB at $P_{IN,AVAILABLE}$ of −12.1 dBm (Fig.6). This shows maximum $OIP3/P_{DC}$of 15 dB in Fig.7 which is great linearity performance at 30 GHz.

CONCLUSION

With new design structure of N-polar GaN MIS-HEMT there is excellent gain and linearity performance of device for receiver application at 30 GHz.. The biasing is done at $V_{GS,Q}$ of −5.125 V, $I_{D,Q}$ of 135 mA /mm and $V_{DS,Q}$ of 7V. It is found that at the $OIP3/P_{DC}$ is 15dB and over a limited range of gate-bias and linearity is sensitive to bias with a two-tone load-pull input-bias sweep .With further device engineering we can study and predict distortion for higher performance device with low power consumption.

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International Journal of Trend in Scientific Research and Development
IJTSRD
ISSN: 2456-6470