300 GHZ DETECTION USING HIGH ELECTRON MOBILITY TRANSISTOR (HEMT) AS SUB-THZ DETECTOR

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Abstract

In this paper, we report the detection of sub-THz (300 GHz) radiation by using High Electron Mobility Transistor (HEMT). The observation of photoresponse are measured against gate voltage. The measured photoresponse is a superposition of a generally increasing response with a decrease in V_{GS} *coupled with a small peak approximately at threshold. The response has also been measured as a function of current, frequency and RF input power and there is evidence that the HEMT can be a sensitive sub-THz detector.*

Keywords: *Sub-THz, Detection, HEMTs, photoresponse.*

I. INTRODUCTION

The race on developing compact Terahertz sources and detectors is one of the hot issues in modern Terahertz electronics. Various across scientific application used THz radiation, such as remote sensing, detection of weapons and explosives and sensing of chemical and biological systems. Therefore the development of sensitive and compact THz detectors are important to advancement of these technologies. Many different type of THz detectors have been developed such as bolometers, pyroelectric detectors, Shottky diode, photoconductive detectors and most recently by Plasma Waves detectors in Field Effect Transistors (FETs).

In HEMT, the plasma waves have linear dispersion law, $\omega = sk$,where s is the plasma wave velocity and k is wave vector. The velocity of the plasma wave is typically order of 10^8 cm/s where this is larger then electron drift velocity in FET channel. These plasma wave velocity also depends on the carrier density in the channel n and the gate to channel capacitance per unit area, $s = \sqrt{e^2 n / mC}$, where e is the electron charge, m is the electron effective mass. For channel appromimation,$= CU_g / e$, where $U_g = V_{gs} - V_{th}$, voltage difference between gate to source voltage and threshold voltage. Hence, plasma wave velocity can be controlled by controlling gate voltage, $s = \sqrt{eU_g / m}$. In this case the fundamental plasma frequency can be written as :-

$$f_0 = \sqrt{\frac{e(V_g - V_{th})}{m}} \Big/ 4L_g$$

As a consequence of this equation leads two important things (i) a sufficiently short (submicron) FET can operate as THz detector and (ii) the resonant frequency of detection can be tuned by the gate voltage [1]. The detection of THz by FETs is one of promising technologies since it can be both selective and tunable . Recently, experimental evidence of detection of THz signal was demonstrated in commercial AlGaAs/

GaAs FETs[2], AlGaN/GaN HFETs[3], a double quantum well FET with periodic grating gate[4] and Si MOSFETs[5].

The aim for this journal is to present the response of a commercial HEMT device, which is biased so that it detects continuous wave (CW) sub-THz radiation up to 300 GHz which as the author concern that this experiment have across the previous work up to 200 GHz in CW sub-THz detection . In this work the transistor that we choose was a commercial transistor manufactured by Avago ATF-36163 High Electron Mobility Transistor. This transistor structure is 0.2 µm gate length and the total gate width of 200 µm were used in this experiments. The observation of photoresponse by the detector has been done by as a function of gate voltage and drain bias. All measurements were made at ambient temperature and in an open laboratory.

II. EXPERIMENTAL SETUP

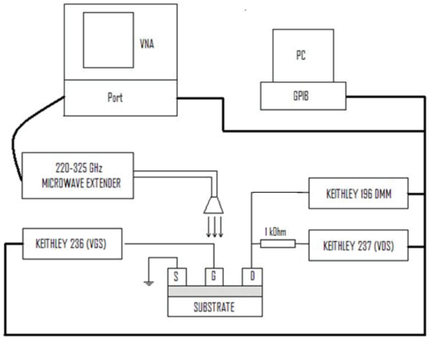

Fig. 1: Experimental setup for this work.

The experimental setup is shown in figure 1. The SMT packaged Avago PHEMTs were commercially sourced and were soldered to a custom THz detector board that allowed the easy connections to the drain, and gate of the device. The source connection was connected to ground. The biasing gate voltages and drain currents were supplied by Keithley source measurement units (SMU) . The drain-source voltage (V_{DS}) was measured using a Keithley Digital multimeter. The sub-THz radiation source was using an Olsen Microwave Lab (OML) vector network analyser extender (V03VNA2-T/R module) which can operate between 220GHz and 325GHz. The VNA extender was connected to an Anritsu Broadband Network Analyzer ME7808B operating in CW mode. This allowed the frequency of operation to be changed. The RF input power to the VNA extender was 13 dBm and the nominal output power from the VNA extender specifications was -25dBm. The RF input power will be vary to see the reaction of photoresponse.

The power from the VNA extender was coupled into the PHEMT device using a length of rectangular waveguide and a horn antenna. The horn was placed directly above the PHEMT but not touching the surface. There were no special antennas connected to the device. To measure the photoresponse of the device to the incident radiation, the value of V_{DS} , measured when the incident radiation was on, was subtracted from the value obtained when the radiation was off. (The power of the incident radiation was turn off by removing the incident RF power to the VNA extender.) Since the photo-response is small, the measurements had to be repeated 100 times and averaged. The experiment was conducted using LabVieW programme and all the measurements data were analyze using Matlab.

III. RESULTS AND DISCUSSION

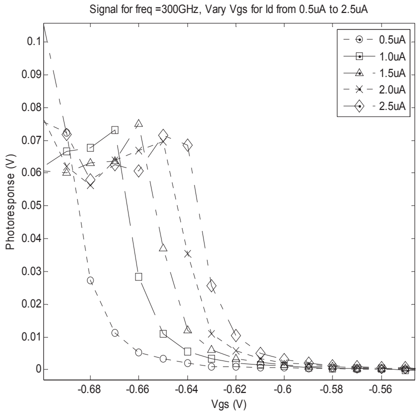

Fig. 2: Photoresponse as a function of gate bias at different drain current at 300 GHz

The photoresponse of the HEMT devices is shown in Figure 2 .This photorepsonse was measured as a function of V_{GS} for different bias currents.The frequency in all these measurements, was constant and set to be 300GHz. In the beginning, the photoresponse is very small until V_{GS} is close to the threshold voltage of the device (-0.6V). When V_{GS} is reduced near to the threshold voltage, the photoresponse begins to increase and then levels off before sharply increasing again. At higher currents, there is also evidence that the photoresponse reaches a maximum.

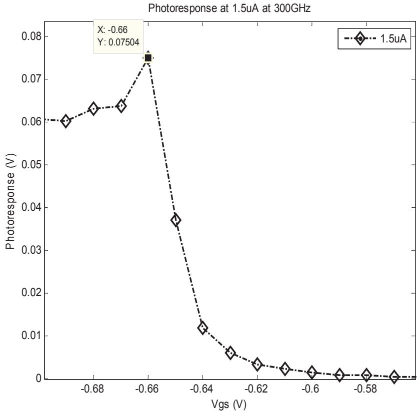

Fig.3: Photoresponse at 5μA along with the corresponding standard deviation.

Figure 3 shows more clearly where the data obtained with a drain bias current of 5μA is shown on its own. From this diagram it is clear the "peak" of photoresponse was recorded at V_{GS}=-0.62V consists of one data point. However, the difference between this point and its neighbours is larger than the standard deviation of the measurements. In addition, this behaviour is seen in other curves presented in figure 2.

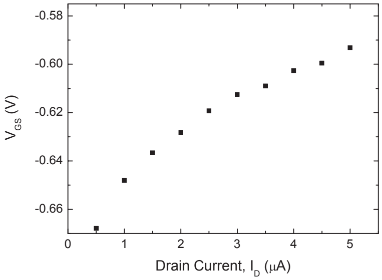

Fig 4: The values of V_{GS} at which the photoresponse is 0.01 as a function of the DC drain bias current.

Another observation from figure 2 is the voltage at which the photoresponse initially increases depends on the drain bias current. To investigate this phenomenon, the voltage at which the detected signal is equal to 0.01 is shown in figure 4. In all cases, the point at which this occurs was between two measured values and so linear interpolation has been used to estimate the value. Based on this figures proofs that the responsivity does increase with bias current but the rate of increase slows down with drain current.

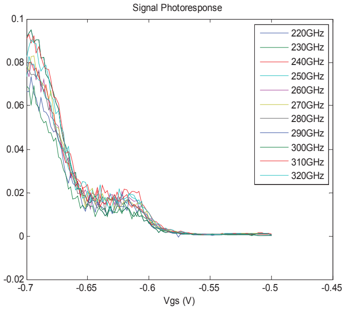

Fig. 5 : Photoresponse signal as a function of gate bias at different frequency 220-320GHz.

As we know the photoresponse effect on biasing current, we continued the experiment on the effect of the photoresponse for various frequencies from 220-320GHz. The photoresponse for various frequencies is shown in Figure 5. In all these measurements, the drain current was kept at 5.0 μA. As we can see in general the shape of the photoresponse $-V_{GS}$ characteristic is approximately nearly the same for all frequencies. However on closer inspection, the frequency dependence of the responsivity at the "-0.62V peak" is different to case when V_{GS}=-0.7.

The research on photoresponse effect continued by experimenting the HEMT with sub-THz radiation with different RF power input from 6dBm, 8dBm and 10 dBm. The experiment setup is still the same where in this stage the Vgs was constant at -0.65V and the drain current was vary from 2uA to 10uA . In these measurement the frequency was set at 300 GHz. The results is shown in figure 6. As a results based on figure 6, as we increased the RF input power in the VNA, the photoresponse also will increased linearly. These evidence proofs that the sensitivity of the HEMT are high due to sub-THz radiation power.

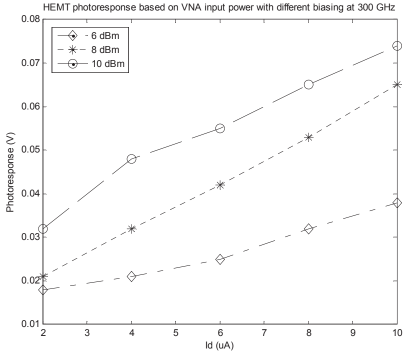

Fig 6 : Peak of Photoresponse at different VNA input power

Previous works on the use of THz detectors show just a single broad peak in the responsivity whose maximum approximately occurs at the threshold voltage of the device. In our results, there is a superposition of a possible small peak with a general increase in responsivity as V_{GS} is decreased below the threshold and the effect on drain current enhancement. Several explanation were put forward regarding this matter. First, the experiment setup for all the other previously reported measurements were totally different from us. In general, a Gunn diode was used as the source of the radiation, and then the radiation will be chopped using mechanical chopper. The signal was then measured using standard lock-in techniques. This is in contrast with our methodology that detects the signals quasi-statically. Second, in term of the device is different. The published works, which used commercial devices, have generally sourced them from Fujistu [2]. Physically, the Fujistu devices have a smaller gate length, nominally 150nm compared to 200nm for the ATF36163. Bare in mind that the physics of the 2D plasma will depend strongly on the device layout and size. Third, in general previously measured peak width was approximately 0.2V. It could be that the result presented is just one side of an unobserved peak. However, V_{GS} could not be reduced any further to test this criterion. (As V_{GS} is reduced below pinch off, the resistance of the channel between the source and the drain rapidly increases. Since, the drain is driven by a constant current source, the drain voltage will increase and reaches 3V the maximum permissible V_{DS} of this device.) Fourth, the measured response of HEMT detector depends critically on the orientation of the polarisation with radiation with respect to the gate finger. [6] However none of the published photoresponse-V_{Gs} characteristic look like the measured characteristic of this work. Fifth, the measurement frequency of this work is different from previous work. [2,6] From comparison with the literature the response does depend on frequency. The results presented in figure 5 do provide some evidence to support this hypothesis because the actual shape of the response with V_{GS} does depend slightly on frequency. However, this the results measured at 220GHz still show a peak that previous workers at 200GHz have not seen before. At cryogenic temperatures (10K) small peaks have been observed in the response as a function of V_{GS} but these disappeared as the temperature increased. At 60K the peaks were barely measureable.[7] It is unlikely these will have the same origin. Six, based on figure 6 there is an evidence that the peak of photoresponse increasing linearly with a drain bias due to VNA RF input power increased. The high sensitivity of HEMT due to sub-THz radiation power detection gives an evidence that the HEMT can be sensitive sub-THz detector. As the author concern, this work have never been published before.

IV. CONCLUSIONS

In summary we have demonstrated the photoresponse to sub-THz radiation of HEMT with 0.2um gate length and 200um width caused by plasma wave detection. The general shape of our response is different to previously reported results and several explanations have been put forward to account for these differences. There is an evidence that the HEMT can be a sensitive sub-THz detector.

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REFERENCES

[1] M. Dyakonov and M. Shur, "Shallow Water Analogy for Ballistic Field Effect Transistor : New Mechanism of Plasma Wave Generation by dc Current," Phys. Rev. Lett. 71, 2465-2468,1993

[2] W. Knap, V. Kachorovskii, Y. Deng, S. Rumyantsev, J.Q. Lu, R. Gaska, M. Shur, G. Simin, X. Hu, M. Asif Khan, C.A. Saylor and L.C. Brunel "Nonresonant detection of terahertz radiation in field effect transistors," J. Of App. Phys, vol. 91, No. 11, 9346-9353, 2002.

[3] F. Teppe, D. Veksler, V. Yu. Kachorovski, A.P. Dmitriev, X. Xie, X.C Chang, S. Rumyantsev, W. Knap, M. Shur,"Plasma wave resonant detection of femtosecond pulsed terahertz radiation by nanometer field effect transistor,"App. Phys. Lett.81,022102,2005

[4] X.G. Peralta, S.J. Allen, M.C. Wanke, N.E. Harff, J.A. Simmons, M.P. Lilly, J.L. Reno, P.J. Burke and J.P. Eisenstein, "Terahertz photoconductivity and Plasmon modes in double-quantum-well field effect transistors," App.Phys. Lett.,vol. 81, no.9,pp.1627-1629,2002

[5] W. Stillman, F. Guarin, V. Yu. Kachorovskii, N. Pala, S. Rumyantsev, M.S. Shur and D. Veksler,"Nanometer Scale Complementary Silicon MOSFETs as Detectors of Terahertz and Sub-Terahertz Radiation," Proc. IEEE Sensors, 2007

[6] M.Sakowicz, J. Lusakowski, K. Karpierz, M.Grynberg, W. Knap and W Gwarek. " Polarisation sensitive detection of 100GHZ radiation by high mobility field effect transistors" J. Appl. Phys, 104 024519, 2008.

[7] S. Boubanga-Tombet, F. Teppe, D. Coquillat,S. Nadar, N. Dyakonova, H. Videlier, W. Knap, A. Shchepetov, C. Gardès, Y. Roelens, S. Bollaert, D. Seliuta,R. Vadoklis, and G. Valušis "Current driven resonant plasma wave detection of terahertz radiation:Toward the Dyakonov–Shur instability" Appl. Phys.Lett. 92, 212101, 2008