220 GHz DETECTION USING 0.35 μM AMS MOSFET AS SUB-THz DETECTOR : DRAIN BIAS DETRACTION

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Abstract—**In this paper we present the detection of sub-THz radiation at 220 GHz by using 0.35 μm AMS Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The design procedure and experimental setup are shown in order to design and characterize the MOSFETs photoresponse. The experiment and observation of photoresponse are measured against gate voltage with a drain current bias detraction at room temperature. 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 and there is evidence that the MOSFET can be a sensitive sub-THz detector in the room temperature.**

Keywords- Sub-THz,Detection, MOSFETs, photoresponse

I. INTRODUCTION

Recently sub-THz and THz radiation detection by Complimentary Metal-Oxide-Semiconductor Field Effect Transistor or MOSFET in conventional CMOS process had been reported by W.Stillman et al.[1]. Both P channel and N channel of MOSFETs can be used as sub-THz and THz detector. Previously, work on detecting CW sub-THz radiation had been done by using HEMT [2]. In the beginning years of plasma wave detector, non resonant plasma wave detection has just been discovered by using HEMT and Silicon FET. These types of detector work as sub-THz and THz broadband detectors. Later on, it had been reported that Silicon-On-Insulater Metal Oxide Semiconductor Field Effect Transistor (SOI MOSFET) can be used as THz detector at different temperature from 8K - 350K [3]. All these devices were tuned to the THz frequency by varying the gate bias, with a drain current enhancement.

In MOSFET devices, the plasma waves have linear dispersion law,

$$\omega = sk \tag{1}$$

where s is the plasma wave velocity and k is wave vector. The velocity of the plasma wave is typically in the order of 10^8 cm/s where this is larger than electron drift velocity in FET channel. This plasma wave velocity also depends on the carrier density in the channel and the gate to channel capacitance per unit area,

$$s = \sqrt{e^2 n / mC} \tag{2}$$

where e is the electron charge, m is the electron effective mass. For channel approximation,

$$n = CU_g / e \tag{3}$$

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 :-

$$f_0 = \frac{\sqrt{\frac{e(Vg-Vth)}{m}}}{4\,Lg} \tag{4}$$

This equation can leads to two important things (i) a sufficiently short (submicron) FET where it can operate as THz detector and (ii) the resonant frequency of detection can be tuned by the gate voltage [4]. THz detection 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[5], AlGaN/GaN HFETs[6], a double quantum well FET with periodic grating gate[7] and HEMTs[8].

II. DESIGN PROCEDURE

The aim for this paper is to present the photoresponse of a MOSFET device, which detects continuous wave (CW) sub-THz radiation up to 220 GHz. As far as the author concern there have never been an experiment done before above 200 GHz in CW sub-THz detection. Several MOSFET devices were designed using CADENCE in AMS 0.35 μm CMOS process technology. In this design the MOSFET's gate length is Lg = 0.35 μm and the gate width, Wg = 5 μm as shown on Figure 1. From equation (4) as the gate length decreases the frequency will increase up to several THz. These MOSFET devices design then, were simulate in

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Layout vs Schematic (LVS) to make sure the connection between layout and schematic are same. As the author concern, the MOSFET devices design for this work are different from the previous published work since the gate and drain were connected directly to the RFPADs which allows electrical (both DC and RF) connections to be made by using RF Probes which have a 75 μm pitch. The maximum frequency of operation of the Picoprobe GGB Industries RF-Probe is 0.22 THz [9].

The layout of the MOSFET devices was sent for fabrication. The observation of photoresponse by the detector has been done by as a function of gate voltage and with drain current enhancement. All measurements were made at ambient room temperature and in an open laboratory.

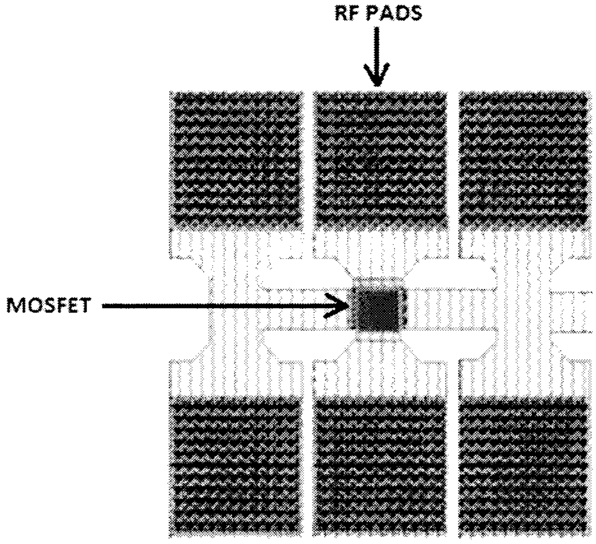

Figure 1: MOSFET with gate length is $L_g = 0.35$ μm and the gate width, $W_g = 5$ μm.

III. EXPERIMENTAL SETUP

From figure 2, the sub-THz radiation was produced by an Olsen Microwave Lab (OML) vector network analyser extender (V03VNA2-T/R module) which operates between 140 GHz up to 220 GHz. The VNA extender was connected to an Anritsu Broadband Network Analyzer ME7808B that operating in CW mode. MOSFET devices were placed on to the XYZ Probe station, so that the 75 μm pitch RF probe can be easily placed on to the appropriate RF pads which allow the connections to the drain, gate and source of the device. Note the devices are configured in common source mode so the source is connected to ground. The biasing gate voltages and drain currents are supplied by Keithley Source Measurement Units model numbers 236 and 237 respectively. The drain-source voltage (V_{DS}) was measured using a Keithley Digital multimeter 238.

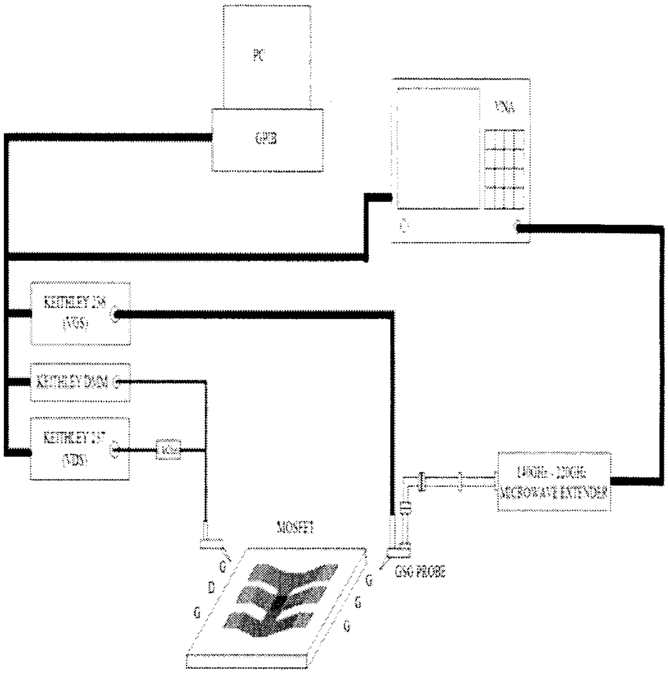

Figure 2: Experimental setup for this work.

The RF power of -13dBm from the VNA extender was coupled into the MOSFET devices using a length of rectangular waveguide connected with 75 μm pitch RF probe. The RF probe was placed directly onto RF pads so that the frequencies can be couple towards MOSFET devices. This method as author concern was never been published before.

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 the average taken. The experiment was conducted using LabVieW programed and all the measurements data were analyze using Matlab.

IV. RESULTS AND DISCUSSION

The photoresponse of the MOSFET devices is shown in Figure 3. This photorepsonse was measured as a function of V_{GS} with the drain current enhancement. The frequency in all these measurements was constant and set to be 220 GHz. In the beginning of the experiment, the photoresponse is very small until V_{GS} is close to the threshold voltage of the device (0.5V~0.6V). When the V_{GS} is reduced near to the threshold voltage, the photoresponse begins to increase and then levels off before sharply increasing again. There is also evidence that the photoresponse reaches a maximum, as the current bias decreases.

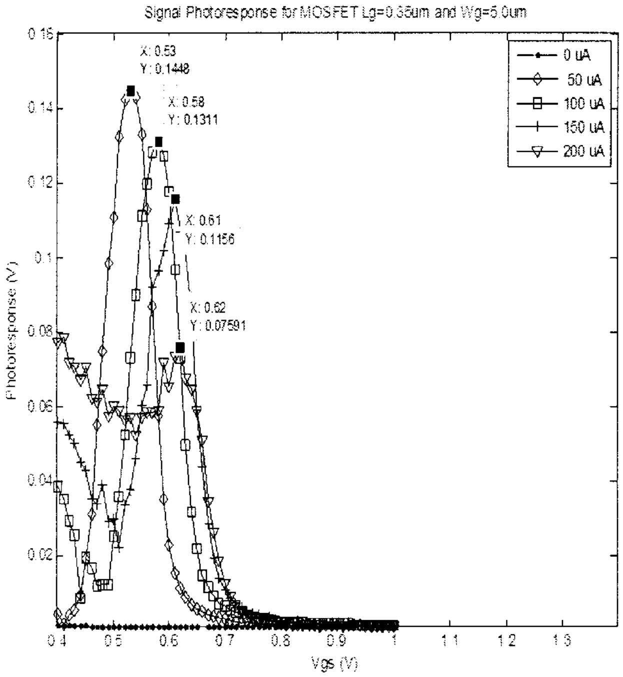

Figure 3: Photoresponse for MOSFET Lg = 0.35 μm, Wg = 5 μm.

Previous published works on the use of THz detectors just shows a single broad peak in the responsivity whose maximum approximately occurs at the threshold voltage of the device. Based on this result, there is a superposition of a possible small peak with a general increase in responsivity as VGS is decreased below the threshold and the effect on drain current enhancement. Several points of discussion were put forward regarding this matter.

Firstly, previous reports on measurement setup were totally different. In general, previous published work used a Gunn diode as the source of the radiation, and then the THz radiation being chopped using mechanical chopper. The signal was then measured using standard lock-in techniques. This kind method is in contrast with the method that been used in this experiment where in this experiment the THz radiation been detected using quasi-statically. Secondly, in terms of devices is totally different from previous published work. Recent worked, most of the transistors have generally sourced them from IBM [10]. Physically, the IBM devices have a different gate length and width. Bear in mind that the physics of the 2D plasma will depend strongly on the device layout, size and CMOS process.

Thirdly, in general previous published paper measured peak width was approximately 0.2V. It shows that the result presented is just one side of an unobserved peak. However, VGS could not be reduced any further to test this criterion. As VGS 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 VDS of this device.

Finally, the measured photoresponse of MOSFET THz detector depends critically on the orientation of the [11]. However, there was none of the published photoresponse-VGs characteristic look like the measured characteristic of this work. The high sensitivity of MOSFET devices due to CW sub-THz radiation detection gives evidence that it can be a sensitive sub-THz detector.

V. CONCLUSION

In summary the photoresponse to sub-THz radiation of MOSFET devices with gate length , Lg = 0.35 μm, and the gate width, Wg = 5 μm caused by plasma wave detection has been demonstrated. The general shape of the response is different to previously reported results and several explanations have been put forward to account for these differences. There is evidence that the MOSFET can be a sensitive sub-THz detector.

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