Silicon junctionless field effect transistors as low noise THz detectors

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Abstract—**This paper describes metal-oxide-semiconductor junctionless field effect transistors working as detectors of THz radiation. The exceptionally high signal to noise ratio has been achieved. These devices may operate as two terminal detectors without any gate bias.**

I. INTRODUCTION

FIELD effect transistors (FETs) have been used for many years as low cost detectors of THz radiation [1]. They are very reproducible, easy to integrate with monolithic antennas and read-out circuits.

Recently it has been demonstrated that also junctionless (JL) metal-oxide-semiconductor FETs can be used as effective THz detectors showing some advantages comparing to standard FETs [2]. In JL FETs the source/drain and substrate areas are of the same type [3].

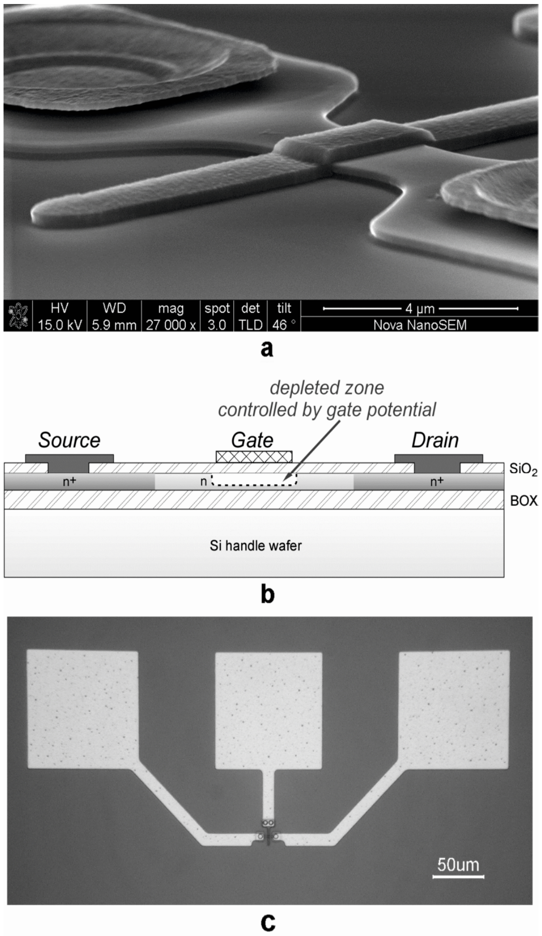

Fig. 1. a) SEM picture of the device. b) On the cross-section along conduction channel the absence of p-n junction (typical for classical MOSFETs) is shown. c) The picture of metallic bonding pads for source, gate and drain

Such a device is fabricated in SOI technology and conductivity of its conducting channel is not related to the inversion layer (like in the case of classical FETs), but depends on the thickness of the conducting channel between the depleted zone (controlled by the gate potential) and the buried oxide. In both cases (JL and standard FETs), using transistors as THz detectors without any drain bias, the total noise is dominated by the thermal noise of channel resistance. While classical FETs are used in subthreshold conditions to get substantial photoresponse on THz radiation, their JL counterparts may operate with an open channel (Fig. 2) showing similar level of the photovoltage measured between the source and drain terminals. The phenomenological approach [4], link expected detector signal with conductivity of source drain channel: $U_{sd} \sim \partial \ln(I_d)/\partial U_g$

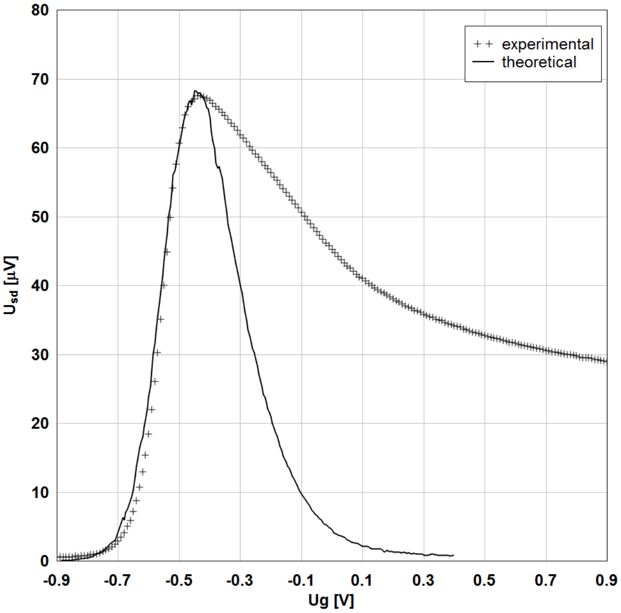

Fig. 2. The photoresponse signal (crosses) of selected device measured in the experimental setup compared with the value expected for MOSFETs (solid line) – normalized $\partial \ln(I_d)/\partial U_g$ including loading effects.

Much lower channel resistance in the case of JL devices should result in a much better signal/noise (S/N) ratio. It is worthwhile to mention that one may improve S/N ratio for classical FETs by slight biasing of the drain against the source allowing small drain DC current to flow. Such a method, however, brings limited advantage due to rapid shot noise increase in the subthreshold range.

II. RESULTS

In this paper the measurements of noise features of JL FETs are reported. The JL FET fabrication process has been described in [5]. The device under consideration had

2.5μm/0.5μm channel width/length with the gate far away (3.73μm) from the source and drain contacts, the device layer thickness was 170nm and the doping density (n-type) ca $10^{16}/cm^3$.

The noise of the JL FET, as well as its response on THz radiation, were measured. The noise measurements were performed with a spectrum analyzer and with a lock-in amplifier. Both methods appeared to be in line with predictions – the Johnson noise was dominant for the detector used with open drain, and the power spectrum density agreed well with the value determined by the resistance of the channel measured between the source and the drain. While for standard FETs their responsivity drops to zero for fully open channel, the detectivity of the JL FET remains significant [2]. This feature allows for using JL FETs in the open channel mode characterized by much lower resistance than the resistance of classical FETs working in the subthreshold range.

If in the case of JL FET, one compares the S/N ratio for subthreshold and open channel ranges, the S/N ratio is 15 times higher for the latter case. Finally, the S/N ratio in our setup (335GHz, transmitter from Virginia Diodes, Inc. providing 2mW of THz power, lock-in frequency 187Hz, equivalent noise bandwidth 0.3Hz) reached 54dB, the value not available for standard n-MOSFETs (with the gate biased to get the highest responsivity) of the similar size fabricated in SOI technology and measured in the same system.

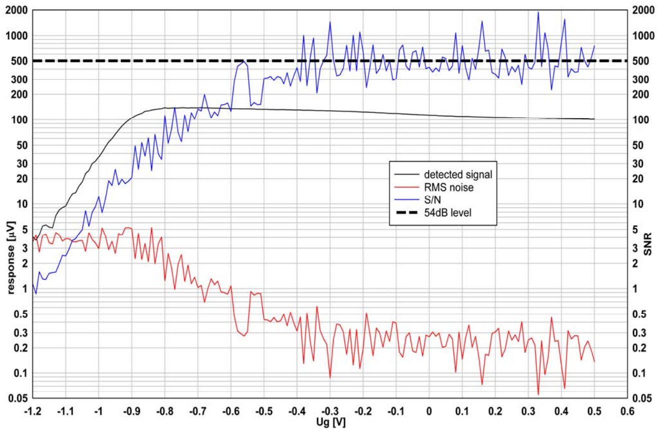

Fig. 3. The photoresponse (black curve) and RMS noise (red curve) of the detector. The blue line is signal to noise ratio, which achieves value of 54dB.

To calculate the responsivity and the noise equivalent power (NEP) values properly, the exact detector size have to be determined. If one assume that effective area A – defined by the gate metallization (shown on Fig. 1c) – is about $0.015mm^2$ (like in [2]), one obtain values of responsivity - 300V/W and NEP=1.1×10^{-10}W/√Hz.

The feature, frequently used to describe infrared detectors, is detectivity D*, which allows to compare detectors of various aperture and is defined as D*=√A/NEP. For described device detectivity is of 1.1×10^{8} cm√Hz/W.

Another advantage of the proposed device is a possibility of signal detection even without applying any gate voltage. It is possible for properly doped channel that remains highly conductive for gate voltage equal to zero. It means that this kind of detectors can be used as a zero-bias two terminal device.

III. SUMMARY

JL FETs used as THz detectors offer significant improvement in S/N ratio comparing with classical FETs due to their lower resistance of the channel. The zero-bias mode results in simplification of read-out circuitries. This device seems to be a good candidate for implementation in communication and imaging.

IV. ACKNOWLEDGMENTS

This work was partially supported by the National Center for Research and Development in Poland grants PBS1/A9/11/2012 and LIDER/020/319/L-5/13/NCBR/2014.

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