Homodyne detection in graphene FET power detectors

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I. INTRODUCTION

Graphene field effect transistors (GFETs) are very attractive for next-generation semiconductor electronics, because of their impressive properties, such as high carrier mobility and velocity. Power detectors based on GFETs have been developed in a wide frequency range [1], [2], [3]. However, the response of these detectors is still 1-2 orders of magnitude lower than that of Schottky diode or MOSFET detectors. In this work, we have analysed the behaviour of GFET power detectors based on the specific nonlinearity of GFETs to find solutions to increase the response.

II. RESULTS

The rectified dc current response to the input RF signal for a FET at zero bias can be expressed as [1]

$$I_{\text{out}} = \frac{1}{4}(g_{\text{m2}} + \alpha^2 g_{\text{ds2}} + 2\alpha \cos\theta g_{11})v_{\text{in}}^2, \qquad (1)$$

where α is the voltage amplitude ratio of input signals applied to the gate and to the drain, θ is the phase difference between them, and v_{in} is the voltage amplitude of the input signal. The g parameters are the second order derivatives of the drain-source current I_{DS}, and can be expressed as

$$g_{\text{m2}} = \frac{\partial^2 I_{DS}}{\partial V_{GS}^2}, \qquad (2)$$

$$g_{\text{ds2}} = \frac{\partial^2 I_{DS}}{\partial V_{DS}^2}, \qquad (3)$$

$$g_{11} = \frac{\partial^2 I_{DS}}{\partial V_{GS}\partial V_{DS}}, \qquad (4)$$

where V_{GS} and V_{DS} are the gate- and drain-bias voltages. Fig. 1 shows the g parameters measured on GFETs with layout, fabrication technology and measurement setup similar to our previous work [1]. Like the semiconductor counterparts, the GFET g_{m2} values at zero bias are relatively low in comparison with the g_{11}. Thus, the contribution of the g_{m2} term to the current response is low. The measured g_{ds2} is also relatively low, which can be explained by the fact that GFETs have a rather linear output characteristic at low fields due to the zero bandgap of graphene. Accordingly, the current response defined by g_{ds2} is also low. Consequently, the dominant term is g_{11}, assuming that signal inputs should be applied at both gate and drain, similar to homodyne detection. The corresponding topologies of a GFET detector operating in this mode are shown in Fig. 2. In contrast, if the input signal is coupled to drain or gate only, the rectified dc current will be much lower, since it is determined by the relatively low g_{m2} or g_{ds2} terms only.

According to the analysis above, there are two ways to improve the current response. One way is to increase the capacitive coupling efficiency between gate and drain terminals using an extrinsic capacitor, as shown in Fig. 2. The other way

is to optimize the detector dimension, i.e. shortening and/or widening graphene channel, since g_{11} is proportional to the ratio of the gate width to length. Note that above analysis does not take into account the effects of parasitic capacitances and resistances, which can decrease the current response by shunting and attenuating the input signal. These effects are important and will be the subject of the future work.
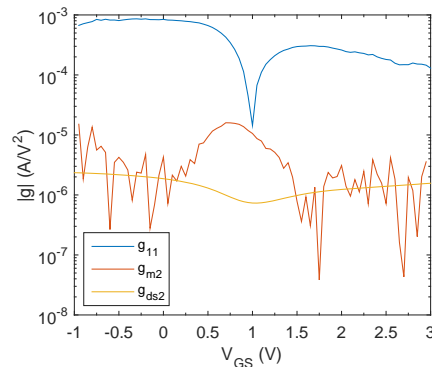

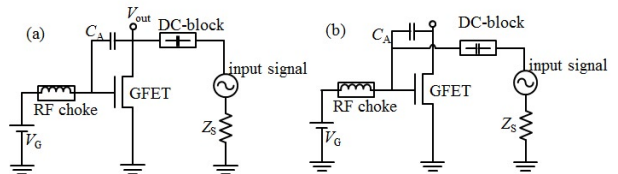Fig. 1.   Measured g_{11}, g_{m2} and g_{ds2} at $V_{DS} = 0$ versus V_{GS}.

Fig. 2.   Two possible topologies of GFET detector with (a) $v_{\text{gs}} = v_{\text{in}}\cos(\omega t)$ and $v_{\text{ds}} = \alpha v_{\text{in}}\cos(\omega t + \theta)$, (b) $v_{\text{ds}} = v_{\text{in}}\cos(\omega t)$ and $v_{\text{gs}} = \alpha v_{\text{in}}\cos(\omega t + \theta)$.

III. CONCLUSIONS

We have analysed the specific nonlinearity of GFETs, and demonstrated that the input RF signal should be coupled to both drain and gate to obtain the highest dc current response of GFET power detectors. To enhance the response further, one can use an extrinsic capacitor between gate and drain, and optimise the GFET channel dimensions.

REFERENCES

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