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Relation between Sharp Resonance and Bias Voltage in CMOS-based Resonator

CMOS 型共振器における鋭い共振特性とバイアス電圧の関係

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1. Introduction

For the purpose of shrinking the size of a clock system, a new principle of an oscillator was proposed in a previous study[1]. A sharp resonance with the quality factor[2,3] of Q>1500 was preliminarily observed at 300 MHz in frequency dependence of impedance measured for the backgate terminal of a MOSFET device fabricated using a standard CMOS process[1]. The result suggested that the impact ionization rate (α) periodically increases with a specific frequency, presumably synchronized with acoustic standing waves excited in the device. Since the α strongly depends on bias conditions of MOSFET devices[4,5], the relation between the sharp resonance and bias voltage was investigated in the present study.

2. Device and Measurement

A 2.5 V n-type MOSFET device was prepared in the double-well structure on a p-type Si substrate using a CMOS process with the minumum gate length of L=0.3 µm. The device has multiple gate electrodes (N=10) with a width of W =40 µm connected in parallel to provide a total channel width of $W_{\rm total}$=400 µm, as illustrated in **Fig. 1(a)**.

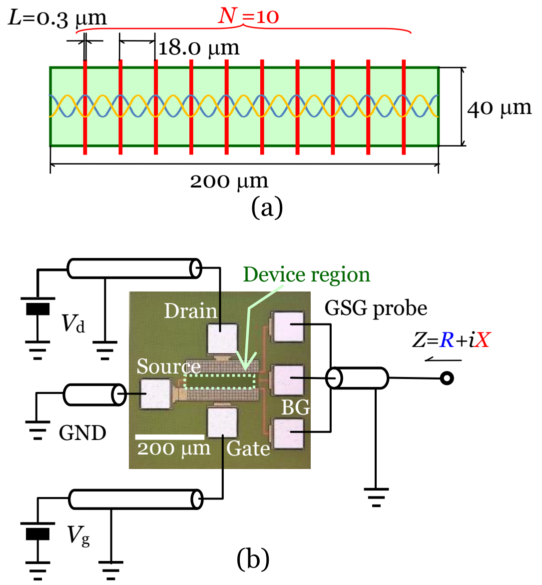

Fig. 1 Structure of the MOSFET-based resonator (a) and measurement circuit (b)[1].

Dummy gate electrodes ($N_{\rm dum}$=24) were inserted between all active electrodes to increase the inter-electrode spacing (d=18 µm)[1,6-8]. The device has electrical terminals connected to the gate, drain, source, and backgate of the device, as shown in **Fig. 1(b)**. The backgate terminal consists of a ground-signal-ground (GSG) port suitable for high-frequency measurement.

Complex impedance (Z=R+iX) was measured from the backgate terminal using an RF impedance analyzer (Agilent E4991A). DC bias voltages were applied to the gate (V_g) and drain (V_d) terminals using a semiconductor parameter analyzer (Agilent 4156C).

3. Experimental Results

Figure 2 shows frequency dependence of R and X measured from 0.02 to 1.60 GHz in 0.002 GHz step without application of bias voltages (V_g=V_d=0 V). Both the R and X approximately agreed with an equivalent series CR model with C=15 pF and R=47 Ω. Under this condition, however, no resonances were observed.

When V_{gs}=0.8 V and V_{ds}=0.6 V were applied, a sharp resonance was observed at 427 MHz, as shown in **Fig. 3(b).** These voltages are within the saturation bias range ($V_{th} < V_{gs} < V_{ds}+V_{th}$, where V_{th}=0.52 V) for the MOSFET.

In contrast, no resonances were observed under a subthreshold bias condition (V_{gs}=0.4 V, V_{ds}=0.6V: V_{gs}<V_{th}) as shown in **Fig. 3(a),** and under a linear bias condition (V_{gs}=1.2 V, V_{ds}=0.6 V: V_{gs}>V_{ds}+V_{th}) as shown in **Fig. 3(c)**.

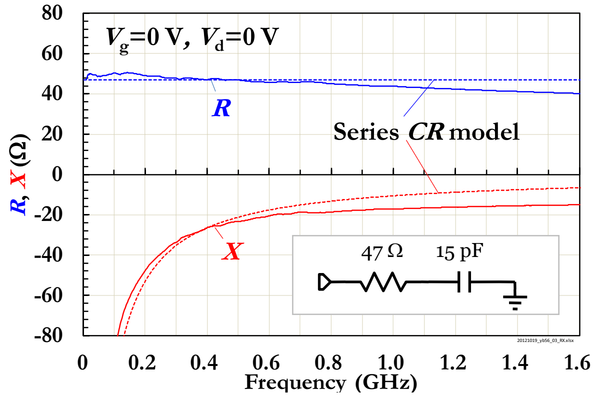

Fig. 2 Frequency dependences of impedance, Z=R+iX, for V_g=V_d=0 V.

4. Discussion

The sharp resonance was only observed in the saturation bias condition, even though the I_d under this condition (2 mA) was smaller than that under the linear condition (13 mA). This suggests that not the number of electrons but their drift velocity should is dominant factor for the excitation of resonance.

Chen *et al.* proposed a phonon laser based on an InP MESFET.[9] They used LO phonons created by hot carriers as a pump (energy source), postulating that the hot carriers accelerated by V_d up to the saturation drift velocity (v_{sat}) lose their kinetic energy through generating LO phonons.

LO phonons can be created not only by scattering of electrons but also by impact ionization[10], through which a hot carrier loses its energy to create a new electron-hole pair. The impact ionization can be accompanied by creation of an LO phonon to compensate the difference of momenta among the decayed hot electron and the created electron-hole pair (**Fig. 4**), whereas the number of created holes can be electrically monitored from the backgate terminal in the case of MOSFET devices.[4]

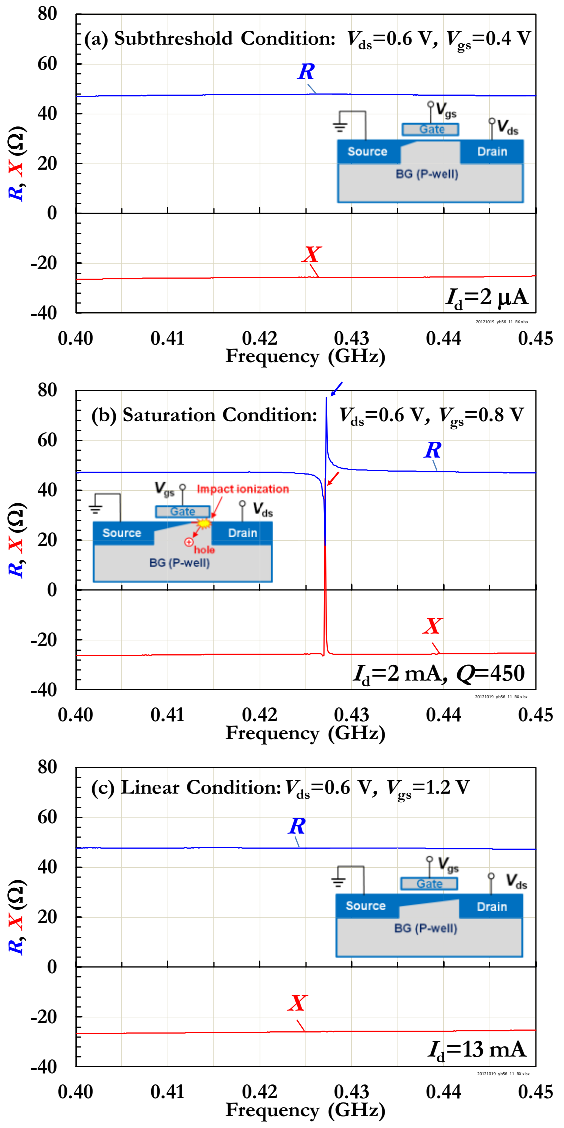

Fig. 3 Frequency dependences of complex impedance, $Z=R+iX$, for various bias conditions.

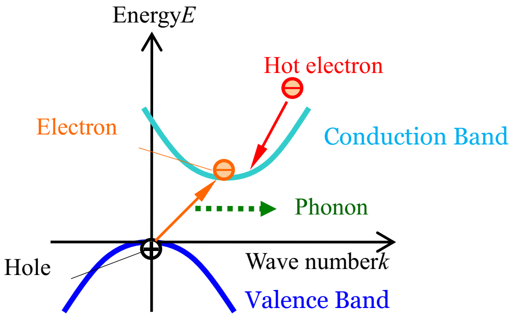

Fig. 4 Phonon creation accompanied by impact ionization in indirect bandgap semiconductor.

The experimental results in this study therefore imply that the impact ionization rate α is periodically increased with a specific frequency, probably caused by the increased number of LO phonons created by hot electrons accelerated by V_d upto a drift velocity near v_{sat}.

5. Summary

From the relation between frequency dependence of impedance and bias conditions measured for a CMOS-based device, it was found that the sharp resonance was observed only under a saturation bias condition. The results suggest that the resonance can be excited using hot carriers accelerated upto near the saturation drift velocity.

References

1. K. Abe : Jpn. J. Appl. Phys. **52** (2013) 070207.
2. T. Ohira: IEEE Trans. Circuits Syst. II, **52** (2005) 846.
3. T. Ohira *et al.*: IEEE Trans. Circuits Syst. II **54** (2007) 810.
4. T. Kamata *et al.*: Jpn. J. Appl. Phys. **15** (1976) 1127.
5. N. D. Arora and M. S. Sharma: IEEE Trans. Electron Dev. **38** (1991) 1392.
6. K. Abe *et al.*: Jpn. J. Appl. Phys. **49** (2010) 074303.
7. K. Abe *et al.*: Jpn. J. Appl. Phys. **51** (2012) 050205.
8. K. Abe *et al.*: Dig. Pap. IEEE SiRF2009 p. 41.
9. J. Chen and J. B. Khurgin: IEEE J. Quantum Electron. **39** (2003) 600.
10. C. L. Anderson and C. R. Crowwell: Phys. Rev. **B** 5 (1972) 2267.