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Detection of Acoustic Oscillation in MOSFET Using Piezoresistance Effect

ピエゾ抵抗効果を用いた MOSFET 中の音響発振の検出

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1. Introduction

For the purpose of realizing precise clock generators on integrated circuits, various types of oscillators have been proposed.[1-3] In the previous papers,[4,5] the author has demonstrated the possibility of exciting acoustic oscillation in a MOSFET (metal-oxide-semiconductor field-effect transistor) with a multiple-gate configuration. Sharp resonance with a quality factor of Q=1500 was preliminarily detected at 300 MHz when DC bias voltages in a saturation condition were applied to the gate and drain electrodes of a MOSFET (V_g=0.8 V, V_d=0.6 V).[4] To confirm the origin of the oscillation, piezoresisntance effect of Si was used for direct detection of the acoustic standing wave in this study.

2. Device and Measurements

Semiconductor crystals with indirect band gap, such as Si or Ge, has large piezoresistance effect.[6] It is expected that resistance of Si should be periodically increased and decreased in accordance with periodic compression and tensile stress induced by acoustic standing wave excited in the Si crystal. In this study, both a piezoresistance detector and an n-type MOSFET with a multiple gate configuration (15 devices connected in parallel) were prepared within the same device area (28.5×195.5 μm) using only a standard CMOS process. The piezoresistance detector (14 devices in parallel) was formed using the same n-type impurity layer as that used for drain or source of the MOSFET. Figure 1 shows the schematic partial cross section of the devices prepared in this study.

As shown in an equivalent circuit (Fig. 2), the MOSFET and the piezoresistance detector were electrically isolated except for the common connection of ground. DC bias voltages were applied to the gate and drain electrodes of the MOSFET, and frequency dependence of complex impedance was measured for the piezoresistance detector.[4,5]

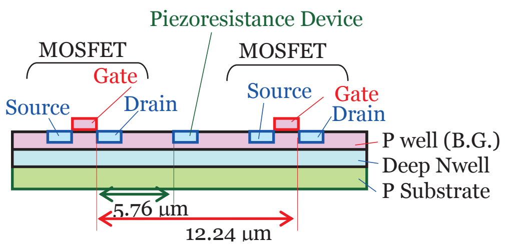

Fig. 1 Schematic partial cross section.

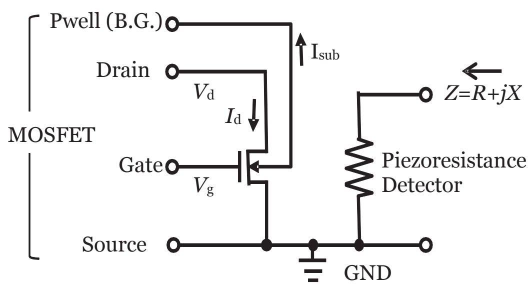

Fig. 2 Equivalent circuit.

3. Experimental Results

Figure 3 shows real and imaginary parts of complex impedance, R and X, measured for the piezoresistance detector, with DC bias voltages being applied to the gate and drain electrodes of the MOSFET (V_g=V_d=0.5 V). Plotted as a function of frequency, both R and X showed sharp resonance peaks at 123 MHz. The quality factor was estimated to be Q=676 using Ohira's method.[7] The background levels of R_0 and X_0 at 110 MHz were 87 Ω and -1.6 Ω, respectively, indicating that the real part is dominant around this frequency. The complex impedance can be equivalently expressed with a parallel RC model with R_0=87 Ω and C_0=0.3 pF.

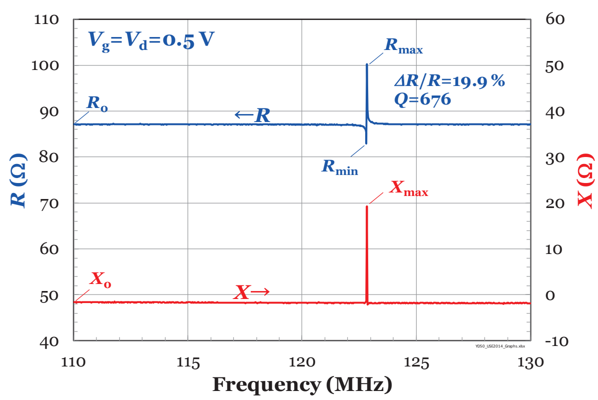

Fig. 3 Impedance of piezoresistance detector.

Near the resonance frequency, R took the minimum and maximum values of R_{min}=83 Ω and R_{max}=100 Ω, respectively, whereas X took only the maximum value of X_{max}=19 Ω. It is noted that the polarity of X changes negative to positive in a very narrow frequency range suggesting that the device works as an inductor at this limited frequency range. It was confirmed that the sharp resonance peaks disappeared when the bias voltages were removed (V_g=V_d=0 V), as shown in Fig. 4.

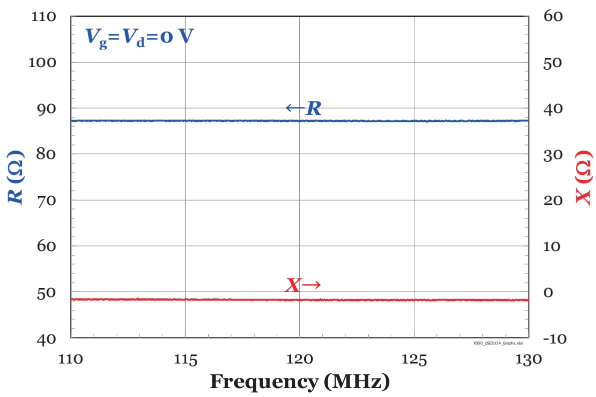

Fig. 4 No resonance without DC bias voltages (V_g=V_d=0 V).

4. Discussion

Assuming that the sharp resonance peaks observed in Fig. 3 are caused by acoustic standing wave exited within the device area of MOSFET, the velocity and amplitude of the acoustic wave were estimated to discuss the validity of the assumption. Since the width of the device area was W=28.5 μm and the resonance frequency was f_r=123 MHz, the velocity of the acoustic wave is estimated to be v =$2Wf_r$ =7011 m/s, which is between the sound velocity of a longitudinal wave (v_L=8430 m/s) and a transverse wave (v_T=5840 m/s) propagating in the Si [100] direction.[8]

Calculated from the maximum and minimum values of resistance, R_{max} and R_{min}, the amplitude of resistance change was $\Delta R/R = (R_{max}-R_{min})/R_0 = 20$ %, where ΔR is the amplitude of resistance change and R_0=87 Ω is the original (background) resistance. Using the piezoresistance coefficient of n-type Si in [100] direction, $\Pi_{11} = -102.2\times10^{-11}$ Pa^{-1},[8] the amplitude of stress change can be estimated as $\Delta X = (1/\Pi_{11})(\Delta R/R)$ = 0.20 GPa, where ΔX is amplitude of stress change. This magnitude of ΔX is reasonable because it is about 1/35 of the breakdown tensile stress of Si, σ_c=7 GPa.[9] Assuming the Young's modulus of Si [100] as E=130 GPa, the amplitude of strain change can be estimated to be $\Delta L/L = 1.5\times10^{-3}$.

5. Conclusion

Sharp resonance (Q=676) was detected at 123 MHz in complex impedance measured for the piezoresistance detector (R_0 =87 Ω) placed within the same device area of a MOSFET having a multiple gate configuration when DC bias voltages (V_g=V_d=0.5 V) were applied to the gate and drain electrodes.

Assuming that the origin of the sharp resonance is caused by acoustic standing wave exited within the MOSFET, the velocity and amplitude of acoustic standing were estimated from the device dimension, W, resonance frequency, f_r, and the maximum and minimum values of resistance, R_{max} and R_{min}. Since both the estimated velocity of v=7011 m/s and the amplitude of strain change of $\Delta L/L = 1.5\times10^{-3}$ were consistent with reported material constants or values, it is concluded that the assumption should be valid, indicating that acoustic oscillation can be excited within the MOSFET device area only with appropriate DC bias voltages being applied to the gate and drain electrodes.

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