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Analysis of MOSFET Electrometer Sensitivity by Radio-Frequency Reflection

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1. Introduction

Highly sensitive electrometers are required for the readout of qubit states [1] and many other applications in sensing [2]. Although single-electron transistors (SET) have been researched for such applications, MOSFET can now attain as high sensitivity as 10^{-3} e/√Hz at room temperature due to the aggressive down scaling [3]. Considering the high-temperature and high-voltage operation as compared with the counterpart and the ease of manufacturing by integrated-circuit technologies, MOSFET electrometers must have a wide range of usage.

In this report, we will focus on the analysis by radio-frequency (RF) reflection, expecting a high-speed operation free from the constraint set by the output resistance and the cable capacitance, and high sensitivity not limited by the low-frequency flicker noise.

2. Experiments

Figure 1 shows the circuit diagram for the RF reflectance measurement. LC resonator including the MOSFET electrometer is connected at the end of the 1-m coaxial cable, and the reflected signal is separated by the directional coupler, and is monitored by the spectrum analyzer. N-channel MOSFET with L=70 or 300 nm and W=110 nm fabricated by 65-nm bulk CMOS process is used as an electrometer. In order to assure negligible gate leakage current, 5-nm gate oxide is used, and the gate-induced inversion-layer extended source/drain is adopted to suppress short-channel effects. Substrate voltage (V_{sub}<0) is applied to accommodate AC signal in the drain. As indicated by Table 1, the MOSFET includes a large stray capacitance C_1 to its gate, and charge signal induced in the channel (in the unit of electron) is calculated from V_q considering C_1, C_2 and C_{in}.

Note that, although the circuit configuration in Fig. 1 is basically the same as that of RF-SET [4], voltage of the carrier signal can be increased more than that for SET, resulting in an improved signal-to-noise ratio (SNR) and elimination of cooled preamplifier.

2. Results and Discussions

Figure 2 shows the frequency spectra of the reflected signal for different levels of charge signal. On both sides of the central carrier signal, charge signals appear 25 MHz away from the center, reflecting the frequency of the input charge signal. Since the levels of the charge signal in the spectra are proportional to the input, we can say that the signal is properly identified. SNR can be obtained as the the charge signal level above the noise floor.

In order to analyze the optimum operation condition DC transfer characteristics of the MOSFET in the linear region (V_d=50 mV) is acquired as shown in Fig. 3. Based on these data and considering the voltage reflection coefficient expressed as $(Z-Z_o)/(Z+Z_o)$, we can calculate the change in reflectance $\Delta\alpha$ for a given amplitude of charge input, where Z is the impedance of the resonator including MOSFET and Z_o is the characteristic impedance of the coaxial cable. Figure 4 shows the calculated $\Delta\alpha$ and experimental SNR for the small carrier voltage V_c of −16 dBm. $\Delta\alpha$ and SNR correspond well and the optimum V_{gg} for maximum SNR can be easily derived as long as the V_c is small and FET can be regarded as a resistor. When the V_c becomes larger, optimum V_{gg} shifts to the negative side for L=70 nm presumably due to the large drain-induced barrier lowering, and is rather insensitive for L=300 nm (data not shown).

Figure 5 shows V_c dependence of the charge sensitivity that is the minimum detectable charge calculated by ΔQ/SNR/√RBW, where ΔQ is the input charge signal in the unit of electron and RBW is the resolution bandwidth of the spectrum analyzer. Thanks to the relatively high applicable voltage (~2.5 V) of the MOSFET, V_c can be raised to 10 dBm, and the charge sensitivity reaches 5×10^{-3} e/√Hz for L=70 nm. Also note that the decrease of the gate length is effective as is seen in the three-hold reduction of δq from that of L=300 nm.

3. Conclusions

By the use of the RF reflection, electrometer consisting of 70-nm-gate MOSFET could operate at the speed of 25 MHz with a charge sensitivity of 5×10^{-3} e/√Hz at room temperature. It was also found that the down scaling of the gate length is effective for the improvement of the charge sensitivity.

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References

[1] J. Gorman, et al. Phys. Rev. Lett., 95 (2005) 090502.
[2] A. N. Cleland, et al., Appl. Phys. Lett., 61 (1992) 2820.
[3] K. Nishiguchi, et al., Jpn. J. Appl. Phys., 47 (2008) 8305.
[4] R. J. Sehoelkopf, et al., SCIENCE, 280 (1998) 1238.

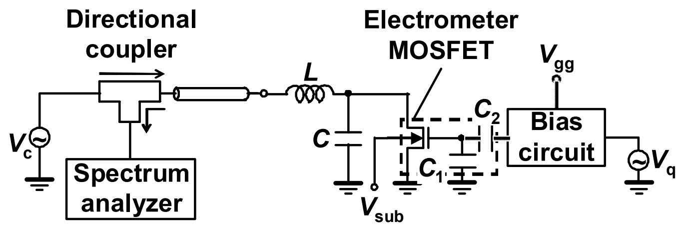

Fig. 1 Circuit diagram for RF reflectance measurement.

Table 1 Operation conditions

Carrier V_c	380 MHz
Charge signal V_q	25 MHz
Resonator L, C	100 nH, 1.6 pF
MOSFET C_{in}	53 aF (L=70 nm) 230 aF (L=300 nm)
Stray C_1	1.4 fF
Coupling C_2	260 aF

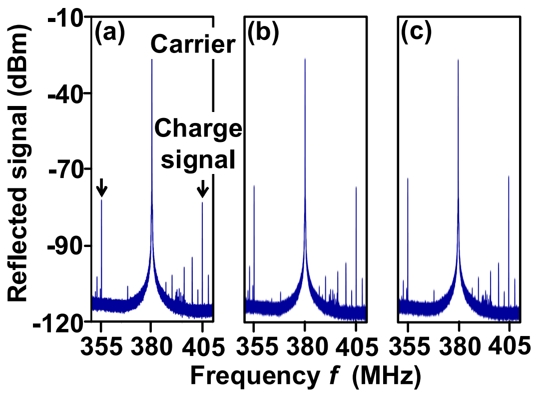

Fig. 2 Frequency spectra of the reflected signal for L=70 nm, V_c=10 dBm, and RBW=3 kHz. Input charge signals are (a) 37, (b) 110, (c) 180 electrons (rms), respectively.

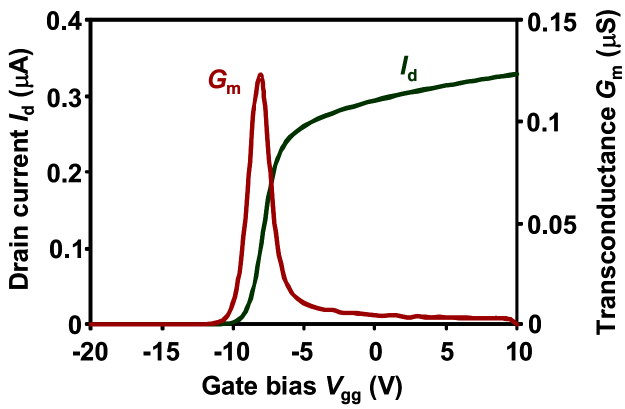

Fig. 3 Drain current and transconductance as a function of gate bias for L=70 nm and V_d=50 mV.

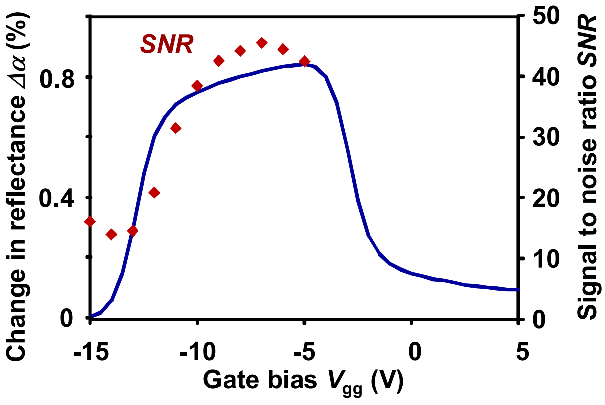

Fig. 4 Calculated change in reflectance (rms) and the measured SNR for L=70 nm, V_c=–16 dBm, V_q=3.5 Vrms and RBW=3 kHz.

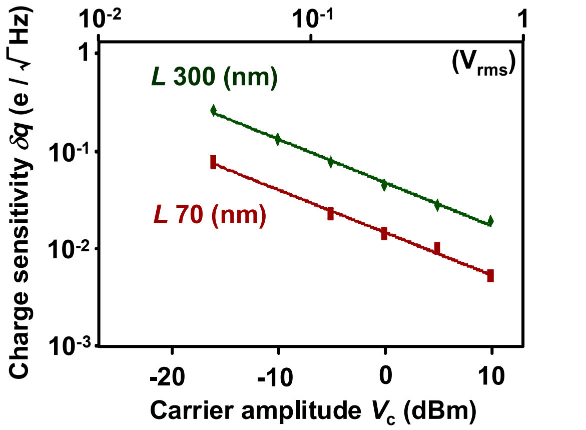

Fig. 5 Charge sensitivity as a function of carrier amplitude for L= 70 and 300 nm.