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 high sensitivity as $10^{-3} \text{e}/\sqrt{\text{Hz}}$ 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 reflection 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. Thanks to the relatively high applicable 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 $5 \times 10^{-3} \text{e}/\sqrt{\text{Hz}}$ for $L=70 \text{nm}$. Also note that the decrease of the gate length is effective as is seen in the three-fold reduction of $\delta q$ from that of $L=300 \text{nm}$.

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 $5 \times 10^{-3} \text{e}/\sqrt{\text{Hz}}$ 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

Fig. 1 Circuit diagram for RF reflectance measurement.

Table 1 Operation conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier $V_c$</td>
<td>380 MHz</td>
</tr>
<tr>
<td>Charge signal $V_q$</td>
<td>25 MHz</td>
</tr>
<tr>
<td>Resonator $L$, $C$</td>
<td>100 nH, 1.6 pF</td>
</tr>
<tr>
<td>MOSFET $C_{in}$</td>
<td>53 aF ($L=70$ nm)</td>
</tr>
<tr>
<td></td>
<td>230 aF ($L=300$ nm)</td>
</tr>
<tr>
<td>Stray $C_1$</td>
<td>1.4 fF</td>
</tr>
<tr>
<td>Coupling $C_2$</td>
<td>260 aF</td>
</tr>
</tbody>
</table>

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.