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Low frequency noise by mobility and number fluctuations in MOS structures

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1. Introduction

The low frequency noise in MOSFET is an important factor to determine the performance of nonlinear circuits in GHz region. It has been found that there are two kinds of origins of the low frequency noise, i.e., number fluctuation (ΔN) [1] and mobility fluctuation ($\Delta\mu_H$) [2]. The former is due to the interaction of carriers with traps near the Si/SiO interface. The latter is due to the fluctuation in the bulk mobility. However, the origin of the low frequency noise in MOSFETs is still debatable [3,4]. The purpose of this research is to evaluate the origin of the low frequency noise quantitatively.

2. Device structure

The MOS structures fabricated in this study is shown in Fig. 1. In this structure, shallow junction region is formed under the gate by Sb ion implantation (3×10^{14}cm^{-2}, 15keV). The gate oxide has a thickness of 5nm. In such a structure, the gate voltage V_g do not almost affect on the number of carriers and the drain current while it can change the position of carriers. Figure 2 shows calculations of the carrier distribution near the Si/SiO interface. The carrier density only in the vicinity of the interface is modulated by V_g. Figure 3 shows the carrier density at the Si/SiO interface. The carrier density decreases in the negative V_g region (V_g <-2V). In other words, carriers are away from the Si/SiO interface in the region of V_g <-2V.

3. Results and Discussion

Figure 4 shows the current-voltage characteristic of the fabricated device (L/W=0.3/2.0μm). There is little dependence of the drain current I_d on V_g as is expected by the calculations. Noise spectrum densities exhibit $1/f$ spectra at the various voltage conditions (Fig. 5). The noise spectrum density obtained includes both the noises generated from source/drain (S/D) region, which are denoted as $S_s(f)$ and $S_d(f)$, and that from the shallow junction region denoted as $S_{int}(f)$. $S_{int}(f)$ has been extracted from the measured noise with the aid of the noise equivalent circuit model [5] shown in Fig. 6. From this model, the total noise $S(f)$ is given by

$$S(f) = \frac{S_s(f)\cdot R_s{}^2 + S_{\text{int}}(f)\cdot R_{\text{int}}{}^2 + S_d(f)\cdot R_d{}^2}{(R_s + R_{\text{int}} + R_d)^2}, \qquad (1)$$

where R_s, R_d and R_{int} stand for the resistances of the source region, drain region, and shallow junction region, respectively. $S_s(f)$ and $S_d(f)$ are measured by using two terminal devices that have only the S/D region. $S(f)$, resultant $S_{int}(f)$ and $S_s(f) + S_d(f)$ are shown in the case of I_d =1mA (Fig.5). It should be noted that the contributions of $S_s(f) + S_d(f)$ are not negligible, but their contribution is about 20%.

Figure 7 showed the dependence of $S_{int}(f)$ on V_g at I_d=0.3, 0.6, and 1mA. Constant noise is observed under the condition of V_g <-3V. In the bias conditions, carriers are away from the Si/SiO interface as shown in Fig. 2. Therefore, $\Delta\mu_H$ becomes the dominant noise due to the disappearance of the effect of the Si/SiO interface. On the other hand, $S_{int}(f)$ increases with V_g in the high V_g region. It is considered that there are two causes of the increase. One is an increase of ΔN, which is promoted by the approach of carriers to the Si/SiO interface (Fig. 3). The other is an increase of $\Delta\mu_H$. It is well-known that $\Delta\mu_H$ is inversely proportional to the number of carriers. Figure 8 shows the number of carriers obtained from the experiment data of resistance. The number of carriers slightly increases with V_g, which decreases $\Delta\mu_H$. Therefore, it is concluded that the increase in noise spectra is due to not $\Delta\mu_H$, but the effect of the Si/SiO interface.

4. Concluding Remarks

In the case where carriers are away from the Si/SiO interface, the mobility fluctuation ($\Delta\mu_H$) becomes the dominant noise because $\Delta\mu_H$ is not influenced by the Si/SiO interface. If carriers exist near the Si/SiO interface, the number fluctuation (ΔN) becomes the dominant noise. It has been found that there are two kinds of fluctuations which are related to the quality of the Si/SiO interface in addition to ΔN, i.e., mobility fluctuation caused by charged traps near the interface ($\Delta\mu_I$) [6], and the fluctuation by the mutual correlation between $\Delta\mu_I$ and ΔN [7]. The noise sources related to the interface are separated from $\Delta\mu_H$ in this study, as the first step toward the detail separation of above-mentioned noise sources.

References

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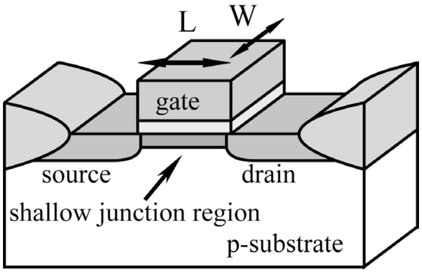

Fig. 1 Device structure having shallow junction region under the gate.

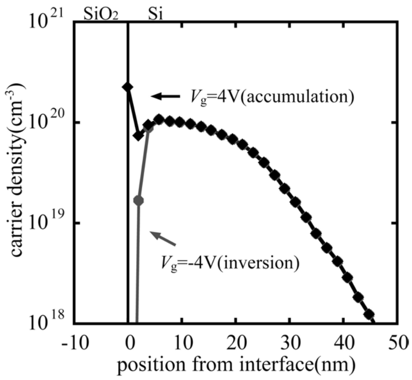

Fig. 2 Comparison between the carrier distribution calculated at V_g=-4V (inversion) and that at V_g=4V (accumulation).

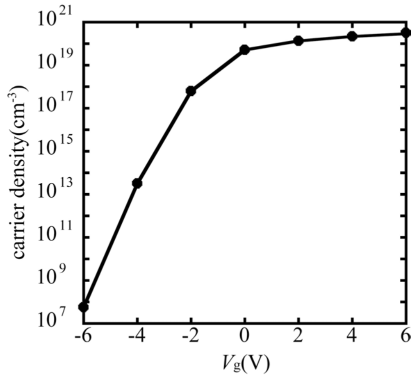

Fig. 3 Dependence of the carrier density at the Si/SiO interface on V_g

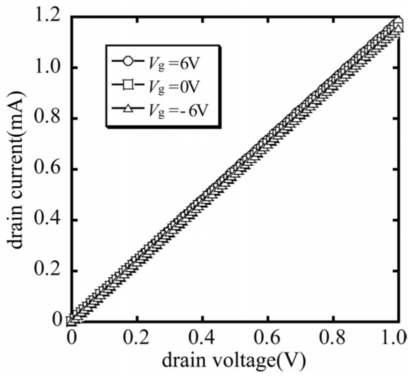

Fig. 4 Current-voltage characteristics of fabricated device for different V_g.

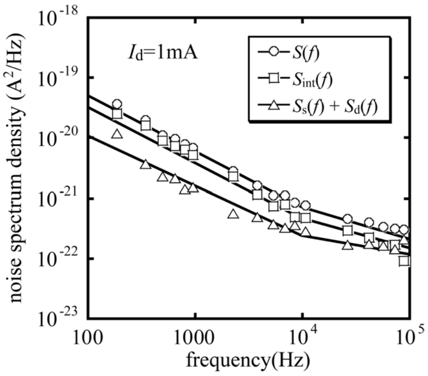

Fig. 5 The noise spectrum densities from the fabricated device. The noise spectrum densities from shallow junction region and S/D region are also plotted.

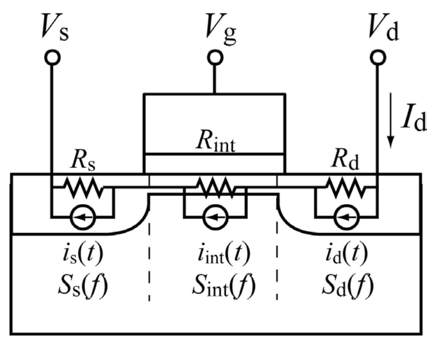

Fig. 6 Noise equivalent circuit model using for the extraction of $S_{int}(f)$ from $S(f)$.

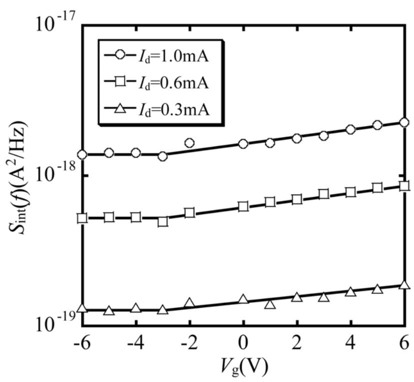

Fig. 7 Dependence of $S_{int}(f)$ on V_g for different I_d.

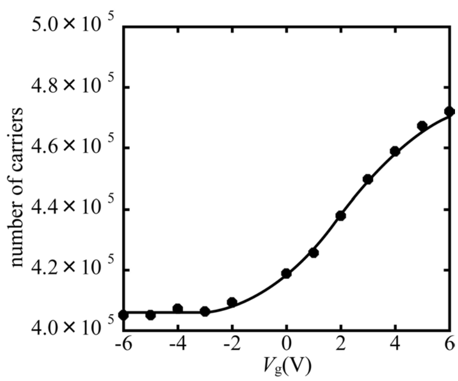

Fig. 8 Dependence of the number of carriers in shallow junction region on V_g.