Low frequency noise assessment of accumulation Si p-MOSFETs

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1. Introduction

Whether the introduction of stress or the change of material such as the Germanium or the Silicon with a (110) crystallographic orientation to fabricate more performing MOSFETs, the enhancement of the drivability is always going along with a strong increase of the low frequency noise level [1]. Among all the potential solutions investigated, a newly developed MOSFET working in accumulation mode rather than in inversion mode such as the conventional MOSFET exhibits several other features that need to be seriously considered. Indeed, in addition to provide a higher drivability, the reliability of these transistors is greatly improved due to weaker applied electric fields [2].



Fig. 1: Schematic of an accumulation p-MOSFET and representation of the several regions that are contributing to the total drain current.

In addition, a proper study of their noise has never been done and is therefore mandatory in order to deeper evaluate their viability as a potential replacement for the present CMOS technology. Therefore, the low frequency noise also known as 1/f noise or even Flicker noise has been studied and compared to the one of the conventional p-MOSFET. The study has been pushed forward with investigating the impact of the doping concentration on the noise since it is a key parameter for the performances of the accumulation MOSFET.

2. Experiment and results

Several p-MOSFETs working in inversion and accumulation modes and featuring three doping concentrations have been fabricated on 50 nm thick (100) crystallographic oriented SOI. The process flow has been identical for all devices. In order to conduct a proper and reliable noise study [3], large-gate-area transistors have been exclusively studied to avoid the dispersion of the low frequency noise and eliminate local effects.



Fig. 2: Drain current-Gate overdrive voltage characteristics of accumulation and inversion Si p-MOSFETs with different N_a .



Fig. 3: Noise versus gate overdrive voltage for an accumulation and inversion Si p-MOSFETs, $N_a=10^{16}$ cm⁻³. The full lines represent the modeling of the total noise while the dotted and dashed lines represent the noise contribution generated by each region, respectively the Accumulation/Inversion channel and the Source and Drain access parasitic resistances.



Fig. 4: Noise versus the gate overdrive voltage for an accumulation and inversion p-MOSFETs, $N_a=2x10^{17}$ cm⁻³. The lines represent the modeling.



Fig. 5: Noise versus the gate overdrive voltage for an accumulation p-MOSFET, $N_a=2x10^{17}$ cm⁻³. The full line represents the modeling of the total noise while the other lines represent the contribution of each region.

The schematic of an accumulation p-MOSFET is depicted in Fig. 1. Contrary to the conventional inversion MOSFET for which the carriers inside the channel are the minority carriers, the conductive channel of an accumulation MOSFET is made of majority carriers which are accumulating at the Si/SiO₂ interface. Their drain current-gate voltage I_d-V_g characteristics are compared with the conventional inversion MOSFETs in Fig. 2. For an equal doping concentration N_a , the accumulation ones have a better drivability than the inversion ones. Moreover, this superiority is even more pronounced when N_a is increased. Indeed, in addition to see its effective electric field E_{eff} at the Si/SiO₂ interface decrease and therefore its mobility increase, the SOI bulk is adding to the channel current a further contribution to form the drain current [2].

Fig. 3 presents the results of the noise study for intermediate N_a . The noise level of the accumulation p-MOSFET is slightly higher than that of the inversion one. Moreover, an accurate modeling of the noise has been possible within the theory [4] developed for the conventional MOSFET. This result indicates that an accumulation layer is behaving in a similar way to the inversion one regarding the 1/f noise and therefore that the interface traps are also the source of the noise in accumulation p-MOSFETs. Like for inversion MOSFETs, the source and drain access resistances of accumulation MOSFETs are also generating noise [5], modeled with the dashed lines in Fig. 3. This noise source needs to be taken into account at high V_g .

The noise measurements have been performed for $N_a = 2 \times 10^{17}$ cm⁻³. The results are reported in Fig. 4. Contrary to the lower doping concentrations, the noise of the accumulation p-MOSFET is lower than that of the inversion one within the usual operating range. Moreover, contrary to the inversion one, the modeling of the noise turned out to be impossible. As depicted in Fig. 1, at low V_g , the SOI bulk is depleted and the current is exclusively coming from the majority carriers confined at the back interface. While V_g is increased, this layer vanishes and the SOI bulk becomes neutral and therefore acts like a resistive material. The majority carriers are afterwards accumulating at the Si/SiO₂ interface below the gate insulator. They generate the channel current that is finally adding to the SOI bulk current. So, the noise contribution of each region has been studied separately. The noise stemming from the SOI bulk has been modeled within the theory proposed by Hooge [6] while the one coming from the channel has been modeled within the theory [4] previously used. The great accuracy of the modeling, which is depicted in Fig. 5 with the full line, indicates the good progress of the present approach. The noise stemming from the back interface and from the SOI bulk is emerging while the one generated by the accumulation layer is not visible anymore. The reason for such a change of behavior when N_a is increased lies in the lower E_{eff} and in the higher Fermi potential.

3. Conclusion

The study of the low frequency noise in accumulation Si p-MOSFETs has been done and revealed that the noise source depends on the doping concentration. Furthermore, we showed that the accumulation p-MOSFET is the most promising replacement for the future CMOS technology since, contrary to the other devices, its drivability is not only enhanced when the doping concentration is increased but that its noise level is at the same time greatly reduced.

References

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