Improvement of 1/f noise by using VHP (Vertical High Pressure) oxynitride gate insulator for deep-sub micron RF and analog CMOS

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ABSTRACT

1/f noise in MOSFET using VHP(Vertical High Pressure) oxynitride gate insulator was studied. 1/f noise is degraded by conventional oxynitride gate insulator. It was found that 1/f noise can be improved by using VHP oxynitride gate insulator.

INTRODUCTION

Oxynitride is going to be used for the gate dielectrics of deep-submicron dual gate CMOS because of its advantage on the suppression of the boron penetration.

On the other hand, market for RF and also lower frequency analog CMOS is expected to rapidly grow and its requirements to the CMOS device characteristics have been seriously considered. In these applications, low 1/f noise is one of the key issues. As a system LSI, these analog circuits should be implemented with digital-logic circuits in one chip, and hence, the analog CMOS have to common the process with the deep submicron logic CMOS as a base.

We have evaluated the influence of the oxynitride gate – made by conventional N2O nitridation – on 1/f noise and found that 1/f noise of oxynitride gate CMOS is about 6dB higher than that of pure oxide gate for both n- and p-MOSFETs, as shown in Figs.1 and 2. In the PMOS case, it has been also found that 1/f noise in dual gate CMOS (p+ poly Si gate surface channel PMOS) is furthermore about 5dB higher than that of the single gate CMOS (n+ poly Si gate buried channel PMOS). Thus, 1/f noise of the pMOSFETs in oxynitride gate dual-gate CMOS can be said to be very high.

In order to overcome this problem, at least the 1/f noise degradation caused by the use of oxynitride gate dielectrics has to be solved. This degradation is presumed to be caused by the accumulation of the nitrogen at the interface between the gate insulator and silicon.

In order to shift the peak position of nitrogen profile from the interface, VHP (Vertical High Pressure) process has been introduced for the formation of the oxynitride gate and 1/f noise improvement has been investigated for the first time.

VHP PROCESS

The process flow for the sample fabrication is shown in Fig.3. As the gate dielectrics, we prepared 3 kinds of the films – pure oxide, oxynitride formed by conventional process, and oxynitride formed by VHP process as shown in Table 1. The equivalent thicknesses of all the 3 gate insulators are set to 5.5 nm. Fig.4 shows schematic cross-section of the VHP reactor and Fig. 5 shows the time chart of pressure and temperature for the VHP process. The reaction time was controlled by the pressure in this case.

There are a number of advantages for the VHP process. First of all, oxidation occurred at high pressure (>10 atm) brings much stronger penetration of oxidant to nitride layer than atmospheric case. Thus the oxide layers can easily grow beneath the nitride layer as shown in Fig. 6, resulting in the shift of the nitrogen peak from the interface, as shown in Fig.7. In the VHP case (Fig.7(a)) the nitrogen peak is at the oxynitride film upper surface. The nitrogen concentration at the silicon interface can be estimated to be almost 0 atm % considering the taling effect in the SIMS profile. On the other hand, the nitrogen peak exists almost at the silicon interface in the conventional atmospheric process (Fig.7(b)), and the nitrogen concentration is estimated to be almost 1%, even though the peak value itself – 1.2 % – is smaller than the VHP case – 5 %.

Another advantage of the VHP process is the lower temperature thermal process such as 700°C as shown in Table 1. Furthermore, at high pressure the thermal conduction though the highly dense gas becomes the major mechanism of the heat transmission rather than thermal radiation, resulting in quite homogeneous temperature distribution, contributing in the quite uniform film thickness – typical sigma value less than 1%

1/F NOISE CHARACTERISTICS

1/f noise characteristics of n- and p-MOSFETs are shown in Figs.8 and 9, respectively. While 1/f noise of conventional oxynitride samples was still 6dB higher than that of pure oxide, 1/f noise of the samples with VHP oxynitride reduced to the same level as the pure oxide, both n- and p-MOSFET cases.

Fig.10 shows interface state density (Dit) dependence on process condition. Dit in VHP process is almost same as that in pure oxide, while that in conventional oxynitride is about two times higher.

These results reveal that the nitrogen profile of the oxynitride gate dielectrics strongly affects the 1/f noise as well as the interface state density. Thus, the nitrogen profile control becomes critically important in the deep-sub micron mixed analog digital CMOS process.

SUMMARY AND CONCLUSIONS

We have shown that 1/f noise of n- and p-MOSFETs is degraded by 6dB when changing the gate dielectrics from pure oxide to conventional oxynitride according to the change from single to dual gate CMOS. Furthermore, 1/f noise of p-MOSFETs degrades by another 5dB with the change in the channel type from the buried to the surface.

In order to overcome the problem caused by the conventional oxynitride, VHP process has been introduced for the oxynitride film formation. By controlling the nitrogen profile in the insulator, dramatically good improvement of the 1/f noise to the pure gate oxide level has been confirmed for both n- and p-MOSFETs.

VHP has a number of process advantage over the conventional atmospheric pressure oxynitridation process, such as low process temperature and highly uniform thermal distribution, and thus it is one of the most promising candidates for the deep-sub micron mixed analog digital CMOS.

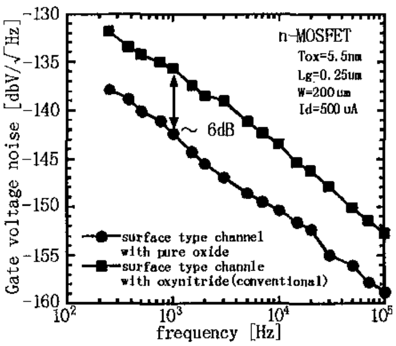


Fig. 1 1/f noise in pure oxide and in oxynitride(conventional), nMOSFET

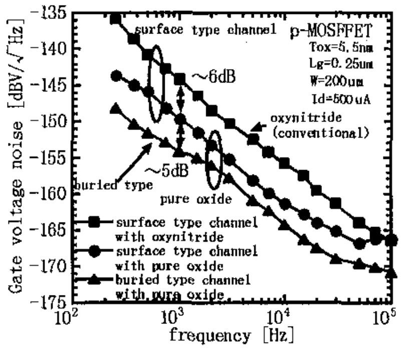


Fig.2 1/f noise comparision between buried type channel and surface type channel, pMOSFET

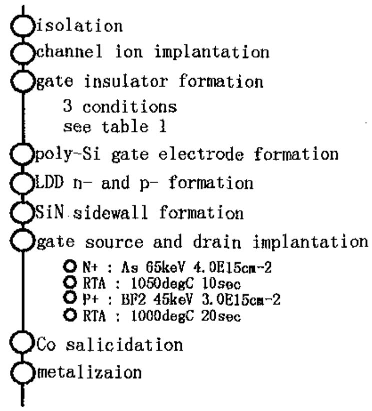
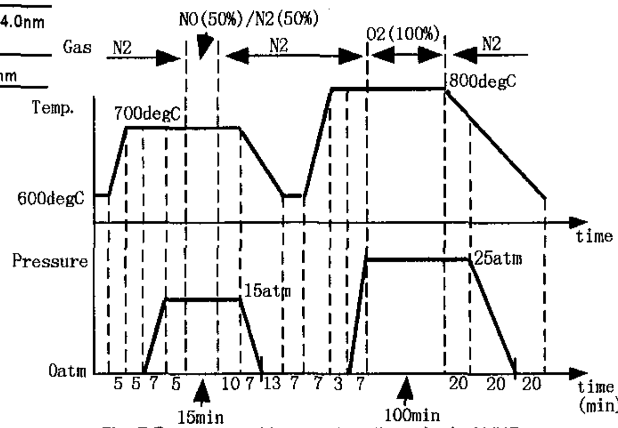


Fig.3 Process flow of dual-gate CMOSFET with oxynitride gate dielectric

Table 1. Process condition of gate insulator formation

VHP process (oxynitride)	1st NO(50%)/N2(50%) : 700degC, 15atm, 15min 2nd O2 : 800degC, 25atm, 100min
conventional (oxynitride)	1st 10%HCl oxidation : 750degC, atmospheric pressure, 4.0nm 2nd N2O : 900degC, atmospheric pressure, 15min
pure oxide	10%HCl oxidation : 750degC, atmospheric pressure, 5.5nm



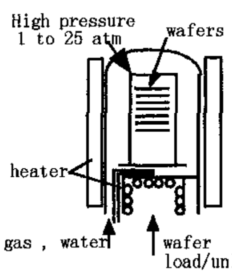


Fig.4 Schematic cross section of VHP vessel

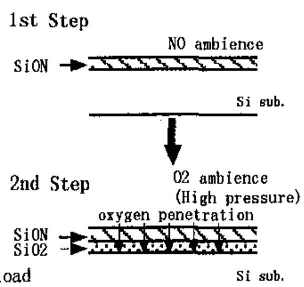
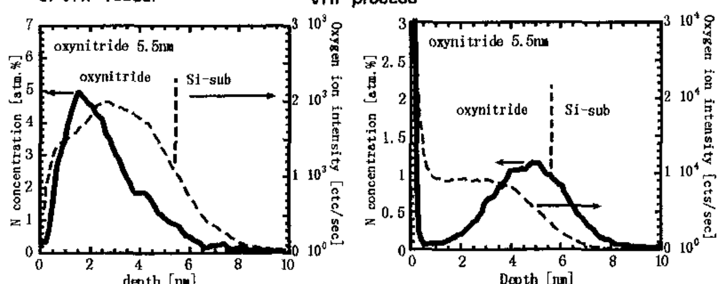


Fig.6 Schematic diagram of VHP process

Fig. 5 Pressure and temperature time chart of VHP process



(a) VHP process (b) conventional process

Fig.7 Nitrogen profile of oxynitride

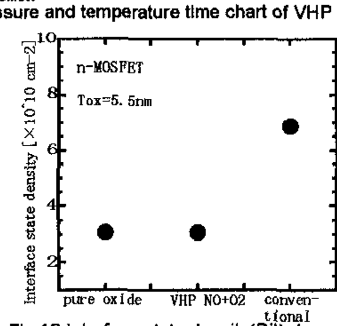


Fig.10 Interface state density(Dit) dependence on oxynitridation process, nMOSFET

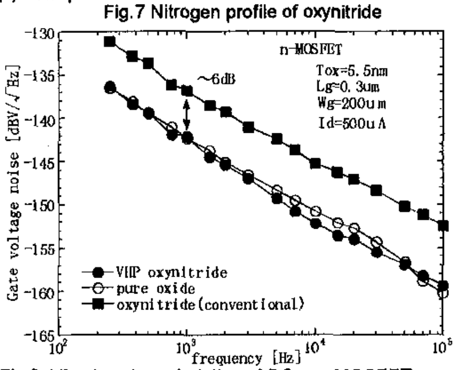


Fig.8 1/f noise characteristics of 0.3um nMOSFET

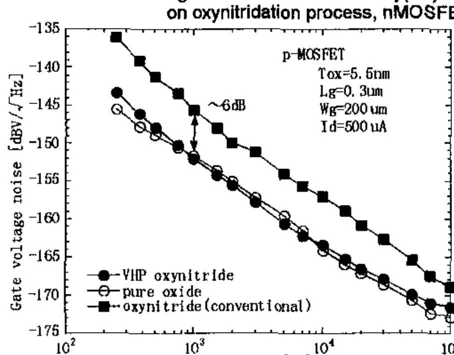


Fig.9 1/f noise characteristics of 0.3um pMOSFET