Enhanced Diffusion of Phosphorus due to BPSG layer in SEG-MOSFETs

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Abstract

We report on the enhanced diffusion characteristics of phosphorus in SEG(selective epitaxial growth)-MOSFETs due to in-diffusion from BPSG (borophosphosilicate glass) layer. Because of structural complexity of SEG-MOSFETs, three-dimensional simulation was implemented and our results successfully show that a great deal of impurity in-diffusion from BPSG to silicon layer generates a lot of interstitial. Therefore, the diffusivity of phosphorus is increased dramatically by TED effect, causing the characteristics of SEG-MOSFETs is degraded severely.

1. Introduction

As the dimensions of MOS devices are shrunk to the 0.1μm and below, ultra-shallow source and drain junctions are strongly required to prevent short channel effects. MOSFETs with ESD(elevated source and drain) realized by SEG of silicon have been proposed as one of the alternative approaches to very shallow S/D junctions for improving short-channel effects[1]. In the case of NMOS devices of DRAM cell, as shown in Figure 1, ESD is faced by BPSG layer that is dielectric material for cell transistor of DRAM. It is known that BSG, PSG, or BPSG yields solid-phase diffusion of boron or phosphorus to the silicon bulk layer [2,3]. As the formation of SEG needs high temperature (>800℃) for a few minutes, the enormous dopant diffusion by highly doped silicate glasses can cause degradation of MOS characteristics. In this paper, we report on the enhanced diffusion kinetics and degradation characteristics of SEG-MOSFETs due to in-diffusion from BPSG layer.

2. In-diffusion characteristics

Figure 2 shows in-diffusion characteristics of BPSG. Epitaxial silicon layer with phosphorus of $4\times10^{19}cm^{-3}$ was grown to 2500 Å, followed by deposition of BPSG and by thermal anneal of 900℃ for 6 minutes. This result shows that BPSG is primarily a source of phosphorus, and the phosphorus out diffusion is enhanced at higher boron concentration. A huge amount of phosphorus in BPSG diffuses into silicon bulk layer, while boron diffusion is retarded. It is because that concentration of phosphorus in BPSG is about 4 wt% and has the segregation coefficient from silicon to oxide of 10, on the contrary boron has the segregation coefficient from silicon to oxide of 0.1.

Figure 3 shows the comparison of diffusion distance between TSUPREM4 default values and that used in this simulation. A huge amount of phosphorus diffusion at high concentrations was successfully observed by our diffusion parameters considering diffusion barrier lowering effect[4,5].

3. SEG-MOSFET degradation

Figure 4 shows phosphorus diffusion results for epitaxial growth layer. Epi growth was performed at 900℃ for 6 minutes and BPSG was additionally deposited on the epi layer in Figure 4(b). After thermal treatment of 900℃, experimental results were compared to simulation, which showed good agreement. In Figure 4(b), the diffusion barrier lowering effect causes a huge amount diffusion of phosphorus into silicon. This in-diffused dopant substitutes the silicon on lattice site, which generates interstitial and causes transient enhanced diffusion of phosphorus in silicon bulk. Diffusion length of phosphorus in bulk layer is increased 15 times greater than that in Figure 4(a). It is found that in-diffusion from BPSG not only increases the doping concentration at the interface area but also causes the dopant in bulk area to be diffused by TED effect.

Based on the above simulation results, degradation effect of 0.15μm NMOS cell device was investigated. Because of structural complexity of SEG-MOSFET as shown in Figure 1, it is hard to get the exact solution by two-dimensional simulation. Therefore, three-dimensional simulation was implemented as shown in Figure 5.

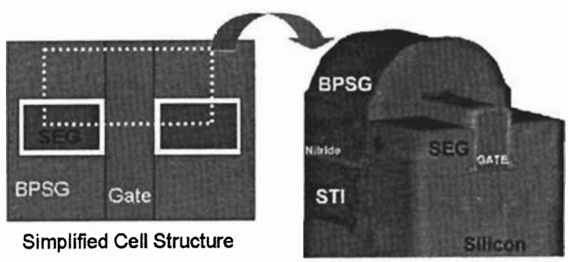

Fig. 1. The simplified structure of NMOS devices of DRAM cell.

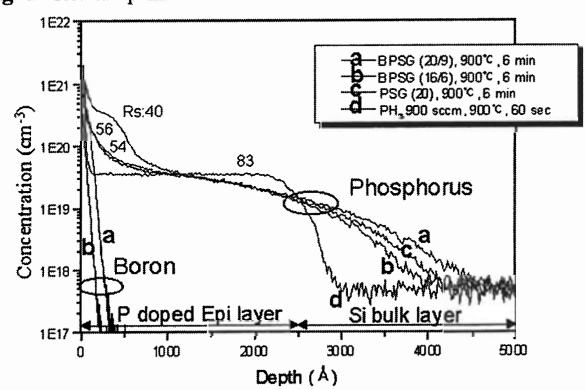

Fig. 2. In-diffusion characteristics of BPSG: Epitaxial silicon layer with phosphorus of $4x10^{19}cm^{-3}$ followed by deposition of BPSG and by thermal anneal of 900℃.

Phosphorus diffused out of BPSG, as mentioned before, not only increases the concentration of N-type dopant at the interface but generates interstitial of which diffusivity is so high that interstitial broadens out into silicon bulk layer immediately. Interstitials kick out bulk phosphorus to diffuse. Y-Z plane of Figure 5 shows that abnormally diffused phosphorus changes the desired doping profile under the gate. Therefore, net doping of channel near the STI interface is decreased or inverted from P-type to N-type, increasing narrow width effect and leakage current.

To prevent such in-diffusion from BPSG, plasma treatments were implemented after BPSG patterning process. Hardening the surface of BPSG layer by plasma treatment effectively prohibits silicon bulk layer from in-diffusion of BPSG layer. Finally, the characteristics of the NMOSFET having elevated source and drain for cell device is shown in Figure 6. Because the source and drain were formed by in-situ doping in epitaxial growth process instead of ion implantation, reverse short channel effect of threshold voltage is not found, which is usually shown in short channel device. Our simulation results show good agreement with experimental data without any fitting manipulation.

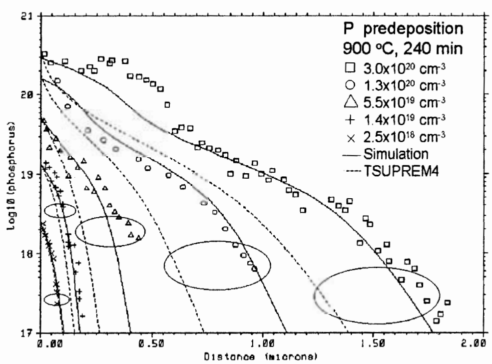

Figure 3. Diffusion characteristics: phosphorus was pre-deposited with various ambient concentration at 900℃ for 240 minutes (SIMS data from [6]).

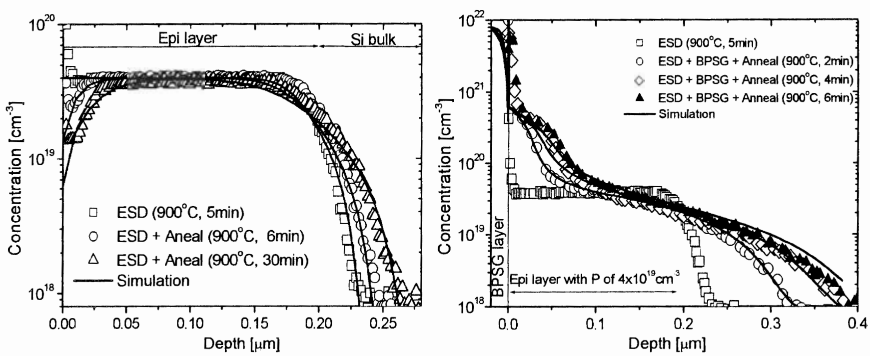

Fig. 4. Phosphorus diffusion results for epitaxial growth layer: thermal anneal of 900℃ after epi growth performed at 900℃ for 6 minutes (a) without and (b) with BPSG deposited on epi layer.

4. Conclusions

In this paper, the degradation of SEG-MOSFETs due to enhanced diffusion of phosphorus is reported. Even though our device has a structural complexity, three-dimensional simulation successfully shows that abnormally diffused phosphorus by BPSG changes the desired doping profile under the gate. Therefore, net doping of channel near the STI interface is decreased or inverted from P-type to N-type.

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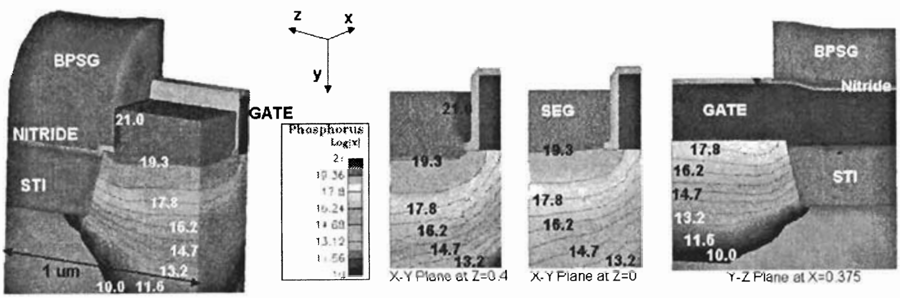

Fig. 5. Three-dimensional simulation result: phosphorus diffused out of BPSG increases not only the concentration of N-type dopant at the interface but interstitial of which diffusivity is so high that interstitial broadens out into silicon bulk layer immediately.

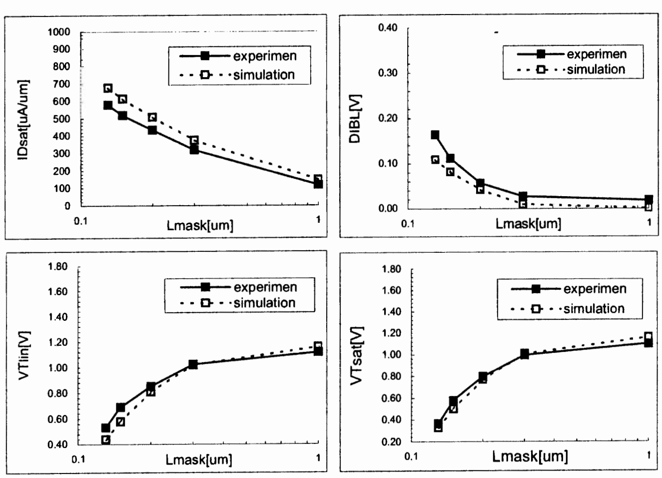

Fig. 6. The electrical characteristics of the cell NMOSFET with ESD.