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An Advanced Air Gap Process for MLC flash memories reducing Vth interference and realizing high reliability.

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1. Introduction

Recently as the use of the mass storage type flash memory expands into DVC and PC, a high-density, low-cost and high-speed of the flash memories are required. As the cell size of flash memory has been scaling down, not only the reading error due to Vth interference but also the fail due to degradation of endurance have become more serious problems. The Vth interference for floating gate (FG) type flash memory is caused by parasitic capacitors closed to the neighboring FG. In order to suppress this interference, the insertion of poly-Si shields between neighboring FGs has been proposed [1]. However, another problem, the side effect in which the degradation of program speed, was occurred. On the other hand, it has been reported that the air gap structure successfully reduce the Vth interference by the lowest dielectric constant [2]. However, formation process of air gap structure is complicated and its endurance characteristics should be improved. In this paper, we demonstrate the high reliable air gap structure with the reduction of Vth interference on 4Gbit multi-level cell (MLC) AG-AND flash memory. Especially, the simple formation process for air gaps and the reduction of hydrogen concentration in the gap-formation film are reported, and the relationship between hydrogen concentration and reliability, i.e. endurance and detrap characteristics, are discussed in detail.

2. Experiment

The process flow of air gap formation is shown in Fig.1. The air gap is formed by two kinds of oxide films. After the memory cells are formed [3], first step film which is used SiH4 as a raw material is deposited by low temperature PECVD (Plasma Enhanced CVD). We call this film “gap film". In this process, chemical reaction becomes supply-limited and the gap film is easy to deposit on the top of the memory cell. Then, width of the memory cell space becomes narrow and the gap film is hardly deposited in the cell. Next, second step film is deposited on the gap film to close air gap. We call this film “cover film". In order to protect from penetration of the unnecessary one like the cleaning solution into air gap, the good coverage film is suitable for the cover film. Cross sectional SEM images after air gap formation are shown in Fig.2. The air gap about 85nm space between FGs was formed by this process.

3. Results and Discussion

The programming characteristic applying air gap is shown in Fig.3. In case of poly Si shield process, we can see that the programming speed decline. However, when applying air gap, programming speed is improved. Also, as the air gap space become larger, the programming speed become faster. This result indicates that the parasitic capacitance between FGs is reduced by forming the air gap structure and CG-FG coupling ratio is improved. Fig.4 shows that the dependence of Vth interference on the air gap space. The Vth interference of cells which have the air gap space about 85nm as shown in Fig.2 is improved from 0.22V to 0.12V. As a result, the reading operation margin was dramatically improved in case of 4Gbit MLC AG-AND flash memory.

Next, we refer about the reliability of the memory cell. The air gap formation flow is simple, but we are worried about the reliability of memory cell. Then, we investigate the influence of hydrogen in the gap film for air gap formation. The properties of the gap film and the cover film which are used by this experiment are shown in Table.1. We examine four kinds of p-SiO (plasma SiO) for the gap film which have difference properties respectively. Also, as the cover film, we investigate by using HDP-USG (High Density Plasma Un-doped Silicate Glass) and Sub atmospheric CVD O3-TEOS (Ozone Tetra-Ethyl-Ortho-Silicate). We evaluate of the hydrogen concentration in the gap film by TDS (Thermal Desorption Spectroscopy). Fig.5 shows that the dependence of the endurance characteristic on the gap and cover film. In case of high hydrogen concentration gap film, Vth shift after 100K P/E cycling was large. This result indicates that hydrogen in the p-SiO diffuses to the tunnel oxide and forms electron trap sites by the heat treatment after the air gap formation. In addition, when the HDP-USG was applied to the cover film, it was proved that the Vth shift could be reduced to 0.6V. It is supposed that the endurance characteristic becomes worse because of drifting hydrogen in gap film to tunnel oxide by high RF bias during the deposition process of HDP-USG [4]. Fig.6 shows that the dependence of the Vth shift caused by detrapping after 10K P/E cycling on the amount of hydrogen of the gap film. In case of high hydrogen concentration gap film, Vth shift was large. This result is similar to endurance characteristic. Fig.7 shows the evaluation result of hydrogen-depth profile by SIMS. When using HDP-USG deposition process, hydrogen concentration of the thermal oxide region is about twice as much as sub atmospheric CVD-O3-TEOS deposition process. As the result, the tunnel oxide degradation model by the air gap process was experimentally proved and the reliability of memory cell was improved drastically.

4. Conclusion

Vth interference was successfully suppressed by applying air gap to 4Gbit MLC AG-AND flash memory. We could achieve high reliability of memory cell by reducing hydrogen of gap film and optimizing cover film deposition process for air gap formation.

5. References

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[3] Y. Sasago et al., IEDM Dig, Tech. Papers, pp.823-826, 2003.
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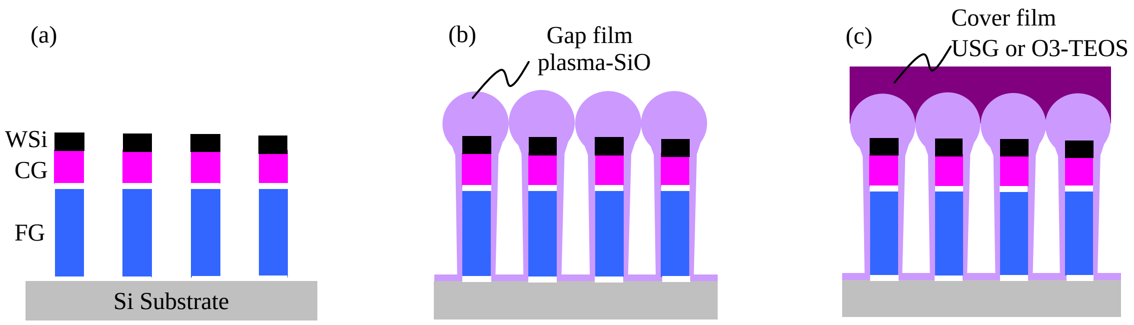

Fig.1 Fabrication process flow of the air gap. (a) the memory cell formation (b) the gap film deposition for air gap formation (c) the cover film deposition to close the air gap

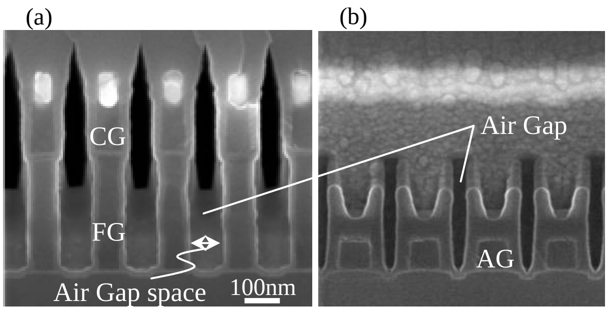

Fig.2 Cross sectional SEM image of 90nm AG-AND memory cell with air gap. (a) bit line direction (b) word line direction

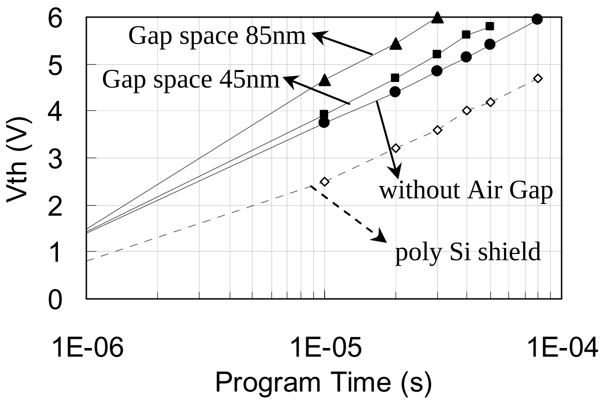

Fig.3 The dependence of program speed on air gap space.

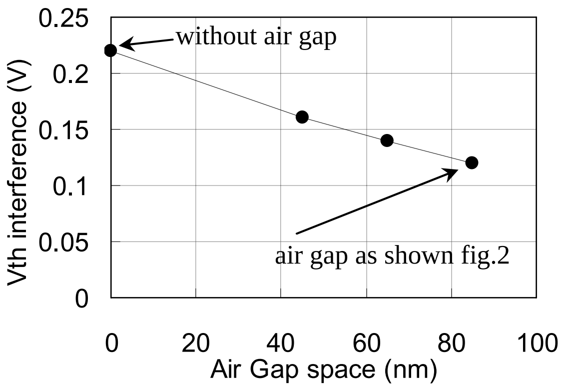

Fig.4 The dependence of Vth interference on Air Gap space.

Table.1 Film list for Air Gap formation (a) H2 concentration of gap film (b) Cover film condition

(a) Gap film

plasma-SiO	(A)	(B)	(C)	(D)
H2 concentration (10^20atoms/cc)	44	2.9	1.8	0.8

(b) Cover film

	(X)	(Y)
Film	USG	O3-TEOS
Process	HDP-CVD	Sub Atmospheric CVD

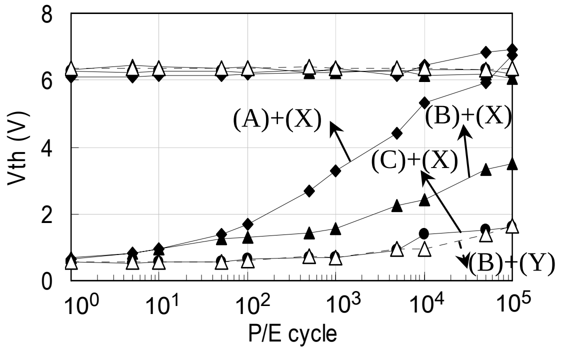

Fig.5 The dependence of endurance characteristics after 100K P/E cycling on kind of films for air gap formation.

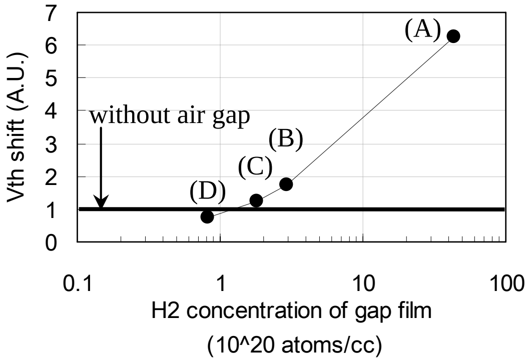

Fig.6 The detrap characteristics after 10K P/E cycling and bake. Bake temperature is 85C.

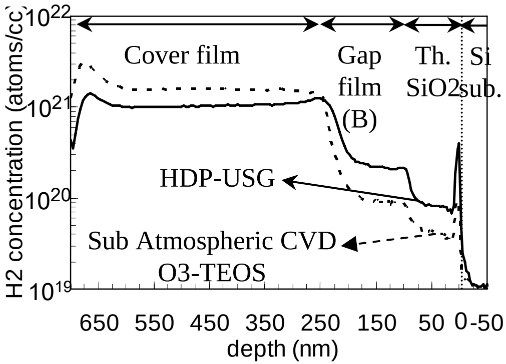

Fig.7 Evaluation of H2 concentration by SIMS.