Modeling of stress-dependent wet etch characteristic for P-SOG STI process

Jeong-Guk Min, Sang-Ho Rha*, Tai-Kyung Kim, Ui-Hui Kwon, Ju-Seon Goo*,
Young-kwan Park and Jeong-Taek Kong
CAE Team, *Process development Team, Semiconductor Business, Samsung Electronics co., LTD.
San #16 Banwol-Ri, Taean-Eup, Hwasung-City, Gyeonggi-Do, 445-701, Korea (E-mail:jg77.min@samsung.com)

Abstract *– Recently, spin-on-glass (SOG) oxide has been used as an important technology to overcome the gap-filling limit of conventional high density plasma (HDP) oxide in shallow trench isolation (STI) process.*

One of them, a novel polysilazane spin-on-glass (P-SOG) film shows a complex mechanical behavior during an annealing process and an abnormal etch loading effect in the wet process. These unique properties of P-SOG film give many opportunities to stress engineering.

This paper proposed the simulation methodology to predict mechanical stresses in STI process by modeling the volumetric shrinkage phenomena of P-SOG and wet etch rate which is dependent on hydrostatic pressure.

By interfacing a commercial FEM code, ABAQUS and in-house topography simulator, each of which has a portion of necessary models regarding P-SOG, we can predict the mechanical stress distribution on the various STI structures with real process profiles.

1. INTRODUCTION

As the design rule of device is scaled down, the new gap-fill scheme such as a hybrid material by P-SOG and HDP (High density plasma) method was introduced in the STI process. And in recent studies, this new scheme has been shown that could improve the MOSFET device performance by using the tensile stress by volumetric shrinkage of P-SOG film in STI process [1-3].

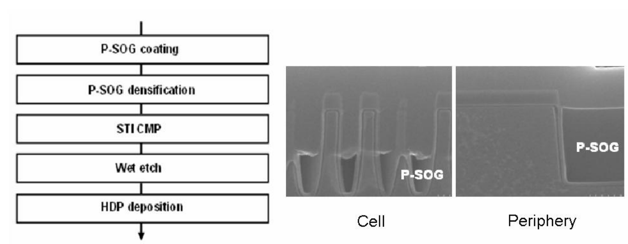
In spite of above positive advantages, Fig.1 shows the unexpected etch loading effect of P-SOG in wet process which becomes a big obstacle to optimizing process. The complex stress behavior and etch loading effect of P-SOG in a wet environment has not been physically explained yet.

In this paper, by modeling the volumetric shrinkage strain, we describe the abnormal thermal behavior of P-SOG films well and propose a new wet etch model which is dependent on hydrostatic pressure using mechanical stress simulation

2. MODELS AND RESULTS

Fig. 2 shows the schematic of an integrated simulation flow to predict surface topography and mechanical stress according to the volume ratio effect of P-SOG/HDP oxides in the hybrid gap-fill scheme of STI process.

The simulation flow includes two novel methodologies. One characterizes the mechanical stress effect of P-SOG by global film shrinkage, and the other performs the topography simulation of wet etch process dependent on the hydrostatic pressure



(a) STI process flow (b) Vertical SEM

Fig. 1. STI process flow and v-SEM photographs after wet etch process

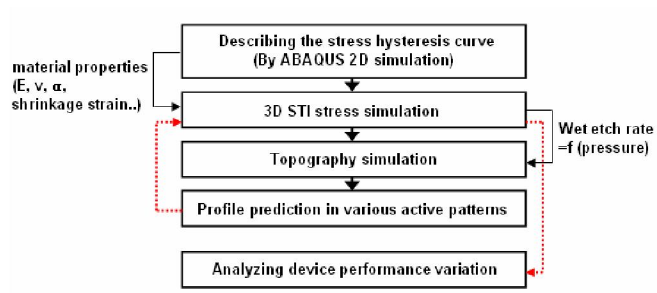


Fig. 2. Schematic of integrated simulation flow.

A. Stress modeling of P-SOG

Unlike the conventional STI gap-fill processes, P-SOG films can be controlled the residual mechanical stresses from tensile to compressive during densification process.

 1-4244-0404-5/06/$20.00 © 2006 IEEE

We should reproduce the stress hysteresis to predict the various thermal behavior of P-SOG. The total strain of P-SOG films is expressed as the following equation.

$$\varepsilon = \frac{\sigma}{E} + \alpha(\Delta T) + \frac{\sigma}{A(\sinh(Bq))^{n}\exp(-\Delta H/RT)} + \frac{\Delta V}{V} \qquad (1)$$

where the first term of equation is elastic strain, in turn thermal mismatch strain, visco-elastic strain and volumetric shrinkage strain.

Here σ is stress, E is Young's modulus, α is thermal expansion coefficient, T is temperature, ΔH is activation energy, q is the uniaxial equivalent deviatoric stress, R is universal gas constant, V is volume and A, B, n are other material parameters.

In Fig. 3, the simulation results are well matched with experimental data.

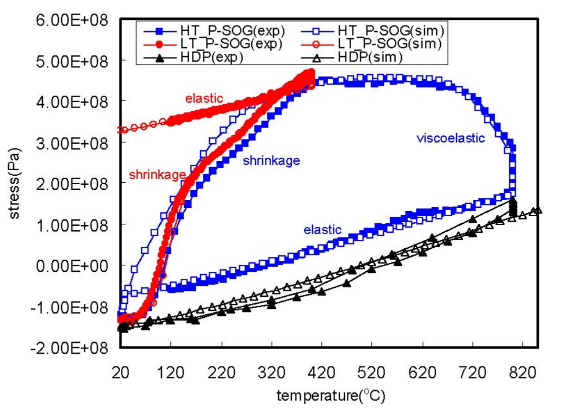


Fig. 3. Comparison of experimental and simulated results for HDP oxide, hot temperature(HT_P-SOG) and low temperature(LT_P-SOG) SOG film.

B. Stress-dependent wet etch modeling of P-SOG

Generally, dry etching process of oxide has a loading effect, but the wet etch rate does not depend on the spatial dimension between active patterns.

But, we proposed etch profile modeling with stress dependency to describe specific etch loading effect of only P-SOG oxides in wet chemical environment. The wet etch rate ERi at each node is calculated from the extracted stress as follows:

$$ER_i = ER_o \cdot \sigma_i \qquad 1 = \frac{1}{N}\sum_i \sigma_i \qquad (2)$$

where ERo is the wet etch rate of the blanket wafer, σ_i is the normalized stress enhancement factor.

Also, the basic theory of this is used as reference equation.

$$\frac{\partial c_H}{\partial t} = D_H\left[\left(1+\frac{\partial \ln f_H}{\partial \ln c_H}\right)\frac{\partial^2 c_H}{\partial z^2} - \frac{V_H c_H}{RT}\frac{\partial^2 \sigma}{\partial z^2} - \frac{V_H}{RT}\frac{\partial \sigma}{\partial z}\frac{\partial c_H}{\partial z}\right] \qquad (3)$$

Here D_H is diffusion coefficient of hydrogen in oxide, f_H is activity coefficient of hydrogen, V_H is partial molar volume of hydrogen in the oxide, R is universal gas constant, T is temperature and σ is hydrostatic part of the stress tensor induced by the presence of hydrogen.

Fig. 4 shows the surface stresses in different STI patterns during wet etch process and Fig. 5 indicates the difference of hydro-pressure stress in trench by various spatial dimensions.

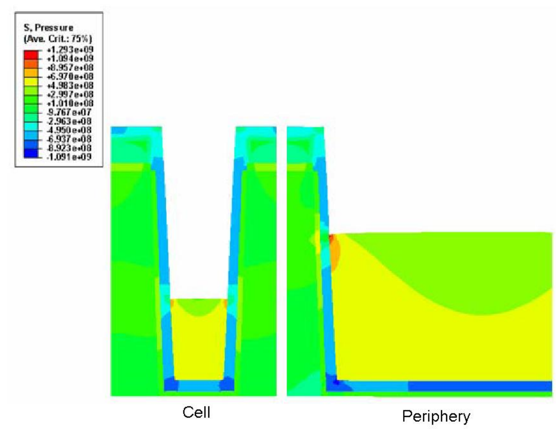


Fig. 4. Stress contour in cell and periphery area.

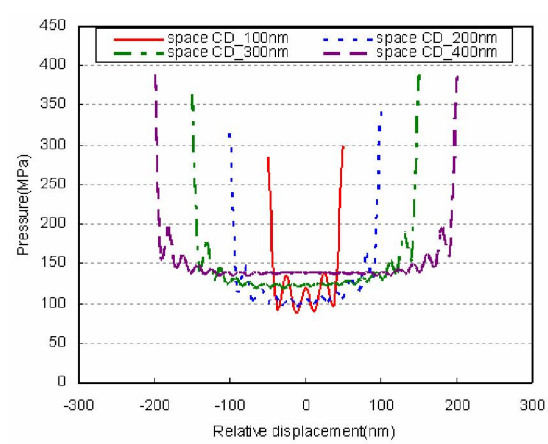


Fig. 5. The difference of hydro-pressure stress in trench by various space sizes

In this work, the relation between the pressure stress and the wet etch rate is introduced in the profile simulation. At the end, we can predict the final step height of P-SOG film in trench using this advanced profile simulation.

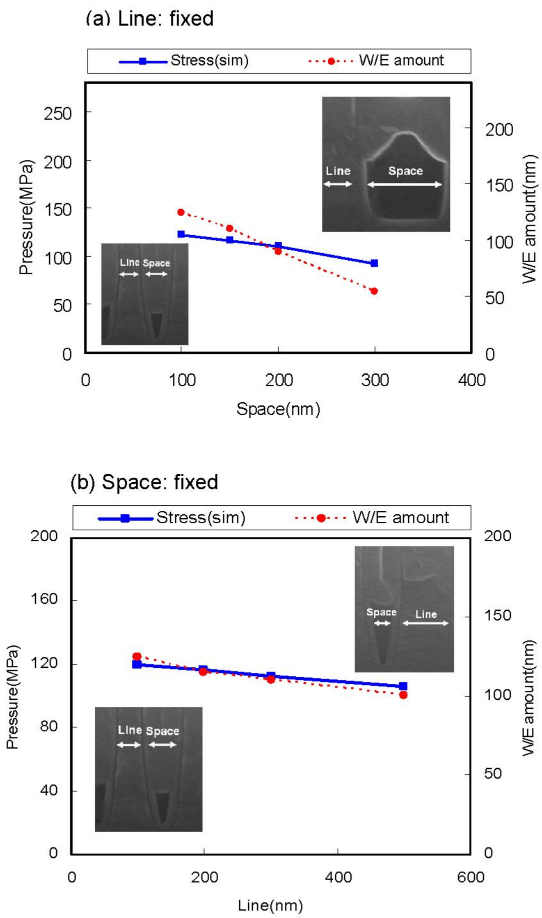


Fig. 6. The matched simulation data with wet etch amount in each patterns.

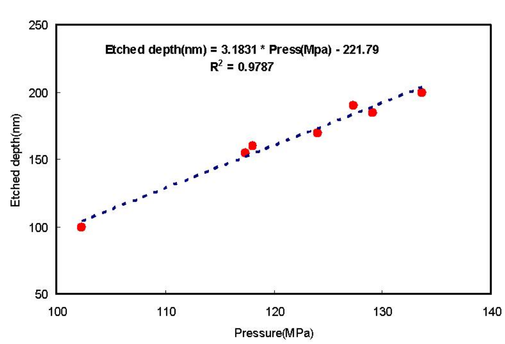


Fig. 7. The relation of simulated pressure stress and experimental etch depth

Fig.6 shows the difference of wet etch profile in various line and space size and Fig. 7 also indicates the good correlation of the simulated pressure stress and wet etch amount of P-SOG film according to the change of space size to measurement.

By considering the volume ratio of P-SOG and HDP oxides in STI, we evaluated the mechanical stress of STI in three active patterns and its effect on device performance. Fig. 8 shows the stress distribution by 3D ABAQUS[4] stress simulation.

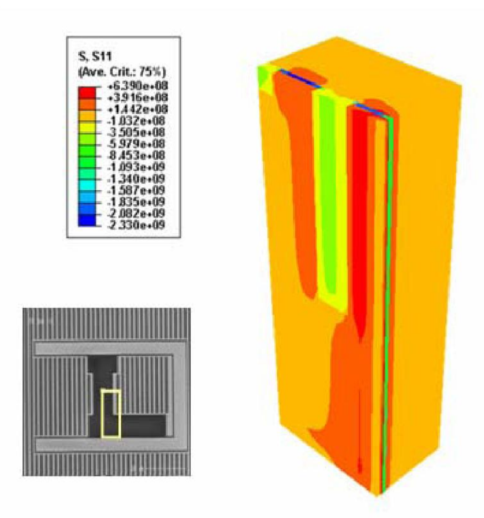


Fig. 8. 3D STI stress simulation result by ABAQUS

Fig. 9 represents the relation between mechanical stresses and experimental ΔIon in NMOS.

As the source and drain length is getting longer, stress component of x direction becomes more tensile whereas that of y direction becomes more compressive.

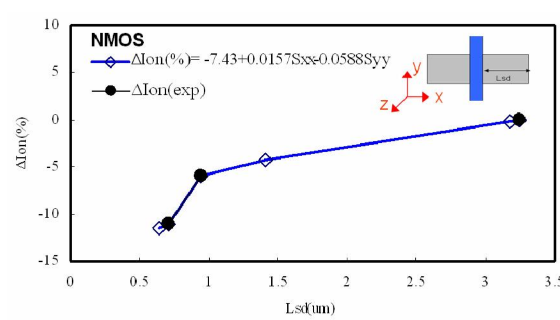


Fig. 9. The relation of stress component and ΔIon improvement in terms of source/drain length

Without the volume ratio of different materials in STI process according to active design taken into account in mechanical stress simulation, the degradation of device performance at NMOS will be underestimated.

3. CONCLUSIONS

To model the mechanical effect of P-SOG in STI process, we proposed simulation methodologies to take into account the thermal behavior with global shrinkage and stress dependency in the wet etch process.

The stress modeling of P-SOG can explain the thermal response at each process temperature and predict the final height of oxides in trench isolation from stress dependent wet etch model. With such a simulation flow, we can notice that the device performance of NMOS is degraded more than expectation.

4. REFERENCES

[1] Jin-Hwa Heo, Soo-Jin Hong, Guk-Hyon Yon, Kazuyuki Fujuhara, U-In Chung, and Joo-Tae Moon, "The P-SOG filling shallow trench isolation technology for sub-70nm device," 2003 Symposium On VLSI Technology Digest of Technical Papers.

[2] Jung-Sik Choi, Jung-Ho Lee, Dong-Jun Lee, Sang-Moon Chon, "A shallow trench isolation using novel polysilazane-based SOG for deep submicron technologies and beyond," 2003 IEEE international symposium on semiconductor manufacturing.

[3] K.Ota, et al. "Stress controlled shllow trench isolation technology to suppress the novel anti-isotropic impurity diffusion for 45nm-node high-performance CMOSFETs," 2005 Symposium On VLSI Technology Digest of Technical Papers..

[4] ABAQUS 6.5 user's manual

 1-4244-0404-5/06/$20.00