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공정변수가 p+ 박막의 잔류응력 분포에 미치는 영향

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Effect of Process Parameters on the Residual Stress Distribution in p+ Films

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ABSTRACT

This paper investigates the effect of thermal oxidation on the profile of the residual stress along the depth of p+ silicon films by quantitative determination method.

Two examples for the application of this method illustrate that most of *p+* region is subjected to the tensile stress except the region near the front surface and that the stress gradient of the film oxidized at 1100 ℃ is more steep than that of the film oxidized at 1000 ℃.

INTRODUCTION

In bulk micromachining, heavy boron doping of silicon is often used for the fabrication of p+ silicon etch stops which used for the construction of the structural components of micromechanical devices such as diaphragms, beams, and mechanical suspensions[1-4].

Since the atomic radius of boron is smaller than that of silicon, a tensile stress will be created as boron atoms enter the lattice substitute silicon atoms. According to the analysis on diffusion, the boron doping profile is not uniform along the depth of the *p+* layer. Thus, the profile of the stress is not uniform. In general, the residual stress distribution in *p+* films degrades the performance of microsensors and microactuators, and produces undesirable results.

The quantitative method to determine the profile of the residual stress along the depth of a highly boron doped silicon film have been suggested[5]. By the quantitative determination of the profile of the residual stress, the effects of the process parameters on the profile of the residual stress can be easily investigated.

This paper provides the results of quantutative study on the effect of thermal oxidation on the profile of the residual stress in p+ silicon films. As examples of the application of this method, the structures are fabricated by two arbitrary diffusion processes, and the profiles of the residual stress are determined.

QUANTITATIVE METHOD

If highly boron doped silicon films having residual stress are etched to make cantilevers, they curl up or down depending on the residual stress gradient along the depth. For the quantitative analysis, the residual stress, σ_x is assumed to be a polynomial function of Y, the coordinate perpendicular to the neutral surface of the cantilever(or the film).[5]

$$\sigma_x = \sum_{k=0}^{n} a_k Y^k \qquad (1)$$

where a_k's are coefficients to be determined. The determination procedure consists of two calculations. One is to determine the stress profile relative to the stress at the neutral surface of the film, that is, to calculate the coefficients a_k's for $k = 1, 2, \cdots, n$, where n is an integer to be determined in curve fitting. The other is to determine a_0, the stress at the neutral surface, which can be obtained from the average of the stress and the relative profile of the stress.

By using the relationship between the stress distribution and the deflection of the cantilever, the deflection can be expressed as a function of y. The function includes a_k's except the constant term, a_o because it is eliminated during the derivation. The amount of the deflection varies depending on the etch depth of the frontside of the cantilever as shown in Fig. 1. The deflections of the ends and the thicknesses of the cantilevers are measured for various cantilevers with different etch depths. Then, the coefficients of the polynomial in Eq. (1) except a_o are calculated from the measured data.

To determine the constant, a_0, the average stress of the p+ silicon film must be measured. Using the rotating

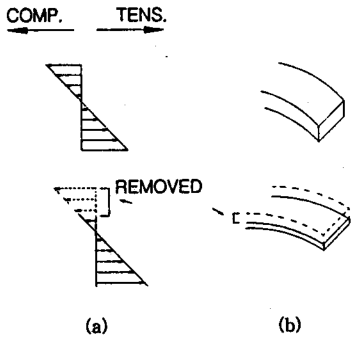

Fig. 1 The 'cantilevers with the front surface not etched(upper in the figures) and etched(lower). (a) Residual stress. (b) Deflection.

beam structure, the average stress is obtained.[5] The numerical analysis on the displacement of the tip under residual stress is performed by using general purpose FEM package, ABAQUS. By measuring the tip displacement, the average stress is determined from the result of the numerical calculation. Finally, it is straightforward to determine a_0 with the average stress and the relative profile of the stress.

FABRICATION

For the fabrication of the structures, n-type, 10~20 Ωcm, (100), double side polished silicon wafers are used. Initially, 0.5 ㎛ thick oxide is thermally grown for the patterning of the windows for boron diffusion. The boron predeposition with a solid source at 1100 ℃ in N_2 ambient gas is performed. Two groups of wafers are processed through different diffusion and oxidation processes. Group (A) are diffused for 9 hours, while Group (B) are diffused for 5 hours. After removal of BSG, the Group (A) are subsequently oxidized in wet O_2 ambient gas at 1100 ℃ for 40 minutes, while Group (B) at 1000 ℃ for 60 minutes. After the double side alignment, the time controlled etch through the backside windows is performed. To fabricate the structures with different frontside etch depths, the backside of the wafers are etched for (t_w - $t_{2\delta}$) minutes, where $t_{2\delta}$ is the time to etch the front surface of the p+ cantilever by 2δ ㎛ and t_w is the time to etch the whole thickness of the wafer at low doping concentration. The photolithography is performed to remove the oxide on the p+ silicon. Finally, both sides of the wafer are etched simultaneously by using EPW for $t_{2\delta}$ minutes so that the frontside of the cantilever is etched by 2δ ㎛. By means of the sequential etch process, the backsides of cantilevers are exposed to etchant for the same time, t_w. In case of the rotating beam structure, the frontside is protected from the etch with SiO_2.

RESULTS AND DISCUSSIONS

The frontside etch depths of cantilevers after the final etch are measured by the α-step. The SEM is used for the cross-sectional observation of p+ silicon films before and after the final etch. The deflections of p+ silicon cantilevers are measured by means of focusing a calibrated microscope. The measured vertical deflections of the ends of cantilevers with various thickness are shown in Table 1. The plus sign of υ_L means that the cantilevers are bent downward. The coefficients of Eq. (1) except a_0 are determined using the measured for various orders of polynomial. Reversely, the deflections of cantilevers can be calculated using the determined coefficients, and compared with the measured deflections. The fifth-order and third-order polynomials are appropriate to express the stress profiles of Groups (A) and (B), respectively, since the sum of square errors no longer reduces significantly. By measuring the tip displacement of the rotating beam with the SEM photograph and comparing it with the result

Table 1. The vertical deflections of the ends of cantilevers with various thickness.

wafers / samples	A			B		
	h(㎛)	υ_L(㎛)		h(㎛)	υ_L(㎛)	
		measured	calculated		measured	calculated
1	2.10	280	280	1.37	169	195
2	1.70	180	181	1.22	-34	-85
3	1.47	176	156	1.17	-137	-150
4	1.44	130	153	1.02	-289	-269
5	1.15	120	107	0.92	-340	-297
6	1.11	95	99	0.82	-268	-293
7	1.07	82	91	0.62	-210	-218
8	1.00	80	76			

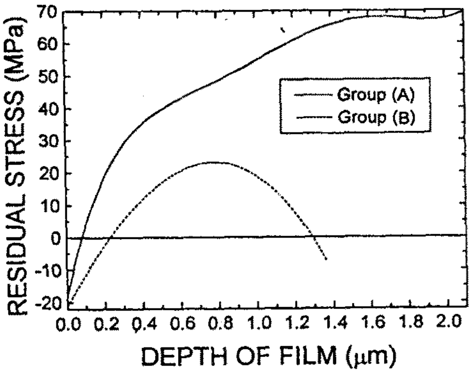

Fig. 2 The calculated profile of the residual stress along the depth of the p+ silicon films.

of ABAQUS simulation, the averages of the residual stress distribution are determined to be 50 MPa for Group (A) and 10 MPa for Group (B), respectively. The coefficient, a_0 is calculated. Fig. 2 illustrates the profiles of the residual stress along the depth of the *p*+ silicon films. The figure shows that the *p*+ film is subjected to tensile residual stress except the region near the front surface where the stress gradient is steep. Group (A) has larger stress in the tensile region and steeper gradient near the surface than Group (B).

CONCLUSIONS

The effect of thermal oxidation on the profile of the residual stress along the depth of p+ silicon films is studied by quantitative determination method.

The experimental result from the films fabricated by two different processes shows that most of the *p*+ region is subjected to the tensile stress, except the region near the front surface.

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