Modeling of Stress-induced Effects on Depletion Layer Capacitance in MOS Capacitor

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INTRODUCTION

Stress-induced effect on the depletion layer capacitance of siliicon becomes important as the semiconductor devices scale down and the switching speed of logic gate becomes higher [1]. Gauge factor of this effect has been reported to be almost comparable with the piezoresistance effect [2]. In the present study, a model which reproduces the stress-induced effects on the depletion layer capscitance of MOS will be discussed.

MODEL

In the present model, the maximum depletion layer (w) of MOS capacitor is expressed as follows (Fig.1):

$$w = \sqrt{\frac{2\varepsilon_{Si}\varphi_S}{qN_A}} \qquad (1)$$

where $\varphi_S = 2(E_i - E_F)/q$ is he surface potential, N_A is the impurity concentration. The depletion layer capacitance is expressed with the maximum layer width: $C_{dep} = w/\varepsilon_{Si}$. The intrinsic Fermi energy (E_i) comprises two terms, i.e. the midgap effect and the density-of-state (DOS) change :

$$E_i = E_{g/2} + \frac{3}{4}kT\ln\left(\frac{m_h^*}{m_e^*}\right) \qquad (2)$$

According to the deformation potential theory, strain splits the fourfold valence bandedge into a pair of degenerate Kramars doublets; heavy and light hole bands. While six folded band minima in the conduction band splits into four and two folded band minima (Fig.2) [3]. As a result, the middle level of the bandgap, that is, the midgap effect changes proportionally to the magnitude of strain as follows,

$$\Delta E_{g/2} = \begin{cases} -2.5\cdot e_l \text{ (eV)} & \text{for tension} \\ 2.3\cdot e_l \text{ (eV)} & \text{for compression} \end{cases} \qquad (3)$$

where e_l is the strain when uniaxial stress is applied.

The DOS effective masses of electrons and holes in silicon are expressed as $m_e^* = 6^{2/3}(m_l m_t^2)^{1/3}$ and $m_h^* = (m_{lh}^{3/2} + m_{hh}^{3/2})^{2/3}$, respectively. Hence, the ratio (m_h^*/m_e^*) without strain is estimated as 0.52. When tensile <110> stress is applied, the DOS effective mass of holes becomes the heavy-holes mass, and that of electrons becomes the DOS effective mass of twofold valley. So the ratio rises to $\left(m_{hh}^*/m_{\Delta 2}^*\right) = 0.98$. Similarly, when compressive <110> stress is applied, the ratio reduce to $\left(m_{lh}^*/m_{\Delta 4}^*\right) = 0.19$. As a result change of the second term is,

$$\Delta\left\{\frac{3}{4}kT\ln\left(\frac{m_h^*}{m_e^*}\right)\right\} = \begin{cases} 0.012 \text{ (eV)} & \text{for tension} \\ -0.020 \text{ (eV)} & \text{for compression} \end{cases} \qquad (4)$$

DISCUSSION

As shown in Fig.3 and Fig.4, the stress effects on the DOS of each valence band depend on stress in different manner for weak stress region and have anisotropy. However, they become nearly equal for large stress region. Table 1 shows the gauge factors of the stress effects on capacitance in weak stress region for three independent crystallographic directions. The characters of the gage factors are discussed by the stress effects on the DOS of valence band.

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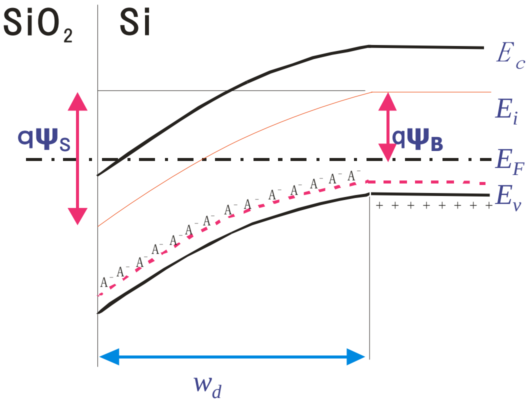

Fig. 1. Band diagram of p-type MOS capacitor with a positive voltage applied to the gate when a stress is applied.

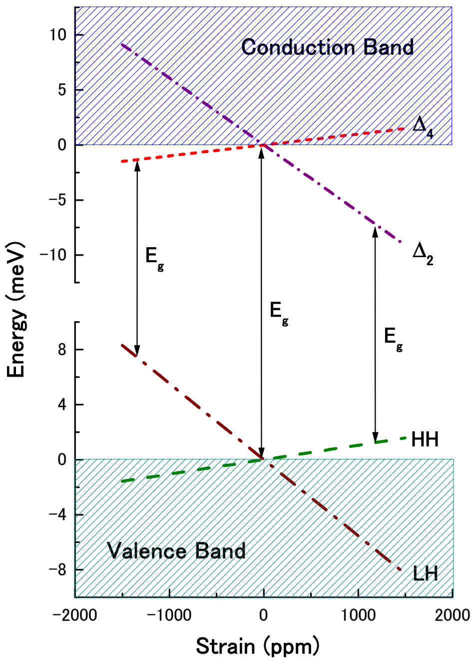

Fig. 2. Schematic drawing of the band splitting of silicon by the application of uniaxial <110> stress. Here E_g denotes the band gap between the band edge of the conduction band and the valence band.

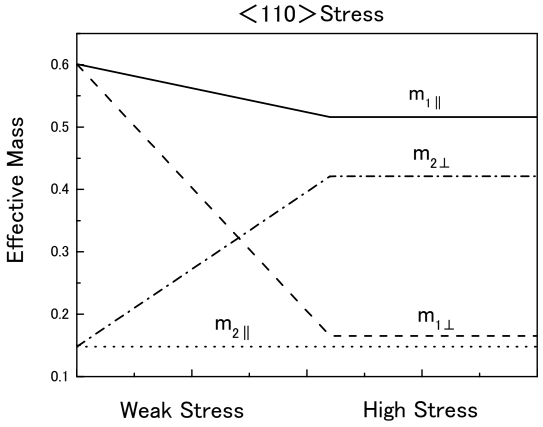

Fig. 3. Schematic drawing of the stress-dependent hole effective masses when <110> uniaxial stress is applied.

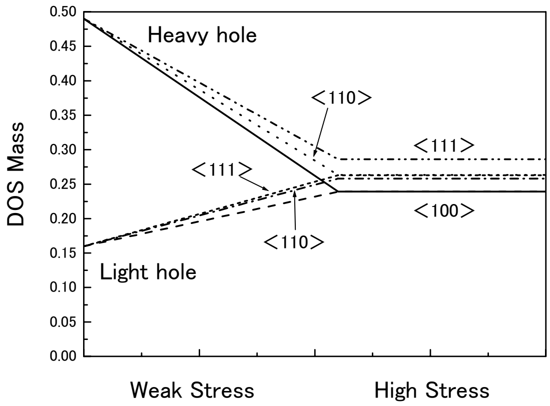

Fig. 4. Schematic drawing of the stress-dependent DOS mass of valence band edge.

Table 1: Gage factors of the stress-induced effects on depletion layer capacitance for three independent crystallographic directions.

Stress	**Direction**	**Gauge Factor**			
		DOS Change		**Midgap Effect**	
		n-type	**p-type**	**n-type**	**p-type**
<100>	Tension	5.5	8.0	-1.3	-
	Compress.	-17	-26	-0.6	-
<110>	Tension	19	32	-1.9	3.0
	Compress.	-30	-48	1.7	2.7
<111>	Tension	-3.1	-5.3	-0.92	-
	Compress.	-39	-61	-0.92	-