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Electron Beam Induced Damage of MOS Gate Oxide

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1. Introduction

MOS gate oxide damage after high energy electron beam injection into LSI devices has been discussed among users of electron beam direct printing method for fine pattern lithography of advanced ASIC and Memory devices [1,2] This report provides evaluation of the gate oxide damage and its characterization on the basis of the threshold voltage (Vth) shift of MOS devices which is one of the criteria for the damage of the gate oxide.

2. EB exposure and Vth shift

Fig. 1 shows experimental result of dependence of Vth shift on EB exposure dose over n channel MOS transistor. The device structure is shown in Fig. 2.

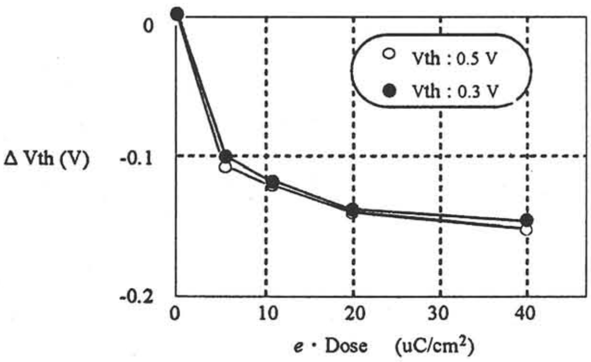


Fig. 1 Vth shift(Δ Vth) of n channel MOS due to electron beam injection. Δ Vth is measured as a relative value to the initial Vth value before the exposure.

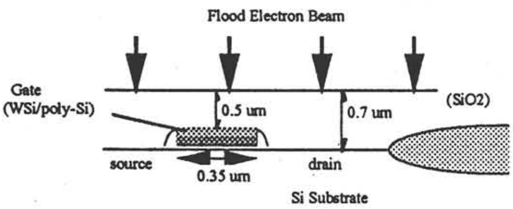


Fig.2 Structure for the MOS device in Fig. 1. Flood electron beam exposure is adopted.

Although Vth shows steep reduction with the EB dose in the beginning of the EB injection, Vth shows smaller shift with the EB dosage in higher dose region. As shown in Fig.1, the dependence of Vth shift on EB dose is identical for MOS transistors with different initial Vth values. Since the direction of the Vth shift is minus with the increace of EB dose, positive charge accumulation with EB dose in the gate oxide is assumed, where the positive charge, i.e., hole of hole-electron pair originating from EB injection is captured by the hole traps in the gate oxide.

3. Hole trapping mechanism

Two processes are proposed for the hole trapping mechanism. One is a process where holes are captured in the intrinsic traps in the gate oxide and another where they are captured in the newborn traps generated by the EB injection.

In the first process, we suppose EB dosage of ΔD into the device. Hole-electron pairs are generated in the device due to electron injection. The amount of the holes, originating from the hole-electron pairs and injected into the gate oxide, is proportional to ΔD and can be denoted by $H \cdot \Delta D$. These holes are captured in the hole traps and accumulated in the gate oxide as fixed positive charges. Denoting the density of the captured holes by Δp, we can obtain next equations.

$$\Delta p = H \cdot \Delta D \cdot ko \cdot (po - p)/po \qquad (1)$$

$$ko = po \cdot s \qquad (2)$$

Here, po is the intrinsic trap density, H the injection efficiency of holes into the gate oxide, ko is the hole trapping probability of the first hole which is injected into the oxide, and s is the cross section for the hole traps. *Eq. (1)* can be rewritten as

$$dp/dD = H \cdot ko \cdot (po - p)/po \qquad (1)'$$

which can be easily solved and we obtain

$$p = po - po \cdot \exp(-ko \cdot H \cdot D/po). \qquad (3)$$

Taking into account the second process, effect of the hole trap generation due to electron injection, *eq. (1)* can be modified to

$$\Delta p = H \cdot \Delta D \cdot ko \cdot (po - p + r)/po \qquad (4)$$

where r is the density of generated traps due to electron injection. Since r is dependent on ΔD, we can have next equation, which is similar to *eq. (1)*,

$$\Delta r = H \cdot \Delta D \cdot fo \cdot (ro - r)/ro \qquad (5)$$

$$fo = ro \cdot c \qquad (6)$$

where ro is the density of atomical sites which should be turned into hole trap sites due to collision with holes, fo the hole trap generation probability and c is the cross section of collision between a hole and a 'potential trap' atomical site. *eq. (5)* is identical to

$$dr/dD = H \cdot fo \cdot (ro - r)/ro \qquad (5)'$$

which can be solved similarly to *eq. (1)'* and we obtain,

$$r = r0 - r0 \cdot \exp(-f0 \cdot H \cdot D / r0). \tag{7}$$

From *eqs. (4) and (7)*, we can finally obtain ,

$$p = c1 \cdot \exp(-s \cdot H \cdot D) + p0 + c2 \cdot \exp(-f0 \cdot H \cdot D / r0) + r0. \tag{8}$$

Here, *c1* and *c2* are

$$c1 = \frac{-p0 \cdot f0 + r0 \cdot (p0 \cdot s - f0)}{f0 - s \cdot r0} \tag{9}$$

$$c2 = \frac{s \cdot r0}{f0 / r0 - s}. \tag{10}$$

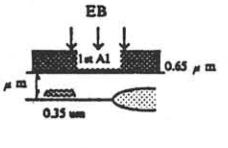
The 1st and 2nd terms of *eq.(8)* represent the hole capturing effect by the intrinsic hole traps and the 3rd and 4th terms represent the capturing effect by the newborn hole traps by the electron injection. The relation between Vth shift and the fixed positive charge density *p* in the gate oxide can be approximately expressed as

$$\Delta Vth = \Delta V_{FB} \fallingdotseq -(e \cdot p / Cox) \cdot (d / tox), \tag{11}$$

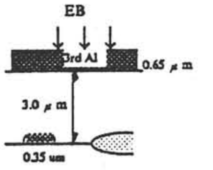
where *d* is the positive cahrge location measured from the gate electrode, *Cox* the capacitance and *tox* the thickness of the gate oxide. Combining *eqs. (8) and (11)*, relation between ΔVth and EB dosage *D* can be finally obtained.

4. Experimental results

Fig. 3 shows the theoretical curves of Δ Vth-EB dose relation together with the experimental results for the two different layer structures A and B.



layer structure A



layer structure B

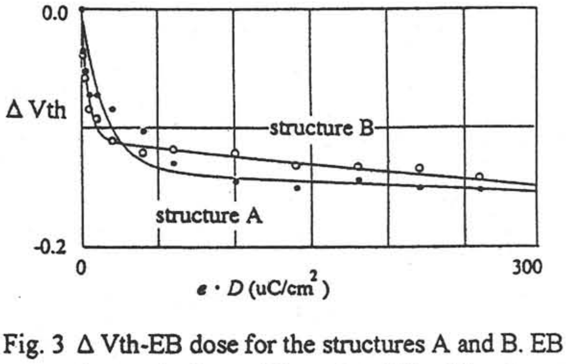


Fig. 3 Δ Vth-EB dose for the structures A and B. EB dosage is changed from 0 to 260 uC/cm ²

Fig. 4 compares the characters of the theoretical curves in Fig. 3 at low EB dose region. For the structure B, the Vth shift is steeeper than for structure A at the beginning of EB dosage corresponding to larger value of parameter *H* meaning higher hole injection efficiency into the oxide. Fig. 5 shows the Monte Carlo simulation result for the deposited energy in the device for each structure.

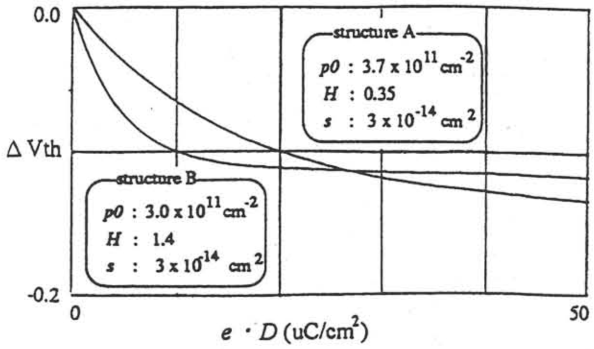


Fig. 4 Δ Vth-EB dosage relation in the low dosage region in fig. 3. Parameter values are shown for structures A & B.

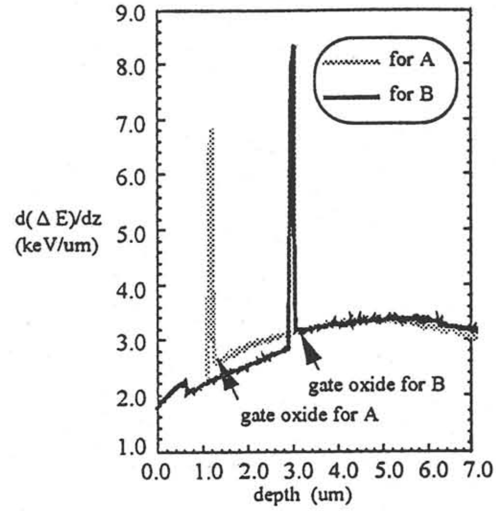


Fig. 5 Depth profile of deposited energy, i.e., transfered energy at the collision to the atomic sites, in the devices with the structures A and B. Deposited energy in the vicinity of gate oxide layer is shown by the arrows.

Comparing the deposited energy around the gate oxide (shown by arrows), the deposited energy for B is higher than the case for A, suggesting higher hole injection efficiency into the oxide, the same result from Δ Vth-EB dose relation.

5. Conclusion

Vth shift of MOS system due to EB exposure can be expressed quantitatively by a function of EB dosage as a solution of a hole trapping model in the gate oxide. Moreover, hole injection efficiency is found to be dependent on device layer structure.

References

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2) S. Yamada, T. Ono, F. Mizuno, Proc.SPIE, 2439, 374(1995).