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Data Retention and Read/Write Characteristics of SEPROM

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A new EPROM named SEPROM, based on a modified SEPOX process, is proposed and evaluated. The SEPROM offers a process compatibility to logic LSI's with higher packing density, since the area of the 2nd gate oxide is equal to that of the 1st gate oxide. For improving coupling capacitance ratio, which relates to write and read operations, a thin 2nd gate oxide is required for SEPROM cell at a risk of degradation in charge retention characteristics. However, measured test device shows sufficiently good characteristics both in programming and charge retention due to the desirable structure of the cell. The SEPROM structure appears to be practical and promissing for both EPROM and logic device application.

§1 INTRODUCTION

In advanced random logic LSI's, an integration of EPROM on a same chip is ofen required and desirable. For that purpose, a process compatible EPROM structure shoud be developed, also pursuing higher packing density. Conventional EPROM cells can not satisfy the demands adequately due to its double poly-Si structure, therefore a new EPROM structure, called SEPROM, is proposed and fabricated by modified SEPOX process [1].

In the SEPROM process, floating gate and isolation field oxide are formed simultaneously by selective oxidation of poly-Si film, so that the floating gate is self-aligned with field oxide edge. Subsequently, control gate is formed togather with gates of MOSFET for both memory peripheral and logic circuits. Therefore, the SEPROM process is compatible with normal MOS LSI's with SEPOX isolation, while maintaining high packing density nature.

On the other hand, the 2nd gate oxide area is structually equal to the first gate oxide area, which may cause a poor coupling capacitance ratio. In order to achieve good read/write characteristics, the 2nd gate oxide has to be thinner at a risk of sacrificing retention characteristics, which is the case with conventional EPROM structures. However, the problem is drastically eased by the SEPROM structure, where the floating gate has a smooth surface without sharp coner edge.

In this paper, SEPROM process and read/write characteristics are described, and then the influence of the thin 2nd gate oxide to the retention characteristics are discussed.

§ 2 SEPROM PROCESS

Fig.1 shows process sequence of SEPROM. At the first step, 1st gate oxide is grown on a p-type substrate followed by channel ion implantations. Nitride film is deposited and patterned to define active area (Fig.1(a)),and then poly-Si is selectively oxidized to form field oxide. After removing masking nitride, 2nd gate oxide is grown on the poly-Si (Fig.1(b)). Subsequently, poly-Si is deposited and then the control gate and the floating gate are patterned simultaneously by the reactive ion etching, followed by post oxidation (Fig.1(c)). Fig.2 shows a perspective view of three-dimentional final structure. In this process , the control gate step coverage is smooth, since the floating gate is buried into the field oxide with the self-aligned manner. Therefore, a thinner 2nd gate oxide is practical and acceptable. Actually, test devices were fabricated and examined where the 1st gate oxide thickness(Tox_1) and 2nd gate oxide thickness(Tox_2) range 300A to 500A,and 300A to 1000A, respectively.

Fig.3 shows SEM photograph of a SEPROM cell where Tox is 500A and Tox is 1000A. As already discussed, the control gate smoothly covered the floating gate to offer a higher reliability.

§3 EXPERIMENTAL RESULTS AND DISCUSSION

Read Characteristics

Drain current I_D is approximately propotional to V_{FG}-Vth value, where V_{FG} is the effective floating gate voltage and Vth is the threshold voltage. Therefore, in order to draw a large I_D value, Tox_2 must be thin so as to gain a large V_{FG} value. Fig.4 shows I_D vs. V_D characteristics before, and after programming. Both Tox_1 and $Tox_2$are 300A. Before programming, I_D is nearly 100 μA when V_{CG} and V_D are 5V and 2V respectively. The results indicate that the Tox_2 should be equal or less than 300A for obtaining good read characteristics.

Write Characteristics

Write characteristics are examined for various Tox_1 and Tox_2. As shown in Fig.5, injected charge value, Q, increases with increase of capacitance ratio of the 1st gate oxide to the 2nd gate oxide. If the ratios are equal, such as $Tox_1=Tox_2=300A$ and $Tox_1=Tox_2=500A$, Q values are nearly equal. Among the oxide conbinations, Tox_1 and Tox_2 are most preferable to be 500A and 300A respectively. The dependence of Q on V_{CG} is similar for each cell and each V_D value. The injected charge Q increases gradually untill reaching certain maximam value and then decrease rapidly. This decrease is caused not by the leakage from the floating gate to the control gate, but by the the dependence of Vth shift on write pulse width as shown in Fig.6. Threshold voltage shift, ΔVth, is notable between 100msec and 1sec whenV_{CG} is 18V, however, for V_{CG}=16V, ΔVth gradually increases as write time increases from 1sec. The difficulty of short time writing for a large V_{CG} is resulted from V_{FG} being too high to obtain a large hot-electron injection. In order to determin the charge injection mechanism V_{FG} in a SEPROM cell was calculated, before and after the rapid Vth change. Considered capacitances in a SEPROM cell are the 1st gate oxide capacitance, C_1, the 2nd gate capacitance, C_2, and drain-floating gate capacitance, C_3. From the charge balance equations, V_{FG} is given by

$$V_{FG} = \frac{C_2}{C_T}\left(V_{CG} - \frac{Q}{C_2} \right) + \frac{C_3}{C_T} V_D$$

where $C_T=C_1+C_2+C_3$ and $Q=C_2\Delta Vth$

From Fig.6, when V_D and V_{CG} are 8V and 18V, respectively, Vth shift is 0.4V at 100msec write pulse, and thus calculated V_{FG} is 8.7V. When writing time reaches to 1sec, ΔVth is 4.1V and corresponding V_{FG} is 7.1V. From these V_{FG} values, it is reasonable to understand that the rapid Vth change is taking place under a condition of $V_{FG} \approx V_D$. It shoud be noted that the hot-electron injection current has a peak value near $V_{FG}=V_D$, generally,thus the above rapide increase for V_{CG} =18V should be regarded by hot-electron injection.

It is also understood from the Vth shift measurement with the bias stress that the injection charge drop in higher voltage region Fig.5 is not caused by the leakage from the floating gate to the control gate. Fig.7 shows the Vth shift under the bias stress to the control gate. As indicated in the figure, it is needed to apply more than 30V to cause Vth shift due to leakage through the 2nd gate oxide, even for Tox = 300A.

In summary, write characteristics of SEPROM is similar to the conventional EPROM, limmited by the capacitance coupling between the 1st and 2nd gate oxide. Therefore, for improving write characteristics of SEPROM cells, capacitance ratio of the 1st gate oxide 2nd gate oxide must be comparable to that of the conventional EPROM's. Consequently, SEPROM requires thinner 2nd gate oxide, that might raise reliability questions. In the next section, charge retention characteristics and reliability issue will be discussed for thin 2nd gate oxide devices.

Charge Retention Characteristics

Charge retention characteristics is closely related to chage transport properties through the 2nd gate oxide. Fig.8 showsthe distribution of the breakdown field strength of the 2nd gate oxide from measuring I-V characteristics. As shown in Fig.9, more than 5MV/cm breakdown field strength is assured even for 300A oxide thickness. The results are reasonable good, considering the oxide layers were grown on poly-Si films. The breakdown field of the 1000A thick oxide is lower than that of the 500A , resulted from the enhanced growth of asperity on poly-Si surface.

From Fig.7, the critical field strength, where ΔVth decrease to 80% of initial value, is estimated from calculated V_{FG}, and ploted in Fig.9. This dependence of the critical field on the oxide thickness agrees with that of the breakdown voltages in Fig.8. In other words, the critical field is maximum at the 500A oxide and is slightly lower for the 1000A oxide. As a result, the charge retention under the bias stress is determined by the 2nd gate breakdown field strength.

Fig. 10 shows the retention characteristics by thermal stress for various Tox_1 and Tox_2. Electron number, n, in the floating gate surrounded by potential barrier due to the oxide interface, is a function of retention time, t, and temperature, T. According to a thermionic emission model, n(t) is given by

$$n(t)/n(0)=\exp(-\nu t \exp(-\phi_B/kT))$$
$$=\Delta Vth(t)/\Delta Vth(0)$$

where ν is the electron-lattice collision frequency and ϕ_B is the barrier hight. Calculated curves are shown as the solid line in Fig.10. As shown in the figure, the declination ratio, n(t)/n(0), reasonably fits the above equation, and calculated ϕ_B ranges 0.85-1.29eV. The result is in good agreement with previously reported values, 1.0-1.8 eV [2)~4)]. Retention time, defined as the time interval untill n(t)/n(0) decreases to 0.8, is about 740 hours at 250°C even for 300A Tox_1 and Tox_2.

From the above retention characteristics, thin 2nd gate oxide SEPROM cells offer sufficiently good reliability, as expected from the structure.

§4 CONCLUSION

A new EPROM structure has been designed and fabricated by SEPOX technology. Sufficiently good device characteristics has also been obtainted. From read/write characteristics, 300A oxide thickness was required for the 2nd gate of the SEPROM. In spite of rather thiner 2nd gate oxide, the charge retention characteristics were better than acceptable. It can be concluded that the advantage of SEPROM structure has been practically confirmed.

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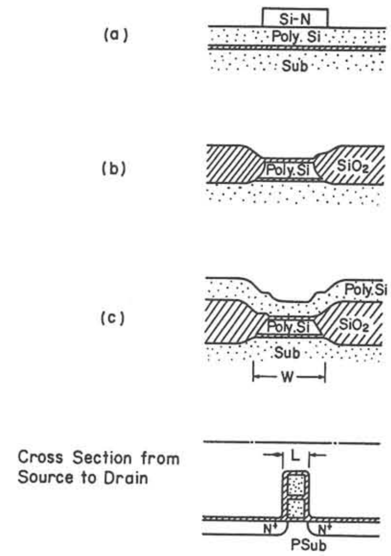

Fig.1 Process sequence of SEPROM

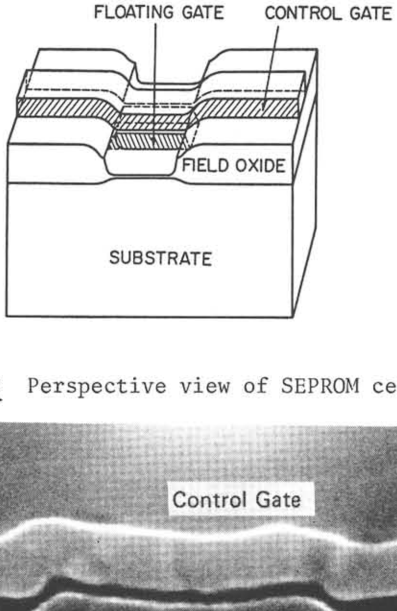

Fig.2 Perspective view of SEPROM cell

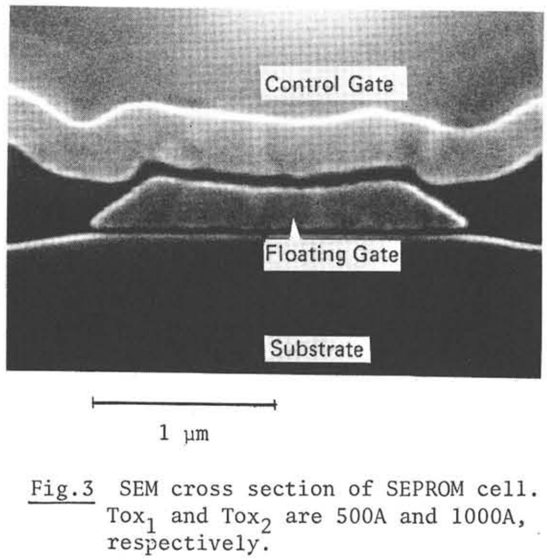

Fig.3 SEM cross section of SEPROM cell. Tox_1 and Tox_2 are 500A and 1000A, respectively.

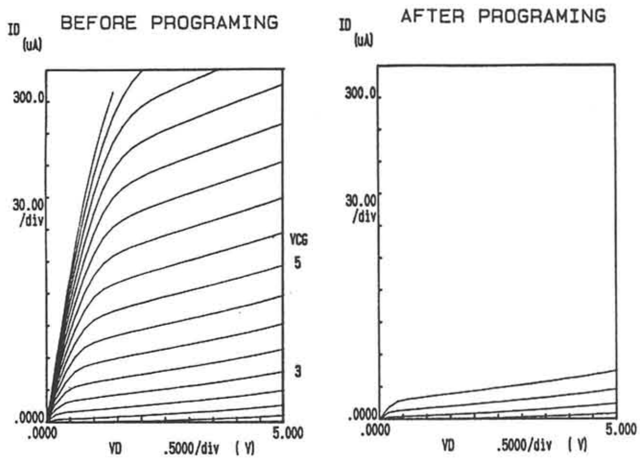

Fig.4 I_D vs. V_D characteristics for a SEPROM cell before and after programming. V_{CG} is up to 9V with 0.5V step. Tox_1 and Tox_2 are 300A, and W/L is 5/2.5.

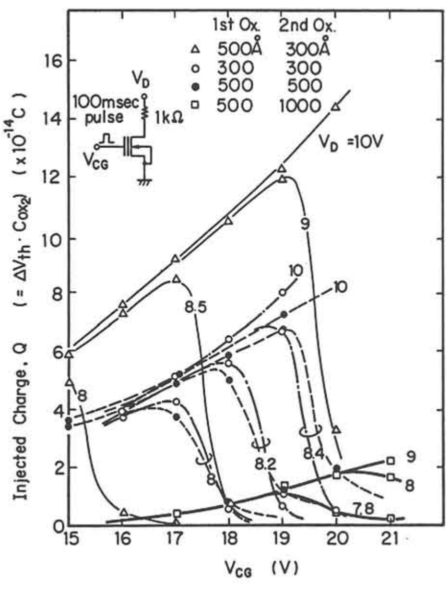

Fig.5 Write characteristics of SEPROM cell. ΔVth is value of threshold voltage shift. W/L is 5/2.5 for all cells.

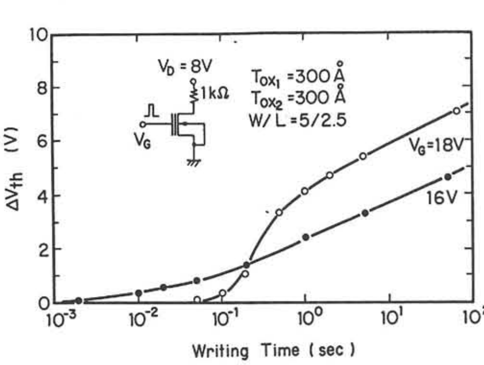

Fig.6 Write characteristics as a function of writing time.

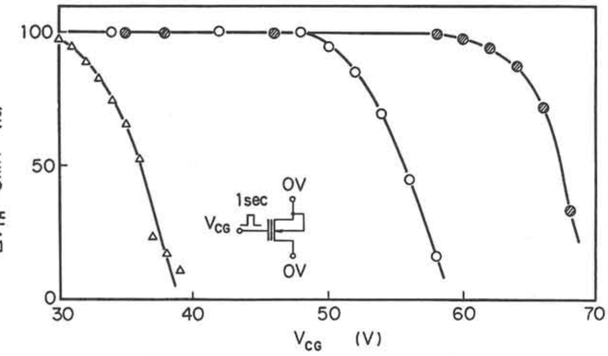

Fig.7 ΔVth shifts caused by V_{CG} bias. Tox_2: 300A(△), 500A(○),1000A(●). Tox1 is constant 500A.

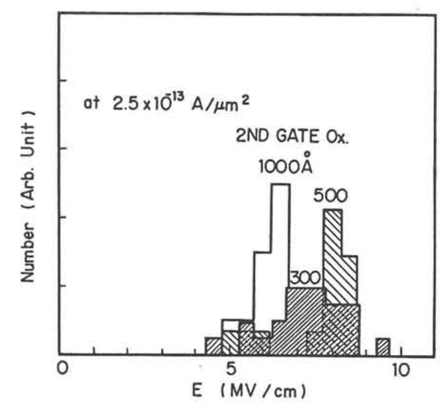

Fig.8 Distribution of 2nd gate oxide breakdown voltages, defined at I= $2.5x10^{-13}A/\mu m^2$.

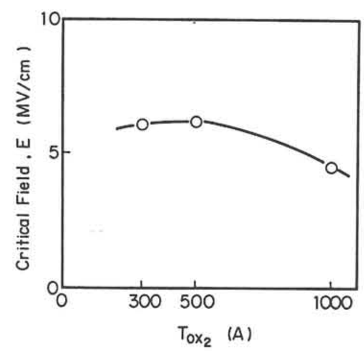

Fig.9 Tox_2 vs. cretical field strength defined as E where ΔVth decreases to 80% from initial values by V_{CG} bias.

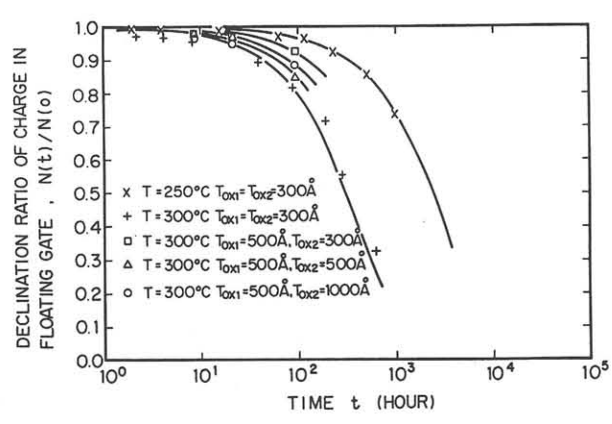

Fig.10 Retention characteristics for various oxide thickness at two different temperatures.