Extended Abstracts of the 19th Conference on Solid State Devices and Materials, Tokyo, 1987, pp. 39-42

Alpha-Particle-Induced Source-Drain Penetration (ALPEN) Effects —A New Soft Error Phenomenon—

Digh Hisamoto, Tohru Toyabe and Eiji Takeda

Central Research Laboratory, Hitachi Ltd.

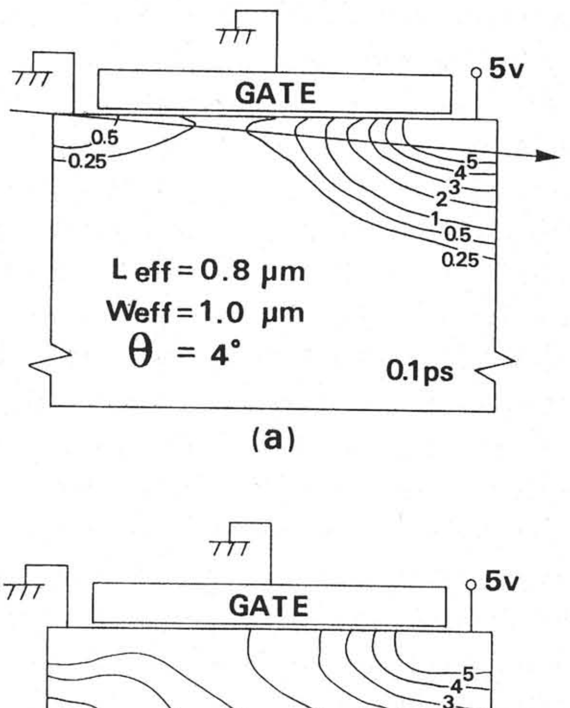
Kokubunji, Tokyo 185, JAPAN

The ALPEN effect is a new alpha-particle-induced soft error caused by alpha particle source-drain penetration. It is investigated using a 3-D device simulator(CADDETH) and a new experimental method. When an alpha particle penetrates between MOSFET's source and drain nodes, the channel turns on, if channel length is sufficiently small. This is because "funneling" fields extend from both source and drain edges. In consequence, this causes a punch-through-like channel current. Experimental results demonstrate that this ALPEN effect indeed occurs, and that it causes a new soft error: "0"-->"1". This new soft-error phenomenon will put severe constrains on the design of Asic, Logic, and static memories as well as dynamic memories in the submicron region.

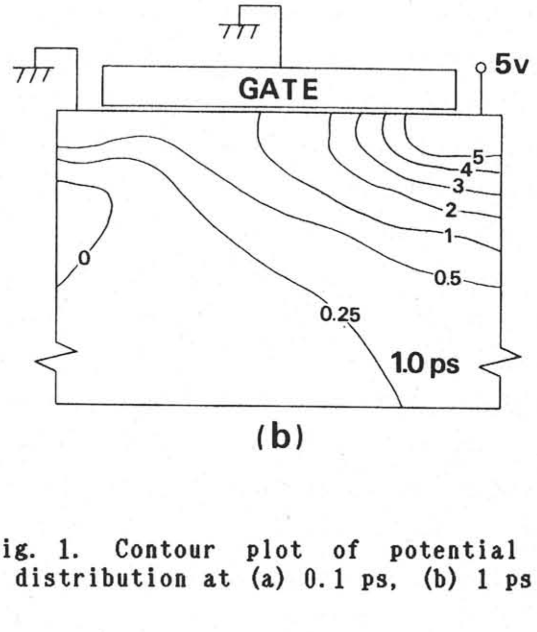
1. INTRODUCTION

Alpha-particle-induced soft errors in VLSI memories must inevitably be a key factor in determining memory cell structure as device geometries become finer and power supply voltage is reduced to around 3V[1]. To date, intensive efforts have shown that the funneling effect, as well as diffusion, plays a significant role in the carrier collection [2]. It has also been reported that an alpha particle causes charge transfer between adjacent trench cells[3] because of funneling field formation.

This paper discusses alpha-particle-induced source-drain penetration effects(ALPEN effects) using a 3-D simulation and experiments. The effective channel length in MOS devices is the shortest distance between diffusion layers in VLSIs. This is liable to induce charge transfer due to "channels" formed by funneling. It is found that a three phase physical model can explain this charge transfer behavior. Furthermore, experimental results support simulation results demonstrating special features of this effect. Charge transfer behavior between source and



(a)



(b)

Fig. 1. Contour plot of potential distribution at (a) 0.1 ps, (b) 1 ps

drain for less than 0.4 μm devices implies that the ALPEN effect will become a significant factor in determing limitations of MOS FET channel length.

2. SIMULATION RESULTS

2.1 Potential Movement

Plots of the channel potential distributions at 0.1 ps and 1 ps after alpha particles penetrate between source and drain nodes are shown in Fig. 1(a)-(b). The incident angle is $\theta = 4°$. A funneling field extends from both source and drain sides, distorting channel potential along the track as shown in Fig. 1(a).

The potential barrier along the channel at various times after alpha-particle incidence is shown in Fig. 2. Note that the ALPEN effect destroys the initial potential barrier, causing a punchthrough-like channel current.

2.2 Carrier Behavior

Electron charge variation and the current at each electrode are shown in Fig. 3. The current is composed by electron, hole and displacement. Based on these figures, ALPEN effects can be divided into three phases as a function of time.

<u>FUNNELING PHASE</u>: Until 1 ps after incidence, since the barrier vanishes completely, the channel is on, despite the low gate bias. Drain collects electron charge but source loses charge. This is the "funneling current" caused by ALPEN effect. The relationship between funneling current, I_f, and Vds is shown in Fig. 4. From this figure, the following relation:

$$I_f \propto \exp(a \cdot Vds) \quad \text{---(1)}$$

is derived. This relation indicates the funneling current can be regarded as punchthrough like[4].

<u>BIPOLAR PHASE</u>: During 1-10ps, the potential barrier begins to recover, but the current continues to flow. That is, electrons transit over the barrier. Since this mechanism is the same as MOSFET behavior in

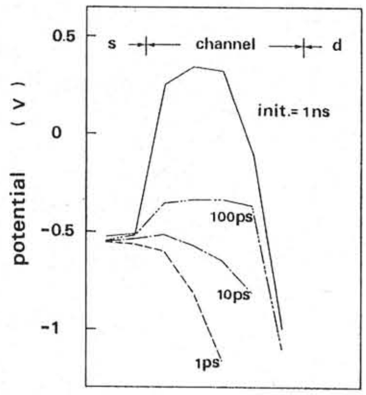


Fig. 2. Potentials along the channel at various time

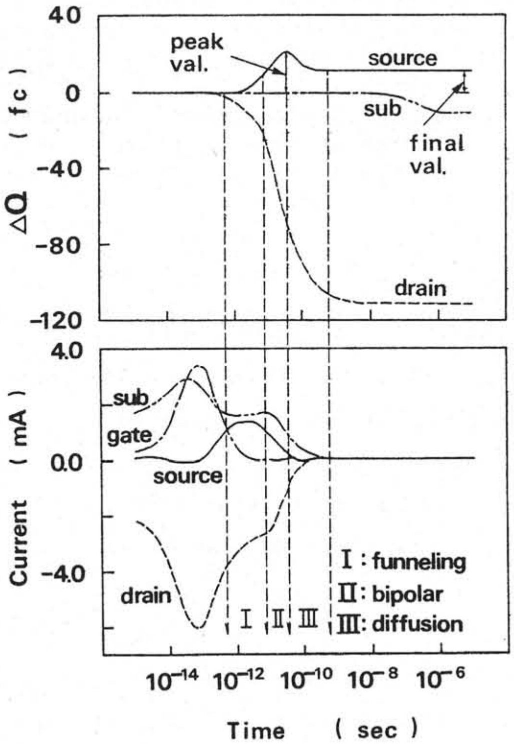


Fig. 3. Collected charge and current versus time

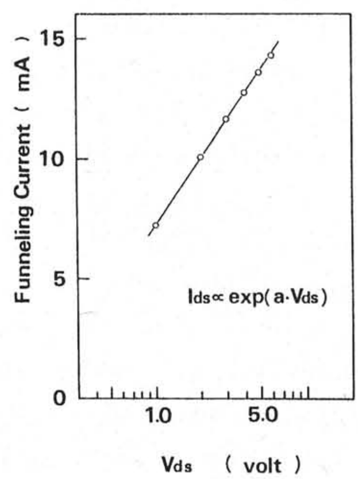


Fig. 4. Effect of Vds on funneling current

subthreshold, it is expressed as bipolar phase[5].

DIFFUSION PHASE: In this phase, different from the other two phases, each node collects electron charge. Since there is no electric field (funneling) except depletion layers, the diffusion mechanism dominates this phase.

The source-collected charge through three phases, Qs, is expressed as:

$$Qs = -Q_{funneling} - Q_{bipolar} + Q_{diffusion} \quad \text{---(2)}$$

If Qs is negative, source node loses electrons consequently. For such a single node as a DRAM cell, the total collected charge, Q_T, is expressed by the diffusion model[2] as:

$$Q_T = Q_{drift}(\text{depletion layer + funneling region}) + Q_{diffusion} \quad \text{---(3)}$$

On the other hand, when Leff is enough small (~funneling length), drain collected charge through three phases, Qd, might be expressed as:

$$Qd = Q_{drift1}(\text{depletion layer+funneling length at channel}) + Q_{drift2}(\text{funneling current}) + Q_{diffusion} \quad \text{---(4)}$$

where Q_{drift2} is the funneling current from source to drain. This equation suggests that the ALPEN effect also increase the total collected charge in conventional soft error mechanism.

3. EXPERIMENTAL RESULTS

Experimental setup is shown in Fig. 5. By carefully timing gate pulses of a precharge MOS Tr. and a switching MOS Tr., the voltage variation at target node in floating state

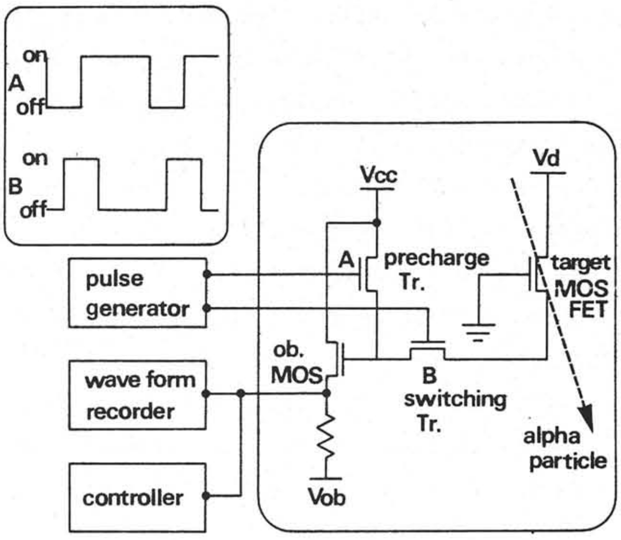


Fig. 5. Experimental apparatus and pulse timing

can be observed. An alpha source, ^{241}Am, is used for compulsory exposure.

In this experiment, if the target node loses electron charge, node voltage should rise. If it collects electron charge, node voltage should drop, resulting in the conventional soft error.

In Fig. 6(a), the level of the target node has risen by 8 mV compared with the normal level which is shown in Fig. 6(b). This means the target node loses about 0.8 fc of the electron charge. In the compulsory exposure, low incident angles (for ex. $< 10°$) can not be realized. If the low incident angle was realized in experiments, more electrons would have been lost. Conversely, in the case of electron collection the level drops as shown in Fig. 6(c).

4. DEPENDENCE ON ANGLE OF INCIDENCE

Fig. 7 shows Qs (in eq. (2)) vs. alpha particle energy(E) relationship with incident

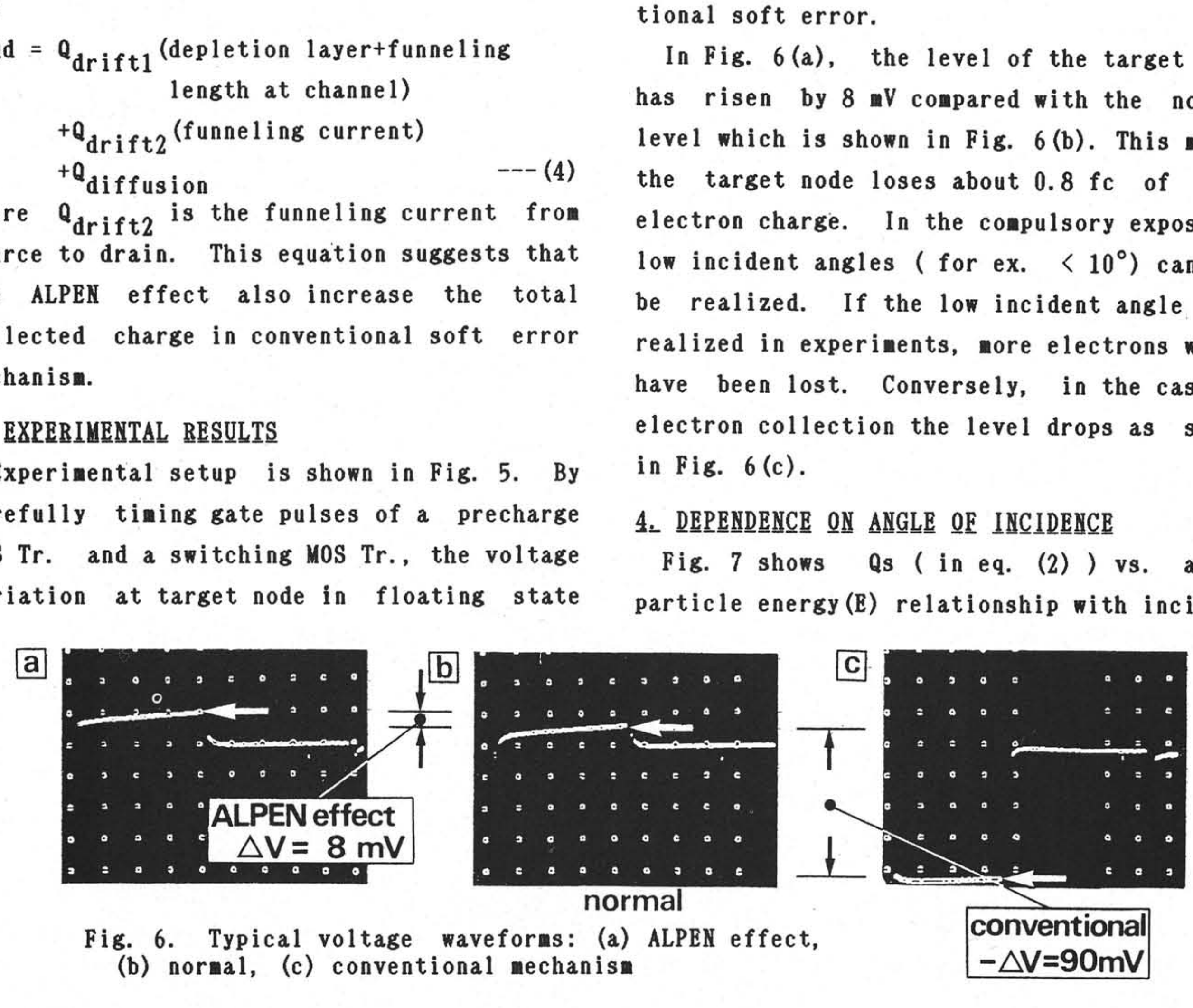


Fig. 6. Typical voltage waveforms: (a) ALPEN effect, (b) normal, (c) conventional mechanism

angle(θ) as a parameter. The device used has Leff=0.8μm and Weff=1.0μm. It can be seen that a bell shaped relation between Qs and E is satisfied and that Qs-peak occurs at $\theta=4^\circ$ and under E =2MeV. This simulation result demonstrates that the condition of $\theta=4^\circ$, and E =2MeV provides the most number of electron-hole pairs near the channel region according to the Bragg curve. In this case, alpha particle penetrates source node, the channel and drain node diagonally, with losing the energy, then stops in the substrate near the device.

5. DEPENDENCE ON Leff AND Cs

Fig. 8 shows Qs as a function of effective channel length (Leff) under various bias conditions. The floating bias condition means that a given electrode(source node) is connected to capacitance Cs, not to a fixed voltage, that is, corresponding to a switching MOS device in dynamic memory. The fixed bias condition(Cs= ∞) corresponds to logic circuit. It should be note that Qs is strongly dependent on Leff. As Leff becomes smaller than 0.4 μm, Qs increases abruptly. Also it is found that Qs decrease with Cs. When Cs is smaller, losing electrons causes larger voltage variation at source. That leads to a larger reduced bias between source and drain, so Qs decreases. Particulary, in the case of fixed bias condition, the funneling current due to ALPEN effect will be more stringent in the region < 0.5 μm.

6. CONCLUSIONS

The newly discovered phenomenon, alpha particle induced soft error (ALPEN effect) has been examined using 3-D simulation and verified by experiments. When an alpha particle penetrates between MOSFET's source and drain nodes, funneling fields cause the channel to turn on and cause the current. It is found that the funneling current due to alpha particle has a strong relation to the punch-through current, therefore depends on Leff. ALPEN effect will impose design and technology restrictions on future short channel device.

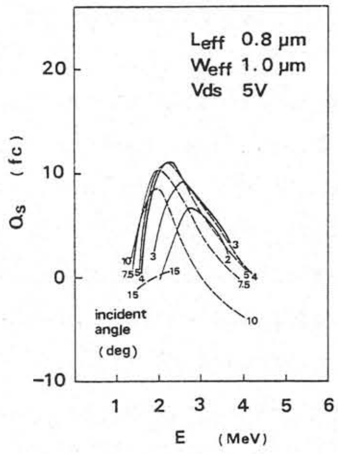


Fig. 7. Effect of incident angle versus alpha-particle energy

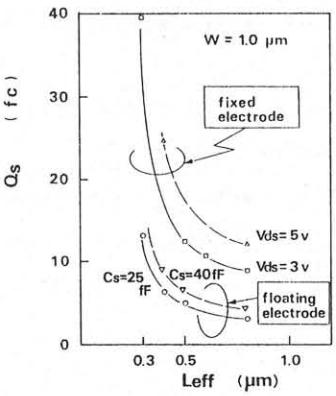


Fig. 8. Effect of channel length at various bias conditions

Acknowledgment

The authors wish to thank Drs. Hitoshi Kawamoto of the Hitachi Device Development Center and Hiroo Masuda of the Hitachi Central Research Laboratory for their helpful discussion.

References

[1] T. C. May and M. H. Woods, IEEE Trans. Electron Devices, ED-26(1979)2.

[2] E. Takeda, K. Takeuchi, E. Yamasaki, T. Toyabe, K. Ohshima, and K. Itoh, IEEE IEDM Proc. (1986)542.

[3] J. S. Chern, P. Yang, P. Pattnaik, and J. A. Seitehik, IEEE Trans. Electron Devices, ED-33(1986)822.

[4] J. J. Barnes, K. Shimohigashi, and R. W. Dutton, IEEE Trans. Electron Devices, ED-26(1979)446.

[5] S. M. Sze, "Physics of Semiconductor Devices", 2nd. Ed., New York, p.446.