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A Radiation-Hard Flash Cell Using Horn-Shaped Floating Gate and N_2O Annealing

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Introduction

Metal-nitride-oxide-silicon (MNOS) EEPROM has been traditionally chosen over floating gate (FG) EEPROM for rad-hard applications due to MNOS' inherent radiation hardness and the poor rad-hard performance of early FG EEPROMs [1-2]. However, FG EEPROM/flash has become the de facto nonvolatile memories in recent years, and with novel device structures and the aggressive scaling in oxide thickness, it is interesting and technologically important to re-evaluate the feasibility of using FG EEPROM/flash cells for the radiation-hard applications.

Recently, we proposed using an N_2O annealing of interpoly oxide to improve the performance of a flash cell with horn-shaped floating gate [3]. In this paper, we show, for the first time, that excellent radiation hardness is also achieved by such novel FG flash structure.

Experiments & Cell Write/Erase (W/E) Operation

Detailed processing steps for fabricating flash cell with horn-shaped FG (Fig. 1) are described in [3]. The first gate oxide is 15-nm thick. The horn-shaped FG was created by performing a LOCOS-type oxidation on the FG. For the control wafers, the polyoxide was grown using a conventional O_2 oxidation. While for the N_2O-annealed wafers, the polyoxide was first grown in O_2 oxidation, followed by an N_2O anneal for 15 min at 925°C. For radiation study, flash cells were subjected to a cobalt-60 source with 1MRad(Si) dose before measurements.

To allow the use of a thick interpoly oxide, while maintaining a thin first gate oxide, a combination known to be beneficial for improving radiation hardness in FG cells [2], without suffering from inefficient erase operation, the cell is erased (i.e., to a low Vth state) by enhanced interpoly Fowler-Nordheim (FN) tunneling through the sharp tip of the horn-shaped FG. For an efficient programming, source-side hot-electron injection is employed [3].

Results and Discussion

The irradiation effects on the write/erase cycling endurance are plotted in Fig. 2 for the cell current in the "erase" state. Since the sense amplifier reference current in our design is 40μA, our results show that the cells survive after subjecting to 1Mrad(Si) Co^{60} irradiation, a very significant improvement over previous report that FG cells failed data retention after 10 -30 krad(Si) irradiation [2]. In fact, cell current even increases (i.e., an improvement) after irradiation. We believe this dramatic improvement is due to the unique cell structure with horn-shaped FG, which allows the use of a thick poly oxide, while maintaining a thin first gate oxide, a combination known to improve FG cell's radiation hardness, albeit inefficient for conventional W/E operation [2]. Our unique W/E mode employing enhanced F-N tunneling through horn-shaped FG allows the use of thick polyoxide without suffering inefficient W/E operation.

From Fig. 2, despite cell current improvement in the "erase" state immediately after irradiation, the irradiated cell's current degrades much more rapidly than that of non-irradiated counterpart when subjected to W/E cycling, especially for control cells without N_2O annealing. As a result, the irraidated control cell fails endurance at only about 20K cycles. In contrast, the irradiated N_2O-cell fails cycling endurance at about 45K cycles. The improvements in the N_2O-cells come from two folds, namely, a larger initial cell current and a less steep degradation rate during cycling. Finally, for the "program" state, cell current remains stable during cycling for both control and irradiated cells (data not shown).

Irradiation effects on W/E efficiencies are also studied. Erase efficiency (Fig. 3) actually improves for both the control and N_2O-cells, due to hole trappings at the oxide/FG interface as a result of irradiation [2], which serve to increase the interpoly electric field during the "erase" operation. In contrast, program efficiency after irradiation is degraded (Fig. 4), especially for the control cell, due again to hole trappings. During "program", some injected electrons will recombine with trapped holes, reducing the total electrons which can reach the FG. N_2O-annealing reduces hole trapping, thus reduces degradation in program efficiency.

Conclusion

A radiation-hard flash cell which not only survives 1 Mrad(Si) Co^{60} irradiation but also depicts an after-irradiation write/erase endurance of over 45 K was reported, for the first time. The superior radiation-hardness was achieved through both a unique split-gate cell structure with horn-shaped floating-gate which enhances the radiation-hardness, and the addition of an N_2O anneal which further improves the after-irradiation write/erase endurance.

Reference

[1] P. J. McWhorter, et. al., IEEE Trans. Nucl. Sci., V. NS-34, pp. 1652-1657, 1987.

[2] E. S. Snyder, et. al., IEEE Trans. Nucl. Sci., Vol. 36, No. 6, pp. 2131-2139, 1989.

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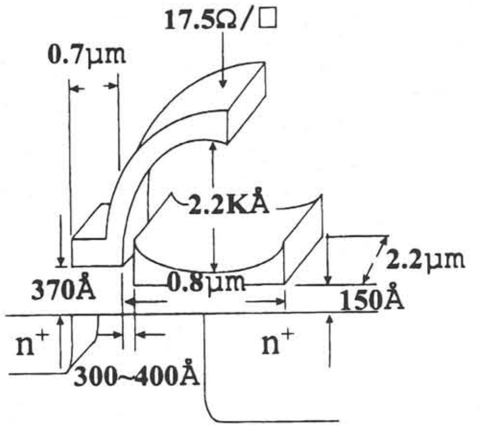

Fig.1:Schematic for flash cell with horn-shaped floating gate.

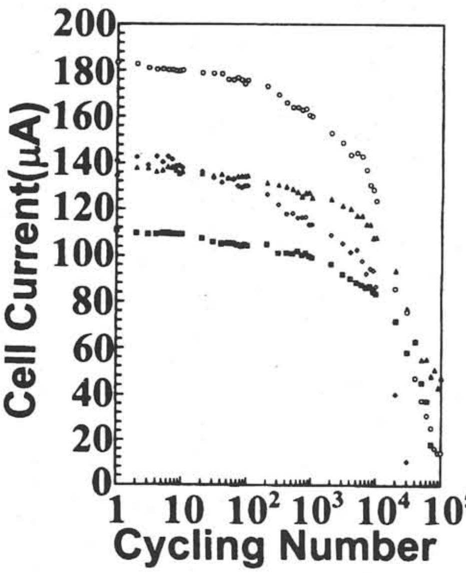

Fig.2: The cell read current in the "erase" (i.e., low Vth) states vs. w/e cycling for control cells before (square) and after (diamond) irradiation; and N_2O-cell before (triangle) and after (circle) irradiation. Cell fails when read current falls below 40μA (i.e., minimum current for the sense amplifier to sense as "erase"). For "erase", a 14-V 800-μsec pulse was applied to CG, with source, substrate and drain ground. For "write", drain was held at 12-V, source at 0.6-V, substrate at ground, and a 2-V, 800μsec was applied at CG. For "read", cell current was measured by applying 4-V to CG, 2-V to source, with substrate and drain grounded.

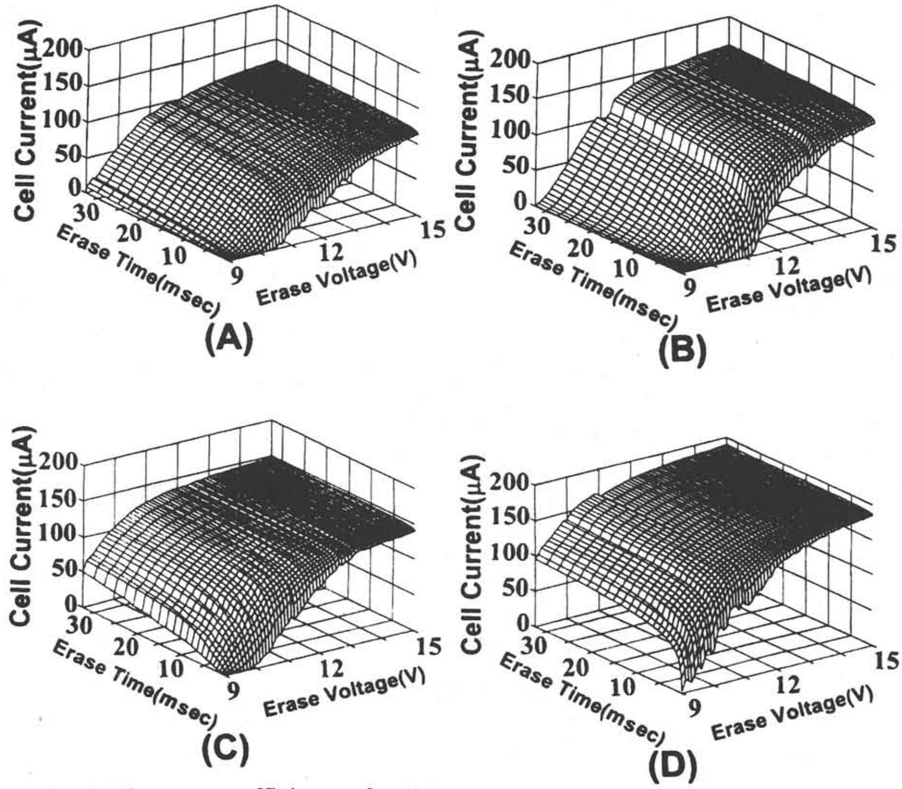

Fig.3: The erase efficiency for (a). control cell before irradiation, (b). control cell after irradiation, (c). N_2O-cell before irradiation, and (d). N_2O-cell after irradiation. For the erase efficiency test, cell current was read when CG was varied with all other terminals grounded.

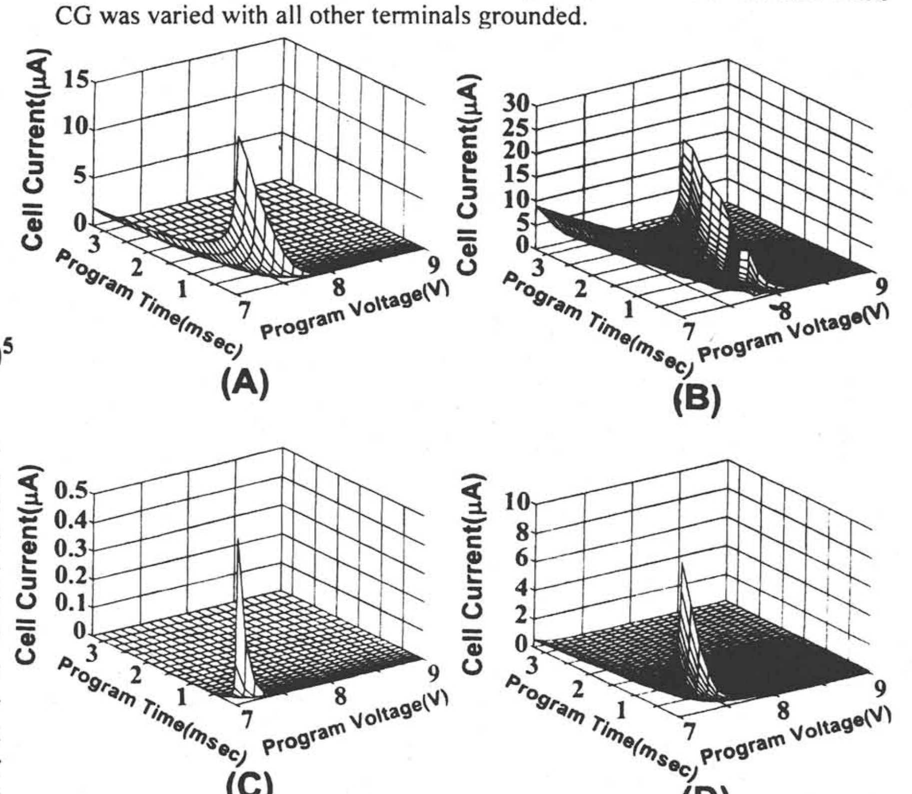

Fig.4: The program efficiency for (a). control cell before irradiation, (b). control cell after irradiation, (c). N_2O-cell before irradiation, and (d). N_2O-cell after irradiation. For the program efficiency test, cell current was read when drain voltage was varied with the CG at 12 V, source at 0.6 V and substrate at grounded.