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Hot Carrier Injection Phenomenon due to Excessive Natural Local Self-Boosting Effect in 3D NAND Flash Memory

Youngseok Jeong[1], Ilsik Ham[1], Seung Jae Baik[2] and Myounggon Kang[1]

[1] Dept. of Electronics Engineering, Korea National University of Transportation,
Room No.307, IT building, 50 Daehak-ro, Chungju-si, Chungbuk 27469, Republic of Korea
[2] Dept. of Electrical, Electronic, and Control Engineering, Hankyong National University
Phone: +82-43-841-5164 E-mail: mgkang@ut.ac.kr

Abstract

In this paper, we analyzed hot carrier injection (HCI) phenomenon due to excessive natural local self-boosting (NLSB) effect in 3D NAND flash memory. The main cell channel can easily be the floating state because the channel is not directly connected to its body, which results in the down-coupling phenomenon (DCP). This reduces the NLSB effect, which may cause the channel potential to decrease and cause a program disturb. However, if the channel potential of the selected word line (WL) becomes too high due to the NLSB effect, HCI phenomenon occurs.

1. Introduction

With the development of highly integrated and low-power electronic devices such as smart phones, solid-state drive (SSD), and tablet PCs, demand for NAND flash memories having the advantages of high speed, small size, and low power consumption is increasing rapidly. Therefore, the need for highly integrated NAND flash memory has become increasingly important. However, as the devices are scaled down, problems such as cell to cell interference (CCI) and limitations in lithography patterning are encountered [1-3]. These problems can be overcome by using 3D NAND flash memories. Moreover, the 3D NAND flash memory structure stacks the cells vertically to increase capacity [4-5]. However, the channel can be floating because the channel of a 3D NAND flash memory is not connected to the body. This could lead to a DCP effect [6]. In addition, when a high voltage is applied, the electrons of the cell are collected due to the potential difference, and the NLSB phenomenon occurs [7]. The NLSB effect does not require the local boosting scheme used in conventional 2D NAND, because it can achieve a sufficiently high potential even if the number of stacks is increased. In a previous research, we examined the NLSB according to the changes in pattern and bias and analyzed NLSB effect due to DCP phenomenon [8-9]. When the channel potential of the WL selected by the NLSB is increased, a large difference is generated in the channel potential of the adjacent WL, which results in a HCI phenomenon. In this paper, we analyzed the HCI due to NLSB effect. To analyze this phenomenon, 3D technology computer-aided design (TCAD) simulation (ATLAS Silvaco™) was used [10].

2. Experimental methods

In this research, we used a 3D NAND flash memory structure with 16 WL, ground select line (GSL) and string select line (SSL) as shown in Fig. 1(a) [6-9]. Fig. 1(b) shows the cell pattern condition of each WL. In this case, the E and P1 pattern means WL threshold voltage (V_t) and E = -1 V, P1 = 1 V.

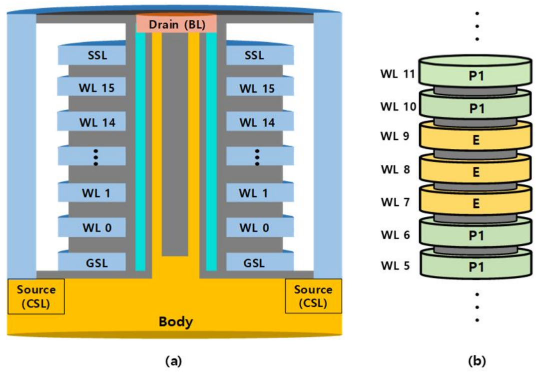

Fig. 1. (a) 3D NAND flash memory structure with 16 layers and GSL, SSL (b) Cell pattern condition for each WL.

Fig. 2 shows DCP, NLSB, HCI timing diagram used for verification and program sequence. To verify the HCI phenomenon due to the NLSB effect, the program voltage (V_{PGM}) = 18 V and the pass voltage (V_{PASS}) = 6 V, read voltage (V_{READ}) are applied to WL8 and others WL, respectively, during the program operation.

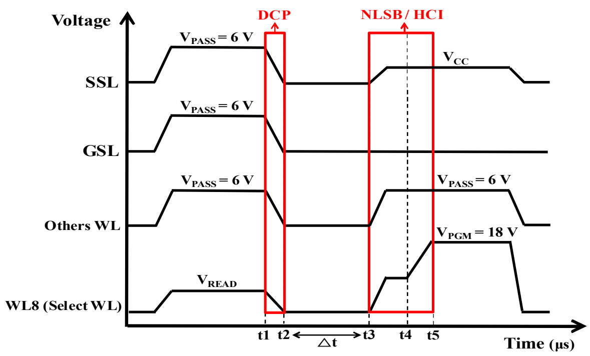

Fig. 2. (a) DCP, NLSB, HCI timing diagram and voltage bias conditions (V_{PASS} =6 V, V_{PGM} = 18 V).

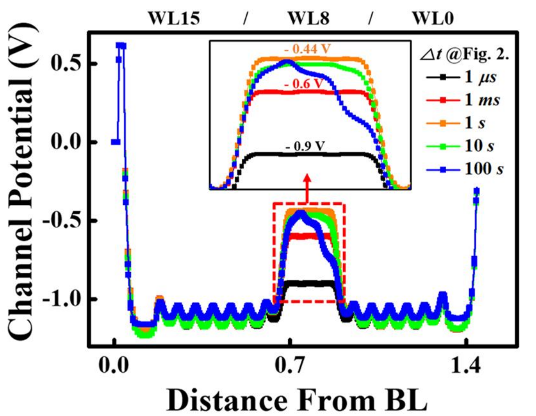

Fig. 3. Channel potential at t2 due to DCP and recovery according to Δt.

After the verification is completed (that is, in the t2 state), the channel potential is reduced due to the DCP effect [6]. Fig. 3 shows the recovery of DCP as Δt is increased by adjusting Δt between t2 and t3 in Fig 2. However, when Δt is 10 s, 100 s, the channel potential of WL 8 decreases, which shows that the potential of the others WL rises due to charge sharing effect [11].

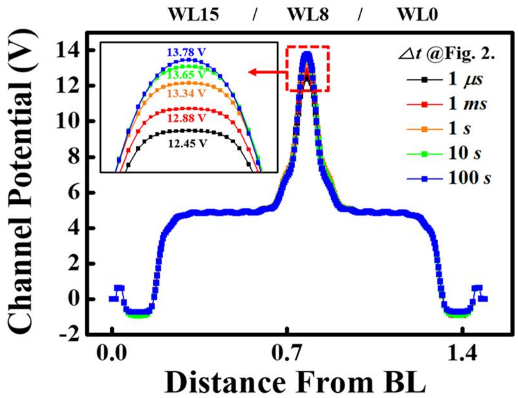

Fig. 4. Channel potential at t5 due to NLSB and NLSB according to Δt.

When V_{PGM} is applied, the channel electrons of the neighboring cells move to the selected WL cell due to the potential difference [7]. Also, as Δt becomes longer, the DCP is recovered and the channel potential of the selected WL is increased. This leads to an increase in the potential difference with the adjacent WL. This causes unintended HCI phenomenon.

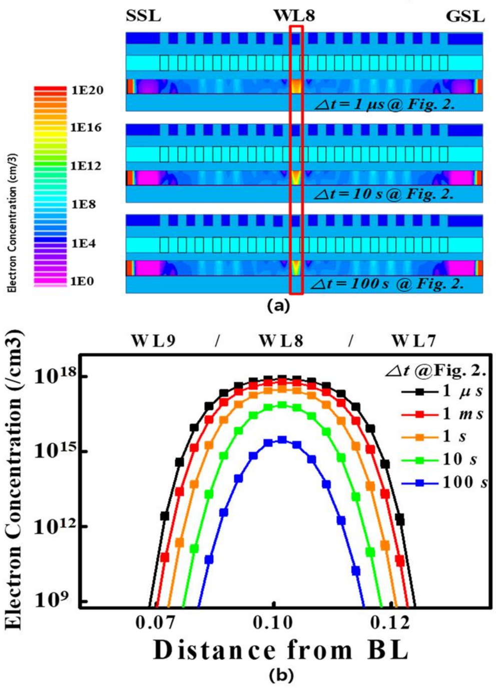

Fig. 5. The electron concentration of the channel after program operation according to the Δt adjustment by (a) vertical diagram (b) graph.

Fig. 5 shows the electron concentration after the program operation by adjusting Δt between t2 and t3 in Fig. 2. As Δt becomes longer, the DCP is restored and the NLSB effect becomes larger. Therefore, the channel potential of WL 8 increases and the channel potential difference with the adjacent WLs increases. As a result, the electrons get higher energies during drifts by a lateral electric field and finally injected into the nitride of selected cell. The electron concentration of the channel decreases due to the occurrence of the HCI phenomenon.

3. Conclusions

In this paper, we analyzed HCI phenomenon due to excessive NLSB effect in 3D NAND flash memory. DCP reduces the NLSB effect and reduces the channel potential during program operation, which results in program disturb. Therefore, to maximize the NLSB effect and reduce the occurrences of program disturb, it is important to reduce the DCP phenomenon. However, if the NLSB effect is increased and the potential of the program cell becomes higher, the channel potential difference with the adjacent cell increases and HCI phenomenon occurs. That is, when the NLSB effect becomes small, program disturb occurs, and when the NLSB effect becomes too large, the HCI phenomenon occurs. Therefore, it is important to maintain an appropriate channel potential in 3D NAND flash memory.

Acknowledgements

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