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V_{th} variation of string SONOS NAND Flash depending on single grain boundary and stored electron charges in an adjacent cell

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Abstract

In 3-Dimentional (3D) SONOS NAND Flash memory, the variation of threshold voltage (V_{th}) due to single grain boundary (SGB) position and stored electron charges effect from the adjacent cell was analyzed using TCAD simulation. As the Bit-Line voltage increases, the position of SGB causing the maximum V_{th} variation was shifted from the center of the channel to the source side. In addition, the stored electron charges in the adjacent cell can cause considerable V_{th} variation depending on the position of SGB.

1. Introduction

Since 2013, 3D vertical NAND Flash memory has been successfully adopted to mass production to overcome the scaling down limitation of planar NAND Flash structure. Most 3D vertical NAND Flash memories use a poly-silicon (poly-Si) as a channel layer, and inherently have the grain boundary problem. When the carriers are trapped in the grain boundary, it generates a localized potential barrier and degrades the electrical characteristics [1]. On the other hand, the 3D vertical NAND Flash mainly adopts charge trap (CT) type which has less interference effect by the adjacent cells and has more simpler fabrication process. However, as the scale down continues, even CT type NAND Flash suffers from the interference issue due to the potential interaction by the adjacent cells [2].

In this work, we investigated the effect of single grain boundary (SGB) position on threshold voltage (V_{th}) variation according to Bit-Line bias (V_d) in NAND flash memory. In addition, the influence of the electrons stored in the adjacent cell with various SGB position was analyzed through the potential interaction mechanism.

2. 3D SONOS simulation structure and bias conditions

Figure 1 shows three Word-Line (WL) string SONOS NAND Flash memory schematic built by Sentaurus (Synopsys, Inc) TCAD tool [3]. The detail simulation parameters are summarized in Table 1.

The two different but important factors are investigated, resulting in considerable V_{th} shift of the target cell: 1) the SGB position and 2) the stored electrons in the adjacent cell. In **Figure 1(a)**, the center of the target cell channel is located at X = 0 nm and the position of SGB is varied. It is assumed that the SGB is located perpendicular to the channel and SGB trap has the U-shaped distribution with a value of $10^{12} \sim 10^{14}$ $cm^{-2}eV^{-1}$ in the energy band [4]. The variation of V_{th} is extracted after programming of the target cell. The nitride trap density (N_{NIT}), 2.2×10^{19} cm^{-3} is used and electron and hole trap energy level are assumed 1.2 and 2.5 eV, respectively [5-6]. To observe the influence of the stored charge in the adjacent cell, we program the adjacent cell as shown in **Figure 1(b)** and analyze the V_{th} variation of the target cell. Bias conditions of program and read operation used in the simulation are summarized in **Table 2.**

3. Result and discussion

Figure 2 shows the V_{th} variation of the target cell with various SGB position and the V_d. As the V_d increases, the influence of SGB on the V_{th} variation can be reduced due to drain-induced grain barrier lowering (DIGBL) [7]. When the V_d is applied at 0.1 V, the V_{th} variation shows its maximum at SGB position = 0 nm. The position of SGB causing the maximum V_{th} variation are moved toward the source side, as the V_d increases. The relation between V_d and the SGB position maximizing V_{th} variation is investigated in detail using the conduction energy band (E_c) profile in the channel. **Figure 3** shows the E_c profile of the target cell at V_d = 0.1 and 1.0 V. When V_d is 1.0 V, the potential barrier of E_c is dominant at source side suggesting that the maximum V_{th} variation occurs by the SGB located near source region.

Figure 4 shows the V_{th} variation of the target cell due to the electron charge stored in the adjacent cell, when the SGB is located at the Middle of the Spacer (GB in MS) or in the Middle of the Channel (GB in MC). The GB in MS can aggravate the effect of stored electron charge in the adjacent cell. In contrast, when the SGB is located at MC, the influence of stored charge can be lowered. The GB in MS can intensify the potential interaction between the programmed adjacent cell and the target cell as shown in **Figure 5**. Contrastively, the effect of the adjacent cell can be suppressed by GB in MC where the dominant position of the potential barrier can be moved from near source to the middle of the channel.

4. Conclusions

The V_{th} variation depending on the SGB position and the stored electrons in the adjacent cell of string SONOS NAND Flash were investigated. To analyze the V_{th} variation effect of the grain boundary position especially in string NAND structure, Bit-Line voltage and stored electron charge in the adjacent cell need to be carefully considered.

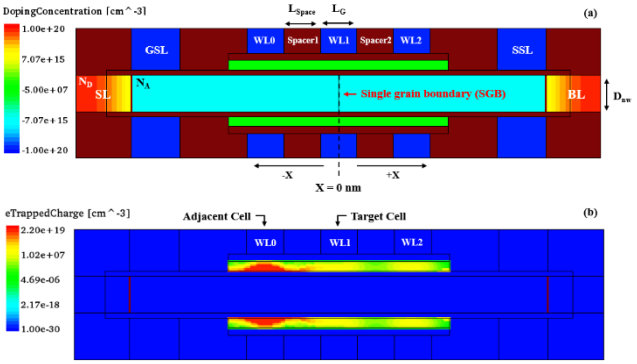

Fig. 1. (a) A schematic of three Word-Line string SONOS NAND Flash memory simulation structure with various single grain boundary (SGB) position and (b) the concentration of trapped electron charge in nitride when the adjacent cell is programmed.

Table I Parameters of three Word-Line string SONOS NAND

Parameter	Description	Value
L_G	Channel length (nm)	30
L_{Space}	Spacer length (nm)	30
D_{NW}	Channel diameter (nm)	30
T_{OX}	O/N/O thickness (nm)	4/8/6
N_A	Channel doping concentration (cm^{-3})	10^{16}
N_D	S/D doping concentration (cm^{-3})	10^{20}
N_{NIT}	Nitride trap density (cm^{-3})	2.2×10^{19}
N_{GB}	Grain boundary trap states ($cm^{-2}eV^{-1}$)	$10^{12} - 10^{14}$

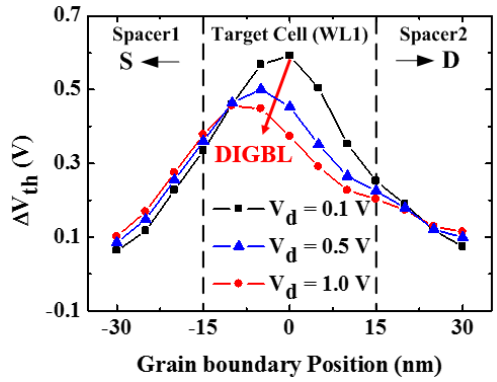

Fig. 2. The V_{th} variation due to various SGB position with V_d = 0.1, 0.5, and 1.0 V (after the target cell program). High V_d shows obvious DIGBL effect. i.e the peak ΔV_{th} value reduction and its position shift.

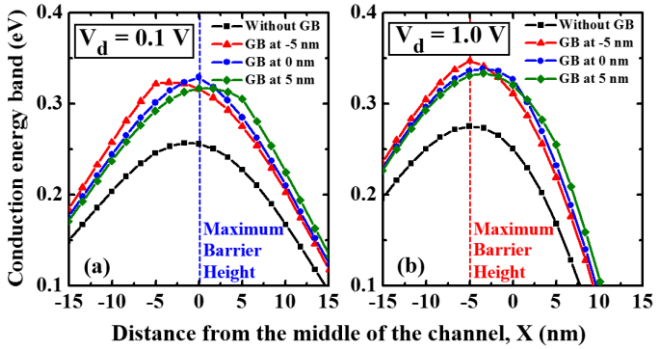

Fig. 3. Conduction energy band of the target cell channel with various SGB positions (X = -5, 0, 5 nm) at V_d = (a) 0.1 and (b) 1.0 V (when V_G~V_{th}). The position of maximum potential barrier height rather depends on V_d (b), than SGB position (a).

Table II Bias conditions of Program and Read operation

Program	Bias (V)	Read	Bias (V)
SL & BL	0	SL/BL	0 / 0.1, 0.5, 1
Pass WL	6	Pass WL	4.5
Program WL	16	Target WL	Up to 4
GSL & SSL	4.5	GSL & SSL	4.5

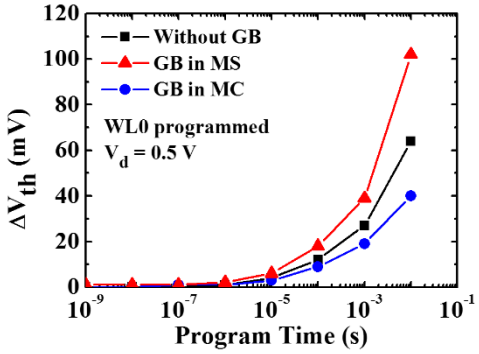

Fig. 4. The V_{th} variation of the target cell (WL1) due to stored electron charge in the adjacent cell (WL0) with various GB position as a function of the adjacent cell program time. The GB in the Middle of Channel (WL1) is preferred.

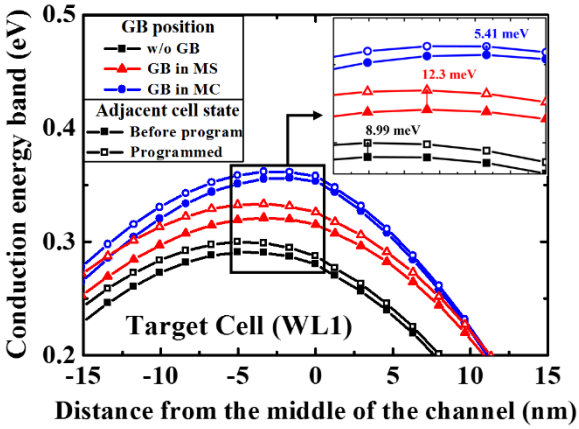

Fig. 5. The potential barrier of the target cell (WL1) with stored electron charge in the adjacent cell and various GB position (when V_G~V_{th}). The GB in MS shows higher potential barrier change after the adjacent cell programmed (12.3 meV) than w/o GB (8.99 meV), and GB in MC is lower (5.41 meV). These are well-fitted to ΔV_{th} behaviors in Fig. 4.

Acknowledgements

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