Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp145-146

Effect of String Tapering on Threshold Voltage Distribution and Its Mitigation in a Vertical Channel 3D NAND Flash Memory

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Abstract

In this work, we have investigated the impacts of taper angle and channel doping on the performance parameters of a vertical channel 3D NAND flash memory. It is found that string current and threshold voltage (V_T) distribution of the word lines (WLs) along the string is influenced by both, taper angle and channel doping. Therefore, non-uniformity in V_T distribution of different WLs due to string tapering is minimized by optimizing the channel doping along the string from top to bottom. Moreover, optimized channel doping leads to an improved string current. These results are crucial for the designing of high performance and reliable future 3D NAND flash memories.

1. Introduction

Several studies have already been conducted to meet the challenges of vertical NAND flash memories [1] - [3]. As the number of word line (WL) layers is increased, the total mold height is also increased, posing new challenges for etching very high aspect ratio channel holes. The radius of WL rings changes continuously along the channel height due channel tapering. In an ideal world, all the WLs should have same initial state threshold voltage (V_T) but the varying channel radius causes initial state V_T variation from top to the bottom WLs. The impact of channel taper angle and the number of WLs on the electrical characteristics of vertical NAND Flash memories has been reported [4], [5] and search for solution is an on-going effort.

In this work the impacts of taper angle and channel doping on the electrical characteristics are investigated, using Sentaurus technology computer-aided design (TCAD) tool. String read current and threshold voltage of WLs along the string (V_T distribution) are studied as functions of channel doping and taper angle. Finally, uniformity of V_T distribution and enhanced read current are achieved by optimizing the channel doping from top to bottom along the string.

2. Simulation Details

Simulated vertical channel NAND structure comprising of 100 word lines, select transistors, SSL (string select transistor), GSL (ground select transistor), BL (bit line) and CSL (common source line), is shown in Fig 1. The thickness of silicon channel, tunnel oxide, nitride layer and block oxide layer in the simulated devices are 15, 6, 5, and 10 nm, respectively.

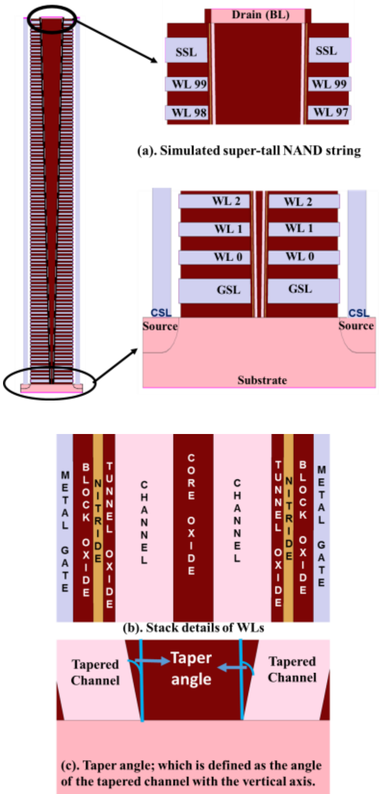

Fig. 1 Structural details of the simulated device showing details of different layers and taper angle. Taper angle is defined here as the angle of the tapered channel with the vertical direction.

3. Results and Discussion

Fig. 2 shows reported string current with the number of stacked WLs [5]. The degradation in string read current with increasing number of stacked WLs has been reflected in the simulation results, as shown in Fig. 3. In order to minimize the current reduction, we have increased the channel doping and it is found that a higher read current is obtained as shown in Fig. 3. This is attributed to the fact that the channel is phosphorus doped (N-type) and by increasing N-type channel doping the desired electron concentration in the channel is increased. This leads to a higher string current. Therefore, higher channel doping is proposed in order to mitigate the string read current reduction.

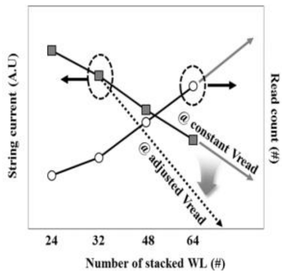

Fig. 2 Reported string current trend by increasing the number of stacked WLs [12].

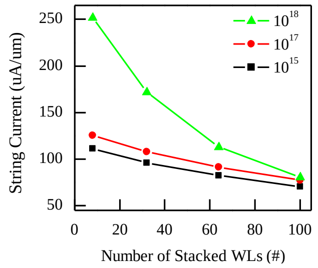

Fig. 3 Simulated string current trend by increasing the number of stacked WLs.

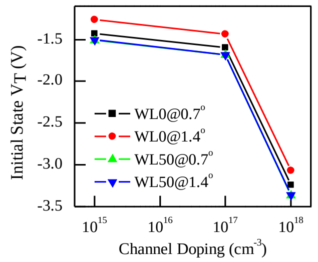

Fig. 4. Simulated Initial state V_T vs channel doping for taper angles of 0.7^0 and 1.4^0.

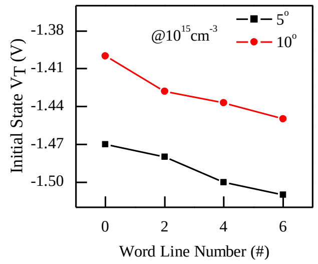

Fig. 5. Initial state V_T vs WL number for taper angles of 5° and 10° at channel doping of 10^{15} cm^{-3}.

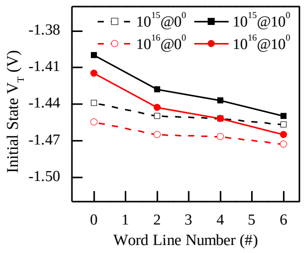

Fig. 6. Initial state V_T vs WL number for channel dopings of 10^{15} cm^{-3} and 10^{16} cm^{-3}, at 0° and 10° taper angles.

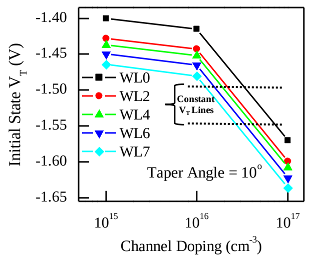

Fig.7 Simulated initial state V_T of different WLs for channel dopings of 10^{15} cm^{-3} to 10^{17} cm^{-3} while keeping the taper angle fixed at 10°.

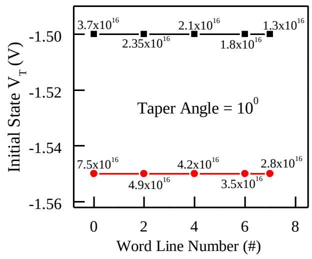

Fig.8 Uniform V_T distribution obtained by varying channel doping.

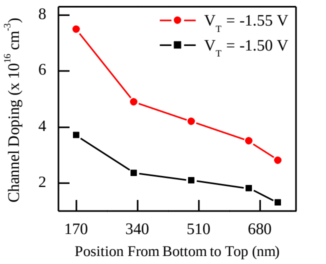

Fig.9 Channel doping vs position along the channel measured from the bottom end of the string for constant VT values of -1.55V and -1.50V.

Fig. 4 shows simulated initial state V_T of WL0 and WL50 in a supertall string with 100 WLs. V_T is plotted with respect to channel doping for taper angles of 0.7^0 and 1.4^0. V_T of different WLs varies with change in taper angle. This is because with change in taper angle, radius of each cell also changes. It is found that V_T decreases as channel doping is increased. Again, this is attributed to the fact that the channel is N-type and this leads to higher cell current and reduced cell V_T.

In order to understand the impact of taper angle on V_T distribution effectively, we have incorporated intense tapering in a short string comprising of 8 WLs. Initial state V_T vs WL number for taper angles of 5^0 and 10^0 are shown in Fig. 5. In this case channel doping is kept fixed at 10^{15} cm^{-3}. V_T of the WLs decreases with position of WLs from bottom to top which is attributed to the variation of effective source/drain resistances of the WLs along the string [4]. V_T of the WLs is also influenced by the variation of taper angle along the string. Therefore, V_T variation is observed due to the taper angle as well as position of the WLs along the string. Fig. 6 shows initial state V_T vs WL number for channel dopings of 10^{15} cm^{-3} and 10^{16} cm^{-3} by keeping the taper angle at 0° and 10°. It is observed that V_T of the WLs decreases with increase in channel doping in all the cases. Therefore, it is concluded that V_T increases with increase in taper angle and decreases with increase in channel doping. Consequently, a uniform V_T distribution can be achieved by optimized channel doping from top to bottom along the string. In order to validate this we have simulated the same string for channel dopings of 10^{15} cm^{-3} to 10^{17} cm^{-3} while keeping the taper angle fixed at 10°. Initial state V_T of different WLs is plotted with channel doping, as shown in Fig. 7. It is observed that an equal initial state V_T of all the WLs is achieved by varying the channel doping while keeping the taper angle fixed at 10°. Hence, V_T non-uniformity can be minimized with the help of varying channel doping at different positions along the string, as shown in Fig. 8. To get more insight into the proposed technique, channel doping distribution is plotted along the channel from bottom to top of the string as shown in Fig. 9. It is found that constant V_T values of -1.55V and -1.50V can be achieved by varying the doping at different positions along the channel.

4. Conclusions

In this work, we have investigated the impacts of taper angle and channel doping on the initial state V_T and string current. A uniform V_T distribution of WLs at various positions along the string is achieved by optimized channel doping along the string from top to bottom. Moreover, a higher string current is achieved by increasing the channel doping of the string. These results will be helpful in the optimization of V_T distribution and string current in 3D NAND Flash memories.

Acknowledgements

One of the author, Upendra Mohan Bhatt, sincerely acknowledges VSE, Applied Materials, USA for an internship.

References

[1] Y. Wang, *et al.*, TVLSI, vol. 22, no. 11, pp. 2402–2410, 2014.
[2] C. C. Hsieh, *et al.*, Proc. Symp. VLSI Technol., 2013, pp. 156–157.
[3] U. M. Bhatt, *et al.*, IEEE TED, vol. 65, no. 5, pp. 1781-1786, 2018.
[4] K. T. Kim, *et al.*, IEEE EDL, vol. 38, no. 10, pp.1375-1378, 2017.
[5] H. Kim, *et al.*, IMW 2017, Zonterey, CA, 2017, pp. 1-4.