A Novel Approach of 3D-NAND Based on Light Emitting Cell for High Reliability and Low Power Consumption

Soo Jin Kim[1], Younghwi Yang[1], Woo Jae Jang[1] and Seung Jae Baik[1]
[1]Samsung Electronics, Hwaseong-si, Gyeonggi-do, Republic of Korea, email: soojin31.kim@samsung.com

***Abstract*—**The development of 3D-NAND has increased the number of vertically stacked cell controlled by word line (WL) for high cell density and low cost. Increasing the number of vertical cell induces higher power consumption and lower current which deteriorates cell reliability. However, the requirements of high cell reliability and low power consumption also have been rapidly increasing, since the demands of storage application in big data and cloud services have been growing. Here, as a unit cell in 3D-NAND, we proposed an optically readable light emitting memory (LEM) which shows both memory performance and light emitting output. A LEM is read by generating light instead of current that indicates states of the cell. Compared to conventional cell requires applying all WLs biases, only the select WL needs read bias to detect light intensity of LEM for reading states of the cell. As voltage is applied only to select WL, power consumption is reduced about 45%. Also read disturb (RD) and low cell current which degrade cell reliability are eliminated then read window is expected to be improved.

I. Introduction

In the recent boost of data storage for computing system, cloud services and data centers, the demands on NAND flash memory and importance of its high cell reliability and lower power consumption have been increasing.[1] However, the development of 3D-NAND regarding cost efficiency and high cell density brings degradation of cell reliability and higher power consumption by increasing cell layer. As shown in Fig. 1a, generally, a read voltage is supplied to all WLs repeatedly for reading a pattern of target cell by sensing current of string. In detail of read operation, after BL is charged up, it is maintained or discharged depending on the cell current (Fig. 2). When the cell induces enough current, pre-charged BL colored by green is discharged while inefficient current keeps charged state. By increase of cell layers, this operation grows power consumption and degradation of cell reliability.

In this point of view, a new approach for operating 3D-NAND is needed to meet all requirements. In this paper, we firstly proposed application of a light emitting memory (LEM) as a unit cell in 3D-NAND. The device, shows both light emitting performance and non-volatile memory behavior, is called light emitting memory.[2] As shown in Fig. 1b, only select WL needs applying bias for generating a light which indicates pattern of LEM. The intensity of luminance in LEM is controlled by memory state. When the LEM emits enough intensity of the luminance, it is received by photodetector on the bit line (BL) side and induces photocurrent. Then, the pre-charged V_{BL} is discharged by the generated photocurrent, which is the same method of reading the pattern in the conventional cell (Fig. 2).

LEM has been reported to simplify display circuit for controlling luminance by emerging light emitting diode and capacitor.[3] Electroluminescent (EL) is based on excitons which is induced by recombination of injected hole and electron carriers in light emitting layer. The working mechanisms of LEMs are based on charge trap and ferroelectric layer as a memory unit by controlling carriers for luminance.[4][5] The previous work shows controlling light intensity by changing the number of electron in charge trap layer or polarity of a ferroelectric layer. In Fig. 3b and Fig 3c, depending on programmed state or erased state, concentration of recombined hole and electron carriers (excitons) in the light emitting layer determines intensity of the light. Under a programmed bias (positive bias), the ferroelectric layer is polarized toward one direction. After applying positive bias, the orientation of the dipole in ferroelectric is not changed. As a result, few holes are stored at the interface of ferroelectric layer then show lower light intensity. In contrast programmed state, a large amount of holes is attracted at the ferroelectric/light emitting layer interface under an erased state. Therefore, the device shows higher light emission. This mechanism successfully controls the amount of recombination for changing intensity of the LEM.

II. Results and Discussion

A. Electrical and Luminous Performance of LEM

To fabricate LEM based on ferroelectric, ferroelectric polymer poly(vinylidenefluoride-co-trifluorothylene) [P(VDF-TrFE)] is used for non-volatile memory unit on Indium tin oxide (ITO) glass as an anode. The deposited film of P(VDF-TrFE) shows needle like crystalline domain. (Fig. 4a) The ferroelectric characteristics of employed 100nm-film was measured and shows switching polarization over 6.5 V, which has hysteresis characteristic with butterfly shape and similar value with previous report, as shown in Fig. 5.[5] After preparing ferroelectric layer on ITO glass, light emitting layer (Super yellow) is coated on the film. Finally, LiF/Al as a cathode is deposited on super yellow. (Fig. 3a)

Based on polarization property of ferroelectric, 6 V was used for read operation and luminance of LEM to avoid changing memory state. The demonstrated LEM shows distinct electrical and luminous performance under programmed and erased states (Fig. 6 and Fig. 7). At the read voltage (6 V), due to few accumulation of hole in programmed state originated by polarization, the 100 uA-lower current is observed than erased state (blue line in Fig. 6). It indicates the built-in potential in ferroelectric layer effectively controls the injection of the carriers in light emitting layer. As a result, LEM programmed under 12 V shows 20cd/m^2-lower luminance due to few recombination of the carriers (blue line in Fig. 7).

B. *Feasibility of LEM in 3D-NAND*

Due to the limitation of sensing error, the current under certain value on string always induces an off-cell error bit. As mentioned above, in order to discharge V_{BL} by the generated photocurrent without deterioration of reliability, the value of current needs to satisfy specific range.

In our experiment, the difference of luminance between PGM/ERS state is 20 cd/m^2 under V_{PGM}=12 V. We assumed that 75% of luminous intensity (15cd/m^2) is able to reach photodetector by considering reflective index of each layers. As shown in table 1, we calculated generated photocurrent in actual area of unit cell with 8980 nm^2. To calculate reasonable expectation, the measurement distance of luminance is adjusted to height of string and general responsivity of photodetector with 0.58 A/W is used. As a result, 8.7*10^{-2} uW is generated in unit cell and it is enough to induce 50nA of photocurrent in photodetector. Based on the results, we confirmed the possibility of LEM being used in 3D-NAND without any deterioration of reliability.

Additionally, multi-level cell (MLC) was demonstrated by changing PGM voltage from 8 V to 12 V. As increasing PGM voltage, the difference of luminance (△luminance) is also increasing from 5 cd/m^2 to 20 cd/m^2, respectively, as shown in Fig. 8. This result indicates that LEM has a potential to adapt unit cell in 3D-NAND with MLC. We also confirmed distinction of programming voltage and read voltage in demonstrated LEM (Fig. 9). Compared to V_{READ}=6 V, the luminance of LEM is decreased by applying V_{PGM}=12 V continuously. Under V_{READ}=6 V, the various states of luminance are able to be detected without changing memory states, which is determined by dipole in ferroelectric film.

C. *Power consumption and reliability*

The power consumption of 3D-NAND based on conventional cell are degraded by increasing the number of WLs, as shown in Fig. 10. It shows the read power consumption of NAND chip including logic, DC, cell current, BL and WL factors. When the number of WLs is increased from generation N_{th} to $N+1_{th}$, the read power consumption is expected to be increased by 20% due to increased WLs. On the other hand, the demonstrated LEM does not require V_{READ} bias so the WL portion can be eliminated, which reduces the power consumption by 45%.

In terms of reliability of the device based on electrical readable cell, the number of applying bias is increasing as followed by increasing WLs. This increased supplying bias results read disturb (RD) which changes the pattern of the cell. Future generation is expected to show twice degraded reliability. However, in the LEM structure, because the V_{READ} biasing to all WLs is not required and the cell state is read by the light not cell current, the degradation of RD can be eliminated, as shown in Fig. 11a. Also, while the WL is increasing, cell current is reducing. As shown in Fig. 11b, future generation is not able to detect pattern of the cell due to the lowest current. However, LEM is sensed by light instead of current. As a result, in 3D-NAND based on LEM is not affected by the number of WLs and expected enhancement of read window.

III. Conclusion

In this paper, we introduced an innovate 3D-NAND based on a LEM cell with non-volatile memory behavior and performance of luminance. The demonstrated LEM is enable to generate distinct intensities of light dependent on memory states and shows possibility of multistate in cell. The generated light induces enough photocurrent for sensing pattern of the cell without deterioration. Because only select WL needs supplying bias, 45% lower power consumption is expected in 3D-NAND based on LEM than conventional cell. According to our calculations, the LEM-based 3D-NAND shows twice more reliable performance. As a result, it is worth to focus that the proposed device could be a new breakthrough for improving cell reliability and lowering power consumption.

References

[1] M. H., T. T., "A Low-Power BL Path Design for NAND Flash Based on an Existing NAND Interface." Journal of Low Power Electronics and Applications 14, 2024

[2] T.A, M. A., I. A., B. K. "Electroformed silicon nitride based light emitting memory device." Appl. Phys. Lett. 111, 053502-1, 2017

[3] X. M., Z. C., M. Z., Y. H., C. H., J. Z., M. H. "Nonvolatile Memory Organic Light‐Emitting Transistors." Adv. Mater., 35, 2307703, 2023

[4] K. S. H., C. T., K. I., B. V., "Memory effect from charge trapping in layered organic structures." Appl. Phys. Lett. 85, 4666-4668, 2004

[5] L. J. H., J.B., C. S. H., K. E. H., P. C., "Non‐volatile polymer electroluminescence programmable with ferroelectric field‐induced charge injection gate." Adv. Funct. Mater., 26, 5391-5399, 2016

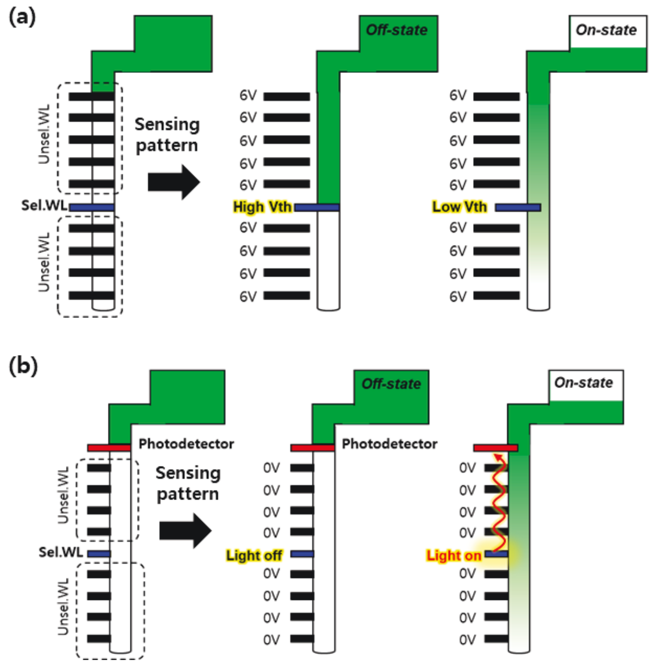

Fig. 1. Schematics of reading pattern in cell based on (a)conventional charge trap memory and (b)light emitting memory for 3D-NAND.

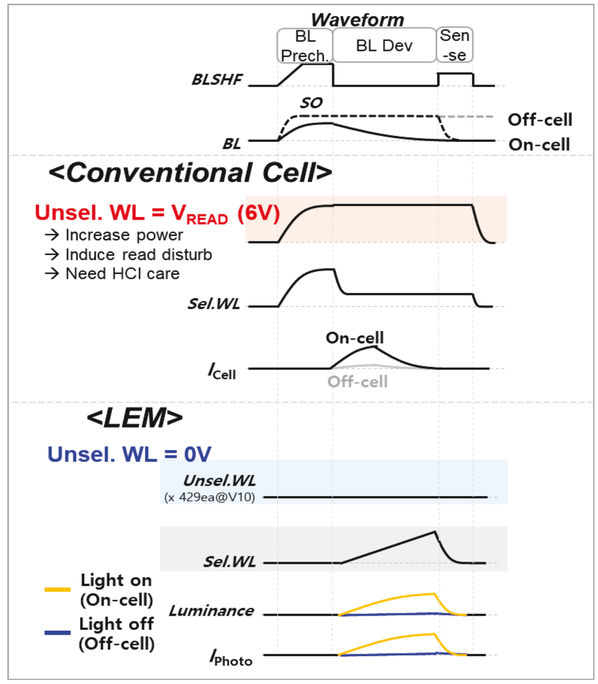

Fig.2. Illustration of the BL read access in 3D-NAND based on conventional cell and LEM.

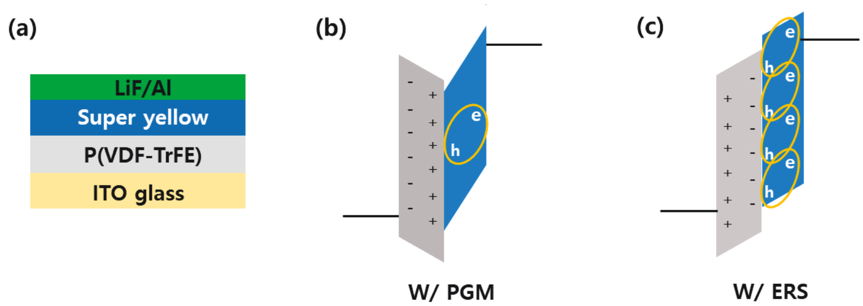

Fig.3. Illustration of (a)device and schematics of working mechanism of LEM based on ferroelectric polymer. Built in potential and amount of carriers under (b)programmed state and (d)erased state.

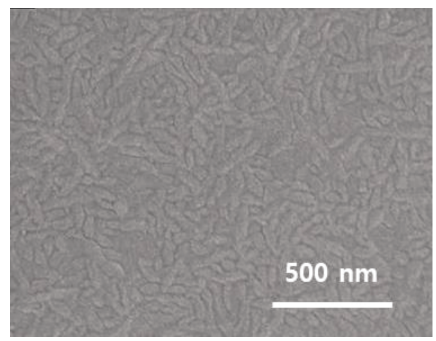

Fig.4. SEM image of deposited P(VDF-TrFE) film.

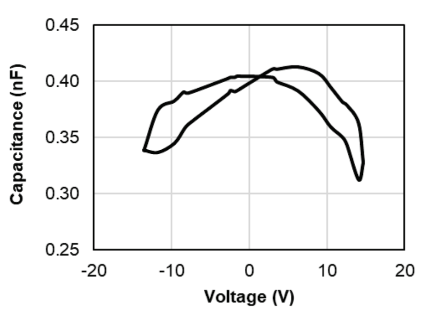

Fig. 5. Capacitance-voltage (C-V) characteristic of Al/P(VDF-TrFE)/Al capacitor.

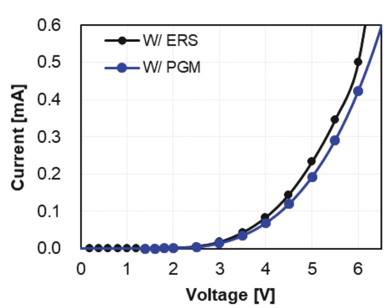

Fig. 6. Electrical performance of LEM after programming/erasing operation.

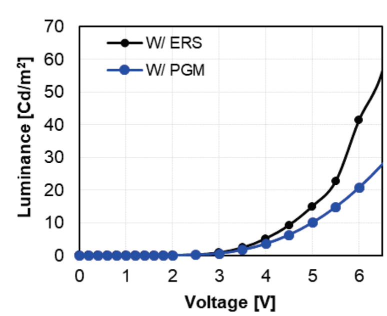

Fig. 7. Luminance of LEM after programming/erasing operation.

ITEM	Parameter	Value
Luminous characteristics	Current density [mA/cm²]	100
	Luminance [cd/m2]	15
	Luminous intensity [W/m²]	0.02196
	Revised luminous intensity	$9.68*10^{6}$
Unit cell	Area [nm²]	8980
Luminance in one unit cell	Current [nA]	0.00898
	Luminous intensity [uW]	$1.9721*10^{-10}$
	Revised luminous intensity [uW]	$8.7*10^{-2}$
Photodetector	Responsivity [A/W]	0.58
	Revised photocurrent [nA]	50

Table. 1. The value for calculating expected photocurrent in unit LEM with actual conventional cell area and experimental luminous characteristics.

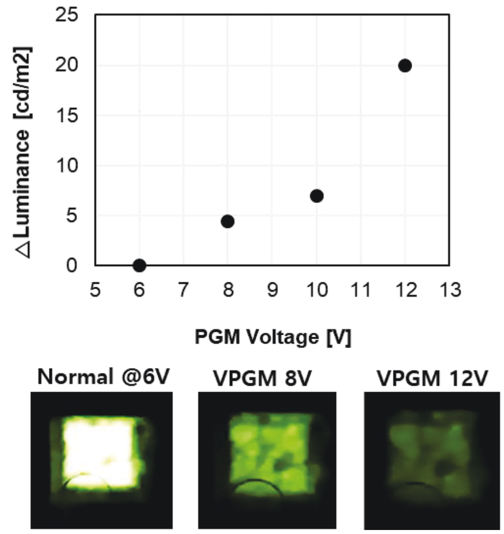

Fig. 8. Difference of luminance between programmed state and erased state under different PGM voltage. Photography of LEM depends on normal and PGM voltage under the same read voltage.

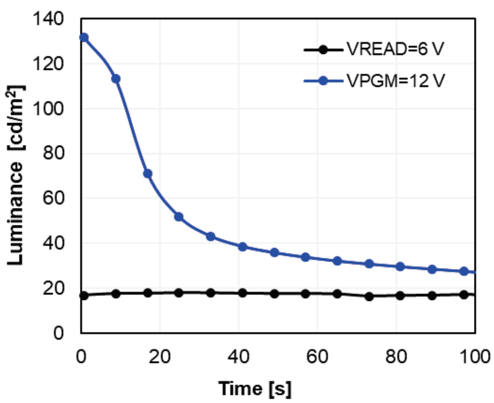

Fig. 9. Changes of luminance under applying continuous bias with VREAD=6 V and VPGM=12 V.

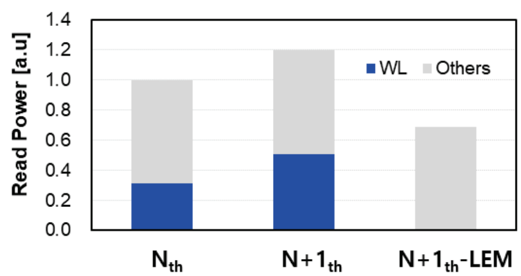

Fig. 10. Predicted value of power consumption by increasing the number of WLs.

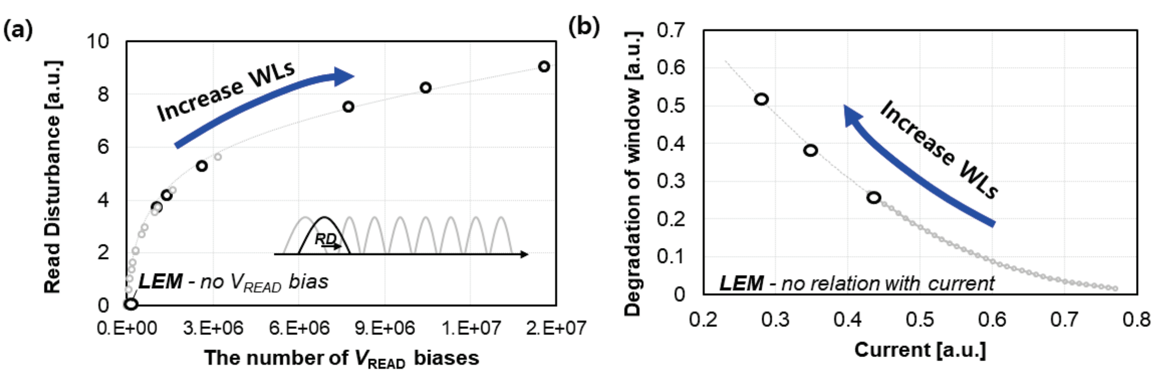

Fig. 11. Calculated value of degraded reliability by (a)RD and (b) cell current while the number of WLs increase.