Spatial Distribution of Localized Charge Carriers in SONOS Memory Cells

Byungcheul Kim, *Member, KIMICS*

Abstract—Lateral distributions of locally injected electrons and holes in an oxide-nitride-oxide (ONO) dielectric stack of two different silicon-oxide-nitride-oxide-silicon (SONOS) memory cells are evaluated by single-junction charge pumping technique. Spatial distribution of electrons injected by channel hot electron (CHE) for programming is limited to length of the ONO region in a locally ONO stacked cell, while is spread widely along with channel in a fully ONO stacked cell. Hot-holes generated by band-to-band tunneling for erasing are trapped into the oxide as well as the ONO stack in the locally ONO stacked cell.

Index Terms—SONOS Memory, Locally ONO Stacked Cell, Single-Junction Charge Pumping Technique, Spatial Distribution.

I. INTRODUCTION

Silicon-oxide-nitride-oxide-silicon (SONOS) non-volatile memory is considered as the most promising flash memory technology in the near future. The reasons are as follows; high-density, low power consumption, and simple& logic compatible process [1-4]. Out of them, the most attractive is realization of two-bit per cell for high volume capacity [5, 6]. In the conventional SONOS concept, operation of one-bit per cell is only possible due to charges stored uniformly in the nitride layer. However, two-bit concept of the SONOS memory has recently achieved by storing charges locally in the nitride discrete traps above junction edges. In order to guarantees reliable two-bit operation in the localized charge-trapping SONOS memory, an understanding of lateral charge distribution in an oxide-nitride-oxide (ONO) dielectric stack is required. Many experimental methods to extract localized trap charge distributions have been developed [7-10]. Nonetheless, the spatial distributions of charge carriers trapped in the ONO dielectric stack have never been clearly characterized. In this paper, we directly show the spatial distributions of locally trapped electrons and holes in a nitride layer of two different SONOS cells by using single junction charge pumping technique.

II. MEMORY CELL STRUCTURES

Figure 1 show schematic cross sections of (a) a locally ONO stacked cell and (b) a fully ONO stacked cell.

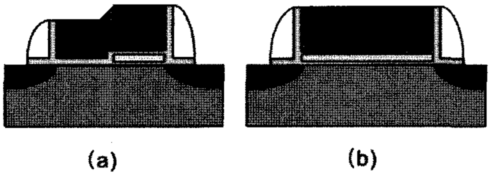
(a) (b)

Fig. 1 Schematic cross sections of (a) locally ONO stacked cell and (b) fully ONO stacked cell.

The memory cells are based on an n-channel MOSFET device. In the locally ONO stacked cell, the ONO dielectrics are only stacked at drain side, while channel region of the fully ONO stacked cell is covered up with the ONO dielectrics. They are fabricated using 0.13 um technology with shallow trench isolation. The locally ONO stacked cell has channel length of 0.15 um in the thin oxide region and 0.1 um in the ONO stacked region. Channel length of the fully ONO stacked cell is 0.25 um. The thicknesses of the stacked ONO are 3.5~4.0 nm for a bottom oxide, 4.7~5.0 nm for a nitride, and 7.0~8.0 nm for a top oxide. The top and bottom oxides of both the locally ONO stacked cell and the fully ONO stacked cell are sufficiently thick to avoid charge direct tunneling.

III. EXPERIMENTAL SET-UP

In this work, the memory cells are programmed by applying 3.5 V to the gate, 4.5 V to the drain, and 1 V to the source for 20 us. The erase is performed by applying -6.5 V to the gate and 5 V to the drain for 20 us. The single junction charge pumping technique is used to evaluate a localized charge trapping characteristics of the SONOS memory cells after programming and erasing, respectively.

An experimental setup for measuring the single junction charge pumping currents is shown in Fig. 2.

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Byungcheul Kim is with the Department of Electronic Engineering, Jinju National University, Jinju, 660-758, Korea (Tel: +82-55-751-3336, Fax: +82-55-751-3339, Email:bckim@jinju.ac.kr)

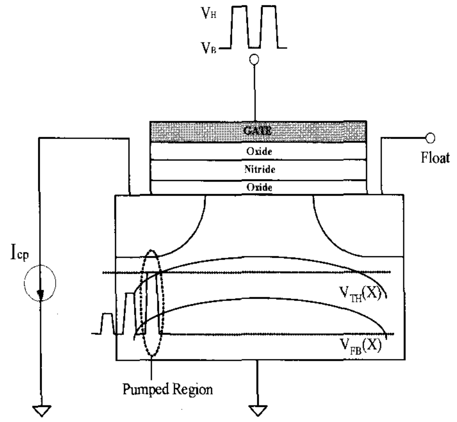

Fig. 2 Schematic diagram for measuring the single junction charge pumping current.

For measuring the single junction charge pumping currents, continuous square pulses are applied to the gate while the substrate is grounded. HP4156C parametric analyzer is used to measure the charge pumping currents from one junction while the other junction is left floating. The gate pulse has a frequency of 10 MHz, 50% duty cycle, rise/fall times of 10 ns and a fixed base voltage (V_b) of -3 V by a pulse generator (HP8110A).

IV. RESULTS AND DISCUSSION

The single-junction charge pumping currents measured separately from the abrupt drain and graded source junctions of the fully ONO stacked cell and the locally ONO stacked cell are shown in Fig. 3.

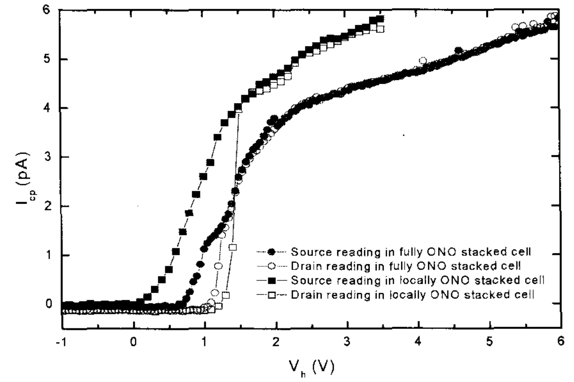

Fig. 3 Single-junction charge pumping currents measured separately from the graded source junction and the abrupt drain junction of the fully ONO stacked cell and the locally ONO stacked cell at initial state.

The charge pumping currents (Icp) from the drain junction for both cells are measured at nearly same pulse height (Vh). However, Icp read from the source junction for locally ONO stacked cell occur at less Vh of a charge pumping pulse than one for fully ONO stacked cell. This means that a local threshold voltage (Vt) of the locally ONO stacked cell is low at source region because the locally ONO stacked cell has only thin oxide at source side.

Figure 4 shows the single-junction charge pumping currents after channel hot electron programming.

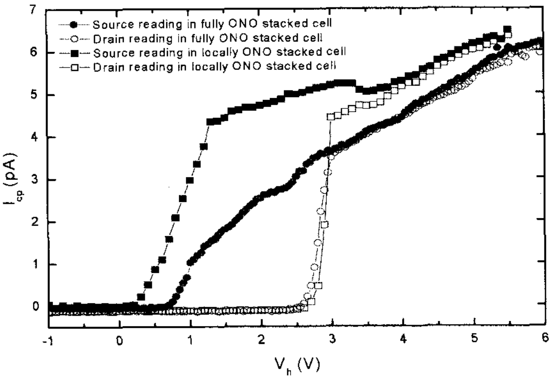

Fig. 4 Single-junction charge pumping currents measured separately from the graded source junction and the abrupt drain junction of the fully ONO stacked cell and locally ONO stacked cell after channel hot electron programming at the drain junction.

After drain programming, the I_{cp} measured from the source junction for both cells shows same results as shown in Fig. 3. However, the I_{cp} measured from the drain junction begin to flow at higher V_h=2.5 V than V_h=1.0 V at initial state.

Figure 5 shows the single-junction charge pumping currents after band-to-band hot-hole drain erasing.

After drain erasing, the I_{cp} measured from the source junction for both cells shows same results as shown in Fig. 3. However, the I_{cp} measured from the drain junction begin to flow at lower V_h=-1.0 V than V_h=2.5 V at programmed state. Moreover, the I_{cp} from the drain junction is measured at lower V_h=-1.0 V than V_h=1.0 V at initial state.

Lateral profiles of the local V_t with distance from source junction can be obtained from charge pumping data shown in Fig. 3, Fig. 4, and Fig. 5.

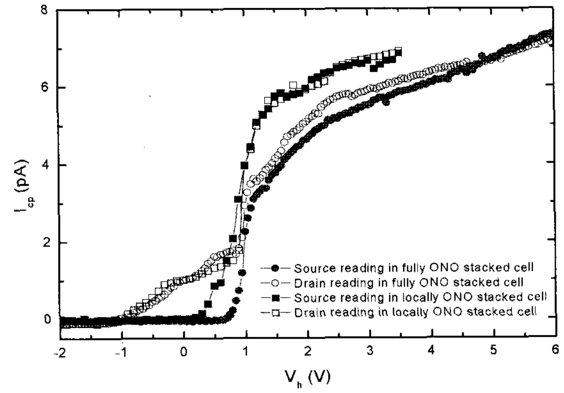

Fig. 5 Single-junction charge pumping currents measured separately from the graded source junction and the abrupt drain junction of the fully ONO stacked cell and the locally ONO stacked cell after band-to-band hot hole erasing at the drain junction.

Figure 6 shows the local V_t distribution of the locally ONO stacked cell and the fully ONO stacked cell at initial, programmed, and erased state.

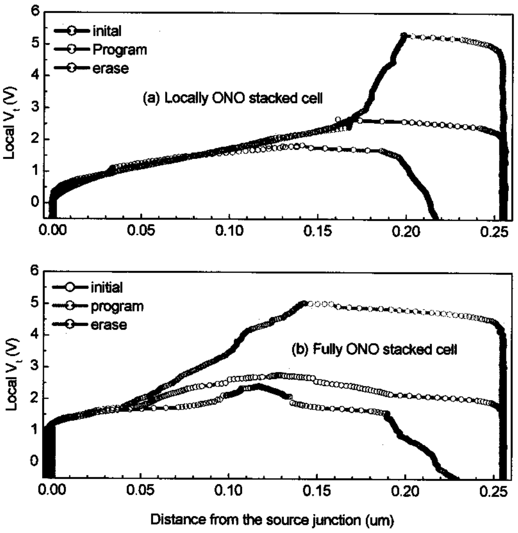

Fig. 6 Lateral profiles of local Vt with distance from source junction at initial, programmed, and erased state for the locally ONO stacked cell and the fully ONO stacked cell.

It is shown that the local V_t at the drain region is higher than one from source junction to channel length of 0.15 um for the locally ONO stacked cell at programmed state, while the programmed local V_t from drain junction to channel center is higher than one at the source region for the fully ONO stacked cell. The local V_t at the drain region is very low at erased state for both cells.

The interface and bulk charges from the obtained charge pumping data can be separated with the assumption that the interface-trap density is spatially uniform along the channel.

The electron distributions trapped into the nitride layer of the locally ONO stacked cell and the fully ONO stacked cell after programming are shown in Fig. 7.

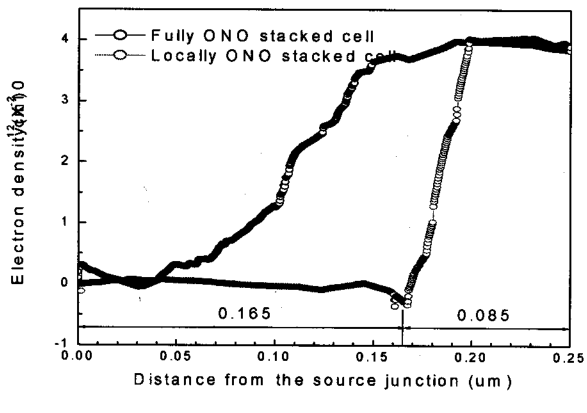

Fig. 7 Trapped electron distributions in the nitride with distance from the source junction at programmed state for the locally ONO stacked cell and the fully ONO stacked cell.

It can be seen that lateral distribution width of injected electrons is limited to length of ONO region in the locally ONO stacked cell, while electrons are spread widely along with channel in the fully ONO stacked cell. The trapped electron charges in the nitride layer are 4×10^{12} cm^{-2}, lateral charge centroid of injected electrons is 0.177 um for the fully ONO stacked cell and 0.217 um for the locally ONO stacked cell.

Figure 8 shows nitride trapped hole distributions of the locally ONO stacked cell and the fully ONO stacked cell after erasing.

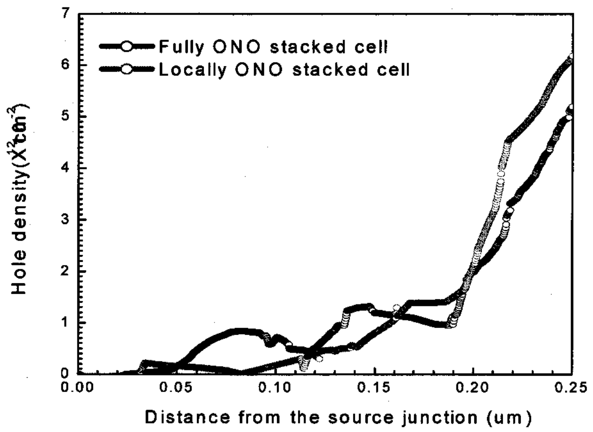

Fig. 8 Trapped hole distributions in the nitride with distance from the source junction at erased state for the locally ONO stacked cell and the fully ONO stacked cell.

It can be seen that hot-holes are injected into not only the ONO stack but also the oxide in the locally ONO stacked cell. Lateral charge centroid of injected holes is 0.194 um for the fully ONO stacked cell and 0.22 um for the locally ONO stacked cell.

V. CONCLUSIONS

We have directly showed the spatial distributions of locally trapped charges in a nitride layer by using single junction charge pumping technique. Injected electrons are limited to length of ONO region in locally ONO stacked cell, while are spread widely along with channel in fully ONO stacked cell. Hot-holes are trapped into the oxide as well as the ONO stack in locally ONO stacked cell.

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Byungcheul Kim
received B.S. degree in Electronic Materials Engineering in 1988 and M.S. and Ph.D. degrees in semiconductor devices in 1990 and 2001, all from Kwangwoon University at Seoul, Korea. From 1990 to 2000, he worked for KEC R&D Center as a senior research engineer. He was a postdoctoral fellow in the BK21 Information Technology at Korea University in 2001. Since september 2001, he has served as an assistant professor in the Department of Electronic Engineering at Jinju National University. His current interests are silicon-oxide-nitride-oxide-silicon nonvolatile memories.