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An Investigation of Light Triggering Effect on the Programming of Gate-less Anti-fuse Cells

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Abstract

This work provides an insight to the light triggering effect in the programming process of Gate-less Anti-fuse (GAF) OTP cell. Programmed by hot electron injection, such process in the GAF OTP is effectively enhanced by light illumination, resulting in a higher read current level. Furthermore, the presence of trigging light and its wavelength during programming is found to also affect the electron de-trapping rate during data retention tests.

1. Introduction

High-density, low-power and versatile functionalities are the key features for integrated circuit elements in portable devices and IOT products [1]. As a consequence of high manufacturing cost and low flexibility of embedded Flash memories [2-3], people are seeking solutions of NVM cells realized by pure CMOS logic technologies. In response, Gate-less Anti-fuse OTP memory structure was proposed in previous studies [4-5]. This gate-less memory structure, consisting of a SiN/SiO_2 structure, enables charge to be stored in a trapping layer independent of gate dielectric layer and critical design rules. This enable the GAF cells to be implement in advanced CMOS technology nodes [6]. Through sub-threshold leakage current induced hot electron injection, electrons can be storage in the SiN layer above the gateless region. The gateless channel, which is below the SiO_2 layer, can be viewed as an optical window, where light penetration into the region affects the programming efficiency of the GAF cell. With the aid of optical illumination, we expect more electrons can be excited and captured by the traps in the SiN layer. In this study, experiments on light illumination effect on the programming characteristics of the GAF cells are performed and measurement results analyzed.

2. GAF Structure and Basic Operation

Illustration of the cross-sectional view of the GAF memory structure is shown in Fig. 1(a). The Resistive-Protective-Oxide (RPO) film is used as the oxide layer in the NO structure, whereas Contact Etching Stop Layer (CESL) serves as the charge storage film. The layout and SEM picture of the gate-less channel in the GAF memory cell are shown in Fig. 1(b) and Fig. 1(c), respectively. The two states of the memory cell obtained by whether there are electrons stored in the SiN film (see the insets in Fig. 2), resulting in different read current level, as demonstrated in the Fig. 2. When light is illuminated, photons is expected to penetrate through the light window, reaching the gate-less channel. For a cell in its fresh state, the initial read current is expected to be affected by the triggering light, see Fig. 3(a). The increase in sub-threshold current can also be induced by raising ambient temperature, as summarized in Fig. 3(b).

When the select transistor (SG) is turned on, and the drain voltage is high enough, sub-threshold leakage under the gate-less channel can induced hot electron injection. The electron injection point starts from the drain side and gradually shifts to the source side, which then progressively turn on the channel. Fig.4 compares the time-to-program characteristics under different select gate and drain voltage, respectively. the measured data suggests a read current of as high as 10μA can be obtained. Table I summarizes the operation conditions of the GAF memory cell.

3. Light Triggering Effect on Programming

The amount of electrons stored in the storage node can be controlled by program time. In order to investigate the effect of light triggering on programming, three programmed states A, B, and C as defined by its read current levels, see in Fig. 5 (a). The corresponding read current characteristics of cells in the three states are compared in Fig. 5(b). Starting at fresh state, the time-to-program characteristics under different triggering light are compared in Fig. 6. Details with respect to the light source are listed in Table II. Measured data reveal that programming speed can be significantly enhanced with illumination. Programming conditions to the three states, and the result is shown in Fig 7. From the measured data, we observed that the effect of light triggering effect on programming is most prominent as it starts from state C, i.e. larger portion of the channel is on. Fig.8 compares the read current distribution after a single programming pulse of -6V and a pulse width of 0.1μs and that after ten consecutive program pulses at dark and under illumination. Significant light triggering effect can exceed cell-to-cell variations.

Fig. 9 shows the read disturb of the GAF memory cell in its fresh and programmed states under different wavelengths of trigger lights. The read disturbance is reduced when memory cell is read under light at both states. Fig. 10 reveals data retention of the GAF cell programmed under light source. Slightly lower electron discharging rate is found in cell programmed under blue light, as compared with that programmed at dark.

4. Conclusions

Higher programmed state can be achieved in Gate-less Anti-fuse memory cell by illuminating light onto the storage node. This light triggered programming can also lower the program operation voltage of the memory cell as well as providing a better data retention. Furthermore, the memory cell is more resilient to read disturbance when it is operating under illumination of light.

Acknowledgement

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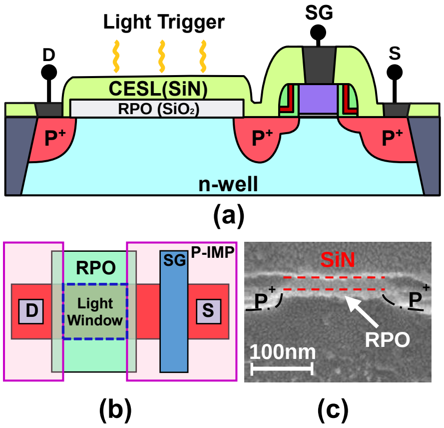

Fig. 1(a) Illustration of the cross-section of gateless-anti-fuse memory cell. (b) layout of the memory cell. (c) The SEM picture of the gateless storage node.

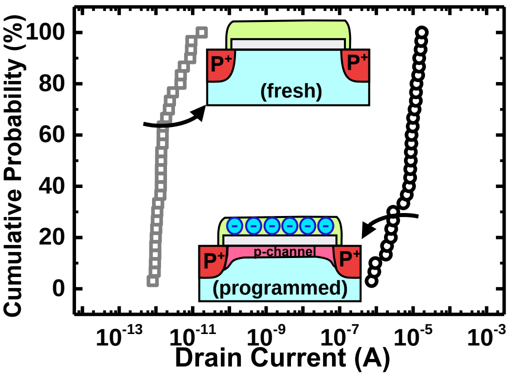

Fig. 2 Read current distribution of a fresh cell, without electrons in SiN layer, and that of cells in their programmed state, with electrons trapped in the SiN layer.

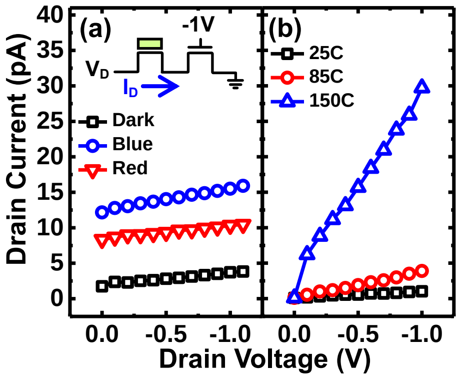

Fig. 3 Initial read current characteristics (a) that measured at dark and under the excitation of triggering lights and (b) that at different temperature.

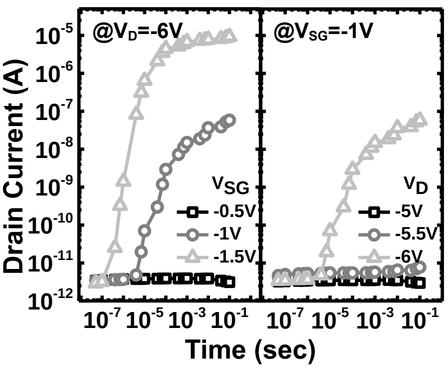

Fig. 4 Time to program. Characteristics under different V_{SG}, V_D. Program can be complete within 100μsec

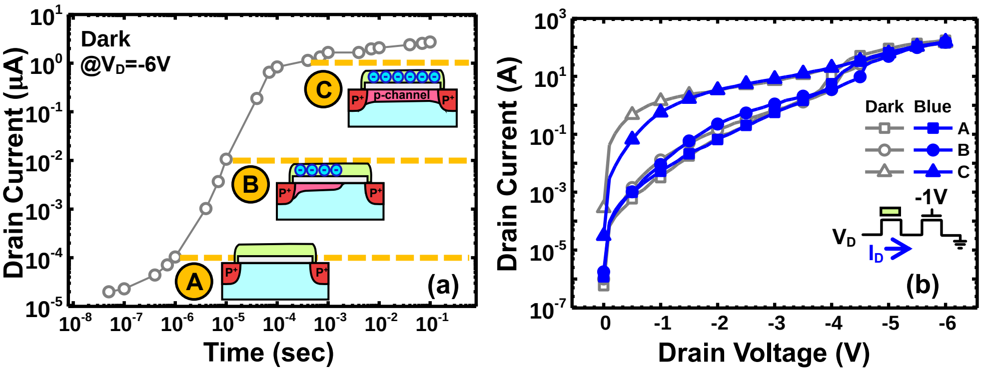

Fig.5 (a) Different states of programming levels. (b) Read current vs V_D at different stages of p-channel gate-less transistor. As the channel extends from left to right gradually at different programming states, its V_D dependence changes, as expected.

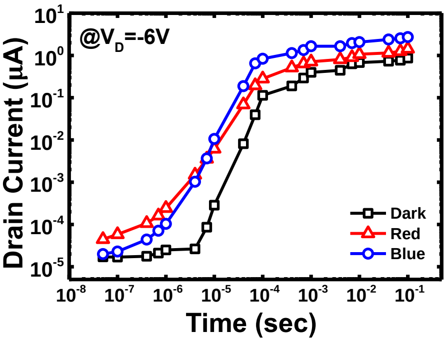

Fig. 6 Time to program under different triggering light suggested that initial leakage current can affect programming speed of this gate-less transistor.

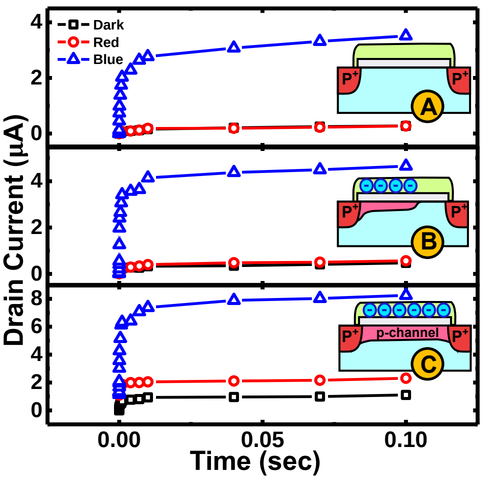

Fig. 7 Time to program characteristics from A, B, C states under triggering lights of different wavelength.

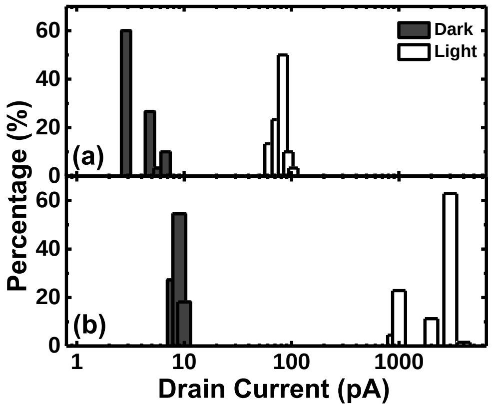

Fig. 8 Read current distribution after (a) 1 programming pulse of 0.1μsec and (b) that after 10 pulses, resulting in large difference.

Table I Program and Read Conditions

	V_{SG}	V_D
program	-1V	-6V
read	-1V	-1V

Table II List of Parameters for the Triggering Lights

	λ (um)	Intensity (#/cm²· s)
blue	450	$7.6x10^{15}$
red	650	$4.5x10^{12}$

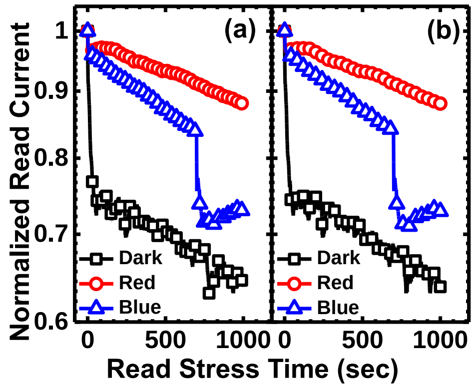

Fig. 9 Read disturbance tests performed (a) at dark and (b) under different type of light source. Data suggest triggering light enhance read stress immunity.

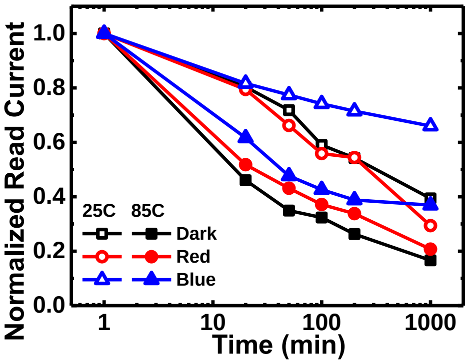

Fig. 10 Electron discharging on cells programmed under different triggering lights. Short wavelength light seems to promote trapping to deeper states for cells in the programmed states, leading to less charge lost.