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Charge Localization During Program and Retention in NROM-like Nonvolatile Memory Devices

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1. Introduction

An alternative solution to standard Flash memories is represented by nitride-trap memories as SONOS or NROM memories. NROM in particular can be operated in 2-bit/cell mode using localized trapping in Si_3N_4 film [1]. Therefore it can comply with the increasing demand of bit density. However these structures are facing retention issues at high temperature and a quantitative analysis of the charge distribution during program and retention is required.

Various techniques have been employed to deduce the distribution of trapped charges injected by channel hot electrons in the Oxide/Nitride/Oxide stack (ONO) of standard NROM devices. Among them we find charge pumping technique [2], GIDL and substhreshold slope monitoring [3], or analyses based on the surface potential model [4] and the measure of reverse/forward programming windows ($\Delta V_tR/\Delta V_tF$; Fig. 1). In this work the method described in [4] will be used on experimental data in order to evaluate the trapped charge distribution in program and retention conditions. The lateral migration (i.e. inside the trapping layer) and vertical migration (i.e. charge loss) of the trapped charges during retention will be quantitatively evaluated. Other trapping layers such as Al_2O_3 and HfO_2 are also investigated.

2. Samples Description and Methodology

The devices under analysis are presented on Fig.2. The gate stack is composed by 5 nm tunnel SiO2 plus 6 nm charge trapping layers: Si_3N_4 deposited by LPCVD or HfO_2 or Al_2O_3 deposited by ALCVD at 350°C. Then, a 10 nm thick High Temperature Oxide (HTO) is deposited as top oxide plus N+ Si-poly gate. After gate etching, standard processing steps include NiSi silicidation. Using the method presented in [4], the charge density $Q_{density}$ and the effective charged length $L_{charged}$ are extracted (Fig.3), based on ΔV_tR and ΔV_tF measured during program and retention.

3. Results and Discussions

Programming dynamics - Fig. 4 shows that the programming dynamics are dependent on the trapping layers and this even for short programming pulses, as shown in [6]. However, as shown in Fig. 5 the location of the charge is independent of the material: indeed $L_{charged}$ is equal to 40 nm for $Q_{density}$ smaller than 10^{13} cm^{-2} (stress time of the order of 0.01 s). This can be explained by the fact that all devices have the same junction profile thus they have identical injection efficiency of accelerated carriers by the electric field [3]. Then when $Q_{density}$ reaches $1.4x10^{13}$ cm^{-2} (stress time over 0.01 s), ΔV_tR continue to increase (Fig. 4) due to the increase of $L_{charged}$ (Fig. 5). Seemingly the traps over drain junction becomes saturated, thus newly injected charges can redistribute in the trapping layer farther from the junction. We conclude that the charge distribution behavior during programming is similar for the three materials, even if the device with Si_3N_4 shows the best capture efficiency during the programming dynamics.

Retention and model - Fig. 7 shows data retention characteristics of devices at 25°C and 125°C. In Fig. 8, the extraction of $Q_{density}$ and $L_{charged}$ shows that the ΔV_tR shift is only due to the lateral charge migration at low temperature (excepted for Al_2O_3 at 125°C, where the vertical charge loss is the dominant mechanism). We stress that at high temperature (200°C) ΔVtR decreases mainly because of vertical electron loss (not shown here). To simulate the lateral migration of the trapped charges the numerical resolution of 1D Drift-Diffusion system is adopted (Fig. 9-10). From Fig. 11 we notice that the diffusion process is negligible with respect to drift, and the drift of charged particles is found equal to $L_{charged}=L_{charged0}+A\ln(t)$ (Fig. 11) with A linearly dependent with $\mu_{eff}Q_{total}/\varepsilon_i\varepsilon_0$ and independent of the shape of the injected charge. μ_{eff} corresponds to an effective mobility that includes the trap/detrap process plus the drift in the conduction band [7]. Fig. 12 quantifies the lateral migration of trapped charges $L_{charged}$ for Al_2O_3, HfO_2 and Si_3N_4. The lateral migration follows a logarithmic law and the lowest drift is observed for Si_3N_4.

4. Conclusions

In this paper, we have quantified the localization of the charges during programming and retention in NROM-like devices, based on experimental measurements (in particular of ΔV_tR and ΔV_tF) and a surface potential model [4]. It appears that during programming the charge is injected on a 40nm-length region in the trapping layer, with a charge density up to $1.4x10^{13}$ cm^{-2}. Then the injected charge density saturates and the trapped charge region broadens. During retention, the lateral migration of the charge appears to be the dominant mechanism of the V_t shift at room temperature. We have been able to quantify this shift based on a 1D drift model (diffusion being negligible).

References

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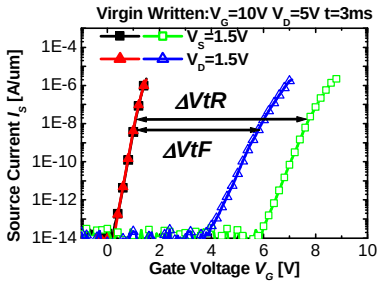

Fig. 1: ΔV_tR (ΔV_tF) is the programming window in reverse (forward) read condition.

	D1	D2	D3
Tunnel Oxide	SiO_2 5nm		
Trapping layer	Si_3N_4 6nm	HfO_2 6nm	Al_2O_3 6nm
Top Oxide	HTO 10nm		

Fig. 2: Devices under analysis. The devices are 10 µm large and 350 nm long.

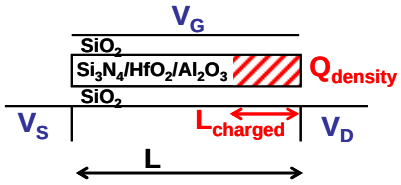

Fig. 3: $Q_{density}$ and $L_{charged}$ as described in [4]. The total charge trapped in the stack is equal to $Q_{density}$ x $L_{charged}$.

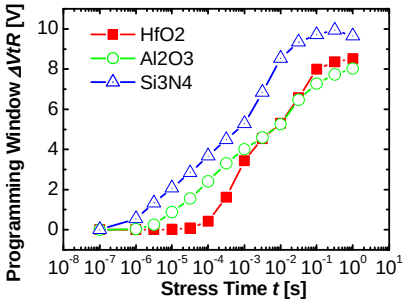

Fig. 4: ΔV_tR dynamics as a function of stress time for virgin devices. Stress parameters V_G=10 V, V_D=5 V, V_S=V_B=0 V.

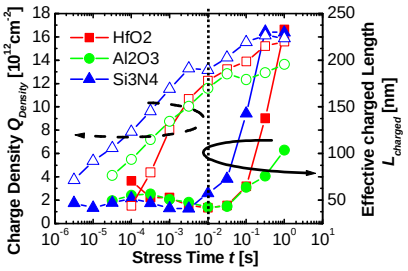

Fig. 5: Extracted $Q_{density}$ and $L_{charged}$ as a function of time from the dynamics of Fig. 4.

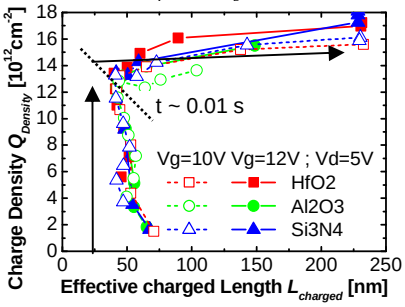

Fig. 6: $Q_{density}$ as a function of $L_{charged}$ extracted from the dynamics of Fig. 4. V_G=10 V & 12 V, V_D=5V, V_S=V_B=0V.

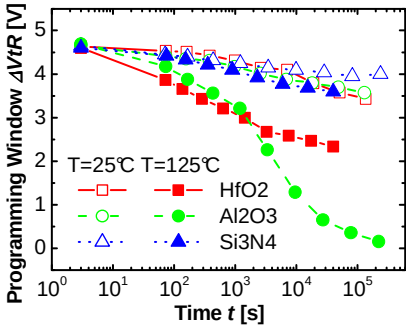

Fig 7: ΔV_tR evolution at 25°C and 125°C during retention for Si_3N_4, Al_2O_3 and HfO_2 trapping layers.

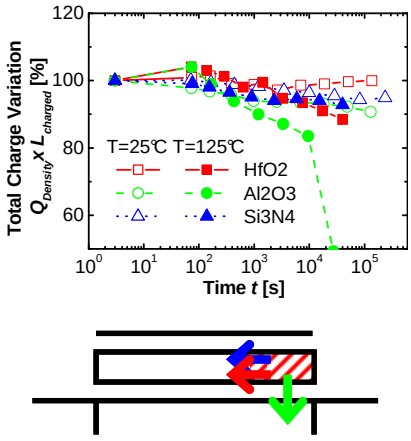

Fig. 8: Total charge variation in the trapping layer $Q_{density}$ x $L_{charged}$ extracted during retention (Fig. 7) at 25°C and125°C.

Drift-Diffusion equations

$$\begin{cases} \frac{\partial n(x,t)}{\partial t} = \frac{\partial}{\partial x}\left[\mu_{eff} n(x,t) E(x,t)\right] + D\frac{\partial^2 n(x,t)}{\partial x^2} \\ \frac{\partial E(x,t)}{\partial x} = \frac{q n(x,t)}{\varepsilon_r \varepsilon_0} \end{cases}$$

Diffusion equation μ_{eff}=0

$$\frac{\partial n(x,t)}{\partial t} = D\frac{\partial^2 n(x,t)}{\partial x^2}$$

Drift equation D=0

$$\frac{\partial n(x,t)}{\partial t} = A^* \frac{\partial}{\partial x}\left[n(x,t) \frac{\int_0^x n(x,t)dx}{\int_0^\infty n(x,t)dx} \right]$$

where $A^* = \frac{\mu_{eff} q \int_0^\infty n(x,t)dx}{\varepsilon_r \varepsilon_0} = \frac{\mu_{eff} Q_{total}}{\varepsilon_r \varepsilon_0}$

Fig. 9: 1D Drift-Diffusion equation and approximations to a perfect diffusion or drift process.

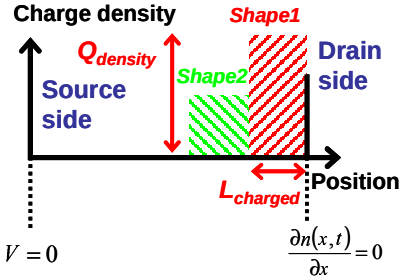

Fig.10: Explanation of 1D model used to model the lateral migration of the charge. Shapes 1 & 2 are used as initial conditions for simulations of Fig. 11.

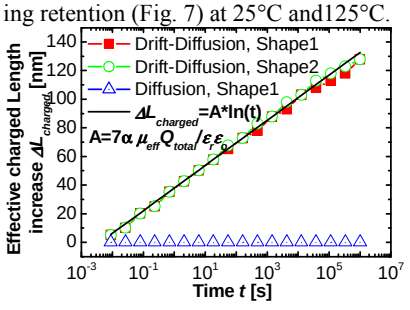

Fig. 11: Numerical resolution of the 1D Drift-Diffusion equations. To note that we obtain a perfect fit with a law equal to $L_{charged}$=$L_{charged0}$+$A\ln(t)$

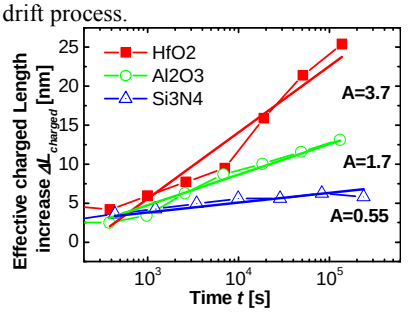

Fig. 12: $L_{charged}$ extracted during retention (Fig. 7) at 25°C for Si_3N_4, Al_2O_3 and HfO_2 trapping layers. A is in nm/s.