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# Lateral Redistribution and Interactive Impacts of Localized Trapped Charges during Retention Baking in SONOS Memory

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## 1. Introduction

SONOS type memory has shown numerous merits such as better scalability, high density, and simple process technology; however, whose reliability remains an unsolved problem. Due to the localized charge trapping characteristic of Channel Hot Electron (CHE) program and Band-to-Band Hot Holes erase, the injected electrons and holes have different distribution. The mismatch may cause charge accumulation after program/erase (P/E) cycling, thus result in the degradation of endurance behavior and affect the data retention as well [1, 2]. It's also found that the localized trapped charges will redistribute due to the thermal emission, and affect the retention capability of the SONOS devices. Some models are then proposed to describe the degradation behavior during baking [2-4]. However, the present models only concern the thermal emission of the trapped charges and investigate their effects on $V_T$, but not obtaining the lateral charge migration. In this paper, a charge redistribution based degradation model is proposed by investigating the retention characteristics of both electrons and holes. Furthermore, the interactive impact between the two kinds of charges in a post-cycled device is also studied.

## 2. Analysis and Model

The CHE and BBHH operations form a localized Gaussian distribution of trapped charges $n_{tr}(x)$ in SONOS cells. The de-trapping of the injected charges happens during baking, which is related with the charge activation energy. The emitted charges n(x) will diffuse caused by the concentration gradient $\Delta n(x)$, and drift along the channel under the influence of the internal electric field due to the $\Delta n_{tr}(x)$, therefore resulting in the lateral redistribution. Fig. 1 illustrates the distribution and redistribution model of the trapped charges. It can be deduced that the migration has a linear dependence with the logarithm of baking time. Moreover, the electrons and holes show different retention behaviors because of their different activation energy and emission cross-section.

## 3. Results and Discussions

The SONOS memory device used in experiments has 0.18 μm $L_{g,drawn}$ ($L_{g\text{-}eff}$ is 0.15 μm) and 14 nm (EOT) ONO layer. A Charge Pumping measurement, which combines both the $CV_b$ and $CV_h$ methods [5], is utilized to extract the lateral profile of the trapped charges.

Fig.2 is the charge pumping current ($I_{CP}$) results of an erased cell at 125 ºC baking, and the calculated distribution of the trapped holes is drawn in Fig. 3. It is found that trapped holes easily redistribute at the initial stage of baking due to its shallow trap energy depth [6]. Nevertheless, the trap-assistant tunneling leads to the charge loss in longer term retention degradation. Fig. 4 compares the charge quantity ($Q_{tr}$) and peak value of charge density ($N_{trm}$) of holes as the function of baking time, where the constant $Q_{tr}$ and linear log (t)-dependent $N_{trm}$ reflect the redistribution process.

Electrons retention characteristic in a programmed cell is also studied, with the $I_{CP}$ curves and the derived distribution profile baking at 125 ºC shown in Fig 5 (a) and (b), respectively. Compared to holes, the migration of trapped electrons is much slighter owing to its higher activation energy. In contrast, the direct tunneling plays a dominating role in the data degradation due to smaller effective mass of electrons.

Different degradation behavior is observed in the cycling induced charge accumulated device in programmed state. Electrons loss can be seen from the $I_{CP}$ results in $CV_h$ method in Fig.6, reflecting the rapid decrease of $V_T$ in the inserted $I_d$-$V_g$ curves. This can be explained by the interactive impact of electrons and holes, as schematically demonstrated in Fig. 7. After numbers of P/E cycling, the two types of charges accumulate at different positions, which enlarges the lateral electric field along the channel and accelerates the drift and redistribution of the holes and electrons. The migrated holes may recombine with the excited-state electrons, therefore deteriorate the electron loss and $V_T$ degradation.

From above discussions, the enhancement of the trap energy level to suppress the holes lateral redistribution, and the fabrication of high quality tunneling oxide to avoid the electrons leakage, are two ways to improve the data retention of SONOS memory.

## 4. Conclusions

In this paper, a degradation model featuring the lateral redistribution mechanism of trapped charges during retention baking is proposed. The degradation behavior of the trapped holes and electrons is found to be dominated by lateral redistribution and tunneling, respectively. However, the recombination due to the migration of localized accumulated charges is the root cause of the electron loss and $V_T$ degradation in a cycled device during retention baking.

## Acknowledgements

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## References

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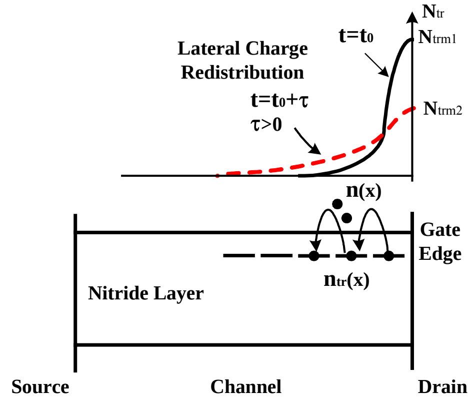


Fig. 1. Schematic demonstration of retention degradation model in SONOS devices.

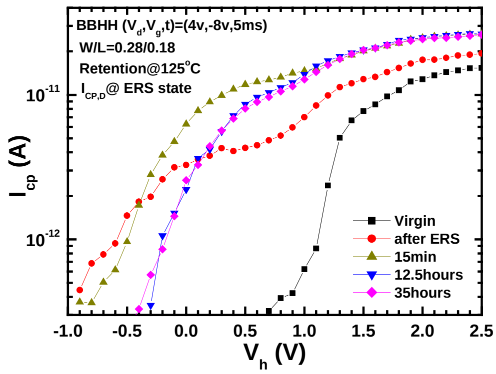


Fig.2. $I_{CP}$ results using $CV_b$ method of trapped holes of an erased cell baking for 15min, 2.5hours, 25hours and 35hours at 125 ºC.

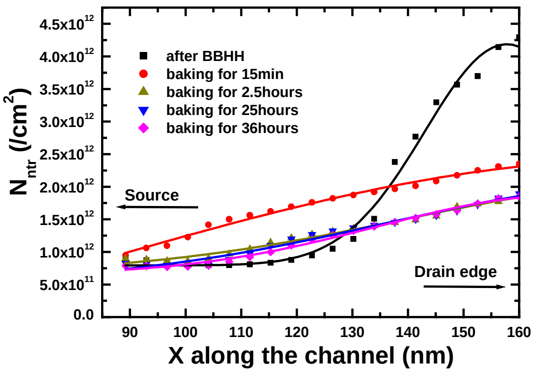


Fig.3. The profile of trapped holes distribution calculated from $I_{CP}$ results in Fig. 2.

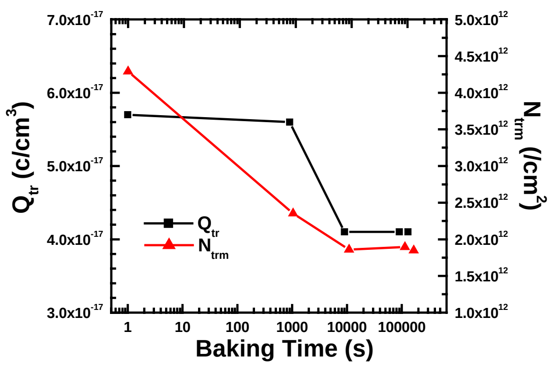


Fig. 4. $Q_{tr}$ and $N_{trm}$ of holes, calculated from Fig.3 as the function of baking time in semi-log scale.

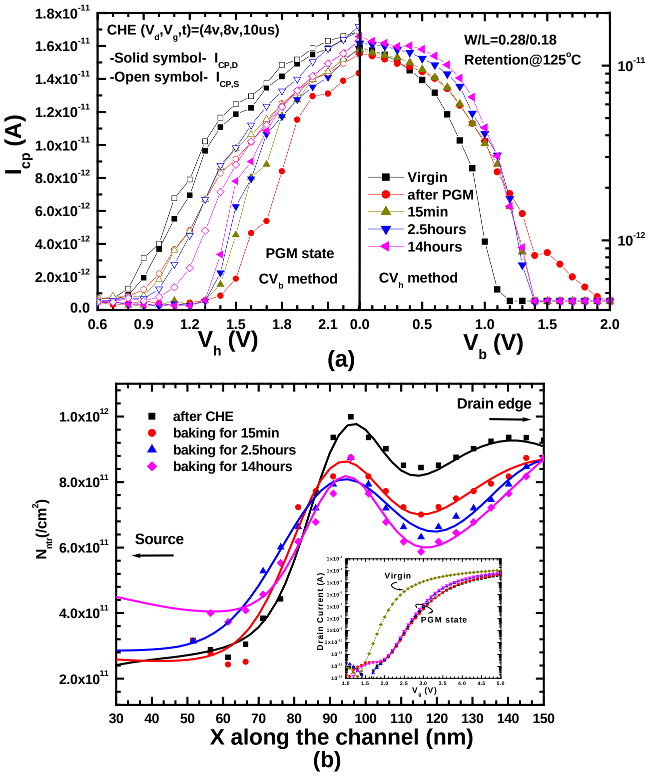


Fig.5. (a) $I_{CP}$ results and (b) the charge distribution profile with $I_d$-$V_g$ currents inserted of a programmed cell baking for 15min, 2.5hours and 14hours at 125 ºC.

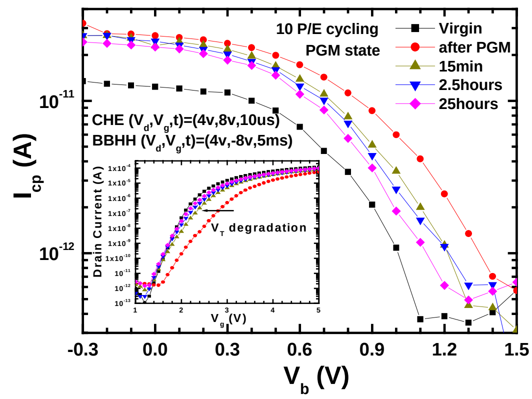


Fig.6. $I_{CP}$ of a cycled device in programmed state at 125 ºC baking. Inserted graph is the $I_d$-$V_g$ currents showing a rapid decrease of $V_T$.

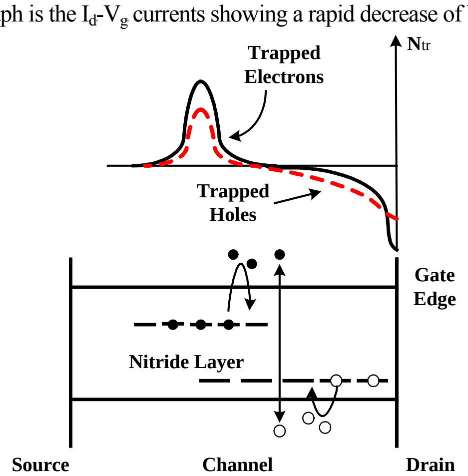


Fig.7. Demonstration of interactive influence between electrons and holes in a cycling induced charge accumulated device during baking.