Investigation of Drain Disturb in SONOS Flash EEPROMs

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Abstract—The mechanism of drain disturb is studied in silicon–oxide–nitride–oxide–silicon Flash electrically erasable programmable read-only memory cells. It is shown that disturb is a serious problem in programmed cells and is caused by injection of hot holes from substrate into the oxide/nitride/oxide stack. The origin of these holes is identified by analyzing the influence of halo doping, channel doping, and channel length scaling on drain disturb. Band-to-band tunneling at the drain junction is normally the dominant source of these holes. It is also shown that holes generated out of impact ionization of channel electrons become dominant in cells with high channel leakage (especially at lower channel lengths). Finally, the effect of repeated program/erase cycling on drain disturb is studied. Drain disturb becomes less severe with cycling, the reasons for which are determined using gate-induced drain leakage measurements and device simulations.

Index Terms—Band-to-band tunneling (BTBT), charge pumping (CP), drain disturb, Flash electrically erasable programmable read-only memories (EEPROMs), gate-induced drain leakage (GIDL), hot holes, silicon–oxide–nitride–oxide–silicon (SONOS).

I. INTRODUCTION

FLOATING-GATE (FG) Flash electrically erasable programmable read-only memory (EEPROM), which has been the primary nonvolatile semiconductor memory for a long time is stated to reach its scaling limitations in a few years [1]. Among the various alternative nonvolatile memories that are being explored, silicon–oxide–nitride–oxide–silicon (SONOS)-type (e.g., NROM) nitride-based charge-trapping memories come closest to replacing FG EEPROMs in the future generations [1]–[4]. In addition to being more scalable than FG EEPROMs, they require fewer masking steps to integrate with core logic, thereby making them attractive for embedded applications as well [2], [3]. When operated using localized charge injection mechanisms (NOR applications) for program and erase, they provide low-voltage operation and also offer multibit-per-cell storage capability through spatial separation of trapped charges [2]–[4]. However, SONOS Flash cells operated

under localized charge injection suffer from program/erase (P/E) cycling endurance and data retention problems, and much work has been done in the past to understand and improve these reliability issues [4]–[7]. This paper shows that in addition to endurance and retention, drain disturb can also become a serious issue for such modes of operation and must be considered for reliable design of memory cells. The mechanism behind drain disturb is established and its dependence on cell doping, program bias, and P/E cycling is discussed. This is an enhanced version of our earlier work [8] and the study of drain disturb in P/E-cycled cells is presented in addition.

Drain disturb or drain stress occurs in gate unselected cells of a NOR Flash array that share the bit line of a cell being programmed using hot-carrier injection [9]. FG EEPROMs suffer from disturb in both programmed and erased states due to charge loss and charge gain, respectively [10]. But drain disturb in SONOS cells is found to be serious only in programmed state, which leads to a continuous drop in threshold voltage (V_{TH}). Although the result is similar to retention loss caused by redistribution and decay of charges in the top-oxide/nitride/bottom-oxide (ONO) stack [5]–[7], [11], drain disturb is found to involve hole injection from Si substrate into the ONO stack. The sources of these holes are determined by studying the effect of channel length, channel doping and bias on disturb. P/E cycling is seen to reduce drain disturb, the reasons for which are also explored.

The details of the devices, measurements, and simulations used in this paper are presented in Section II. Section III-A discusses the effect of drain disturb on the cell V_{TH} and its dependence on drain bias. The mechanism behind drain disturb is established in Section III-B by studying the effect of channel length, doping, and substrate bias on disturb. The effect of P/E cycling on disturb is discussed in Section III-C. Conclusions are presented in Section IV.

II. DEVICE, MEASUREMENT, AND SIMULATION DETAILS

Measurements were performed on isolated stack-gate SONOS cells with ONO thickness of 5.8/8/5 nm, width of 2 μm , and drawn gate lengths (L) of 0.25 and 0.35 μm . To study the effect of doping on drain disturb, cells with additional implants (halo and channel compensation) were used. Fig. 1 shows the schematic of the cell along with different doping implants. Channel compensation implants used in this paper reduce the natural V_{TH} of the cell, and as well reduce the programming speed under channel-hot-electron (CHE) injection (due to lower fields at drain junction). Halo implants increase

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Fig. 1. Schematic of SONOS cells used in this paper, showing different implants (details in Table I). The ONO dimensions are 5.8/8/5 nm and the gate stack length is 250 nm (unless mentioned otherwise).

TABLE I

DOPING DETAILS OF THE SONOS CELLS USED FOR MEASUREMENTS ALONG WITH TYPICAL NATURAL V_{TH} VALUES AND PROGRAM TIMES. PROGRAM TIME (T_P) WAS MEASURED FOR A CONSTANT V_{TH} SHIFT (~ 2.5 V) FROM VIRGIN V_{TH} , AT A FIXED PROGRAM BIAS 8/5/0 V

Device	Channel Implant	Halo Implant	Natural V_{TH} (V)	Typical T_P (μ s)
Normal	B	–	2.5	~ 20
Compensated	B, BF ₂ , As	–	0.9	~ 100
Halo	B	B	3.2	~ 7

the programming speed under CHE injection (higher fields at drain junction) as well as the natural V_{TH} of the cell. Table I lists the different implants used, along with corresponding V_{TH} values. Most of the experiments were done on normal cells (no compensation, no halo) unless mentioned otherwise.

Programming was done using CHE injection at a bias ($V_G/V_D/V_B$) of 8/5/0 V. Erase was done through injection of hot holes at a bias of $-8/5/0$, unless mentioned otherwise. These holes are generated by band-to-band tunneling (BTBT) in the drain region and are heated by the lateral field in drain-substrate junction before injection [12]. Drain disturb measurements were done by grounding the gate terminal and maintaining other terminals at same bias as during program. I_D-V_G measurements were taken in reverse read mode by interchanging source and drain terminals during read [2]. V_{TH} was determined from I_D-V_G using constant current definition ($I_D = 8 \mu A$ at $V_D = 0.1$ V). Charge-pumping (CP) measurements were done using fixed base ($V_{BASE} = -4.6$ V) and varying top (V_{TOP} up to $+4.6$ V) gate pulse having frequency of 400 kHz. Gate-induced drain leakage (GIDL) measurements [13] were done at V_D of 2 V, which is high enough to give reasonable I_{GIDL} but low enough not to disturb the cell V_{TH} . I_D-V_G measurements were taken at regular time intervals during program, erase and disturb, while CP and GIDL measurements were done at the start and end of program, erase and disturb.

Well-calibrated ISE-TCAD tools DIOS and DESSIS [14] were used for process and device simulations, respectively. A nonself-consistent full-band Monte Carlo simulator [15] was used for simulating hot carrier distributions in silicon. The phonon and impact ionization scattering parameters were adjusted to obtain good match with experimental and simulated substrate and gate currents. The device potentials used in Monte Carlo simulations were obtained from DESSIS.

Fig. 2. Measured V_{TH} shift (with respect to virgin V_{TH}) in a SONOS cell during program, erase and program state drain disturb conditions. No drain disturb was observed in erase state in the time scale shown here. Erase and disturb measurements were done on two different cells programmed to same program V_{TH} .

III. RESULTS AND DISCUSSION

A. Identification of Disturb Mechanism

Fig. 2 shows the experimental program, erase and drain disturb (referred to as disturb from now) transients of a SONOS cell. The erased V_{TH} is the same as the virgin cell V_{TH} and programmed state was fixed at a V_{TH} of 2 V above virgin V_{TH} . A huge drop of V_{TH} is observed under disturb condition in a programmed cell, while erased cell does not show any significant change of V_{TH} in the same time scale (not shown). This clearly shows that drain disturb can be a serious problem in programmed cells. In a localized CHE programmed SONOS cell, electrons trapped near the drain side of ONO stack are responsible for increasing the V_{TH} (local high V_{TH} determines the overall cell V_{TH}). Therefore, the decrease in V_{TH} during disturb can occur due to redistribution of these trapped electrons in ONO, their escape from ONO (similar to that of retention loss [11]), or injection of holes into the ONO stack (similar to that of erase) and needs to be resolved.

Fig. 3 shows measured V_{TH} drop during disturb as a function of drain bias. V_{TH} drop increases at higher V_D as shown and this drop is monotonous with time for all V_D . These observations rule out vertical or lateral charge redistribution in ONO to be the major cause behind disturb, as explained below. In these programmed cells, the lateral spread of trapped electrons was found to be 40–50 nm, of which about 30–40 nm is above channel region and the rest in gate-drain overlap region [16]. The peak of this distribution is near the gate edge and the magnitude gradually decreases toward center of the channel. The cell V_{TH} is mainly determined by electrons trapped above the channel region. Vertical movement of these electrons away from the Si/SiO₂ interface or a decrease in their peak concentration due to their lateral redistribution (toward center of the channel) can reduce V_{TH} . Increasing V_D is unlikely to accelerate movement of electrons in either of these modes that result in a monotonous V_{TH} drop. Hence, redistribution of trapped electrons in ONO cannot be the main cause behind drain disturb.

Fig. 3. Measured drain disturb transients of a programmed SONOS cell at different disturb V_D . Drain disturb was measured on different cells programmed to the same level and the V_{TH} shift shown is with respect to the program-state V_{TH} .

Under disturb condition, a programmed cell is in OFF state and changing V_D mainly affects the fields in drain-substrate junction and gate-drain overlap region. Therefore, disturb mechanism should be accelerated by fields in these regions, which makes hot-hole injection into the ONO stack a likely cause for disturb. Due to absence of drain coupling in SONOS cells, V_D does not have much control over vertical fields in ONO above the channel region. Furthermore, electron ejection from drain-gate overlap region cannot lead to significant V_{TH} shifts. The mechanism of hot-hole generation under disturb condition could be similar to that in erase, except for a lower vertical field in drain-gate overlap region as the gate is unselected. This is explored next by comparing disturb with erase.

To compare disturb and erase, the distributions of hot holes generated by BTBT under these conditions were simulated using a Monte Carlo simulator. A programmed cell with charge (equivalent to the ONO trapped charge) placed at the Si/SiO₂ interface was used for these simulations [16]. Fig. 4 compares the lateral profiles of channel hot-hole density and transverse electric field along channel in a programmed SONOS cell under erase and disturb conditions. The profiles of hot-hole distribution and vertical field during disturb are similar to erase, although with lower magnitudes, suggesting injection of BTBT generated holes as a possible cause for disturb.

CP [16]–[18] is used to verify hole injection and any resultant generation of interface traps (N_{IT}) after disturb and erase. Fig. 5 compares CP current (I_{CP}) measured using fixed base and varying top method in SONOS cells after erase and disturb. For this, two identically programmed cells were separately subjected to erase and disturb (a longer disturb time was used to get similar V_{TH} shift as in erase). I_{CP} before and after programming (similar for both these cells) is also shown for comparison. A large increase in I_{CP} (due to N_{IT} generation) is seen after erasing the cell. It is well known that hole injection in MOSFET causes N_{IT} generation [19]–[21] and the increased I_{CP} after erase reflects this. A similar large I_{CP} increase is also seen after drain disturb (longer time) suggesting hole injection during disturb too. Moreover, note that the rising edge of I_{CP} – V_{TOP} curve shifts to lower V_{TOP} value after disturb

Fig. 4. Simulated profiles of normal electric field and channel hot-hole concentration (Monte Carlo simulated) across the channel in a programmed SONOS cell under erase and drain disturb conditions. To simulate the program state, charge equivalent to the program trapped charge is placed at Si/SiO₂ interface [16].

Fig. 5. I_{CP} of SONOS cells measured using a gate pulse with a fixed base and varying top. I_{CP} characteristics after drain disturb and erase (in two different cells programmed to same V_{TH} level) are shown along with virgin and programmed cell characteristics. A longer disturb time was used to get similar V_{TH} shift as in erase.

and erase compared to the virgin/programmed cells. This is due to reduced local V_{TH} after erase/disturb as compared to virgin/programmed cells. It can be reasonably assumed that erase and disturb do not significantly alter V_{TH} and V_{FB} profiles near the source and center of channel. The reduction in V_{TH} , therefore, occurs near the drain region and indicates hole injection in that region. Loss of electrons (those injected during program) cannot be the dominant cause for this shift in I_{CP} – V_{TOP} curve as that would never shift the rising edge of postdisturb or posterase I_{CP} curve beyond the virgin curve. The much larger shift of the rising edge after erase compared to that after disturb indicates a larger reduction in the local V_{TH} after erase due differences in injected hot-hole profiles.

Fig. 6. GIDL currents in a SONOS cell measured before and after drain disturb in a programmed state. The GIDL current before programming (initial) is also shown for comparison. GIDL curve gradually shifts to the left during disturb and even shifts beyond the initial (preprogram) curve for sufficiently large disturb like the one shown here.

As a further confirmation for hole injection during disturb, Fig. 6 compares the measured GIDL characteristics before and after disturb in a programmed cell. Unlike V_{TH} , GIDL current (I_{GIDL}) is very sensitive to the charges in gate-drain overlap region, as it is exponentially dependent on vertical field in that region [22]. GIDL curve shifts toward more positive V_G (larger I_{GIDL} at a given V_G) after programming due to electron injection into the ONO above overlap. During disturb, GIDL curve gradually shifts back toward more negative V_G indicating a decrease in negative charges in the overlap region. However, the shift of postdisturb (after sufficiently long disturb time) GIDL curve beyond the initial curve indicates hole injection during disturb, as only electron ejection would bring the postdisturb GIDL curve close to (not beyond) the initial curve.

B. Impact of Device Structure and Doping

The above results clearly show that hole injection into ONO stack is the key cause for drain disturb in a programmed SONOS cell. Similar to erase, disturb involves BTBT at the drain junction, heating up of resultant holes in the junction lateral fields, and their subsequent injection into the ONO stack. Under disturb condition, trapped electrons in ONO together with V_D can provide the necessary vertical fields in the gate-drain overlap region for BTBT and hole injection. To verify this further, the dependence of drain disturb on channel length (L), channel doping, and halo implants is studied next. BTBT is independent of L , but depends on both channel doping and halo implants, which change the fields in the drain-substrate junction. The fields are lower in the presence of compensation, leading to reduction in hot holes (less heating). On the other hand, halo implants increase these local fields resulting in larger heating.

Fig. 7 shows the V_{TH} shift as a function of time, measured in cells with and without halo doping (no compensation) under disturb condition at different V_D . The presence of halo increases disturb as expected (larger field and BTBT), which agrees well with hot-hole injection being the dominant cause

Fig. 7. Drain disturb transients measured at different V_D in SONOS cells with and without halo implants. The V_{TH} shift shown is with respect to the program-state V_{TH} . Before taking the disturb measurements, the cells were programmed for a V_{TH} shift of 2 V from virgin state.

Fig. 8. V_{TH} shift under drain disturb (for fixed time) in SONOS cells with and without compensation implant at different L . The cells were programmed for a V_{TH} shift of 2 V from virgin state, before measuring disturb.

of disturb in SONOS cells. Fig. 8 shows the V_{TH} shift under drain disturb (for fixed time) as a function of V_D in SONOS cells of different L , with and without compensation implants. Disturb increases at higher V_D for all L and for both normal and compensated cells. Normal cells show weak dependence of disturb on L (for all V_D) as BTBT is weakly dependent on L . However, compensated cells show a large increase in disturb as L is reduced, contrary to expectation. For the present case, channel compensation influences disturb only slightly in $L = 0.35 \mu\text{m}$ cells, while it drastically increases disturb in $L = 0.25 \mu\text{m}$ cells (for all V_D). This suggests the possibility of another cause for drain disturb in compensated cells, which is strongly activated at low L .

It is unlikely that the presence of compensation changes the fact that hole injection, and not electron loss or redistribution, is the main cause for disturb. It is more likely that more hot holes are being injected in compensated cells having lower L . One possible source of this additional component could be the channel leakage current. Localized charge trapping in SONOS cells degrades the subthreshold slope of programmed cells [16], [22], which can lead to channel leakage current even under disturb

Fig. 9. Drain disturb transients measured with source terminal grounded and floating, in SONOS cells (a) without and (b) with compensation implant. Floating the source terminal during disturb eliminates the channel leakage current.

conditions, especially at scaled L . The channel electrons can undergo impact ionization due to large lateral fields and the generated holes can also get heated and injected into ONO stack. Compensated cells have a lower V_{TH} , resulting in higher channel leakage current under similar disturb bias, which could lead to larger disturb in these cells.

To confirm the presence of channel leakage component in disturb, and compare its contribution with BTBT component, separate disturb measurements were done with the source terminal open. An open source terminal eliminates channel leakage current but does not affect BTBT near drain junction. Fig. 9 shows disturb transients in cells with and without compensation, measured with source terminal grounded and open. As expected, disturb in noncompensated cells changes very little when source terminal is open, indicating that main contribution is from BTBT. On the contrary, cells with compensation show a drastic reduction in disturb when the source terminal is open, indicating that channel leakage is a significant contributor to disturb in these cells. As BTBT and channel leakage show opposite trends with V_B , studying the dependence of disturb on V_B can also confirm the presence of these two components.

Note that as V_B becomes more negative, BTBT increases but channel leakage current decreases (due to body effect).

Fig. 10. (a) Drain disturb transients measured at different V_B in programmed SONOS cells with and without compensation implant. Increasing $|V_B|$ increases BTBT but reduces channel leakage. (b) Measured V_{TH} shift during drain disturb (fixed time) as a function of V_B in SONOS cells with and without compensation, at different L .

Fig. 10(a) shows disturb transients as a function of V_B in normal and compensated cells. A smaller L is deliberately chosen to increase leakage component for compensated cells. Disturb increases with increasing $|V_B|$ in normal cells showing BTBT as the dominant cause for disturb in these cells. Disturb decreases with $|V_B|$ in compensated cells showing channel leakage as the dominant component leading to disturb. However, note that channel leakage would reduce at higher L even for compensated cells and this also should reflect in the disturb dependence on V_B . Fig. 10(b) shows V_{TH} shift during disturb as a function of V_B in cells with different L . Decrease of disturb with increasing $|V_B|$ is observed only in shorter compensated cells but not the longer ones, which confirms channel leakage as the main cause behind increased disturb in compensated cells having scaled L .

In summary, the above results clearly show that injection of holes from substrate into ONO stack causes drain disturb in programmed SONOS cells. The main source of these holes is BTBT at the gate-drain overlap. In addition, holes can also get generated from impact ionization initiated by channel leakage current, which can become dominant at lower L in cells with low channel doping.

Fig. 11. Drain disturb transients in programmed SONOS cells as a function of P/E cycling. The comparatively larger initial V_{TH} drop in 10k cycled cell is due to the degraded retention with cycling [11]. The program and erase biases were chosen for a good endurance. Inset shows the P/E cycling window.

Fig. 12. Program-state and erase-state GIDL currents measured in a SONOS cell before and after 10k cycling. The corresponding P/E cycling window is shown in the inset of Fig. 11.

C. Effect of P/E Cycling on Drain Disturb

Fig. 11 shows the effect of P/E cycling on charge loss drain disturb in a programmed normal SONOS cell (inset shows the V_{TH} window during cycling). Disturb gradually decreases with P/E cycling, starting from the first P/E cycle. As disturb originates from BTBT at the gate-drain overlap for normal uncompensated cells, Fig. 12 shows GIDL characteristics measured in uncycled and 10k cycled cells. The reduction of program-state I_{GIDL} after cycling clearly shows a reduction in BTBT, which is consistent with reduction of program-state disturb in cycled cells. GIDL characteristics in the cycled cell also show a distinct skew compared those in the uncycled cell (the difference in I_{GIDL} in uncycled and cycled cells becomes larger at larger $|V_G|$ values).

Compared to virgin cell, a P/E cycled cell has additional interface traps (I_{CP} continually increases with cycling starting from the first one [11], shown later). Furthermore, repeated P/E cycling can also result in accumulation of trapped electrons above the channel region [23]. However, this cannot be significant for the present P/E conditions because of the good memory window observed during cycling (shown in the inset of

Fig. 13. Simulated GIDL curves of a SONOS cell in the presence of ONO trapped charge and interface traps. Trapped charge is placed at the Si/SiO₂ interface in two Gaussian packets (packet A in overlap and packet B above channel) and interface traps are placed uniformly across the channel (traps are donor type in lower half and acceptor type in the upper half, and are uniformly distributed in energy). The skew in GIDL curve occurs in the presence of either a charge dipole (positive charge in A and negative charge in B), or interface traps.

Fig. 11). Charge accumulation can still be present in the overlap region, which does not affect V_{TH} window but significantly affects GIDL, which is analyzed below.

Before proceeding further, we wish to point out that a reduction of I_{GIDL} (which originates from BTBT) also causes erase speed to reduce after cycling (not shown). However, its effect is not seen on the cycling window (inset of Fig. 11) as a slightly longer erase time, than needed to get the required V_{TH} shift, was used here. During BTBT erase, localized hole injection causes V_{TH} to saturate at longer erase time and erasing the cell for longer time has very little effect on V_{TH} transient. Note that when V_{TH} is laterally nonuniform along the channel, the region with highest local V_{TH} controls I_D and determines the overall cell V_{TH} . A cell programmed using CHE injection has its peak V_{TH} near drain. Once these injected electrons are erased, further hole injection in that region has no effect on cell V_{TH} unless the hole injection region is very wide, spreading deep into the channel. So using longer erase time has no effect on erase state V_{TH} at the start of cycling, but helps to offset any reduction in erase speed with cycling and results in a good cycling window [11].

Simulations were used to qualitatively study the effect of trapped charges and N_{IT} on GIDL characteristics. Trapped charges were placed at the Si/SiO₂ interface as two Gaussian packets on either side of drain junction—one in overlap (packet A) and one above channel (packet B), and interface traps were placed uniformly across the interface. Fig. 13 illustrates two sample cases where trapped charge and interface traps skew the simulated GIDL curve compared to the curve with no charge or traps. Negative trapped charge in both packets A and B increases I_{GIDL} for all V_G and shifts the GIDL curve toward higher V_G (no skew; not shown). Similarly, positive trapped charge in both packets A and B decreases I_{GIDL} for all V_G and shifts the GIDL curve toward lower V_G (again no skew; not shown). However, a skew (larger drop in I_{GIDL} at more negative V_G) in the GIDL curve was observed compared

Fig. 14. I_{CP} measured in virgin state, after programming from virgin state, and in programmed state after different number of P/E cycles. A gate pulse with a fixed base and varying top was used for measuring I_{CP} .

to no-charge case when trapped charge in packet A and B differs in sign, with positive charge in packet A and negative charge in packet B. A similar skew was not observed with negative charge in packet A and positive charge in packet B. In addition, presence of interface traps was also found to decrease I_{GIDL} at more negative V_G and resulted in a skew similar to experiments. The condition of positive charge in A and negative charge in B can occur in program-state if P/E cycling results in accumulation of trapped holes in the overlap region (note that excess electrons can be stored above the channel region by performing program after 10k P/E cycles). But as erase-state GIDL characteristics also show a skew after cycling (Fig. 12), it is clear that formation of charge dipole is not the only reason for GIDL skew. Interface trap generation appears to be another (additional) likely cause behind this skew.

To verify the presence of positive charge in the overlap and/or interface traps in cycled cells, Fig. 14 shows virgin state I_{CP} and programmed state I_{CP} measured at different stages during cycling. The maximum I_{CP} continually increases with cycling and the rising edge of $I_{CP}-V_{TOP}$ curve gradually shifts to more negative V_{TOP} with increasing P/E cycles. As mentioned earlier, hot-hole injection causes interface trap generation and the continual increase in I_{CP} shows that N_{IT} increases continuously with cycling. This makes interface trap generation one of the causes for reduction in GIDL and disturb with cycling. On the other hand, shift in the rising edge of $I_{CP}-V_{TOP}$ curve to more negative V_{TOP} values shows a reduction in the minimum local V_{TH} of the cell with cycling. As the local V_{TH} has minima in source/drain regions near the gate edges (in present conditions), this indicates a gradual increase of positive charge above the drain region with P/E cycles. Thus, it is likely that reduction in disturb with P/E cycling occurs due to reduction in BTBT, which (in present conditions) is both due to positive charge accumulation above the overlap and interface degradation.

Simulations were used to further explore the influence of trapped charge and interface traps on BTBT under disturb condition. Trapped charge and interface traps were placed using a similar scheme as mentioned earlier. It was found that current arising from BTBT reduces in the presence of either positive

Fig. 15. Simulated band-to-band generation rate across the channel (near interface) of a SONOS cell under disturb condition, in the presence of ONO trapped charge and interface traps. The drain junction is at about $0.11 \mu\text{m}$ and the center of channel is at origin. Trapped charge and interface traps are placed using a similar scheme as mentioned in Fig. 13. Band-to-band generation rate decreases in the presence of positive overlap charge (packet A) or interface traps.

trapped charge in the overlap, or interface traps. Fig. 15 shows the simulated band-to-band generation rate across the channel (near interface) for two sample cases. The peak band-to-band generation rate decreases in presence of positive trapped charge or interface traps. This reduction in band-to-band generation rate is found to occur due to the increase of potential near the interface in drain region. Both positive overlap charge and interface traps, which also contribute positive charge when unoccupied (donor type), can increase this potential. While trap-assisted tunneling also can increase in the presence of interface traps, here this may be offset by the reduction in BTBT itself due to increased potential. Thus, both interface traps and positive charge trapping near the drain junction can reduce drain disturb.

IV. CONCLUSION

Program drain disturb in SONOS Flash EEPROMs is investigated. Programmed SONOS cells suffer a severe charge loss disturb caused by injection of hot holes from substrate into the nitride. The two main sources of these holes are determined to be BTBT generation in the drain region, and channel leakage through impact ionization. BTBT is dominant in normal (no compensation) cells with and without halo doping for all L and compensated cells at large L . Channel leakage becomes dominant in compensated cells as L decreases and can cause severe bottleneck for cell scaling.

It is seen that program-state drain disturb becomes less severe with P/E cycling. The reasons behind this reduced disturb are analyzed using simulations. Simulations indicate that lower disturb is caused by reduction in BTBT generation, which in turn is either due to the presence of interface traps or accumulation of positive trapped charge in overlap region. Measurements show that P/E cycling results in a continuous increase in interface traps and also leads to a gradual accumulation of positive charge near the overlap (under given conditions), establishing both of them to be the causes behind reduced disturb. The reduction

in BTBT also affects erase speed during cycling and using a slightly longer erase time is needed to maintain a good cycling window.

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