Electrical Breakdown of Amorphous Hydrogenated Silicon Rich Silicon Nitride Thin Film Diodes

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Abstract—Electrical breakdown, both intrinsic and extrinsic, of thin film diodes used as switches in active matrix addressed liquid crystal displays has been studied using electrical measurements, thermal measurements, thermal 3D simulations, electrical simulations and post breakdown observations. The diodes used in this study consist of a layer of 30 nm amorphous hydrogenated silicon rich silicon nitride, sandwiched between metal electrodes. It will be shown that breakdown under dc bias is a thermal process. Thermal breakdown is shown to occur above a temperature level of 234 °C and is triggered by the onset of hydrogen effusion. Under certain conditions, low ohmic links are formed as a result of breakdown. Breakdown due to very short pulses (50–500 ns) shows a remarkable asymmetry in breakdown current between polarities. A hypothesis on this asymmetry is presented. Measurements suggest that a relation exists between current flow induced state creation in the nitride and breakdown phenomena. Furthermore, a statistical measurement technique is presented that uses breakdown to monitor the switch reliability in active matrix LCD production.

I. INTRODUCTION

THIN Film Diodes (TFD) based on hydrogenated amorphous silicon rich silicon nitride have shown to constitute useful switches in active matrix addressed LCD's [1]–[3]. The switches consist of a layer of 30 nm of a semi-insulating semiconductor ($a\text{-SiN}_x\text{:H}$, $x \approx 0.5$) [4] sandwiched between two metal electrodes (Fig. 1). The device physics and the electrical characteristics have been described before to some extent [5]. The active matrix liquid crystal displays that are made in this technology have been shown to exhibit excellent video performance and display uniformity if the appropriate driving scheme is chosen [6].

Thorough knowledge of the breakdown phenomena of the TFD's is needed, because breakdown is a threat to the reliability of the switches, for example through electrostatic discharge. Since the used semiconductor is a relatively new material and has a relatively large bandgap (2.0 eV), it is hard to predict the breakdown behavior.

Recently, breakdown of thin layers of dielectrics sandwiched between two metal electrodes has also drawn attention in the field of voltage-programmable antifuses for field programmable gate arrays. The use of amorphous silicon, a stacked structure with an oxide-nitride-oxide layer [7] and a

Fig. 1. (a) Layout of a TFD, side view. (b) Layout of a TFD, top view.

stacked structure with layers of silicon rich silicon nitride [8], [9] have been reported. Although breakdown is the programming mechanism, the reported data about the physical process preceding and during breakdown is not extensive.

In this paper the intrinsic breakdown mechanism of TFD's is elucidated with measurements and simulations. Breakdown is electrically described in terms of voltage and current behavior caused by electrical pulses on a time scale from 50 ns to dc. The physical behavior before, during and after breakdown is described. Explanations and hypotheses will be given for the observed phenomena, which are partially confirmed by simulations. Furthermore, an example of how breakdown can be used to determine the potential operational reliability of the switches will be shown. The statistical breakdown measurement that will be presented allows us to obtain information on extrinsic defect densities and failure modes related to the production

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process, as well as the limits of electrical reliability of the switches.

II. THEORETICAL

The current conduction mechanism of TFD's has been investigated before [5] and is governed by thermally assisted quantum mechanical tunnelling through a reverse biased Schottky barrier. Hydrogenated amorphous silicon based devices are known to suffer from degradation under current flow, which influences device performance. In previous work degradation was observed in amorphous silicon solar cells [10] under illumination, and in thin film transistors [11] and in TFD's [12], [13] due to current flow. In the case of TFD's during normal usage, it was shown that degradation is caused by band-to-band recombination of holes and electrons [14]. The recombination energy is believed to supply the energy for the breaking of a Si-H bond, thus creating a metastable state. Later it was shown by Nieuwesteeg *et al.* [15] that the location of the state creation in the nitride is dependent on the electric field and the polarity. It was shown that two degradation mechanisms are present, the first being caused by band-to-band recombination and mainly present as degradation near to the cathode (*cathodic* degradation). The second mechanism governs the degradation under high electric fields ($E > 2 \times 10^6$ V/cm). From photoemission measurements under electric bias, Nieuwesteeg *et al.* showed the existence of photons with energies above the Tauc optical gap. This was taken to be indicative for the existence of hot electrons, which should be expected near the anode, because most of the energy of the electrons passing through the nitride is released if the electrons enter the anode. The released energy can be exchanged to the anode or the $a\text{-SiN}_x\text{:H}$ network near the anode, resulting in enhanced hole emission into the $a\text{-SiN}_x\text{:H}$ [13] or enhanced hole generation in the $a\text{-SiN}_x\text{:H}$ near the cathode. The concept of enhanced hole generation [16] or enhanced hole emission [17] due to cooling of hot electrons near the anode has also been used to explain breakdown in SiO_2 . The damage is present near the anode. For this reason the term *anodic* degradation was introduced [14]. Because breakdown also takes place at electric fields above 2×10^6 V/cm, the anodic degradation mechanism will also be considered in relation to breakdown. Changes in IV characteristics due to degradation will be termed *drift* here.

III. INTRINSIC BREAKDOWN

A. Experimental

TFD's were made with $a\text{-SiN}_x\text{:H}$ thickness of 30 nm, with areas varying from $3 \times 4 \mu\text{m}^2$ to $250 \times 250 \mu\text{m}^2$. All electrical measurements were carried out for both polarities of the device, *bottom-injection* and *top-injection*. Bottom-injection is defined here as the polarity at which electrons flow from the bottom to the top electrode, top-injection is the reverse polarity. In order to study the breakdown behavior under electrical bias the following measurements have been carried out. First, ramped voltage, ramped current and constant current measurements were carried out using a semiconductor

Fig. 2. IV characteristics of a TFD with an area of $100 \times 100 \mu\text{m}^2$, semiconductor layer is 30 nm.

parameter analyzer. Second, IV measurements were performed to monitor TFD drift during stressing and breakdown measurements. Third, pulsed measurements were executed, utilising constant voltage pulses, with pulse lengths varying from 5 μs to 5 ms, and duty cycles varying from 1:4 to 1:100. Unipolar as well as bipolar constant voltage pulses were used. Finally, a measurement using a transmission line method (TLM) has been used to investigate the breakdown behavior using single shot pulses of 50–500 ns. The TLM setup was originally designed for the studying of the transient behavior of electrostatic discharge protection devices for the IC industry.

In order to find any relation between breakdown and degradation mechanisms, drift measurements and breakdown measurements have been carried out on different types of samples. In our case three process variables were varied, which were believed to modify only the interface properties of the $a\text{-SiN}_x\text{:H}$, not the bulk properties. The drift measurements were performed using bipolar and unipolar pulses of 10 μs with a period of 0.4 ms at a current density level of 10 A/cm^2 during 10 minutes. At this current density the anodic degradation mechanism is assumed to dominate.

Breakdown behavior under dc electrical bias has also been studied by thermal measurements using infrared microscopy. The thermal behavior of the device has been simulated statically as well as dynamically using a 3D simulation package. The thermal behavior of the device has also been recorded using an infrared video camera.

Finally, the post breakdown state has been analyzed using optical microscopy and scanning electron microscopy (SEM). In order to be able to study the post breakdown state of the silicon nitride, a Cr etch was applied that etches the Cr electrode down through the breakdown channel (but only if the nitride layer has been interrupted due to breakdown). The Cr etch also removes the top electrode.

B. Results

If a linear ramped voltage is applied, breakdown occurs at a certain intrinsic level. Initially, the normal I-V characteristic (Fig. 2) is measured. If the bias becomes too large, breakdown is the result. The post breakdown status is dependent on the circumstances, especially on the current compliance level of

Fig. 3. TFD current response to a linear ramped voltage, TFD size $9 \times 13.5 \mu\text{m}^2$. The solid line shows a low ohmic post breakdown status, achieved by limiting the current at a level of 5 mA. The dashed line shows a high ohmic post breakdown status, achieved by limiting the current at a level of 50 mA.

the measurement equipment. Two typical responses of the current responding to a ramped voltage are given in Fig. 3. For current compliance levels in the range of 1–10 mA, an ohmic link is formed. Stable, linear resistances have been found in the range of 50–250 Ω using $9 \times 13.5 \mu\text{m}^2$ TFD's. The post breakdown resistance is 60–100% higher for devices broken down using top-injection with respect to devices broken down using bottom-injection current. The breakdown power values obtained from ramped voltage measurements using 60 nm thick semiconductor showed no significant deviations from the values obtained with 30 nm samples. If a linear ramped current is applied, breakdown usually does not occur. In Fig. 4 a typical response of the voltage to a linear ramped current is shown. Apparently, an effect is present that causes a decline of the TFD voltage. Experiments using constant currents to measure time dependent breakdown revealed that it was very difficult to achieve breakdown this way. The drift mechanism causes a field reduction within a second, whereafter breakdown is less likely to occur. In practice it will mean that the TFD will either break down immediately or not at all if a constant current is applied.

Breakdown phenomena under dc electrical bias have also been studied using an infrared camera and video equipment. Light flashes during breakdown were observed. Heating of the device itself to a large extent has been observed. Under very slow ramp rates, boiling liquids have been observed. Breakdown forced by dc bias intrinsically always occurs in the centrepont of the active TFD area.

Constant voltage pulses have been applied to the devices to force breakdown. Wave forms of pulses in the range of 5–500 μs with moderate bias show negative space charge build-up in the first microseconds of the pulse, resulting in a decrease of the current after a few microseconds. Pulses with large bias, approaching breakdown values show a strong increase of the current during the pulse. Fig. 5 shows the evolution of the response of the current under ramped-voltage pulses of 10 μs . The following is observed: (1) the breakdown current level is higher for top-injection than for bottom-injection, (2) the increase in current due to the ramping of the voltage per

Fig. 4. TFD voltage response to a linear ramped current, TFD area is $9 \times 13.5 \mu\text{m}^2$.

Fig. 5. (a) TFD bottom-injection current response to voltage pulses (TFD area $9 \times 13.5 \mu\text{m}^2$). (b) TFD top-injection current response to voltage pulses (TFD area $9 \times 13.5 \mu\text{m}^2$).

step is higher for bottom-injection, (3) during the pulse, the current increases especially close to breakdown level. The first observation is also dependent on the pulse length, which is shown in Fig. 6. For pulses shorter than 50 μs an increase of the top-injection breakdown current with respect to the bottom-injection breakdown current is observed. It is also shown in Fig. 6 that there is a certain region (50–1500 μs) where the top-injection breakdown current is lower than the bottom-injection breakdown current. Single shot pulses were applied to the TFD's using a Transmission Line Method (TLM) [18]. In Fig. 7 an example of a waveform that can be observed is given, the point at which breakdown occurs is indicated. The breakdown current that is recorded is the maximum current that can be forced through the TFD just before breakdown

Fig. 6. Pulsed breakdown of TFD's with an area of $9 \times 13.5 \mu\text{m}^2$, duty cycle 1:20, unipolar pulses.

Fig. 7. Breakdown of a TFD forced by a transmission line measurement (TLM) pulse (500 ns) under top-injection. TFD area is $20 \times 20 \mu\text{m}^2$.

occurs. A breakdown event forced by the TLM lasts 6–7 ns. Fig. 8 shows the breakdown current density for $100 \times 100 \mu\text{m}^2$ TFD's as a function of pulse width. Note the difference of the time scale compared to Fig. 6. A remarkably large difference in breakdown current density between top- and bottom-injection is observed. Also a strong area dependency is found, as is shown in Fig. 9. The breakdown current shows a rather linear dependency with TFD area for bottom-injection, which is quite different from the behavior at top-injection. The figure also shows a difference in breakdown current density for both polarities that goes up to a factor 30 to 40. However, a rather large batch to batch variation of the breakdown current density is recorded, typically a σ/μ value of 0.15 is found. This explains differences in absolute values shown in Figs. 7–9. Space-charge build-up was not recorded with TLM. Finally, the breakdown voltages as a function of TFD area are shown in Fig. 10. The voltages have been corrected for series resistance in the TLM setup and the structures. Also with the TLM low ohmic links in the range of 50–250 Ω were formed at breakdown.

The drift measurements at 10 A/cm^2 using pulsed top-injection and bottom-injection biases showed an asymmetric drift, which can be related to the anodic degradation mechanism. A batch of eight differently processed TFD's has been produced. Three process variables which were known to modify the interface properties only were changed. After that, the drift properties of each sample were measured

Fig. 8. Breakdown current density for both polarities, TFD area is $100 \times 100 \mu\text{m}^2$, using TLM (50, 100 and 500 ns pulses).

using pulses of $10 \mu\text{s}$, duty cycle 1:20, bottom- and top-injection. The breakdown properties were measured using a TLM. Fig. 11 shows the relation that has been found between the drift, caused by bottom-injection stress, and the bottom-injection breakdown current using a TLM. Fig. 11 suggests the existence of an inversely proportional relation between bottom-injection drift and breakdown. Such a relation was *not* recorded in top-injection.

Thermal measurements have been performed under constant current bias by means of infrared thermal microscopy on $100 \times 100 \mu\text{m}^2$ structures. The temperature of the TFD's was measured at a current density just below dc breakdown level. The temperature determination is combined with a spatial resolution of better than $10 \mu\text{m}$. The actual temperature was determined to be 234°C ($\pm 10\%$). The real breakdown temperature is somewhat higher, because the measurements have been carried out just below dc breakdown level, but are expected to be lower than 300°C .

Thermal simulations in 3D have been carried out. A simulator [19] has been used which translates a thermal model into an electrical equivalent, which in turn can be simulated using an electrical circuit simulator. The simulations were performed under the assumption that the heat generation is equally distributed over the area. This yields an underestimation of the maximum heating. Fig. 12 shows the temperature distribution of the nitride over the area in the case of dc-bias (constant current). It confirms that breakdown forced by dc bias is expected in the centrepoint of the TFD area. Fig. 13 shows the temperature rise in time from 0 to 3 ms for a breakdown power value that is approximately three times as high as with a ramped voltage measurement. After $10 \mu\text{s}$ the temperature rise in the hottest point (the centrepoint) is already almost one third of the end temperature.

Finally, post breakdown observations have been carried out using optical microscopy and scanning electron microscopy (SEM). If breakdown is forced using dc bias or pulses with a pulse length longer than $20 \mu\text{s}$ the breakdown spot can always be found in the centrepoint of the TFD area. Below $5 \mu\text{s}$ the breakdown spot can be found at random in the TFD area. Under top-injection using a TLM, breakdown occurs at or

Fig. 9. Breakdown current under bottom-injection and top-injection as a function of TFD area using the TLM, pulse width 100 ns.

Fig. 10. Breakdown voltage using TLM (pulse length 100 ns). The values have been corrected for series resistance in the TLM setup and the structures.

Fig. 11. Correlation between anodic degradation (drift) and breakdown; three process variables that modify the interface properties in some way have been varied (this gives 8 different samples). The breakdown forced by the TLM is under bottom-injection. The drift is caused by pulsed bottom-injection stress, but has been measured in top-injection to obtain the largest measurable effect.

near the edges. Figs. 14 and 15 show examples of breakdown spots using a ramped voltage measurement, resulting in low ohmic links, after etching off the topelectrode. The breakdown spot diameters are typically around $1 \mu\text{m}$. The thickness of the nitride layer has in most cases not changed. Still, a large change in color can be observed using a light microscope, which indicates a change in refractive index, which in turn indicates a change in chemical structure or composition of the nitride.

C. Discussion

Breakdown under dc bias, both in bottom- and top-injection, is apparently a thermal process. The thermal measurements, the thermal 3D simulations and the observations done during the research are all in agreement with this explanation. The heat generation is due to current flow. Since the current transport is thermally stimulated [5], most of the current will be conducted in the hottest areas, which might create a dangerous "hot spot" situation. However, the TFD's are quite stable and

can be stressed severely without the occurrence of sudden breakdown. An opposing mechanism exists, which is the drift mechanism that reduces the field strength at the cathode [13]. This mechanism has a relatively large time constant which is illustrated as the ramp rate is varied. If the voltage is ramped linearly, the current is ramped exponentially. If we compare this with linear ramping of the current, it is clear that the ramp rate of the latter is much slower. In the case of a ramping voltage, breakdown is easily achieved. In the case of a ramping current, the drift mechanism gets enough time to reduce the cathode field at the hotter areas, thus reducing current flow there. The whole TFD heats up, resulting in a dropping TFD voltage, which is illustrated by Fig. 4. A part of this voltage drop is also caused by degradation due to the high current density. This is illustrated by the fact that the graph of Fig. 4 is not fully reversible.

The temperature at which breakdown is triggered has been measured to be at least $230 \pm 25^\circ\text{C}$. This value has to be corrected because the measurement conditions were somewhat below the breakdown level. This correction yields an estimate

Fig. 12. Static 3D thermal simulation: temperature rise of the TFD area under the assumption that heat generation is equally divided over the TFD area. The centrepoint of the TFD suffers mostly from heat generation. Power per area = 1000 W/cm^2 .

Fig. 13. Temperature rise due to dissipation in the nitride layer, power = 10^4 W/cm^2 , TFD area is $10 \times 10 \mu\text{m}^2$.

of $280 \pm 40^\circ\text{C}$. At this temperature, the onset of hydrogen effusion is reported [20], [21], which means that a rapid increase of deep state concentration is expected. This in turn causes the onset of Poole-Frenkel conduction [5], [22], which leads to rapid current concentration in the hottest area. That in turn leads to a rapid further increase in current density in the hottest area. The temperature now rises very quickly, eventually leading to melting of the $\alpha\text{-SiN}_x\text{:H}$ and parts of the metal electrodes. Even evaporation may be the result, which is confirmed by Fig. 15, in which an open channel is shown. After breakdown, the voltage has sharply dropped due to the high conductivity of the breakdown spot, which is probably caused by diffusion of metal atoms from the electrodes into the molten $\alpha\text{-SiN}_x\text{:H}$. This is confirmed by the relatively large breakdown spot diameter that is in the order of $1 \mu\text{m}$, which excludes pure metal filaments to be responsible for the conduction. Now, power dissipation is reduced and if the current or voltage is not ramped up further, a stable ohmic link is left behind.

The thermal simulations show that heating is also the major cause of breakdown on the time scale that is used with the constant voltage pulsed measurement. The increase of the current during the pulse is also explained by heating of the device. However, the two other observations that were mentioned with the result of the pulsed measurement need another explanation, which will be illustrated with the discussion on the TLM measurements.

In the following a hypothesis will be given that explains the large difference in breakdown current (Fig. 8) between both polarities while the breakdown voltage is approximately equal (Fig. 10). In Fig. 9 the breakdown current is shown with TFD area as the variable. Bottom-injection breakdown current increases rather linearly with TFD area, where top-injection breakdown current shows a tendency toward saturation with large area TFD's. In our opinion, this different behavior is indicative of different breakdown mechanisms.

First, the top-injection breakdown characteristics under TLM will be analyzed. In Fig. 7 the breakdown voltage and breakdown current pulses under top-injection are shown. Although the current is constant before breakdown, the voltage shows a drop. The slope of the voltage drop can be measured as a function of TFD area. The result is shown in Fig. 16.

Two explanations for the voltage drop can be argued. The first is space charge evolution in the nitride. In the case of a decreasing voltage a positive space charge build-up is responsible. However, in practice only negative space charge build-up is recorded if pulses under $10 \mu\text{s}$ are applied. Furthermore, a strong area dependency is not expected in that case. The second explanation is heating. As was also present with the dc and pulsed measurement, in the case of heating there is a strong area dependency, which is confirmed by Fig. 16. In the case of TFD's with larger areas, the effect of the current density in the "hot" area, which occupies a relative small area, is camouflaged by a larger "cold" TFD area, resulting in a lower average breakdown current density

Fig. 14. Thermal breakdown, top-injection, resulting in a low ohmic resistance. The bottom electrode is not etched, which means there is no etchable channel.

(measured over the whole TFD area) and a lower voltage drop during the pulse.

In the following a hypothesis for the top-injection breakdown behavior will be given. This behavior can probably be explained from a device asymmetry with respect to polarity. The largest asymmetry is the presence of a native oxide layer at the Cr/a-SiN_x:H interface (the bottom interface), which has a thickness of about 2 nm. This native oxide layer on the bottom metal is known to influence the tunnel transmission probability of carriers [23]–[25] severely. Fig. 11 shows the relation between anodic degradation and bottom-injection breakdown current for 8 different types of samples. For top-injection the proportional relation between anodic degradation and bottom-injection breakdown current shown in Fig. 11 is absent, indicating again a difference in breakdown mechanisms for top- and bottom-injection.

We now offer a hypothesis that provides an explanation for the large difference in bottom and top-injection breakdown current. In this hypothesis it is assumed that the amount of hole injection is the triggering factor for breakdown. Anodic degradation has been related to hole injection from the anode, while the hole generation rate at the anode has been related to cooling of hot electrons at the anode [5]. The hole *generation* rates at the anode for both polarities will be approximately equal for both polarities, because the breakdown voltages, and therefore the electric fields, are quite equal for both polarities. The hole *injection* rates however will be significantly different, because the hole injection rate depends on the hole tunnel transmission probability, which is much lower for top-injection because of the native oxide layer at the bottom interface. Thus, hole injection from the anode under bottom-injection will be much higher than hole injection under top-injection. A secondary effect may enhance the previous and is caused by the piling up of holes behind the native oxide layer under bottom-injection,

thus causing positive feedback for breakdown because the electric field at the cathode is enhanced.

Finally, the behavior of the breakdown current for the pulsed measurement (Fig. 6) can be explained as a result of the same mechanism as was suggested with the TLM measurements. It shows the beginning of a transition from thermal breakdown (dc) to (hot) carrier related breakdown (TLM, bottom-injection).

IV. THE STATISTICAL BREAKDOWN MEASUREMENT TECHNIQUE

A. Introduction

Reliability of the switches in the active matrix of an AMLCD is of great importance. Hence, measurement methods are needed that provide a good indication for the electrical reliability of the switches. The normal TFD-R display structures are not suited for such a measurement method, because the switches can only be accessed indirectly. In this study a new method for monitoring the reliability of the active matrix will be given that uses a specially designed test structure, which can be handled by a step-and-repeat prober. Information about the reliability of the TFD's can be gained by measuring a statistically significant amount of TFD's.

B. Experimental

The test structure contains over 33 000 TFD's in 8 configurations, which enables the studying of breakdown and reliability in terms of bulk effects, edge effects, area dependency, polarity and processing variables. Mapping of failures is possible, enabling post breakdown failure analysis.

Statistical analysis using breakdown is often used in the characterization of MOS gate oxides [26]. Forced electrical

Fig. 15. Thermal breakdown, bottom-injection, resulting in a low ohmic resistance. The bottom electrode is etched through the visible breakdown channel.

Fig. 16. Top-injection breakdown using a TLM, 500 ns pulses. Shown are the voltage drop, and the breakdown current density.

breakdown is used in this study in a similar way to characterize the reliability of the TFD's. In the case of TFD's, breakdown can reliably be achieved using a ramped electric field or using microsecond pulses, of which the voltage is ramped up. Both methods have been implemented, the first has the advantage of flexibility, the latter has the advantage of achieving breakdown at a higher intrinsic level, enabling detection of more extrinsic defects. Before breakdown is forced, electrical parameters can be measured, giving the possibility to correlate extrinsic defects with electrical parameters.

C. Results

Intrinsic and extrinsic (defect-related) breakdown can be distinguished by plotting the cumulative number of failures against the breakdown voltage or breakdown current in an extremal probability plot. The analysis is based on the assumption that defects in the TFD enhance breakdown phenomena, thus causing breakdown to occur at a lower voltage or current level compared to the intrinsic level. An example of a

Fig. 17. Cumulative failures of 4320 $4 \times 100 \mu\text{m}^2$ and 4320 $100 \times 4 \mu\text{m}^2$ TFD's. Intrinsic and extrinsic (defect related) breakdown can clearly be distinguished. The transition point from extrinsic to intrinsic breakdown is indicated by arrows.

statistical breakdown measurement using a ramped electrical field is given in Fig. 17, in which the influence of different TFD configurations on reliability is shown. In this way, the effects of edges can be elucidated by measuring devices with a different length/width ratio. Clearly, the $4 \times 100 \mu\text{m}^2$ structure shows over 3 times as many extrinsic failures as the $100 \times 4 \mu\text{m}^2$ structure, which could be attributed after post breakdown inspection to a somewhat larger defect probability at the longer step coverage edge of the $4 \times 100 \mu\text{m}^2$ structure. Further, different extrinsic failure modes can be detected, as is shown in Fig. 18. Here a voltage gap is present between the extrinsic failures that occur below 6.5 V and those above 7.8 V, indicating a change in failure mode. In this particular case, the

Fig. 18. Cumulative failures of 2 * 4320 TFD's, using dc breakdown, showing failure mode with certain threshold level (above 7.8 V) for the process A.

Fig. 19. Cumulative failures of 2 * 4320 TFD's, using pulsed breakdown. Process B (from Fig. 18) shows a nonideality, by shifting the breakdown voltage to higher levels. In process C it is eliminated.

second failure mode was obtained by intentional insufficient cleaning of the bottom contact in process A.

All of the TFD's in Figs. 17 and 18 have broken down at a value far beyond normal operating voltages, which means that it is not a measure for the yield, but for the potential operational reliability of the switches. By using short length pulses rather than a dc ramped electrical field, the intrinsic breakdown level can be shifted to higher values and more nonidealities can be measured. An example of such a measurement is shown in Fig. 19. Although Fig. 18 shows no extrinsic failures in the process B material, the pulsed breakdown measurement on the same devices in Fig. 19 shows a nonideality. Clearly, the process C material is superior to process B.

Non-uniform semiconductor layers and rough interfaces contribute to the spread in breakdown levels. Figs. 18 and 19 show that intrinsic breakdown occurs in a small range, which is an indication of good uniformity of the semiconductor layer. Finally, we point out that this method can also be applied for studying processes that are not feasible for normal

LCD production, e.g., for processing of switches without the transparent pixel electrode.

V. CONCLUSION

We have carried out an experimental study of the physics of electrical breakdown in amorphous hydrogenated silicon rich silicon nitride thin film diodes. Electrical measurements, thermal measurements, static and dynamic 3D thermal simulations, electrical simulations and post breakdown observations have given insight in the intrinsic breakdown mechanisms on a time scale from 50 ns to dc. It was found that breakdown is thermal from pulses of 50 μ s to dc and is symmetric with respect to polarity. Thermal breakdown is possibly caused by H-effusion out of the a -SiN_x:H, causing rapid deep state creation, eventually leading to melting and breakdown. Furthermore, it was found that the drift mechanism stabilises the thermal behavior of the TFD's, leading to an enhanced breakdown resistivity. By choosing a suitable current level, the TFD's can be used to produce stable low ohmic antifuses.

Below pulses of 50 μ s, an asymmetry was found with respect to polarity. The top-injection breakdown current is then higher than bottom-injection breakdown current, up to a 30 to 40 times for 50 ns pulses. A correlation was found between the drift mechanism that is related to hot carrier phenomena, and breakdown using very short pulses under bottom-injection.

A statistical breakdown measurement has been presented that enables improved failure analysis and quick feed-back to the relevant TFD processing parameters. The method may also be useful as a tool for monitoring the production process and insuring diode reliability in active matrix LCD's.

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