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Bias dependence of instability mechanisms in amorphous silicon thin-film transistors

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We have measured the bias dependence of the threshold voltage shift in a series of amorphous silicon-silicon nitride thin-film transistors, where the composition of the nitride is varied. There are two distinct instability mechanisms: a slow increase in the density of metastable fast states and charge trapping in slow states. State creation dominates at low fields and charge trapping dominates at higher fields. The state creation is found to be *independent* of the nitride composition, whereas the charge trapping depends strongly on the nitride composition. This is taken as good evidence that state creation takes place in the hydrogenated amorphous silicon (a-Si:H) layer, whereas the charge trapping takes place in the a-SiN:H. The metastable states are suggested to be Si dangling bonds in the a-Si:H, and the state creation process similar to the Staebler–Wronski effect. The confirmation of state creation in a thin-film transistor means that states can be created simply by populating conduction-band states in the undoped material. The slow states are also thought to be Si dangling bonds, but located in the silicon nitride matrix.

There is considerable interest in instability mechanisms in amorphous silicon devices. Solar cells show photodegradation, which has been attributed to the light-induced increase in the density of Si dangling bonds in the hydrogenated amorphous silicon a-Si:H.[1] Thin-film transistors (TFT's) also show this photodegradation,[2] but the more important instability is the threshold voltage shift observed under prolonged bias.[3,4]

This was originally attributed to charge trapping in slow states located in the amorphous silicon nitride, which is usually used as the gate dielectric.[3] However, more recently, an alternative model involving the slow creation of states in the a-Si:H has been proposed.[5] The states are metastable, since the effect can be annealed out. The states were suggested to be Si dangling bonds, due to certain similarities to the photoinduced degradation.[5]

The essential difference in the two models is that in Ref. 3 charge is slowly trapped into electron states which always exist but are in poor communication with the a-Si conduction band. In the alternative model,[5] there is a slow process of creation of extra states, which once created are in good communication with the a-Si conduction band. In other words, there is a slow increase in the number or density of *fast* states.

In a recent letter,[6] we reported bias stress measurements on amorphous silicon-silicon nitride ambipolar thin-film transistors. These experiments allowed us to distinguish, for the first time, between the two mechanisms. Furthermore, they gave us a measure of the relative contribution of each mechanism, when both were present at the same time. These experiments gave us conclusive evidence that indeed both mechanisms do occur. The state creation dominated at low positive bias, whereas charge trapping dominated at higher positive bias as well as negative bias. However, strictly, they did not indicate whether the states were in the nitride gate insulator or the a-Si:H semiconductor.

In this letter, we investigate further the bias dependence of the threshold voltage shift. In particular, measurements on a series of transistors, in which the composition of the nitride is varied, give important evidence that the state creation process takes place in the a-Si:H layer, whereas the charge trapping takes place in the a-SiN:H gate insulator.

A series of amorphous silicon-silicon nitride thin-film transistors with the inverted staggered structure was prepared. The gate insulator was silicon nitride made from silane and ammonia. The gas ratio NH_3:SiH_4 was varied between samples, but the a-Si:H was grown under identical conditions for all samples. Two types of the device were made: firstly, test devices using a n^+-Si wafer as substrate and gate electrode and secondly, matrix arrays of devices on glass substrates using Cr gates, i.e., typical devices used in active-matrix addressing of liquid-crystal displays.[7] The results from both devices were identical. In addition, we performed the same experiments on an ambipolar TFT, which showed both electron and hole conduction.[6]

We measure the bias dependence of the threshold voltage shift as follows. First the sample is annealed to 180 °C for 1 h. The transfer characteristic is measured using a specially built fast electrometer. The transistor is then subjected to a bias stress of V_{GB}, for 10^3 s at 40 °C, and the transfer characteristic is remeasured. The threshold voltage shift for electron accumulation, ΔV_T, is defined from the intercept, as indicated in Fig. 1, but in all cases a parallel shift is observed, i.e., there is no degradation of the field-effect mobility. The sample is then annealed to 180 °C again, which restores the original characteristics. The same sample is then subjected to stress at a different bias V_{GB} and so we can determine ΔV_T as a function of V_{GB}. Figure 1 shows typical results for two values of V_{GB} on the same sample. On some of the matrix arrays, we checked the results using a fresh sample for *each* stress voltage. The results were the same.

Figure 2 shows the results for a series of transistors grown with varying nitrides, but identical a-Si:H and labeled A, B, C, and D. We have characterized the nitrides by var-

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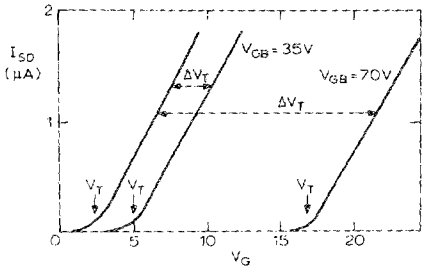

FIG. 1. Example of transfer characteristics before and after bias stress for two values of V_{GB} (sample C of FIG. 2).

ious techniques. The most significant variation is the band gap, which was 3.8, 4.3, 4.7, and 5.0 eV for samples A, B, C, and D respectively.

The results show that, as we increase V_{GB}, ΔV_T increases slowly at first, then above some critical value of the bias, V_{GC}, ΔV_T increases more rapidly. The value of V_{GC} and hence the value of ΔV_T above V_{GC} depends on the nitride composition. Below V_{GC}, the magnitude of ΔV_T is *independent* of the nitride composition. Clearly there are two mechanisms, one dominant at lower biases, one dominant at higher biases.

We now repeated the same experiment on an ambipolar TFT, but this time, we measured the threshold voltage shift of the electron *and* hole branch. We also performed another series of experiments, where the stress time was 4 h. In Fig. 3, we plot ΔV_T for both the electron and hole branches for both stress times. By comparing ΔV_T for electron conduction with the results in Fig. 2, we can see that the ambipolar TFT has a similar characteristic, with a well defined V_{GC}. The band gap of the nitride in this ambipolar TFT was 4.5 eV, consistent with Fig. 2. The bias dependence of ΔV_T for hole conduction is quite different and actually negative for low positive bias.[6]

Figure 4 shows the breakdown of these results on the ambipolar TFT into created states and charge trapping in slow states, using the method previously described.[6] Figure 4 clearly shows that the larger contribution for biases below V_{GC} is the state creation, whereas above V_{GC} it is charge trapping in slow states. From this result, it is reasonable to conclude that the same is true for all the samples in Fig. 2 as well.

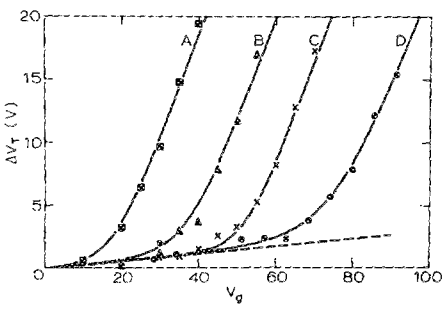

FIG. 2. Threshold voltage shift as a function of bias stress voltage, V_{GB} for TFT's, with four different nitrides. The dashed line indicates the nitride-independent component.

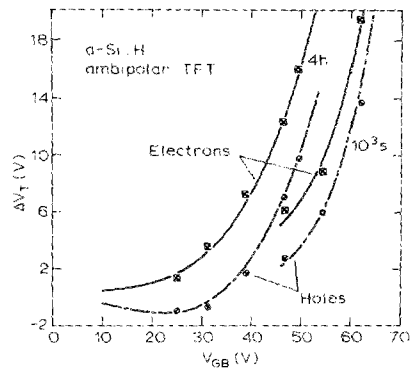

FIG. 3. Threshold voltage shift for electron and hole conduction as a function of bias-stress voltage, V_{GB}, for two stress times, 4 h and 10^3 s.

Because of the strong dependence of the charge trapping on nitride composition, we conclude that the slow states are located in the nitride. Similarly, because the state creation is independent of nitride composition, we conclude that the state creation is confined to the *a*-Si:H layer.

From the results of Fig. 2, we can see that for wide band-gap nitrides, the dominant instability mechanism at gate voltages of 15–20 V (typical values in most applications) is metastable state creation. However, as we change the composition and decrease the nitride band gap, the value of V_{GC} rapidly moves into this range, so the dominant instability mechanism becomes charge trapping in the nitride. This will certainly be the case for the "graded nitrides" used by Street and Tsai,[8] so their "slow states" will be charge traps in the off-stochiometric nitride.

We propose that the metastable states created in the *a*-Si:H are Si dangling bonds, as previously suggested.[5] The process has some similarities to the Staebler–Wronski effect,[1] where Si dangling bonds are known to be created,[9] as a result of illumination. The creation of Si dangling bonds, in the present case, is the direct result of populating the conduction-band-tail states, as the Fermi level is moved up in energy relative to these states. Weak Si–Si bonds may be broken, when at least one of the antibonding electron states is occupied, according to the reaction:

$$2Si_4^0 + e^- \rightarrow Si_3^- + Si_3^0.$$

There is increasing evidence that this reaction will proceed, whenever the band-tail states are populated, whether

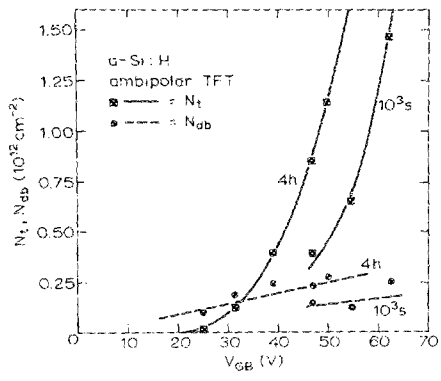

FIG. 4. Densities of created dangling bonds N_{db} (cm^{-2}) and trapped charge in the nitride N_t, derived from the data in Fig. 3.

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this is by light (Staebler–Wronski effect),[1] through excess carrier injection,[10] in doped layers,[11] at elevated temperatures[12,13] or through external band bending in undoped material, as in the present case. The persistence of the created states after bias removal implies a stabilizing step, such as provided by H diffusion. However, the detailed energetics and the exact role of H diffusion in these reactions[13] remain to be resolved.

The slow states located in the nitride are also thought to be Si dangling bonds, as originally proposed.[14] This defect is situated in the nitride band gap at an energy close to the Si conduction band.[14] We originally suggested that the rate determining mechanism for charge transfer into these states was by hopping at the Fermi level.[3] This model was also adopted by Street and Tsai,[8] who then suggested that the nitride dependence of the hopping rates was due to changes in the wave function, rather than the trap density, since the measured Si_3^0 density (from ESR) did not vary. The results of Fig. 2 suggest a strong field dependence to the charge trapping mechanism, which might be explained by field-enhanced hopping at the Fermi level.[15] The values of V_{GC} are much less than the fields necessary for the onset of the high-field conduction in nitride, by the Poole–Frenkel mechanism, but are reasonable for the above interpretation. Careful measurements at voltages below V_{GC} reveal a small but significant contribution due to charge trapping, which might be the low-field (ohmic) component of the hopping. However, further work is needed to confirm these suggestions.

[1] D. L. Staebler and C. R. Wronski, J. Appl. Phys. **51**, 3162 (1980).
[2] M. J. Powell, B. C. Easton, and D. H. Nicholls, J. Appl. Phys. **53**, 5068 (1982).
[3] M. J. Powell, Appl. Phys. Lett. **43**, 597 (1983).
[4] M. J. Powell, Mater. Res. Soc. Sympo. Proc. **33**, 259 (1985).
[5] A. R. Hepburn, J. M. Marshall, C. Main, H. J. Powell, and C. van Berkel, Phys. Rev. Lett. **56**, 2215 (1986).
[6] C. van Berkel and M. J. Powell, Appl. Phys. Lett. **51**, 5 Oct. (1987).
[7] M. J. Powell, J. A. Chapman, A. G. Knapp, I. D. French, J. R. Hughes, A. D. Pearson, M. Allinson, M. J. Edwards, R. A. Ford, M. C. Hemings, O. F. Hill, D. H. Nicholls, and N. K. Wright, Proceedings of the International Display Research Conference (Institute of Physics, London, 1987), pp. 63–66.
[8] R. A. Street and C. C. Tsai, Appl. Phys. Lett., **48**, 1672 (1986).
[9] H. Dersch, J. Stuke, and J. Beichler, Appl. Phys. Lett. **38**, 456 (1981).
[10] N. Nakamura, K. Watanabe, M. Nishikuni, Y. Hishikawa, S. Tsuda, H. Nishiwaki, M. Ohnishi, and Y. Kuwano, J. Non-Cryst. Solids **59-60**, 1139 (1983).
[11] R. A. Street, J. Non-Cryst. Solids **77-78**, 1 (1985).
[12] Z. E. Smith, S. Aljishi, D. Slobodin, V. Chu, S. Wagner, P. Lenahan, R. Ayra, and M. Bennett, Phys. Rev. Lett. **57**, 2450 (1986).
[13] R. A. Street, J. Kakalios, C. C. Tsai, and T. M. Hayes, Phys. Rev. B **35**, 1316 (1987).
[14] J. Robertson and M. J. Powell, Appl. Phys. Lett. **44**, 415 (1984).
[15] N. Apsley and H. P. Hughes, Philos. Mag. **31**, 1327 (1975).

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