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Thermally induced metastability in amorphous silicon thin-film transistors

Yi Sang Lee, Hye Yong Chu, and Jin Jang
Department of Physics, Kyung Hee University, Dongdaemoon-ku, Seoul 130-701, Korea
Byung Seong Bae, Kwang Soo Choi, and Choochon Lee
Department of Physics, Korea Advanced Institute of Science and Technology, P.O. Box 150 Chongyangri, Seoul, Korea

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The effect of thermal quenching on the characteristics of hydrogenated amorphous silicon thin-film transistors using amorphous silicon nitride as a gate insulator has been studied. We find that rapid quenching produces changes in the field-effect conductance which are completely reversed by annealing. Rapid quenching produces a decrease in the off conductance and an increase of the on conductance. The decrease of the off conductance is due to the increase of the dangling bond density. On the other hand, the increase of the on conductance can be explained as either the decrease of the interface state density between amorphous silicon and the silicon nitride or the decrease in source series resistance by thermal quenching.

Hydrogenated amorphous silicon (*a*-Si:H) thin-film transistor (TFT) is one of the best switching elements for liquid-crystal display panels.[1] Research is being done to enhance the on conductance and to decrease the threshold voltage in *a*-Si:H thin-film transistors. Light illumination[2] or positive gate bias[3] produces a decrease of the on conductance and an increase of the threshold voltage, and this is believed to be mainly due to the creation of the dangling bonds in *a*-Si:H.

In this letter we report that rapid quenching from above the thermal equilibrium temperature gives rise to the increase of the on conductance and the decrease of the off conductance in *a*-Si:H thin-film transistors. The decrease of the off conductance is due to the increase of the dangling bond density in *a*-Si:H and the increase of the on conductance can be explained as either the decrease in the interface state density or the decrease in the series resistance.

The devices used in this letter were made by the successive deposition in a rf plasma discharge of layers of silicon nitride, amorphous silicon, and heavily phosphorus-doped (n^+) amorphous silicon. A cross section through a device is shown in Fig. 1.

All three layers are deposited at a substrate temperature of 250 °C. The rf power levels used for the deposition are 0.1 W/cm^2, and the amorphous silicon nitride is prepared by the decomposition of silane ammonia mixture $NH_3/SiH_4 = 7.5$. An n^+ layer is 1% phosphorus-doped *a*-Si:H, and the n^+ layer between the source-drain electrode was removed by a plasma etching using CF_4. All the measurements reported in this letter were performed using structures with a channel length of 10 μm and a width to length ratio of 10. The thicknesses of the silicon nitride, amorphous silicon, and n^+-silicon layers are 0.3, 0.3, and 0.04 μm, respectively. Before measurements, the sample was annealed at 250 °C in vacuum of 10^{-5} Torr for 1 h in order to remove the surface adsorbates and the residual light-induced effect. Rapid cooling was performed by flowing water into the substrate holder, and the current voltage characteristics were measured by a programmable electrometer (Keithley model 617) interfaced to an Apple II microcomputer.

Figure 2 shows the drain current versus gate voltage characteristics with a drain voltage of 5 V in annealed and quenched states. The current versus voltage curves were measured at 30 °C after annealing at 230 °C for 1 h in vacuum and then cooled to 30 °C with a cooling speed of 1 °C/min. This is the annealed state. The quenched state is obtained after rapid quenching from 230 to 30 °C with a cooling speed of $\sim$20 °C/s. Both the on/off current ratio and the on current are enhanced by rapid quenching. On the other hand, the off conductance decreases by quenching. The quenching effect is nearly absent when the quenching temperature is less than 160 °C, and the effect is very small when it is 180 °C.

Figure 3 shows the temperature dependence of the field-effect conductance with a gate voltage of 20 V for the annealed and quenched states. The conductance shows the activated behavior. The activation energy is the difference between the conduction-band edge and the effective quasi-Fermi level. Therefore, rapid quenching results in the shift of the quasi-Fermi level toward the conduction-band edge and this should be explained as the decrease in the density of bulk or interface states, or a combination of the two effects by quenching. Figure 4 shows the effect of rapid quenching on the field-effect mobility in *a*-Si:H TFT. The mobility is enhanced by 6% and the threshold voltage decreases by 0.9 V. Figure 5 shows the effect of rapid quenching on the drain current-voltage characteristics with the fixed gate voltages. The current is significantly enhanced by quenching.

For intrinsic *a*-Si:H, the subband-gap optical absorption

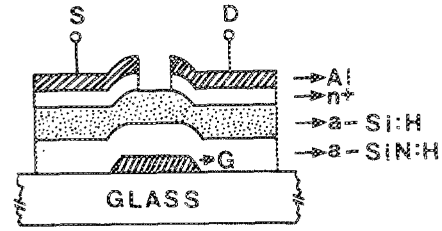

FIG. 1. Cross-sectional structure of an amorphous silicon thin-film transistor.

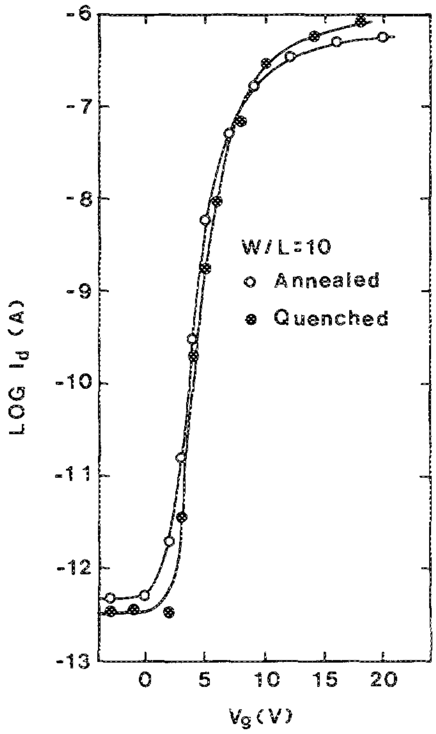

FIG. 2. Effect of rapid quenching on the gate voltage dependence of the drain current in amorphous silicon thin-film transistor.

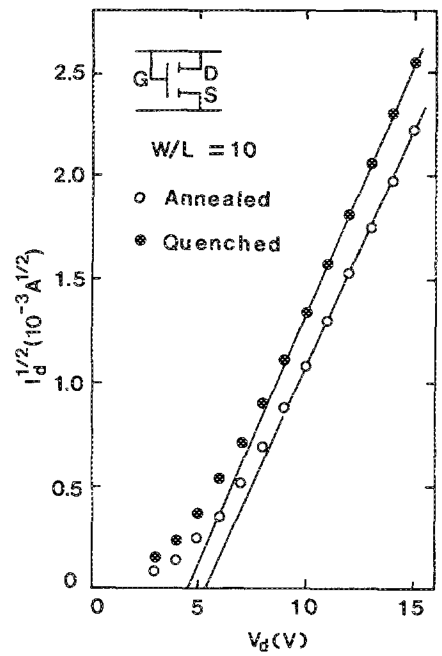

FIG. 4. Effect of rapid quenching on the field-effect mobility and the threshold voltage.

coefficients are determined by photothermal deflection spectroscopy or by constant photocurrent increase after rapid quenching,[4] and this appears to be due to the creation of dangling bonds by electron-hole recombination.[5] The conductivity of undoped a-Si:H decreases by rapid quenching, and this is due to the creation of the dangling bonds.[6] The additional dangling bond lowers the dark conductivity as is the case in the Staebler–Wronski effect in undoped a-Si:H.[7] The thermal equilibrium temperature is the temperature at which the defect structure comes into equilibrium within a few minutes and is ~200 °C for undoped a-Si:H.[8] The photoconductivity experiments[8] confirm that the defect density increases by rapid quenching in undoped a-Si:H. Therefore, the defect density in the bulk of undoped a-Si:H will increase by rapid quenching.

The field effect and the on conductance will decrease as the dangling bond density or the gap state density increases, as can be seen in the light soaking effect[2] on the drain current in a-Si:H TFT structure. Accordingly, our results can be explained as the decrease in the interface state density or as the decrease in the series resistance in the n^+ contacts by thermal quenching.

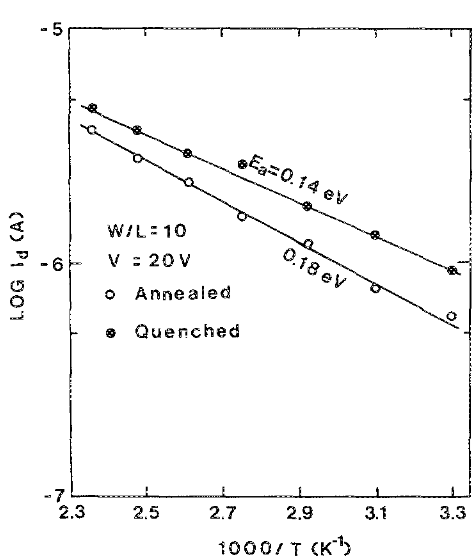

FIG. 3. Effect of rapid quenching on the temperature of the drain current when the gate voltage is 20 V.

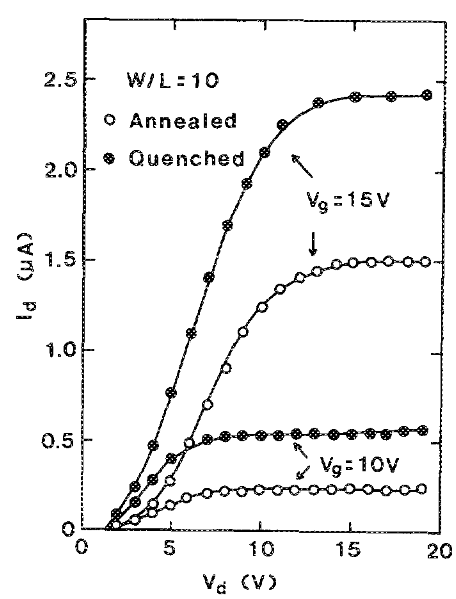

FIG. 5. Effect of rapid quenching on the drain current vs source drain voltage for gate voltages of 10 and 15 V.

The thermal equilibration process in doped and undoped a-Si:H is essentially explained as the motion of hydrogen in the material even though the microscopic picture is still controversial.[9] The diffusion coefficients of hydrogen in doped and undoped a-Si:H have been measured, and the diffusion process has been much discussed.[10] However, the motion of hydrogen in amorphous silicon nitride prepared by plasma decomposition has not been studied so far, and the hydrogen bonding in the interface between silicon nitride and amorphous silicon is still the problem to clarify.

From our experimental results, the hydrogen bonding in the interface appears to change by quenching so that the density of interface states decreases. We can determine the change in the interface state density from the shift in the threshold voltage and the capacitance of the silicon nitride used in our experiment. The interface state density decreases by 1.1×10^{11} cm^{-2}. This calculation is based on the assumption that the density of bulk gap states does not change by quenching. Therefore, the value is somewhat underestimated.

The active dopant concentration and compensating dangling bond density in doped a-Si:H depends on the temperature at above the thermal equilibrium temperature. In the interface region between the silicon nitride and amorphous silicon, the state density depends on the temperature above the thermal equilibrium temperature, which appears to be in the range of 180–200 °C because the on conductance increases very slightly when the TFT is quenched at 180 °C. The thermal equilibrium temperature of the interface region between the silicon nitride and amorphous silicon is close to that of undoped a-Si:H.

Another explanation is possible on the increase of the on conductance. The decrease in the gate to channel series resistance caused by the increase of conductivity of n^+a-Si:H upon rapid cooling can increase the on conductance. The relatively high value (5.4 V) of the threshold voltage for our device may be due to severe current crowding. The thermal equilibrium changes in the n^+ contacts and/or the bulk a-Si:H will affect the effective source series resitance causing a change in the threshold voltage. However, for a TFT with a threshold voltage of 3.1 V, we observed a decrease of the threshold voltage by 0.5 V upon rapid quenching from 230 °C. This result indicates that our observations are mainly due to the changes in the defect densities.

From the repeated experiments, we found that the changes produced by rapid quenching are completely reversed by heating at 230 °C for 1 h and then slow cooling to 30 °C. Further work is needed to clarify the origin of the thermally induced metastable effect in amorphous silicon thin-film transistors.

In summary, we find that rapid quenching produces changes in the field-effect conductance in amorphous silicon thin-film transistor which are completely reversed by annealing. Rapid quenching produces a decrease in the off conductance and an increase of the on conductance. The increase of the on conductance can be explained as the decrease of the interface state density between amorphous silicon and the silicon nitride or as the decrease in the series resistance in the n^+ contacts, and the decrease of the off conductance is due to the increase of the dangling bonds in a-Si:H.

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[1]T. Sunata, K. Miyake, M. Yashi, Y. Murakami, Y. Ugai, J. Tamamura, and S. Aoki, IEEE Trans. Electron Devices **ED-33**, 1218 (1986).
[2]M. J. Powell, B. C. Easton, and D. H. Nicholls, J. Appl. Phys. **53**, 5068 (1982).
[3]A. R. Hepburn, M. J. Marshall, C. Main, M. J. Powell, and C. Van Berkel, Phys. Rev. Lett. **56**, 2215 (1986).
[4]Z E. Smith, S. Aljishi, S. Slobodin, V. Chu, S. Wagner, P. M. Lenahan, R. R. Arya, and M. S. Bennett, Phys. Rev. Lett. **57**, 2450 (1986).
[5]Z E. Smith and S. Wagner, Phys. Rev. B **32**, 5510 (1985).
[6]Z E. Smith, S. Aljishi, D. S. Shen, V. Chu, D. Slobodin, and S. Wagner, *AIP Conference Proceedings* (American Institute of Physics, New York, 1987), Vol. 157, p. 171.
[7]D. L. Staebler and C. R. Wronski, Appl. Phys. Lett. **31**, 292 (1977).
[8]T. J. McMahon and R. Tsu, Appl. Phys. Lett. **51**, 412 (1987).
[9]R. A. Street, M. Hack, and W. B. Jackson, Phys. Rev. B **37**, 4207 (1988).
[10]R. A. Street and J. Kakalios, Philos. Mag. B **54**, L21 (1986).