Threshold Voltage Control of a-Si TFT by Delta Doping of Phosphorous

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Keywords : delta doping, threshold voltage

Abstract

Delta doping method can separate the threshold voltage control region from the charge transport region in a-Si TFT, whereby the threshold voltage of a TFT could be modified. Threshold voltage could be changed by delta doping, while field effect mobility was estimated to be 80% of that of standard TFT.

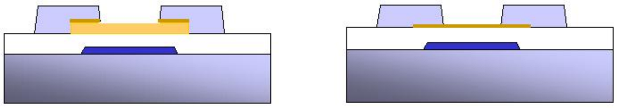
1. Introduction

Amorphous silicon thin film transistor (a-Si TFT) is used for simple gate driver circuits eliminating gate driver IC's as well as active matrix devices for LCD's. Also active matrix organic light emitting display(AMOLED) is another probable application of a-Si TFT due to its excellent uniformity.[1] However, device stability of a-Si TFT under bias temperature stress is the biggest concern[2,3]. If threshold voltage of a-Si TFT can be modified, bias stress could be well designed to minimize threshold voltage shifts.

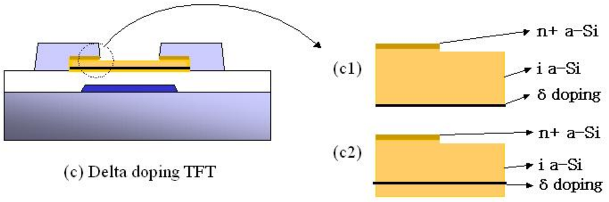
In amorphous silicon, donor states of P^{4+} move Fermi level position near to the conduction band, while P^3 bonding configuration increases band tail states resulting in poor electron mobility. This makes threshold voltage modification by channel doping ineffective, where a-Si TFT with negative threshold voltage would give a benefit for AMOLED. We examined delta doping technique to modify threshold voltage of a TFT as a normally-on device.

2. Experimental

A vertical structure of a standard a-Si TFT is shown in Fig.1. Silicon nitride (a-SiNx) was deposited by plasma enhanced chemical vapor deposition(PECVD) as a gate dielectric. The thickness of a-SiNx was 400 nm. A-Si and n-type a-Si was deposited subsequently in the same PECVD chamber. Thickness of a-Si and n+ a-Si was 170 nm in total. A-Si or n+ a-Si was deposited with gas pressure of 1.5 Torr, substrate temperature 350 deg.C. SiH4 gas was supplied in H2 carrier gas with dilution rate of 1:4 for either intrinsic or n+ a-Si layer. A-Si island was defined by photolithography, Source/drain metal layer of molybdenum (Mo) was deposited by sputtering, followed by photolithography to make source/drain electrodes. After defining S/D electrodes, n+ a-Si layer existing between source and drain electrodes was removed by dry etching. Then 200nm of a-SiNx was deposited as a passivation layer.



(a) Standard TFT (b) n-type channel TFT



(c) Delta doping TFT

Fig.1. TFT structures for experiments (a) normal standard TFT, b) Test Device with n-type channel, c1) TFT with N-δ-i Structure, c2) TFT with N-i-δ-i structure)

Three different TFT structures were fabricated.(Fig.1) As a standard device, ordinary a-Si TFT was fabricated. Also n-type channel TFT(Fig.1.b) was fabricated to compare with a standard TFT(Fig.1.a) and delta doping TFTs. Two kinds of delta doping structure were fabricated as illustrated in Fig.1(c1 and c2). Type c1(N-δ-i structure) has delta doping layer(δ) at the interface of gate dielectric(aSiNx) and a-Si, and type c2(N-i-δ-i structure) has delta doping layer inside a-Si layer with various buffer thickness of 10nm to 40nm.

For type c1 test(N–δ–i Structure), doping concentration was changed in the range 0.125% to 1.0% of PH3 / SiH4 ratio. The thickness of delta doping layer(δ) were 5 nm, 10 nm, 20 nm and 40 nm.

For type c2 test(N–i–δ–i Structure), doping concentration and thickness of delta doping layer was fixed as 0.25% and 10nm, respectively.

The characteristics of TFTs were measured by hp4156 semiconductor parameter analyzer.

3. Results and discussion

To check field effect modulation of n+ a-Si, type b TFT(Fig.1.) was evaluated. The n+ a-Si channel showed little conductance modulation even with a highest gate voltage of 30 V. Channel conductance modulation by gate electric field for n+ a-Si channel TFT is less than 3% of neutral conductance of n+ a-Si layer. It showed ohmic behavior with linear I_{DS}-V_{DS} curve regardless gate bias voltages. The thickness of n+ a-Si channel was 10 nm. N+ a-Si layer is nearly metallic state where Fermi level is almost pinned.

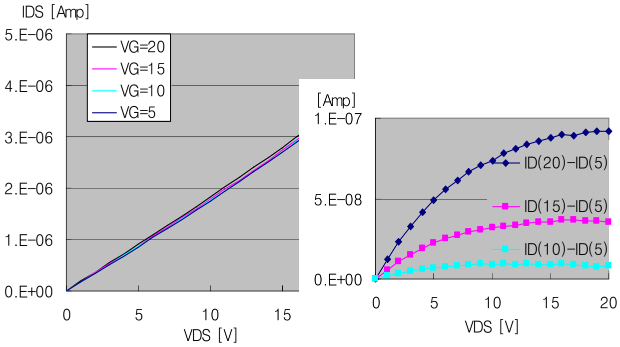


Fig.2. Characteristics of a TFT with n+ a-Si Channel. Conductance Modulation by Gate Bias Occurs about 3% or Less.

N–δ–i TFT

In analogy to channel doping of field effect transistor(FET) of crystalline Si, delta doping layer of n+ a-Si was inserted between gate dielectric and amorphous silicon layer. (Fig.1. type c1) Transfer characteristics are shown in Fig.3.

As dopant concentration in the delta doping layer is increased, threshold voltage shifts towards negative direction, subthreshod swing increases and on-current decreases. Electron mobility degrades abruptly as soon as phosphorous dopants are added. (Fig.4.)

Delta doping layer at the interface can move Vth negatively, on the other hand electron mobility degrades to 25% because of increased density of band tail states near Fermi level of n+ a-Si.

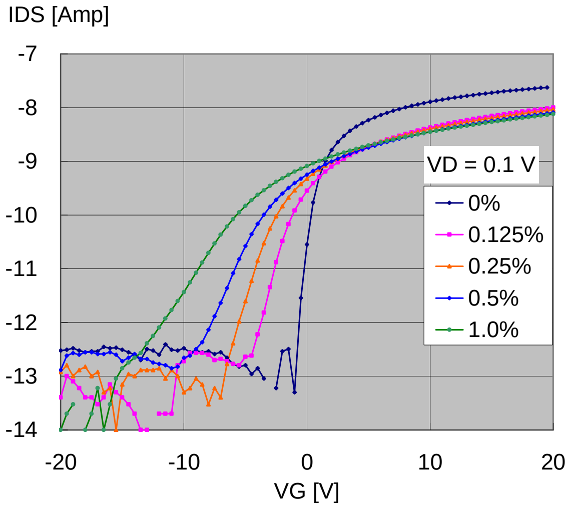


Fig.3. Transfer Characteristics of N–δ–i Structure with Various Doping Concentration

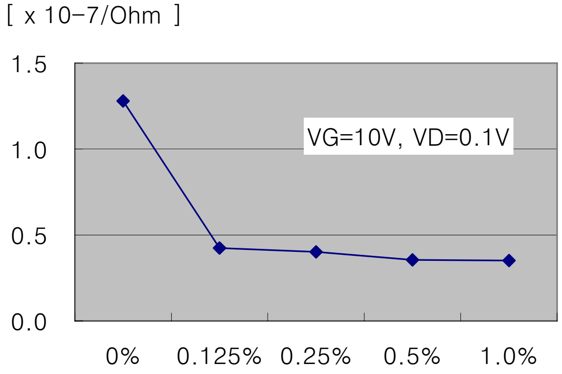


Fig.4. Channel Conductance of N–δ–i Structure with Various Doping Concentration of δ Layer (VG=10V, VD=0.1V)

N–i –δ–i TFT

Fig.5. shows that electron mobility could be recovered by inserting a buffer layer, while the threshold voltage be changed by a delta doping layer. From conductance change with buffer layer thickness, we can estimate the effective channel of a-Si layer is limited within around 40nm depth. (Fig.6.) It is notable that delta doping layer now contributes to channel conductance in case buffer layer is thicker than 40 nm.

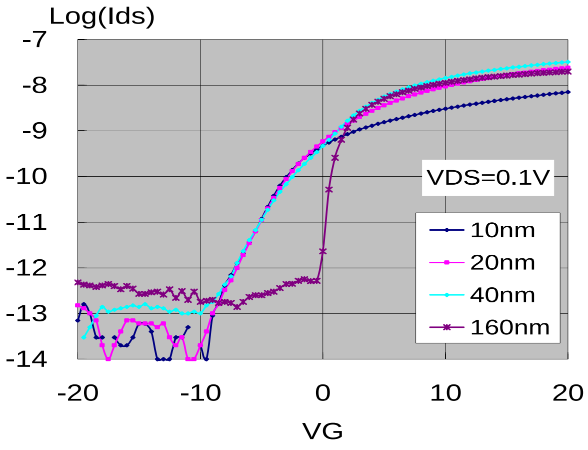


Fig.5. Transfer Characteristics of N-i-δ-i Structure with Different Buffer Layer Thickness (VDS=10V, Doping Concentration = 0.25%)

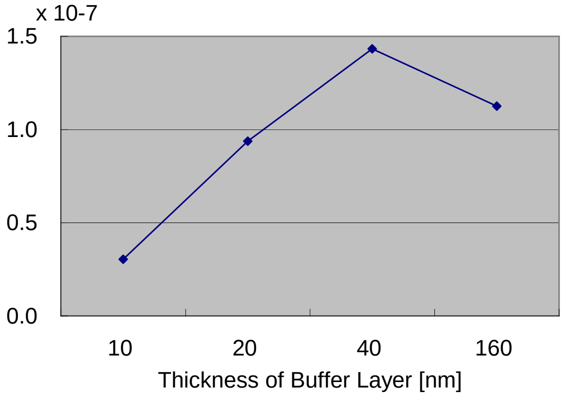


Fig.6. Channel Conductance of N–i–δ–i Structure with Buffer Layer Thickness (VG=10V, VD=0.1V)

4. Summary

By delta doping method threshold voltage could be modified with the on-current almost similar to a standard TFT. This method could be well used for AMOLED based on a-Si TFT whereby normally-on TFT could be used to design a pixel circuit free of threshold voltage shift. A threshold voltage could be changed by dose control of delta doping, where a dose can be decided by the thickness and concentration of the delta doping layer.

5. References

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