Switching Characteristics of a-ITZO Based Thin Film Transistor

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***Abstract*- This study examines the thickness of SiO_2 dielectric materials in a-ITZO TFT using a numerical simulation performed by the Silvaco Atlas software. The switching characteristics of the device are investigated. The thickness of dielectric oxide material varies significantly between 180 nm and 50 nm, and device characteristics are studied. The significant results as threshold voltage of -0.65 V, mobility of 16.51 $cm^2V^{-1}s^{-1}$, sub-threshold swing 0.049 V/dec and I_{on}/I_{off} of $1.43x10^{11}$ is obtained in simulation of ITZO TFT for 50 nm optimum SiO_2 dielectric material thickness. The switching characteristics of the device are also affected by the use of high k dielectric material. The simulation results for an a-ITZO TFT(high k dielectric material) include a V_T of -0.42 V, μ of 31.15 $cm^2V^{-1}s^{-1}$, S of 0.034 V/dec, and I_{on}/I_{off} of $1.71x10^{10}$.**

Keywords- a-ITZO TFTs, Dielectric thickness, Dielectric materials, high k materials

1. INTRODUCTION

Amorphous oxide based semiconductor is one of the excellent materials for fabrication of the thin film transistor (TFT). The switching speed, processing temperature, uniformity, threshold voltage, and on-off current ratio are significant parameters to consider while selecting material for thin film transistors. Thin film transistor is promising device for the flat panel display or display application. Resolution is one of the key parameter for the display devices. a-Si and Poly-Si are incapable of producing high resolution displays due to their mobility, high processing temperature, and electrical characteristics [1].

Zno, IGZO, SnO_2, and GaZnO are suitable oxide materials for a thin-film transistor. Several researchers have extensively studied IGZO-based TFT because to its superior electrical properties, but IGZO materials have disadvantages such as element scarcity and indium toxicity [3]. ITZO is a viable alternative to IGZO because to its mobility and excellent stability [2].

SiO_2 is the gate oxide dielectric material that is most often used in TFT. The performance of the device is depends on the gate capacitance per unit area. The thickness of the gate oxide material is decreased to increase the performance of the device. Due to the rise in tunnelling gate leakage current, the thickness of the dielectric material cannot be reduced beyond a certain point. Consequently, the use of high-k dielectric oxide gate materials is an additional method to enhance the performance of the device. [4]. There are some of high k dielectric material are available for the gate oxide material as given in figure 1.

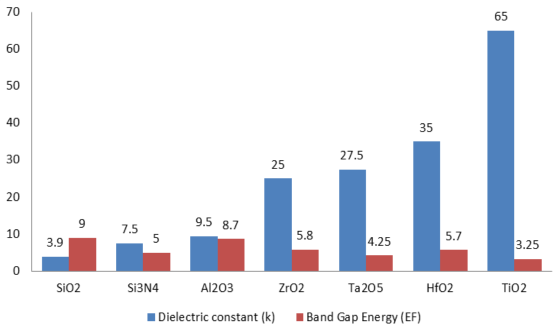

Figure 1: Dielectric constants and band gap energies for various dielectric materials

As given in Figure 1, the material with a low dielectric constant has high band gap energy, while the material with a high dielectric constant has lower band gap energy. There is a tradeoff between dielectric constant and band gap energy. HfO_2(k=35) is a good choice as a in place of SiO_2 (k=3.9) to improve the device performance.

This main goal of this study's to evaluate the electrical properties of the TFT and examine the variation of the thickness of the SiO_2 gate oxide. Also, the author investigates the impact of high dielectric constant material in lieu of SiO_2 gate oxide.

2. DEVICE STRUCTURE

In this research article a simplified cross section bottom gate structure adopted. The bottom gate Silivco structure simulated and analysis the effect of thickness of SiO_2 gate oxide material and obtain significant electrical characteristics to improve the device performance [4]. To simulate the movement of carries through the structure, Atlas applies the Poisson's and continuity equations to this grid.

The device structure of the ITZO based TFT as illustrate as shown in figure 2.The active channel layer of ITZO is 20nm and the dielectric oxide material (SiO_2) thickness is varied 50nm to 180 nm to obtain significant results. The metal contacts for the source, drain, and gate terminals are made of the Mo (molybdenum) material.

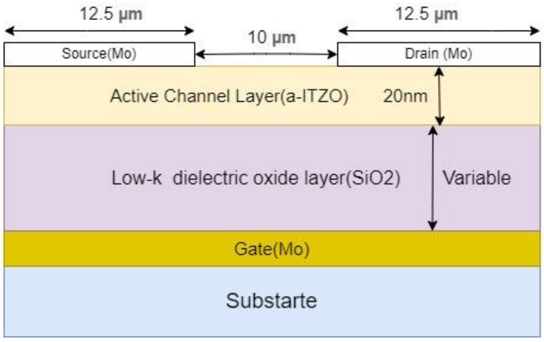

Figure 2: Device structure of a-ITZO TFT

3. SIMULATION RESULTS

Figure 3 illustrates the impact of a reduction in dielectric thickness in the transfer I_{DS}-V_{GS} characteristics of an a-ITZO TFT. The author analyzed the effect of dielectric thickness at the constant drain to source voltage V_{DS}=6V. The thickness of the SiO_2 gate dielectric T_{SiO2} decreased from 180 nm to 50 nm, and the results are presented in Table 2. There are certain electrical characteristics such as threshold voltage, field effect mobility, sub-threshold swing, ON current or saturation current and OFF current or leakage current and the ratio of the ON and OFF currents.

The threshold voltage is significantly improved from -1.88 V to -0.65 V; this is as a result of the increased slope of the linear extrapolation line that has the highest slope of the transfer characteristics in the linear plot. [1].

Mobility is significantly increased from 4.24 $cm^2V^{-1}s^{-1}$ to 16.54 $cm^2V^{-1}s^{-1}$ due to reduced dielectric oxide material thickness by 180 nm to 50 nmFor switching applications, devices must have a high degree of mobility. The sub-threshold swing is significantly decreased from 0.81 V/dec to 0.049 V/dec. As the thickness of the dielectric oxide material decreased from 180 nm to 50 nm, the ON/OFF current ratio improved continuously, from $1.63x10^9$ to $1.43x10^{11}$.Figure 4 shows output I_{DS}-V_{DS} characteristics of the ITZO TFT at constant gate to source voltage V_{GS}=20V.The significant results obtain at 50 nm oxide thickness.

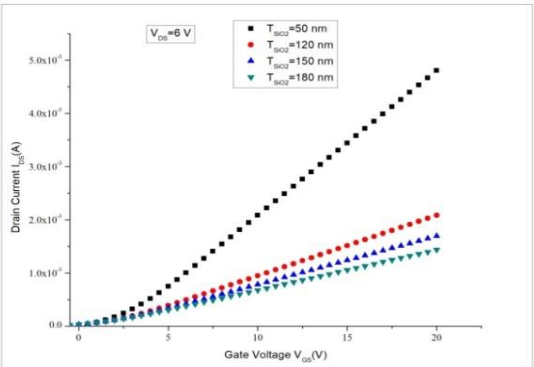

Figure 3: Transfer characteristics (IDS-VGS) for different dielectric thickness

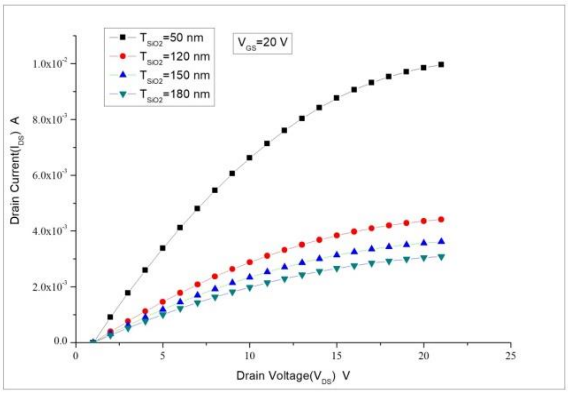

Figure 4: Output characteristics (IDS-VDS) for different dielectric thickness

The thickness of the gate dielectric is the most important characteristic for determining the performance of the device. The thickness of the gate oxide is reduced, hence enhancing the gate capacitance per unit area and improving the device's performance. A limiting value of the thickness of the gate dielectric improves the performance of the device up to the limit, after which the device's performance degrades. Due to the rise in tunnelling gate leakage current, SiO_2 cannot offer appropriate reliability beyond the limiting value of gate dielectric thickness. The transistor performance degraded due to increase in power consumption in the device [1,7]. To enhance the electrical characteristics of the device, the TFT simulates using a high k dielectric material instead of a low k dielectric material. The table 2 summaries numerous data and concludes that the electrical properties are enhanced when the high k dielectric material HfO_2 is substituted for the low k dielectric material SiO_2. Figure 5 illustrates the impact of various dielectric materials on the transfer I_{DS}-V_{GS} characteristics of the ITZO TFT. The author analyzed the dielectric oxide material as such as SiO_2,Si_3N_4 and HfO_2 for the 150 nm thickness. The different gate dielectric materials affect the electrical characteristics of the TFT as shown in table 2.The threshold voltage is significantly improved from -1.60 V to -0.42 V. The mobility is significantly increased from 5.18 $cm^2V^{-1}s^{-1}$ to 31.15 $cm^2V^{-1}s^{-1}$, when dielectric oxide material move from low dielectric (SiO_2) to high dielectric (HfO_2).The sub-threshold swing is significantly decreased from 0.51 V/dec to 0.034 V/dec. The ratio of ON /OFF current is improved continuously from $0.430x10^{10}$ to $1.71x10^{10}$ when dielectric oxide material move from low dielectric (SiO_2) to high dielectric (HfO_2).

The illustration in Figure 6 shows the output characteristics I_{DS}-V_{DS} of the a-ITZO TFT with oxide thickness 150 nm at V_{GS}=20V for various dielectric constants.

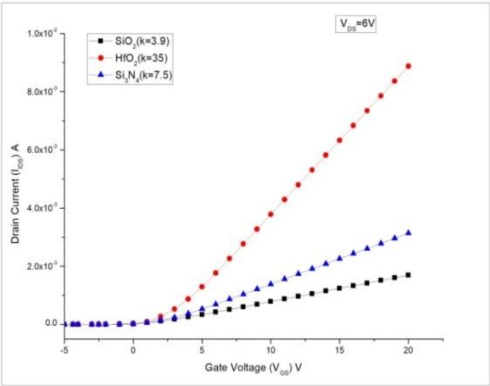

Figure 5: Transfer characteristics (IDS-VGS) for different dielectric materials

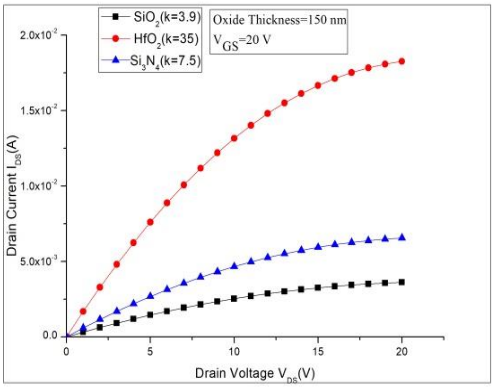

Figure 6: Output characteristics (IDS-VDS) for different dielectric materials

Table 1: Effect of gate dielectric thickness on the electrical characteristics at VDS=6V

T_{SiO2} (nm)	V_T(V)	μ_{FE} ($cm^2V^{-1}s^{-1}$)	S (V/dec)	I_{on}(A)x10^{-3}	I_{off}(A)x10^{-13}	I_{on}/I_{off} x10^9
180	-1.88	4.24	0.81	1.43	8.80	1.63
150	-1.60	5.18	0.51	1.69	3.94	4.30
120	-1.31	6.6	0.079	2.09	2.18	9.57
50	-0.65	16.51	0.049	4.81	0.335	143

Table 2: The electrical characteristics of the TFT are improved for the high k dielectric material.

Dielectric material T=150nm	V_T (V)	μ_{FE} ($cm^2V^{-1}s^{-1}$)	S (V/dec)	I_{on}(A) x10^{-3}	I_{off}(A) x10^{-14}	I_{on}/I_{off} x10^{10}
SiO_2	-1.60	5.18	0.51	1.69	0.394	0.430
Si_3N_4	-0.92	10.38	0.035	3.13	6.71	4.67
HfO_2	-0.42	31.15	0.034	8.88	0.52	1.71

4. CONCLUSION

The effect of gate oxide thickness on an a-ITZO TFT was simulated using Silvaco Atlas in this study. When the thickness of the dielectric SiO_2 decreased, the device's electrical characteristics improved. The capacitance of the device is also improved and performance of device significantly improved. Quantum effect causes a reduction in dielectric thickness, which leads to current leakage and an increase in power dissipation, both of which degrade the transistor's performance [8, 9]. Using high k dielectric materials, such as HfO_2 and Si_3N_4, is the optimum approach to improving the performance of the devices. The electrical properties of the TFT, such as threshold voltage, mobility, subthreshold voltage, and I_{on}/I_{off} current, are enhanced when a high-k material is utilised as gate oxide layer.

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