ISSN 2348 – 8034
Impact Factor- 3.155

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

STUDY AND SIMULATION OF A FUNCTIONAL TFT FOR THE DEVELOPMENT OF X-RAY SENSOR

Priyanka K B[*1], Dr. B S Satyanarayana[2] and Dr. S C Prasanna Kumar[3]
[*1]M.Tech IVth Sem Dept of E&I RVCE,Bangalore, India
[2]Principal RVCE, Bangalore, India
[3]Head of the Department, Dept of E&I RVCE, Bangalore, India

ABSTRACT

Advanced imaging is emerging as an area of increased technological importance in domains including Medical, Aerospace, Security and Non - Destructive Test (NDT). The medical diagnostic X-ray is currently the most common medical procedure. Most new innovations appear in medical imaging where the emphasis is on maximizing imaging quality and minimizing patient dose. An improvement in image quality and dose utilization is an added advantage in flat panel X-ray technology. After all, an ideal digital X-ray imaging system is needed which offers portability. Even though these flat panel X-ray detectors are portable, they seem to be of larger size when it is compared with a compact X-ray source which is of smaller size than these flat panel detectors. However, it is still possible to reduce the size and weight of the X-ray detectors further to make it a pocket sized which could be achieved by using flexible substrates, so that the detectors would be carried anywhere making the imaging easy. Hence, in this project, it is hoped that such small sized devices can be simulated and would try to fabricate the product with the materials being grown in the RVCE lab.

Keywords- *X-ray, a-Si:H (Hydrogenated amorphous Silicon) Thin Film Transistor, Silvaco Tool, Density of defect states, Transconductance.*

I. INTRODUCTION

The field of flexible electronics began the advent of space exploration. Advanced imaging is emerging as an area of increased technological importance in domains including Medical, Aerospace, Security and Non - Destructive Test (NDT). Conventionally, snapshot images or radiographs were in use in order to obtain the image using film/screen system. But it is time consuming and furthermore image quality is not good. X-ray image intensifiers are usually avoided due to its bulkiness and extremely expensive since the real time aspects of the image are also important. Digital Radiography (DR) is the key advancement in imaging. This made the imaging process easy since it is able to collect, store and analyze more information at a faster rate. This makes the images available at different places as well as it is transmitted over long distances in real time. Digital radiography also offers computer assisted diagnosis and are much less costly than their analog part, which is also an easily approachable process. a-Si:H (Hydrogenated amorphous Silicon) TFTs(thin Film Transistors) are a special kind of field effect transistors which finds their basic application in liquid crystal display and flexible electronics. Also TFTs are most suitable for display and sensor technologies. It is also well known as a switching device in active matrix arrays and in large area electronics. Depending on the type of the application, there are different requirements on device performance. TFTs are flexible, lightweight, shock resistant, and relatively inexpensive which are expected to be used in wide range of applications including large, economic, high-resolution displays, wearable computers, that’s why they are called as the fundamental building blocks for state-of-the-art microelectronics.

II. SPECIFICATIONS AND TOOLS USED

A. *Specifications*

The basic operation of the a-Si TFT can be understood via a band diagram similar to that of the c-Si MOS field effect transistors. The main difference between the c-Si and a-Si is that the space charge in a-Si TFT is not ionized doping atoms, but filled with mid gap trap states and localized band tail states. At zero gate bias, the a-Si TFT is more likely close to the flat band condition with the mid gap having Fermi level close to it. The drain-source current in the device, at this point, is dominated by hopping conduction at the Fermi level, which is typically low because hydrogen passivation of mid gap defects. This is often referred to as the “off current” (I_{off}) of the TFT. When the gate voltage is increased, the conduction band and valence band bend downwards and the Fermi level moves through the gap states. The space charge is dominated by filled gap states, and the occupancy of the band tails increases exponentially with increase in gate bias. When a small amount of band tail electrons get thermally excited above the mobility edge, the drain current increases. Consequently the drain-source current also has an exponential dependence on increasing gate voltage bias. This is referred to as the sub-threshold region. When the gate voltage is increased further, the Fermi level crosses a threshold where the space charge in the tail states exceeds that of the gap states and the total space charge increases linearly with the gate voltage. After this point, the free electrons above the mobility edge, and therefore the drain-source current, also increase linearly with the applied gate-source voltage. The gate voltage at which this transition occurs is called the "threshold voltage" (V_T) of the TFT. The drain-source current beyond for gate voltage greater than V_T is called the "on current" (Ion). The typical drain-source current vs gate-source voltage transfer characteristics of an a-Si TFT is shown in Figure 1, along with the various parameters discussed above.

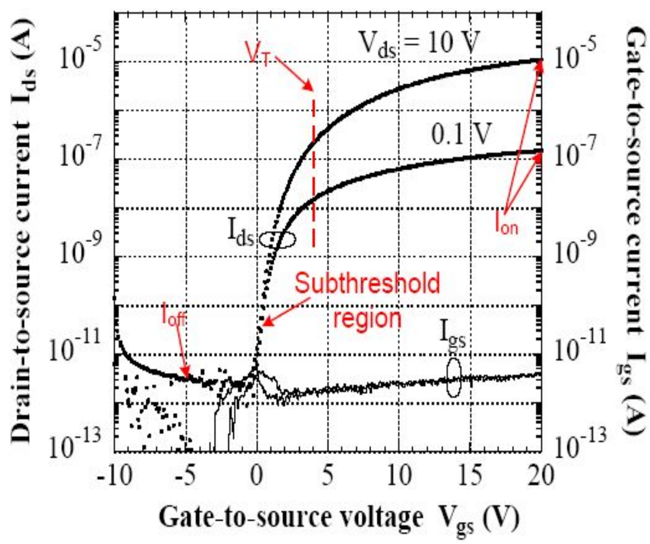


Fig. 1 Typical drain-source current vs gate source voltage transfer characteristics of an a-Si TFT.

In a-Si TFTs the field effect modulation of free electron density is similar to that of the c-Si MOs transistors. Similarly, its electrical characteristics can also be described with the conventional MOS equations:

$I_{DS,\ Saturation} = (V_{GS}-V_T)^2$

$I_{DS,\ Linear} = (V_{GS}-V_T-V_{DS}/2)\ V_{DS}$

Where μ_{FE} is the effective field-effect mobility, V_T is the effective threshold voltage, C_{SiNx} is the capacitance of the gate dielectric SiN_x, W is the channel width and L is the channel length. V_{DS} is the drain-source voltage bias and V_{GS} is the gate-source voltage bias. By performing least-square linear fitting of the drain-source current to the gate-source voltage in the linear curve and taking square root of the drain-source current to the gate-source voltage in saturation region (Figure 2) of the device transfer characteristics will help to extract the effective field effect mobility as well as threshold voltage. As it is, slope of the fit (transconductance) can be used to calculate the mobility and extrapolation of the fit gives the threshold voltage.

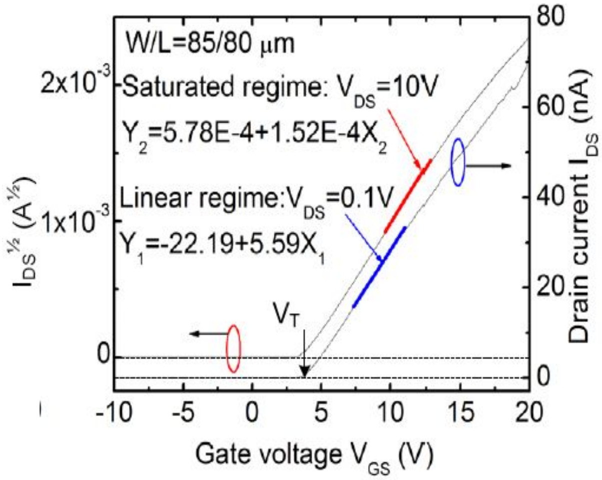


Fig. 2 Least-squares linear fits of the linear and saturation drain-source current vs gate-source voltage curves.

Performance metric	Typical Value
Mobility-μ_{FE} (cm^2/Vs)	0.5 – 1
Threshold voltage-V_T (V)	1 – 3
Subthreshold slope (mV/dec)	300 – 1000
Off current-I_{off} (pA)	0.1 – 1
On/Off (current) ratio	10^5-10^7

Table. 1 Typical values for a-Si TFT performance metrics

B. Tools Used

Silvaco is the Electronic Design Automation software (EDA) and TCAD process and device simulation software. It is the tool used for simulation purpose. It has two modules such as, Atlas (device simulation work) Athena (Process simulation work). Atlas is one of the silvaco module which helps for the simulation of optical, electrical and thermal behavior of the semiconductor devices. Also it provides physics based modular and extensible platform to analyze DC, AC and time domain responses for all semiconductor based technologies in 2D and 3D. TFT is an Atlas module that simulates disordered material systems. TFT enables to define an energy distribution of defect states in the band gap of semiconductor materials. This is necessary for the accurate treatment of the electrical properties of such materials as poly-silicon and amorphous silicon. Athena is nothing but the process simulation framework which involves: diffusion, ion implantation, oxidation, physical etching and deposition, lithography, stress formation and silicidation in semiconductor industry.

III. NUMERICAL MODELING

Simulation of amorphous silicon thin film transistor (a-Si:H) can be done using the Silvaco tool. The procedure for complete simulation of a-Si TFT includes process simulation with the help of ATHENA for creating the structure of a-Si TFT and device simulation using ATLAS for modeling the parameters. Defect statement is the key command in TFT simulation [9]. It is used to define a continuous density of trap states in the silicon and the relevant trapping cross sections. Since a-Si has a disordered structure it consists of defect states, where in, an energy distribution of localized states in the band gap of a-Si:H has to be implemented to consider the trapped charge in the gap states. The

ISSN 2348 – 8034
Impact Factor- 3.155

density of state profile of a-Si:H is well known to have exponential distributions of conduction and valence band-tail states due to the lattice disorder, and also to have Gaussian distribution of deep states (or defect states) originated from the dangling bonds.

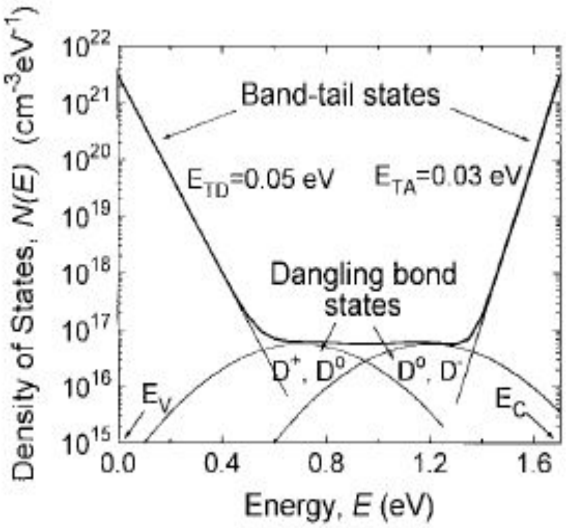
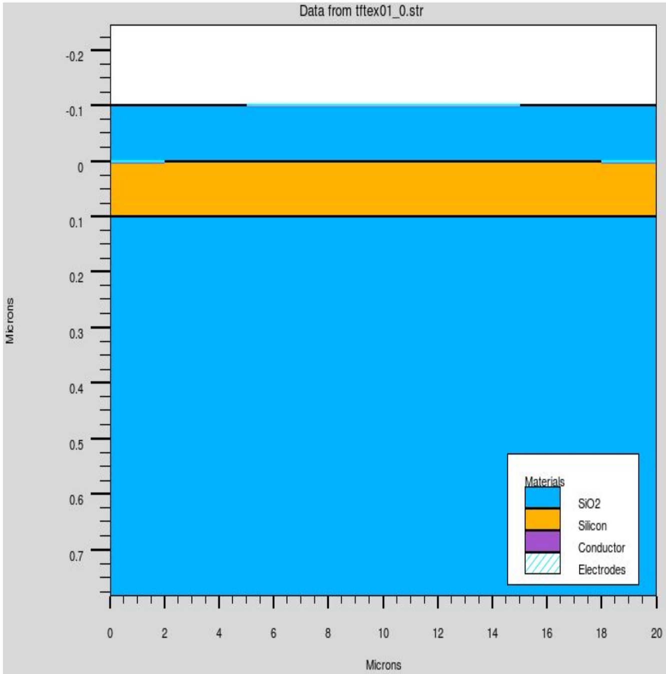
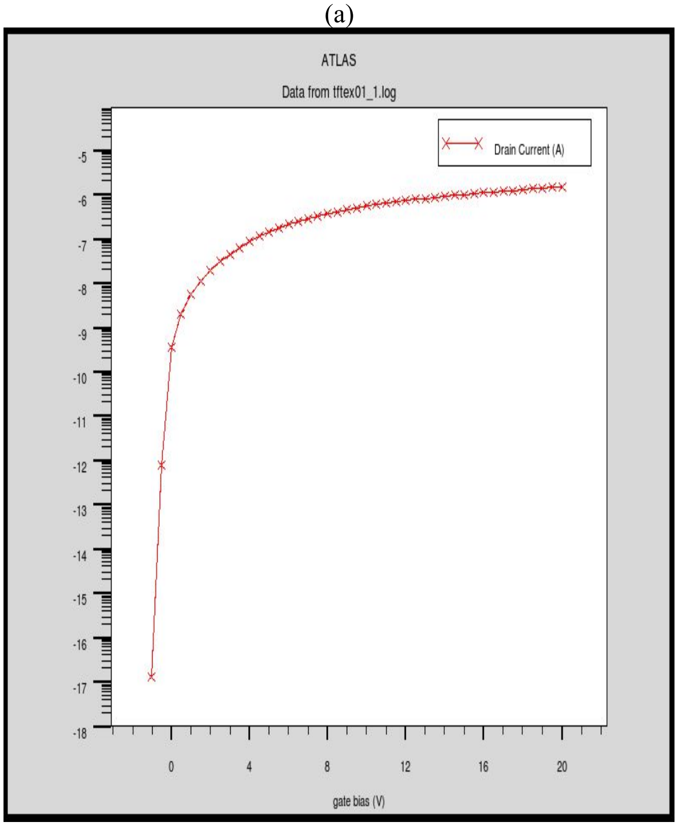


Fig. 3 A model density of states in a-Si:H used in the simulation: D^-, D^o, D^+ are the defect states due to dangling bonds. D^-, D^o substantially means the electron trap states, D^o, D^+ means the hole trap states respectively, in this calculation.

The purpose of the work is to explore the physical parameters responsible for the changes in the transfer characteristics as well as I_D (drain current) vs V_{GS} (gate-source voltage) curve of the a-Si TFT. The properties of n-channel TFTs can be determined using acceptor like states. In order to study the influence of the acceptor-like states on drain current, various simulations with different values of WTA has been performed. The values are 0.017, 0.020, 0.025, 0.030, 0.035, 0.040 and 0.045 eV. The simulation uses Gummel or Newton method for solving the unknown parameters. Higher value of WTA indicates the wider acceptor-like tail and defines the properties of amorphous silicon, while lower value of WTA indicates the narrow acceptor-like tail and defines the properties of polycrystalline silicon [18]. For the remaining material parameters, default values are used such as: NTA=$1x10^{21}$, NTD=$1x10^{21}$, NGA=$1.5x10^{15}$, NGD=$1.5x10^{15}$ $cm^{-3}eV^{-1}$ and WTD=0.049, WGA=0.15, WGD=0.15 eV. The donor-like states are kept same for all simulations. Higher value of WTA results in higher simulated density of acceptor-like states. Acceptor-like states are easily filled by electrons when it is having lower density of states by applying positive gate voltage which leads to higher drain current and transconductance (ratio of change in drain current to the change in gate voltage over a defined, arbitrarily small interval). Higher gate voltage is required to fill the acceptor-like states for the materials having higher density of acceptor states. Hence, to obtain optimal drain current, higher gate voltage is required. So it can be concluded as, the density of acceptor-like states is higher in a-Si:H than in nc-Si:H and poly-Si:H. Following are few simulation results performed for a-Si:H TFT using Silvaco tool.

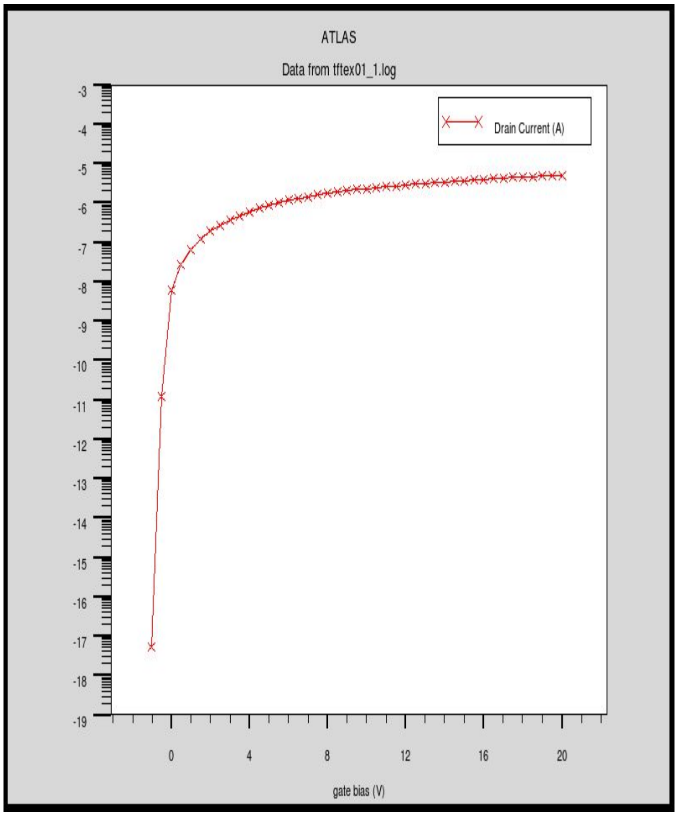


(a)

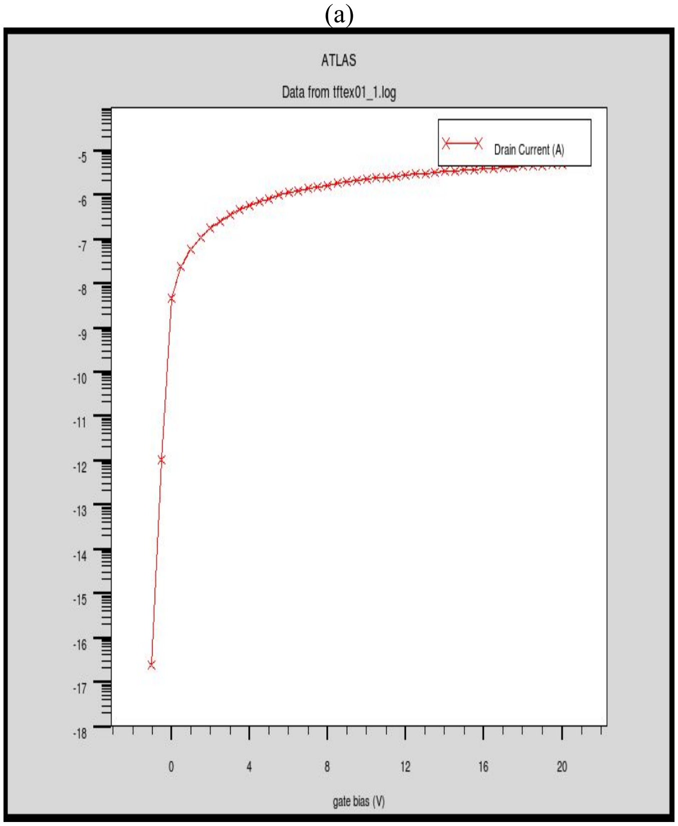


(b)

Fig. 4 Structure of a-Si:H TFT (a) and a plot of drain current(I_D) vs gate-source voltage (V_{GS}) with gate voltage varied from 0v-20v (b).



(a)



(b)

Fig. 5 Plot of drain current (I_D) vs gate-source voltage (V_{GS}) with WTA=0.020 (a) and WTA=0.025(b).

IV. CONCLUSION

Device simulation shows that the acceptor-like defect states are filled at quite higher gate voltages in a-Si:H TFTs than the nc-Si:H TFTs, but with the same threshold voltages. The typical shape of transconductance curve for a-Si:H can be obtained before acceptor-like states are filled. So it is concluded that higher gate voltage is required in order to obtain the optimal drain current from TFT for further signal conditioning process, which in turn leads to better performance of a-Si:H TFT device in a sensing array.

REFERENCES

1. *Anchal Sharma, Charu Madhu, Jatinder Singh , "Performance Evaluation of Thin Film Transistors: History, Technology Development and Comparison: A Review ", International Journal of Computer Applications (0975 – 8887) Volume 89 – No 15, March 2014*
2. *Yifei Huang , "Novel Approaches To Amorphous Silicon Thin Film Transistors For Large Area Electronics", A Dissertation Presented for Doctor Of Philosophy, Princeton University November 2011.*
3. *Jackson Lai, "Active Matrix Flat Panel Bio-Medical X-ray Imagers", Doctor of Philosophy In Electrical and Computer Engineering Waterloo, Ontario, Canada, 2008.*
4. *Powell MJ, van Berkel C, Franklin AR, Deane SC, Milne WI. Defect pool in amorphous-silicon thin-film transistors. Phys Rev B 1992;45:4160–70.*
5. *M. J. Yaffe and J. A. Rowlands, "X-ray detectors for digital radiography," Phys. Med. Biol., vol. 42, pp. 1–39, 1997*
6. *J. T. Rahn, F. Lemmi, J. P. Lu, P. Mei, R. B. Apte, R. A. Street, R. Lujan, R. L. Weisfield, and J. A. Heanue, "High resolution X-ray imaging using amorphous silicon flat-panel arrays," IEEE Trans. Nucl. Sci., vol. 46, no. 3, pp. 457–461, 1999.*
7. *E. Kotter and M. Langer, "Digital radiography with large-area flat-panel detectors," Eur. Radiol., vol. 12, no. 10, pp. 2562 2570, 2002.*
8. *Atlas Users Manual, Device Simulation Software.*
9. *R.A. Street, Hydrogenated Amorphous Silicon, Cambridge University Press, 1991.*
10. *Michael Hack, Michael S. Shur, Fellow, Ieee, And John G. Shaw, "Physical Models for Amorphous-Silicon Thin-Film Transistors and Their Implementation in a Circuit Simulation Program", IEEE Transactions On Electron December 1989.*
11. *Karim Khakzar and Ernst H. Lueder, Fellow, IEEE, "Modeling of Amorphous-Silicon Thin-Film Transistors for Circuit Simulations with SPICE", IEEE Transactions On Electron Devices, Vol. 39, No. 6, June 1992.*
12. *Richard L. Weisfield dpiX, LLC; 3406 Hillview Ave., Palo Alto, CA 94034-1345 USA, "Amorphous Silicon Tft X-Ray Image Sensors.*
13. *Richard L. Weisfield*, Mark Hartney, Roger Schneider, Koorosh Aflatooni, Rene Lujan dpiX, LLC, Palo Alto, CA 94304, "High Performance Amorphous Silicon Image Sensor for X-ray Diagnostic Medical Imaging Applications".*
14. *Silvaco Atlas User's Manual, Device Simulation Software*
15. *Large Area Amorphous Silicon Sensor Arrays, X-ray Imaging Solutions by dpix.*
16. *T. Tredwell, J. Chang, J. Lai, G. Heiler, and J. Yorkson, "Flat panel imaging arrays for digital radiography," in Proc. Int. Imager Sensor Workshop, Bergen, Norway, Jun. 2009.*
17. *R. Street, W. Wong, T. Ng, and R. Lujan, "Amorphous silicon thin film transistor image sensors," Philosoph. Mag., vol. 89, nos. 28–30, pp. 2687–2697, Oct. 2009.*
18. *W. Wong and A. Salleo, Flexible Electronics, Materials and Applications. New York, NY, USA: Springer-Verlag, 2009.*
19. *D. Dosev, B. I~n_ıguez, L.F. Marsal, J. Pallares, T. Ytterdal, "Device simulations of nanocrystalline silicon thin-film transistors", Solid-State Electronics 47 (2003) 1917–1920.*