Extended Abstract

(For Ph.D. Open Seminar)

Process-to-System Level Study of Low-Voltage Thin Film Transistors: Fabrication, Modeling, and Simulation

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Recently, thin-film transistors (TFTs) have garnered significant attention from researchers due to their wide range of applications, including electronics, gas sensing, memory circuits, medical devices, and optoelectronics. Advancements in deposition techniques have proven highly effective in developing cost-effective, solution-processed, low-voltage TFTs that meet the requirements of various applications. Based on the type of semiconductor used, TFTs are classified as either organic thin-film transistors (OTFTs) or inorganic thin-film transistors. Both have their unique advantages: OTFTs are preferred for flexible applications, such as flexible LEDs, memories, and sensors, whereas inorganic thin-film transistors are commonly used for transparent and optical applications. The investigations reveal that the requirements of low-power applications can be met by utilizing low-voltage TFTs operating at 1–2 V with high-k dielectric materials such as $SrZrO_x$, HfO_2, etc. Furthermore, by using organic semiconductors, solution-processed, cost-effective, low-voltage, flexible, and silicon substrate-based OTFTs can be fabricated for gas sensing and electronic applications. The Silvaco-Techmodeler and Silvaco-Gateway tools have been employed to realize various complex analog and digital circuits. This thesis focuses on the fabrication and simulation of low-voltage TFTs for sensing and electronic applications.

Chapter 1 of this thesis explains the background and advancements related to TFT devices, different types of TFT architecture and configuration depending upon semiconductor and dielectric materials, the fundamental and working operation of TFT devices, various techniques employed for thin film deposition, the history and introduction related to compact modelling of TFT devices and the role of compact modelling in the realization of analog and digital, different stages involved for compact modelling of TFT devices using the Silvaco-Techmodeler tool, and applications of TFT devices.

Chapter 2 of this thesis explains the fabrication of Ag-doped PBTTT-C14 (poly[2,5-bis(3-tetradecylthiophen-2-yl)thieno[3,2-b]thiophene])-based OTFTs developed on silicon substrate, and $SrZrO_x$ is used as a high-k dielectric, which led to a low voltage of 1.5 V. The floating film transfer method (FTM) has been used for film deposition as it is cost-effective in nature with minimal wastage of chemicals. Film characterization of semiconductor and dielectric layers ensures smooth films free from trap charges. This Ag-doped PBTTT-C14-based OTFT on a silicon substrate has been used for the sensing of H_2S gas, which gives the sensing response higher than 80% and a limit of detection (LoD) of ~15.17 ppb.

Chapter 3 explains the fabrication of the PBTTT C-14-based OTFT device established over a flexible PET substrate, and the composition of PMMA and $SrZrO_X$ in 20:80 is taken to be utilized as a high-k dielectric material. This PBTTT C-14-based OTFT device operated at a low voltage of 1 V. The film of PBTTT C-14 has been deposited by means of the FTM technique. Active layer and dielectric film characterization is performed along with this bandgap. Capacitance-frequency and leakage current density of the dielectric layer are also estimated. This fabricated flexible OTFT device is compact modelled using the Silvaco-Techmodeler tool. The experimental data and modelled data completely superimpose on each other, assuring a small fraction of error of less than 1 %. This compact, modelled, flexible OTFT is used for the implementation of an inverter circuit over the Silvaco-Gateway platform and exhibits a high gain of 39.77 and a small propagation delay (τ_{PD}) of 35 ns.

Chapter 4 explains the simulation of an inorganic semiconductor, an amorphous indium gallium zinc oxide (a-IGZO)-based low-voltage TFT, using the Silvaco-Atlas tool, followed by an analysis of the device characteristics. This chapter describes the materials used for the electrodes (PET for all electrodes), gate oxide (HfO_2), and semiconductor in the simulation of a fully transparent, flexible, low-voltage thin-film transistor. The device characteristics confirm that the fully transparent TFT operates at an operating voltage of 2 V. Furthermore, this device is compactly modeled using the Silvaco-Techmodeler tool, and using this compact, flexible, transparent, and low-voltage model, full adder and full subtractor circuits are simulated using the Silvaco-Gateway tool, and with the help of transient analysis, respective truth tables are verified.

In ***Chapter 5***, compact modelling using Silvaco-Techmodeler is explained in a detailed manner and elaborated upon, highlighting its need and importance. The devices fabricated and simulated in the previous chapters are compactly modelled, demonstrating perfect matching and superimposition of curves between the modelled data and the simulated or fabricated data, with a small margin of error (less than 1%). Additionally, diagrams and graphs are provided to support the content. This model is subsequently imported for circuit simulation. The Silvaco-Gateway tool is used to implement circuits utilizing the compact modelled devices. Circuits such as inverters, full adders, full subtractors, half adders, logic gate families, 1-bit magnitude comparators, and 4:1 multiplexer are implemented. The respective truth tables, transient characteristics, and voltage transfer characteristics are verified. Based on these characteristics, parameters such as voltage gain and propagation delay are evaluated. The working of the Silvaco-Gateway tool is explained in detail. Additionally, a brief user guide is provided, describing how to use the Silvaco-Techmodeler and Silvaco-Gateway tools effectively.

In ***Chapter 6***, the stability analysis of a-IGZO-based low-voltage TFTs is performed. The device has been simulated by means of the Silvaco-Atlas tool. Factors such as the thickness of the semiconductor layer (10/20/30 nm), the thickness of the dielectric layer (70/60/50/40 nm), and the semiconductor-interface properties, which impact the device performance parameters, are observed, and the change in threshold voltage ΔV_{TH} = V_{TH} ("off-on state") $-$ V_{TH} ("on-off state") is analysed and discussed. Graphs are provided to support and illustrate all the results.

In ***Chapter** 7*, a summary of all the case studies, work, and overall conclusions is presented.

List of Publications

1. **M. S. Mehrolia**, D. Kumar, A. Verma and A. K. Singh, "Fabrication and Characterization of Self-Assembled Low Voltage Operated OTFT for H_2S Gas Sensor for Oil and Gas Industry," in *IEEE Transactions on Electron Devices*, vol. 71, no. 1, pp. 769-776, Jan. 2024, doi: 10.1109/TED.2023.3336301. **[IF:2.9]**

2. **M. Singh Mehrolia**, D. Kumar, A. Verma and A. Kumar Singh, "Fabrication and Compact Modeling of Low-Voltage Flexible Organic TFT Using Self-Assembly of Conductive Polymer Channel Over High-k PMMA/$SrZrO_x$ Dielectric," *in IEEE Transactions on Electron Devices*, vol. 71, no. 10, pp. 6055-6060, Oct. 2024, doi: 10.1109/TED.2024.3442165. **[IF:2.9]**

3. **M. Singh Mehrolia**, A. Verma, A. Kumar Singh, N. K. Chourasia and A. Pandey, "A Proposed Fully Transparent, Flexible, and Compact Modeled Low-Voltage TFT for Implementation of Full Adder and Subtractor," in *IEEE Journal on Flexible Electronics*, vol. 3, no. 11, pp. 477-483, Nov. 2024, doi: 10.1109/JFLEX.2024.3400760.

4. **M. Singh Mehrolia,** A. Verma and A. Kumar Singh, "Comparative Analysis of Compact Modeled of Low-Voltage OTFTs on Flexible and Silicon Substrates for the Implementation of Logic Circuits," in *IEEE Journal on Flexible Electronics*, vol. 3, no. 7, pp. 341-347, July 2024, doi: 10.1109/JFLEX.2024.3471489.

5. **M. Singh Mehrolia,** A. Verma and A. Kumar Singh, “ Comprehensive Stability Analysis of Fully Transparent Low-Power Thin-Film Transistors: Role of Device Design and Electrical Parameters”. *IEEE Journal on Flexible Electronics* **(Under Review)**

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