Design, fabrication and measurement of metal-semiconductor field effect transistor based on zinc oxide material

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Abstract: The paper mainly focuses on the design, fabrication and measurement on Zinc Oxide (ZnO)-based Metal-Semiconductor Field Effect Transistor. The research problem in this study is difficulty on observing the electronic properties of ZnO materials to fabricate the high performance transistor design with non-toxic semiconductor materials. Even though the wide band gap materials of Group III and V possess high performance properties for fabricating the power electronics devices, the harmful impacts could not be reduced. The research solution for the problem statement in this study is emphasized on the non-toxic materials of Group II and VI-based high performance power electronics devices fabrication. The experimental studies of the device fabrication were conducted by Pulse Laser Deposition (PLD) process in standard laboratory. The step-by-step procedures for MSFET device fabrication were discussed and the confirmation of developed device fabrication was completed. The approaches on all measurement were completed based on band diagram condition, quantum interference on metal-semiconductor materials, and current-voltage characteristics. The step by step measurement for fabricated device for the proposed structure could be confirmed by standard measurement techniques. The proposed design has been validated for the utilization of high performance applications. The physical properties and physical characteristics for measurement results were confirmed by the theoretical analyses. The numerical analyses have been completed with the help of MATLAB. All results have been proved by recent research works.

Keywords: Metal-semiconductor; Transistor; Zinc oxide; Band diagram design

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1. Introduction

Recently, oxide semiconductor materials have been of great interest due to application for optical devices such as light emitting diodes (LEDs), laser diodes (LDs) and Metal-Semiconductor Field Effect Transistor (MSFET). Zinc Oxide (ZnO) has enthralled extensive consideration due to its superior physical properties and wide technological applications (Hla Myo Tun, 2020; Myo Tun, 2018; Tun & Nwe, 2022). The wide direct-band gap of ZnO is 3.37eV and it has a large exciton binding energy of 60meV, which tasks efficient excitonic emission processes at room temperature and enables devices to rationale at a low threshold voltage. ZnO (as a group-II oxide) proves vast guarantee for applications in blue/UV light emitters and photodetectors, over and above transparent electronics, chemical sensors, spintronics, and varistors. Various techniques, such as magnetron sputtering, reactive evaporation, pulse laser deposition (PLD), metaorganic chemical vapor deposition (MOCVD) and molecular bean epitaxy (MBE) can be constructive for ZnO thin films deposition. In this approach, the Metal-Semiconductor Field Effect Transistor (MSFET) could be fabricated by using PLD technique (Allen et al., 2007; Bayraktaroglu et al., 2008; Ishitani et al., 2018; Koike et al., 2005; Sasa et al., 2006, 2008).

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The MSFET is a prominent candidate for high power applications. At present, we have fabricated III-V compound based FET system but there have been many unwanted situations because of its waste. Therefore, we focused on the non-toxic materials like ZnO for the applications of high performance device fabrications in semiconductor electronics for future (Heo, Norton, et al., 2004; Heo, Tien, et al., 2004; Sze & Ng, 2006; Tsukazaki et al., 2005; Wang et al., 2007). To the most excellent of our knowledge, there have been few complete investigations reported about the device fabrication to confirm the high performance optoelectronic properties of ZnO-based MSFET.

Efficient field emission by ZnO nanostructures and films was confirmed and opens up the prospect of their use in vacuum microelectronics equipment. The high exciton binding energy of ZnO favors a more efficient exciton mechanism for generating light at room temperature (Nakahara et al., 2010; Yamamoto et al., 2010). Due to the field emission characteristics of ZnO materials, the high performance power electronic devices like MSFET could be designed and fabricated. The theoretical investigations could be observed in recent works (Hla Myo Tun, 2020) and the confirmation of experimental results is needed to be granted. The specific objectives of this study are to check the optimal solution for device fabrication process, to confirm the physical properties of the fabricated device, to prove the high performance properties of the fabricated device with theoretical analyses, and to show the novel experimental studies on the semiconductor device fabrication in a standard laboratory.

The purpose of this study is to describe the proposed structure of ZnO MSFET and the detailed procedure steps for the fabrication of such MSFET. This research aims to provide a comprehensive understanding of the design and fabrication of ZnO MSFETs, so as to make significant contributions in the development of semiconductor technology. By focusing on clear explanations and detailed steps, it is hoped that the results of this study can provide useful guidance to researchers and practitioners in this field, as well as improve the general understanding of ZnO MSFET semiconductor devices.

2. Proposed Structure of ZnO MSFET

The proposed structure of ZnO MSFET has been developed by using ZnO material for channel layer. At first, the specific substrate of sapphire material was used and the ZnO layer could be deposited upon the substrate for channel layer. After that the insulation layers for three electrodes of Source (S), Drain (D) and Gate (G) have been developed by using Pulsed laser deposition (PLD) techniques. Fig. 1 shows the structure of MSFET for this works.

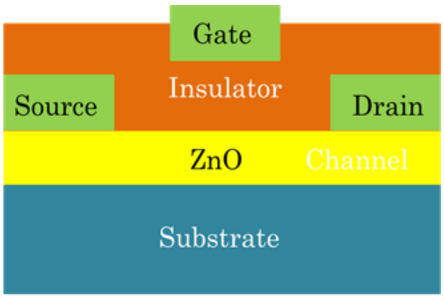

Figure 1. Structure of MESFET

PLD is a physical vapor deposition technique where a high power pulsed laser beam is concentrated to raid a target of the desired composition. Material is at that moment vaporized and deposited as a thin film on a substrate fronting the target. This process can take place in ultra-high vacuum or in the occurrence of a background gas, such as oxygen when depositing films of oxides.

3. Experimental setup

For the deposition of Calcium Oxide (CaO), the following value for fabrication processes were utilized for device fabrication.

Table 1. Experimental parameters

Description	Value
Laser_PLD-2	120 mJ
Frequency	5 Hz
Attennuator	7
Stage	Off AXIS
Focus Lens	+25
Pressure	3.0×10^{-2} Torr
Temperature	Room Temperature
Time	50 Minutes

4. Device fabrication process

The important thing is substrate and the sapphire material is appropriate for fabricating the MSFET. At first, the resist layer has to be done by using spin coater machine. After that high power UV light has passed onto that resist layer, the developer could be confirmed by making the pattern of MSFET on the substrate (Bang et al., 2003; Elliott, 1957; Lu et al., 2007; Myo Tun, 2015; Urbach, 1953; Xue et al., 2006). Therefore, the deposit layer of calcium oxide for making the electrodes. The acetone is very important for removing the unnecessary layer onto the substrates. Based on these processes, the MSFET structure with ZnO material could be acquired for measurement.

In the band diagram design of p-ZnO/N-ZnO homojunction, $N_a = 4 \times 10^{17} cm^{-3}$ and $N_D = 2 \times 10^{19}$ are used as doping concentration for p-region and N-region as shown in Fig.3. Under thermal equilibrium conditions (i.e.no biasing voltage), when the two materials are joining, the Fermi level will be a constant line across the junction. These materials have equal band gap but typically have different doping. Different doping level will happen band banding and depletion region will be formed. Although the process of homojunction structure is similar to that of heterojunction structure, there are no band edge discontinuities in homojunction. That is the fundamental concepts for fabricating the MSFET design.

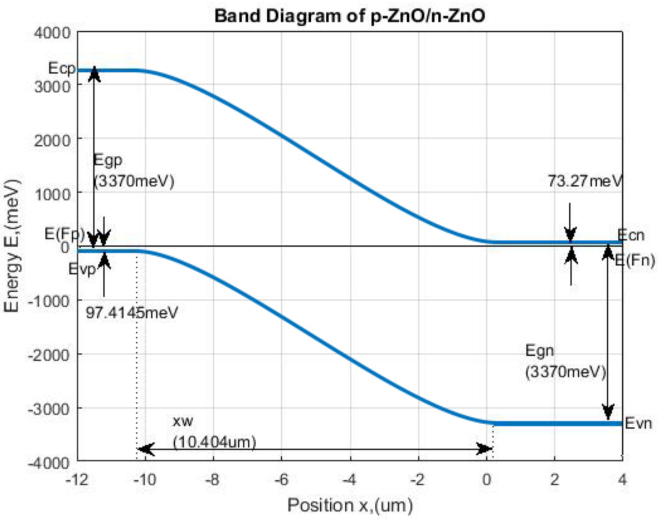

Figure 2. Band Diagram of ZnO for Two Junction at MSFET

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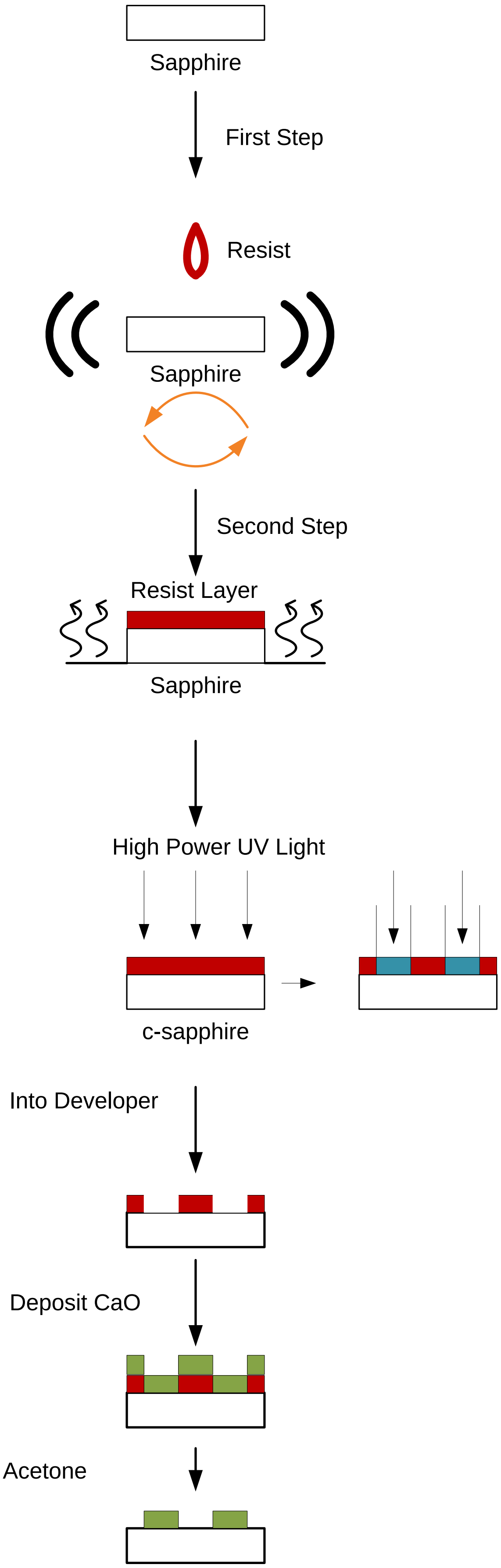

Figure 3. Step by Step Procedures for Fabricating MSFET

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5. Results and discussion

After getting the physical processes of fabricating the MSFET structure by using ZnO material, the finalized structure of MSFET structure has been completed for measurement. Fig. 4 shows the developed MSFET structure for specific purposes. This is done by water liftoff process and ultrasonic process for cleaning the structure of MSFET.

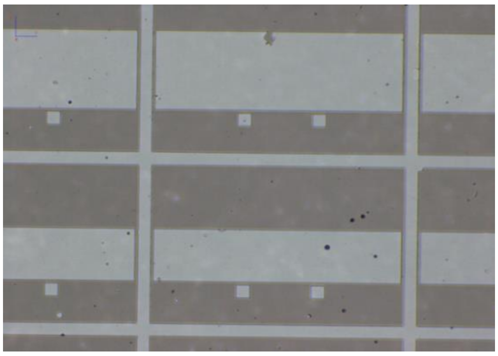

Figure 4. Developed MSFET structure

Fig. 5 shows the measurement of developed MSFET. The drain and source nodes are very important electrodes for specific measurements. The measured result of conductivity between source and drain after annealing is shown in Fig. 6. The result is liner from the experimental and numerical analyses and it was confirmed that the developed MSFET has obtained the high performance results.

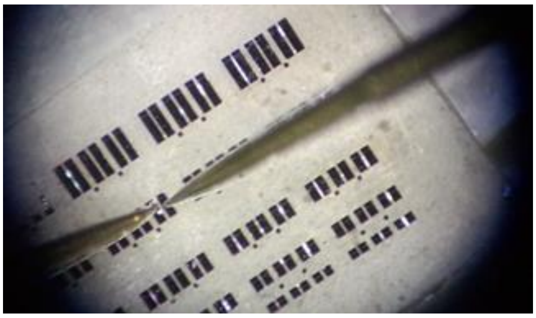

Figure 5. Measurement of developed MSFET

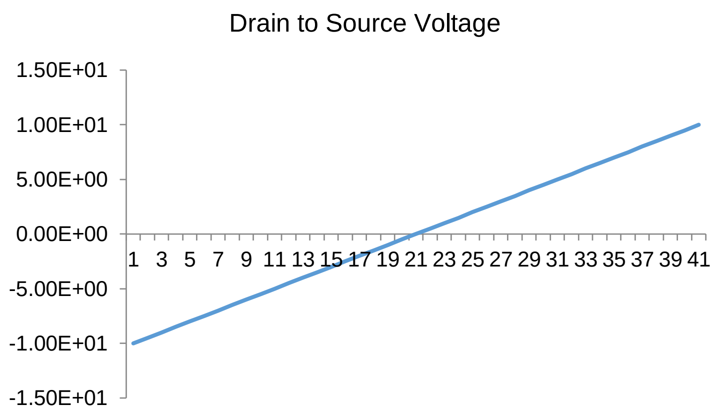

Figure 6. Measurement of conductivity for MSFET

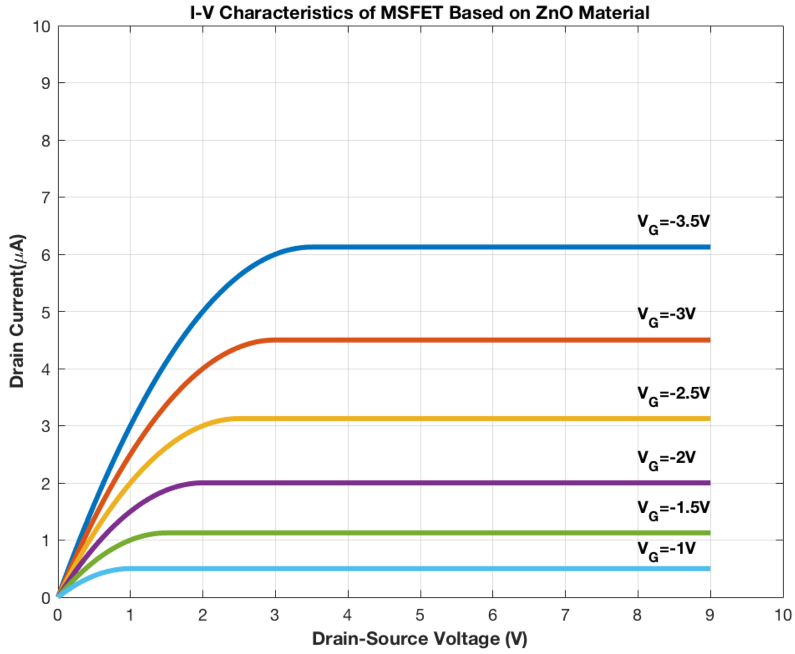

Figure 7. I-V Characteristics of MSFET

Fig. 7 demonstrates the I-V Characteristics of MSFET. When the gate to source voltage is off condition, there is no gate current could not appear. At that time there is no drain flow through the source terminal. It is called the OFF condition for cut-off stage. When the gate to source voltage reaches the threshold level, the drain current pass through the source terminal and that region is called the active region. In this measurement, the values of gate voltage from -1 V to -3.5 V for the numerical analysis have been observed. After getting the measurement on current voltage characteristics for ZnO MSFET, the proposed structure confirmed that the high performance devices could be utilized for high power applications.

6. Conclusion

We proposed a novel process for making the MSFET structure. We fabricated Metal-Semiconductor Field Effect Transistors Structure based on ZnO on Sapphire. ZnO is a promising candidate for channel of power device applications because of its excellent material properties and suitability for mass production. We finished our novel fabrication process by using Pulsed Laser Deposition techniques. We found that very clear pattern on the substrate but some area is good and some area is not good because of the Calcium Oxide could not remove after lift-off. We could not get the good specimen after using acetone but we could receive good electrodes after alloy annealing process. The numerical analysis on current and voltage measurement for proposed MSFET could be carried out by using MATLAB. Our MSFET structure development paves the way for high performance devices that will advance the power semiconductor industry and reduce global energy consumption.

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Declarations

Author contribution

Hla Myo Tun: Conceptualization, Formal analysis, Funding acquistion, Investigation, Validation, Visualization, Project administration, Resources, Supervision, Writing - original draft, Writing - review & editing. Rizky Ema Wulansari: Conceptualization, Data Curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing. Devasis Pradhan and Zaw Min Naing: Investigation, Validation, Visualization.

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Competing interest

All authors worked together for sustainable development in photonic engineering technology. The collaboration between all authors is very strong and concrete. They published several research articles in scientific society. The corresponding authors have received research grants from JICA project for Enhancement of Engineering Higher Education in Myanmar.

Ethical Clerance

There are no human subjects in this manuscript and informed consent is not applicable.

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