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Development and Characterization of Tribotronic Transistor based on ZnO thin film

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Summary:

In this work, we present a tribotronic field effect transistor (T-FET) composed of a ZnO active layer and Al interdigitated electrodes (IDEs). Integrating the gate dielectric with one of the triboelectric surfaces, we demonstrate the modulation of carrier transport by the triboelectric potential generated during contact separation cycles. The electrical characterization of the T-FET is carried out measuring the output voltage of the device under varying contact forces and distances for different triboelectric materials. The resulting modulation proposes a promising device for self-powered interactive electronics.

Keywords: tribotronics, T-FET, ZnO, self-powered electronics, interdigitated electrodes

Introduction

The growing demand for sustainable electronics and intelligent sensing systems has led to the development of a new field of tribotronics [1]. The merging of semiconductors and triboelectric devices can result in direct modulation of conventional electronics using mechanical triggers such as human touch or ambient motion.

Typical tribotronic transistors operate by replacing the traditional gate electrode with a triboelectric material that can also be utilized as the gate dielectric. The charge transport in the semiconductor channel is modulated by the electrostatic potential induced during the contact-separation cycle of the triboelectric surfaces. Several tribotronic devices have demonstrated promising results and applications [2].

This work focuses on the fabrication and electrical characterization of a Triboelectric FET (T-FET) based on a ZnO thin film as an active channel. This device demonstrates the feasibility of a mechanically controlled ZnO FET while also exploring low complexity fabrication methods and material versatility.

Materials and Methods

Figure 1a shows a schematic representation of the T-FET. The device is fabricated using standard microelectronic techniques offering minimal and scalable device architecture. Several dielectrics were evaluated as the triboelectric gate including FEP, PET and Kapton. The interdigitated source and drain aluminum electrodes were patterned on an oxidized silicon wafer, following a lift-off process. Various device geometries were evaluated with the distance between the electrodes, that corresponds to the channel length of the T-FET, ranging from 55μm to 405μm.

A thick (300nm) ZnO active layer was patterned and deposited by RF magnetron sputtering. Following the same process, a 200nm SiO_2 layer was deposited for device passivation. To create a smooth dielectric top surface suitable for triboelectric gating, 1.5 μm of AZ5214E photoresist was spin-coated and hard-baked onto the device. The final device is shown in Figure 1b.

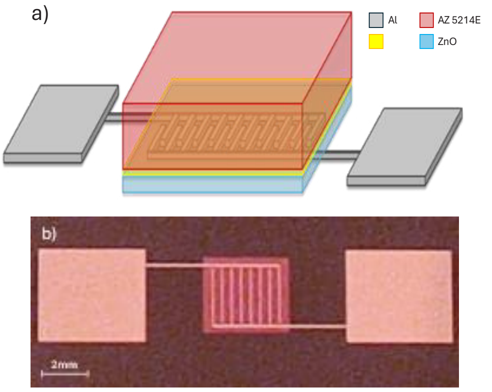

Fig. 1. (a) Schematic representation and (b) photograph of the T-FET.

All measurements were performed under ambient conditions using an in-house system for the periodic linear motion of the dielectric surfaces

(Fig 2). The T-FET was mounted onto a stationary stage while the triboelectric films were attached to a 3D printed base. Subsequently, they were mounted onto the movable stage of a linear motor and carefully aligned with the active area of the T-FET. The source-drain voltage (V_{SD}) was measured using a Keithley 2400 Source Measure Unit (SMU). The transient voltage measurements were realized using varying contact forces and separation distances while a constant current was applied.

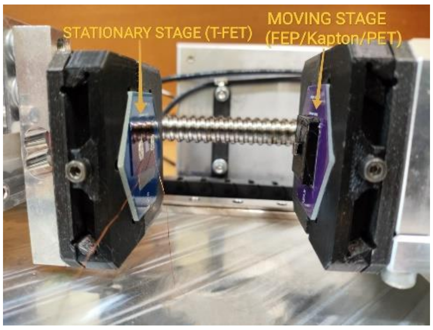

Fig. 2. Setup for the characterization of the T-FET

Results

The triboelectric modulation of the ZnO channel is achieved through controlled contact-separation with precise tuning of the spacing between the triboelectric surfaces and the force applied during contact. During contact there is a charge exchange between the photoresist deposited on the T-FET and the triboelectric material. The surface charge density depends on the relative electron affinities of the materials. The accumulated surface charges remain localized on the dielectric surfaces, when they are separated, inducing an electrostatic potential to the gate.

Figure 3 shows the source-drain voltage (V_{SD}) response as a function of time and in terms of the relative displacement of the T-FET and the triboelectric surface, following an original contact between the two surfaces.

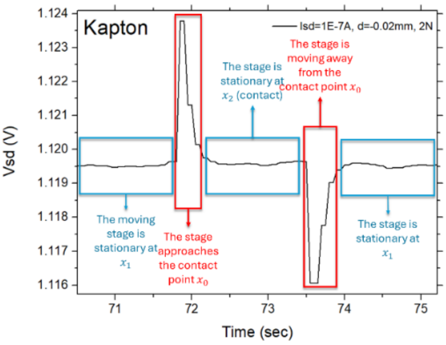

Fig. 3. Change of the source-drain voltage as a function of the relative motion between the T-FET and the triboelectric surface.

A signal change is observed in the source-drain voltage when the two surfaces are in relative motion due to the potential difference that is induced and modulates the carrier concentration in the ZnO channel.

Figure 4 shows the change of the source-drain voltage as a function of the distance of the triboelectric surface from the T-FET for different triboelectric materials. At a fixed distance, the output signal depends on the material of the triboelectric gate. This behavior is expected since the amount of charge that is exchanged between the two surfaces depends on the relative position of the materials in the triboelectric series, which is a manifestation of their respective electron affinities. From the analysis of the results, optimal material combinations can be identified to maximize the influence of the triboelectric gate on the transistor channel. The initial contact force between the two surfaces plays also an important role and will be further analyzed in subsequent work.

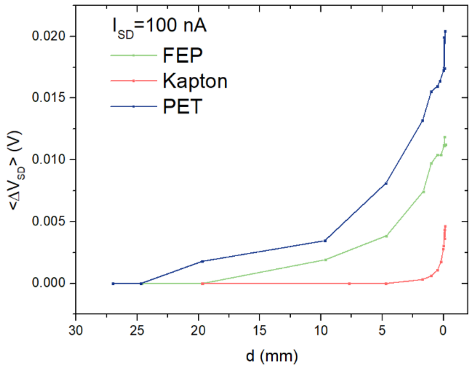

Fig. 4. Change of the source-drain voltage as a function of the distance of the triboelectric surface from the T-FET for various triboelectric surfaces.

Our work demonstrated that IDE based triboelectric FET can be utilized as mechanically-gated electronic components that could be exploited for sensing and logic applications.

References

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