

A Tunable Surface Acoustic Wave Device on Zinc Oxide via acoustoelectric interaction with AlGaIn/GaN 2DEG

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Introduction

Surface acoustic wave devices have many applications in signal processing, radio frequency (RF) communications, and sensing [1]. The most common utilization of these devices is for filtering electromagnetic signals in communications systems. However, since the physical dimensions of the inter-digitated transducers (IDT) determine the frequency response, it is very difficult to attain tunable devices for programmable applications. Great effort has been made to achieve an integrated solution to this in III-V semiconductors. One such work utilizes the piezoelectric the GaN buffer layer in an AlGaIn/GaN epi for acoustic propagation, while a metal-insulator-semiconductor (MIS) structure is used to tune the SAW response [2]. Unfortunately, the MIS structure results in a weak interaction only achieving a phase tunability of 0.07%. Recent work, uses thin film Zinc Oxide (ZnO) as a piezoelectric on top of n-type ZnO on GaN achieving a high tunability of .9% [3]. In this work, we demonstrate a ZnO on AlGaIn/GaN heterostructure capable of achieving high tunability as well as impacting properties of the SAW filter not previously reported.

Fabrication

Figure 1 illustrates the fabrication process used to construct the device. A bi-layer of photoresist is patterned via photolithography and developed. Electron beam deposition is used to deposit Ti (400Å), Al (8000Å), Ni (400Å), and Au (8000Å) for the electrodes on the AlGaIn. These are then annealed in a rapid thermal annealer at 900°C to form ohmic contacts to the 2DEG. A thick bi-layer of photoresist is patterned to define the ZnO area. The ZnO is deposited by RF Sputtering at 150 °C at a power of 200W, a pressure of 2 mTorr, an Ar to O₂ ratio of 1:1. The ZnO is then lifted-off. An SEM image of the cross-section demonstrating the crystallinity ZnO is shown in Figure 2. The IDTs are then defined by patterning a bi-layer of photoresist by a laser writer and depositing 600Å of Al. An additional lift-off lithographic step is used to deposit an additional 1000Å of Au for probing. Micrographs of the finalized structure are shown in Figure 3. The IDTs have 24 pairs of fingers with a pitch of 1.5µm and are 1mm apart.

Results

S-parameter measurements are performed using RF-probes and a Keysight network analyzer model ENA 5061B. Figure 4 (a) demonstrates the measured S₂₁ of the device at 0 volts and 25 volts of applied bias. At 0V, the SAW response appears weak and obscured, however, under the application of 25V, strong modes appear at 585MHz, 1.45GHz, and 1.98GHz. This occurs due to the appearance of an accumulation region at the ZnO/AlGaIn interface as depicted in Figure 4 (a) and similar to that reported in [4]. As drift carriers increase in the 2DEG, the accumulation region in the ZnO is depleted, allowing the SAW to emerge. As a result, this effect causes this device to exhibit interesting properties. Figure 4 (b-d) demonstrates how the different aspect of the frequency response change with bias. The velocity of the SAW decreases by up to up to 0.77% with bias due to piezoelectric stiffening caused by the electro-acoustic effect between the SAW and the carriers in the 2DEG and can be described by the expression in Figure 4 (b). Due to the added effect from the accumulation region, changes in bandwidth and SBR are also observed. The 3dB bandwidth improves with applied voltage up to 2.74%, while the SBR at 10MHz from the center frequency increases up to 18dB. Figure 4 (e) tabulates compares the performance of this device compared to similar work, however, those devices do not exhibit control over SBR and bandwidth.

Conclusion

In this work, we have demonstrated a tunable SAW filter with a high phase tunability of 0.77% at 585 MHz, an order of magnitude higher than previous work at a similar frequency [2], but also with the ability to affect other metrics of its frequency response such band-width and side-band rejection ratio. To our knowledge, this effect has not been previously reported and can have potential applications in RF and microwave communications.

[1] Campbell, C. K., Acoustic Wave Devices. Proc. IEEE 77, [2] Pedrós, J., et al. Appl. Phys. Lett. 96, 10–13 (2010). 1453–1484 (1989).

[3] Li, R., et al. Appl. Phys. Lett. Appl. Phys. Lett. 107, (2015).

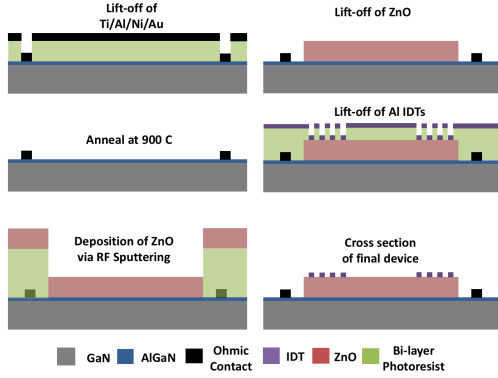


Fig. 1: Fabrication Process of ZnO SAW Delay line on AlGaN/GaN Epi.

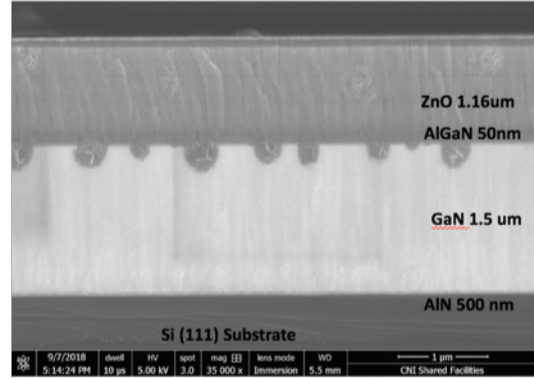


Fig. 2: SEM Cross Section of ZnO growth via RF Sputtering on AlGaN/GaN Epi.

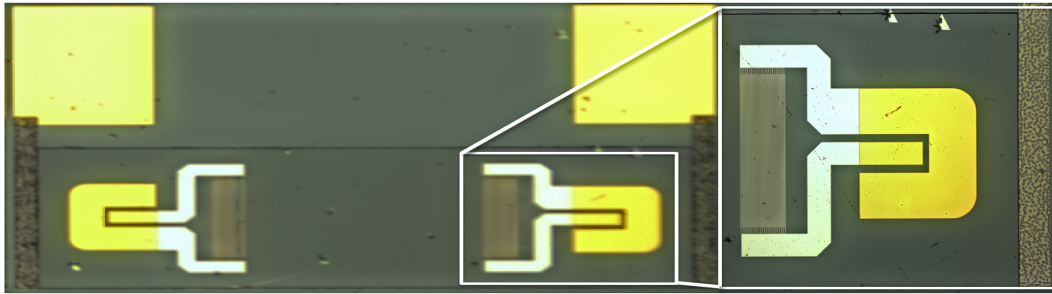


Fig. 3: Micrograph Top View of ZnO SAW device on AlGaN/GaN. Each IDTs have 24-pairs and a pitch of 1.2um. The distance between IDTs is 1mm.

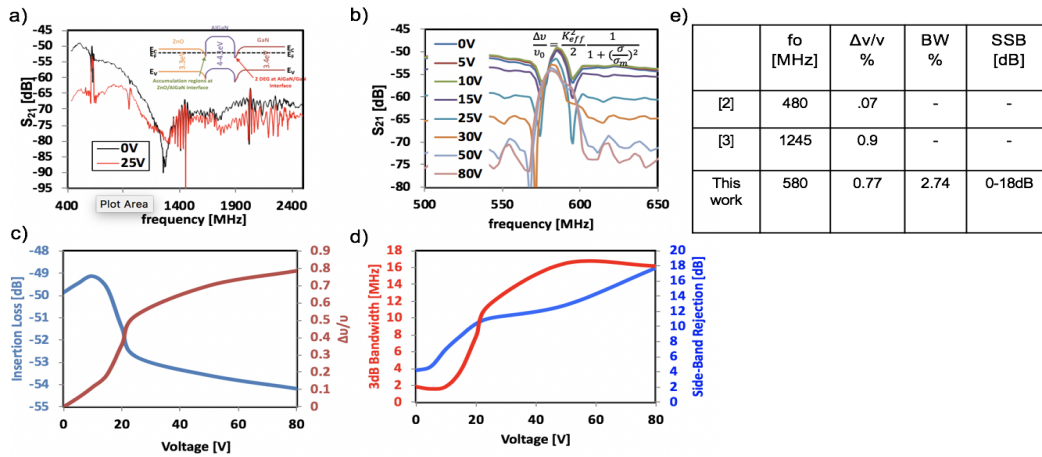


Fig. 4: (a) Broadband measurement of insertion loss demonstrating the appearances of 1st and 2nd order SAW modes after the application of a voltage. (Embedded Band diagram) (b). Fundamental SAW mode under different voltages exhibiting shift in overall response. (Expression of acousto-electric effect) (c) Insertion Loss and change in acoustic velocity vs voltage. (d) 3dB Bandwidth of filter and side-band rejection vs voltage. (e) Table of Filter metrics compared to previous works.