Acoustoelectric Amplification of Surface Acoustic Waves on ZnO deposited on AlGaN/GaN Epi

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Introduction

The integration of surface acoustic wave devices with GaN HEMT technology is an area that has generated significant interest from the long-range radio and radar community. Reported devices rely on accessing the underlying epitaxial layer and then releasing it from the substrate to minimize mechanical losses [1, 2]. Due to reliability concerns that arise from strain resulting from bowing, the GaN layer is grown from 1.3μm-1.7μm. This limitation can lead to less then desirable electromechanicial coupling and acoustic velocity due to the dispersion relation between the wavelength and the thickness of the piezoelectric material. Recently, amplification of surface acoustic waves by a two-dimensional electron gas in GaN has been demonstrated in [3]. This is a promising result that can compensate for high insertion loss, however, the ability to tune the thickness of the piezoelectric layer to a particular frequency is still desirable. To address this, we propose the utilization of thin-film ZnO deposited on GaN to serve as a piezoelectric. ZnO has been demonstrated to have a high electromechanical coupling and a acoustic wave velocity suitable for microwave frequencies on several substrates [4, 5]. Furthermore, acoustic gain is also achievable in this structure and its merits can be investigated by revisiting the models for gain and noise developed in [6, 7]. Figure 1 shows that the ZnO/AlGaN/GaN structure is capable of high frequency gain and lower noise figure then it's InSb/SiO2/$LiNbO_3$ predecessor. In this work, we report the observation of acoustoelectric gain in an experimental device with a greater power ratio then previously reported. We believe this structure can be a pathway that leads to the union of the versatility and signal processing power of SAW devices with the high-power high-speed III-V technology.

Fabrication

The process flow is depicted in 2. Transducers were patterned on the GaN epi via photolithographic wet-etch process. A bi-layer of resist was then spun and patterned via optical lithography prior to sputtering for the lift-off of ZnO. The ZnO was deposited at a rate of 2Å/s in a pressure of 2mTorr and grown to 1μm at a temperature of 150°C. The sample was then placed in two solvent baths for the lift-off process to occur. Figure 3 shows the micrograph of the ZnO delay line on GaN.

Device Results

S-parameter measurements were performed using a Keysight E5070A network analyzer connected to the device via high frequency probes. Bias tees were used to apply the DC electric field between the IDTs. Figures 4a-c show that as the bias is increased, the insertion loss of the forward wave S_{21} improves more than the reverse wave S_{12}. This non-reciprocity indicates the acoustoelectric effect is active in the device, offering gain with a total loss compensation of $4.3dB$ as seen in Figure 4b. This is equivalent to a power ration of 1.64 which higher then that observed in [3]. The current draw is plotted in Figure 4c, showing that the device consumes $300mW$ of power at peak loss compensation. There are clear improvements to the process and design that can improve the actuation of the SAW waves by the IDTs and improve the charge and electron wave propagation in the structure. Also, Shottky contacts were used for the IDTs, so this interface has to be forward biased for current to flow. This leads to further loss in transduction of the SAW wave in the ZnO. With ohmic contacts patterned separately on the AlGaN layer to access the 2DEG, significant further improvements in the performance can be expected.

Conclusion

We believe that our results indicate the electroacoustic gain is taking place in the ZnO/AlGaN/GaN structure with a larger gains then previously achieved. The incorporation of a separate piezoelectric adds significant flexibility in design that can lead to higher performance. With further investigation and optimization of the process and design, we project that this structure can lead the way to seamlessly integrate low loss SAW devices on III-V technology.

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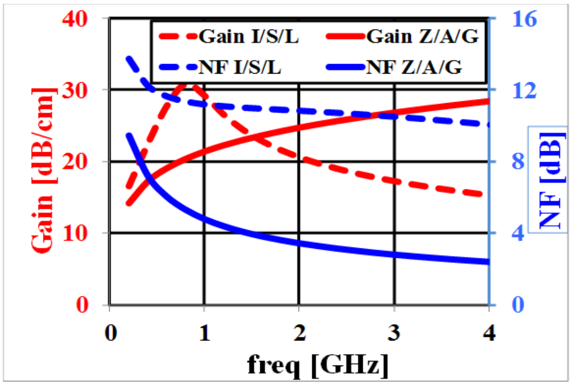

Fig. 1: Comparison of Gain and Noise performance of $InSb/SiO_2/LiNbO_3$ (I/S/L) and the ZnO/AlGaN/GaN (Z/A/G) structures. Calculations for the I/S/L were made by using the parameters specified in [6]. For the Z/A/G device, the electromechanical coupling of 0.03 is used with a 3500 m/s acoustic velocity [4]. The mobility of the GaN was reported to be $1750cm^2/Vs$ by the supplier.

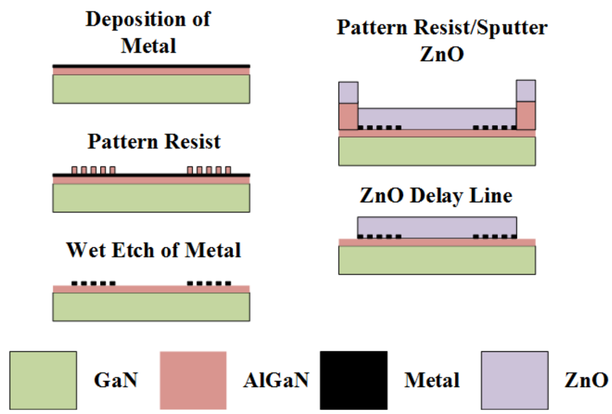

Fig. 2: Fabrication process of ZnO/AlgaN/GaN structure with transducers.

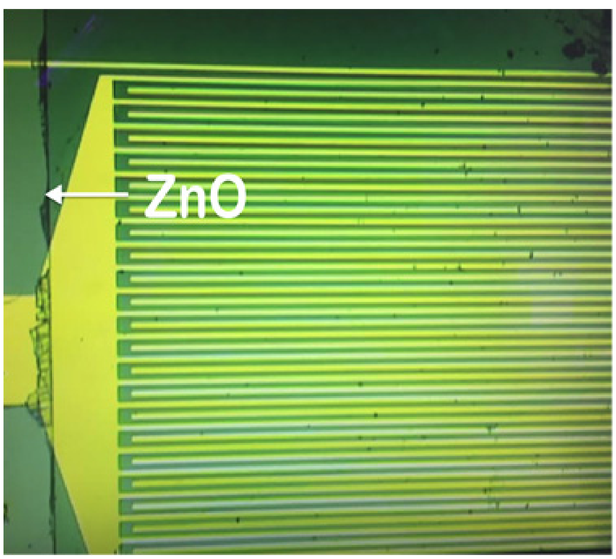

Fig. 3: Micrograph of the ZnO delay line on GaN.

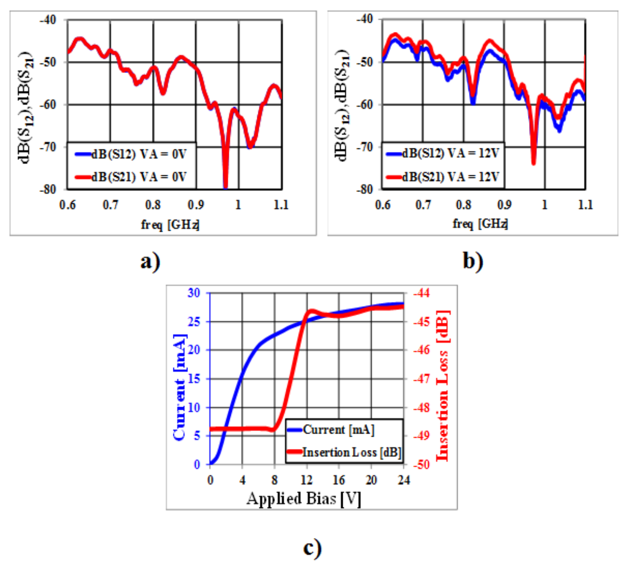

Fig. 4: a) S_{12} and S_{21} of ZnO delay line with 0V of Applied Bias. b) S_{12} and S_{21} of ZnO delay line with 12V of applied bias demonstrating clear evidence of non-reciprocity. c) Current Draw and insertion loss at 860MHz vs. applied voltage.