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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 283-284
18-20 November, 2009

Characteristics of ZnO thin film surface acoustic wave devices fabricated using Al_2O_3 film on silicon substrates

Wen-Ching Shih, Tzyy-Long Wang†, and Ming-Hsien Chu (Graduate Institute in Electro-Optical Engineering, Tatung University, Taiwan, R.O.C.)

Abstract

ZnO films with c-axis (0002) orientation have been successfully grown by RF magnetron sputtering on interdigital transducer (IDT)/Al_2O_3/SiO_2/Si substrates. The Al_2O_3 films were deposited on SiO_2/Si substrates by electron beam evaporation. Crystalline structures of the films were investigated by X-ray diffraction, atomic force microscopy and scanning electron microscopy. The 2^{nd}-order phase velocity of the surface acoustic wave (SAW) device with a 7.5 μm thick Al_2O_3 buffer layer was measured to be about 5432 m/s, which approaches that (5840 m/s) of ZnO/ IDT/sapphire. The experimental result is beneficial to replace the expensive single crystalline sapphire substrate with Al_2O_3 buffer layer at lower cost for the high frequency SAW devices, and is also useful to integrate the semiconductor and high frequency SAW devices on the same Si substrate.

1. Introduction

ZnO (zinc oxide) is a member of the hexagonal wurtzite class and has a high electromechanical coupling factor, making it a useful material for surface acoustic wave (SAW) devices.[1)] Several techniques have been developed for forming ZnO films. The most commonly used technique is sputtering because it is possible to obtain good orientation and uniform films close to single-crystal morphology even on amorphous substrate or at low substrate temperature.[2,3)] The ZnO thin films have been deposited on various substrates including GaAs, sapphire,[4,5)] InP, Si, quartz and diamond. Among these substrate materials, sapphire is widely used for high frequency SAW devices due to its high acoustic velocity and low loss.[6)] It is desirable to fabricate piezoelectric film on a high acoustic velocity substrate to ease the difficulty of fabricating submicron electrodes. However, the sapphire substrate is much more expensive than Si wafer, and it is still very difficult to grow large size of Al_2O_3 single crystal. In this paper, we fabricate the ZnO thin film on interdigital transducer (IDT)/Al_2O_3/SiO_2/Si substrate with an electron beam (e-beam) evaporated Al_2O_3 buffer layer for high-frequency SAW device applications. We will examine the speeding-up effect of Al_2O_3 films on SAW. The Al_2O_3 buffer layer is expected to replace the expensive single crystal sapphire substrate for high-frequency SAW device with lower cost. The results could be also useful to integrate the semiconductor and high frequency SAW devices on the same Si substrate.

2. Experimental procedure

The Al_2O_3 films used in this study were prepared using e-beam evaporation of the Al_2O_3 pellet. The background pressure was below 5×10^{-5} torr. The deposition conditions are DC current of 70 mA, substrate temperature of 300°C and distance of evaporation source to substrate of 15 cm. IDTs with 5 μm line-width and line-to-line spacing were fabricated on the Al_2O_3/SiO_2/Si substrates by a conventional photolithographic technique and the lift-off process. Each transducer has a 20 μm period and 1 mm aperture. The number of the finger pair is 80 and the propagation distance between the input and output transducers is 5 mm. After the fabrication of the IDTs, we deposited the ZnO film on above by RF magnetron sputtering.

The thickness of the Al_2O_3 and ZnO films was measured by Dektak^{3}ST α-step surface profiler. The stoichiometry of the Al_2O_3 buffer layer was measured by energy dispersive spectroscopy (EDS). The cross-sectional morphology of the films was examined by using field emission scanning electron microscope (FE-SEM, JEOL JSM-6500F), whereas the surface roughness was estimated using the atomic force microscopic micrograph (AFM, Digital Instruments) under tapping mode. The frequency response of the fabricated SAW devices was measured by Agilent 8720ES network analyzer.

3. Result and discussions

From the EDS measurement of the Al_2O_3 overlayer, we can see that the atomic ratio of Al/O of the Al_2O_3 buffer layer is about 2/3, which means that the quality of the Al_2O_3 overlayer deposited by e-beam evaporation is acceptable for further application. Figures 1 and 2 show the measured frequency responses for ZnO (3.5μm)/IDT/sapphire and ZnO (3.5μm)/IDT/Al_2O_3(7.5μm)/SiO_2/Si substrates, respectively. The center frequency of ZnO /IDT/sapphire layered SAW device was measured to be about 292 MHz, and the corresponding 2^{nd}-order phase velocity ($v=f\times\lambda$) calculated from the center frequency is 5840 m/s. On the other hand, the center frequency of ZnO/IDT/Al_2O_3/SiO_2/Si layered SAW device was measured to be about 271.6 MHz, and the corresponding 2^{nd}-order phase velocity is 5432 m/s. From Figures 1 and 2, we can see that the speeding-up effect of Al_2O_3 films on SAW. The Al_2O_3 buffer layer is expected to replace the expensive single crystal sapphire substrate for high-frequency SAW device with lower cost.

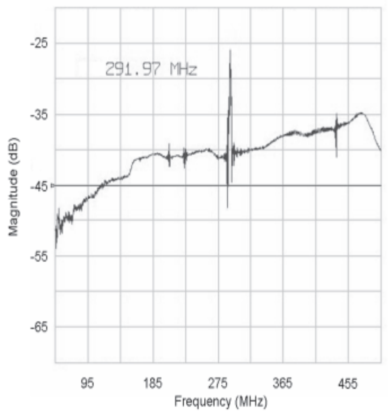

Fig. 1. The measured frequency response of the ZnO (3.5μm)/IDT/sapphire layered SAW device.

4. Conclusions

The 2^{nd}-order phase velocity of the ZnO/IDT/Al_2O_3/SiO_2/Si layered SAW device with a 7.5 μm thick Al_2O_3 buffer layer was measured to be about 5432 m/s, which approaches that (5840 m/s) of ZnO/ IDT/sapphire. The experimental result is beneficial to replace the expensive single crystalline sapphire substrate with Al_2O_3 buffer layer at lower cost for the high frequency SAW devices, and is also useful to integrate the semiconductor and high frequency SAW devices on the same Si substrate.

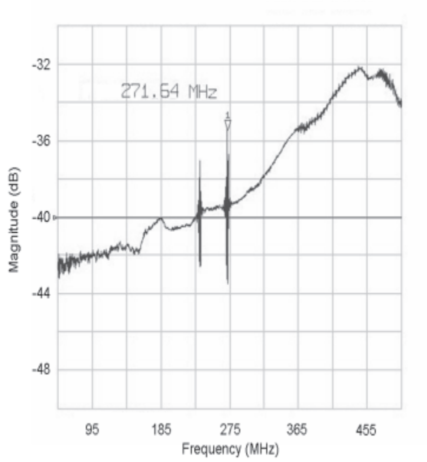

Fig. 2. The measured frequency response of the ZnO (3.5μm)/IDT/Al_2O_3(7.5μm)/SiO_2/Si layered SAW device.

Acknowledgements

This work was sponsored by the Tatung University, Taiwan, R.O.C.. The authors deeply appreciated their financial and technical support.

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