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Film Bulk Acoustic Resonator Based on Zinc Oxide Thin Film

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Abstract
A piezoelectric thin film sandwiched between two metal electrodes is basic structure for high frequency bulk acoustic wave devices. For that propose, the RF magnetron sputtering deposition for piezoelectric ZnO film formation and its such application for film bulk acoustic resonator (FBAR) devices are presented. Several critical parameters of the RF magnetron sputtering process deposition pressure, RF power, substrate temperature, O_2 concentration and the target to substrate distance were determined to clarify their effects on the material characteristics of the ZnO. Highly c-axis oriented thin films as thick as 5.7 μm were grown and analyzed. Compressive stresses were observed. The FBAR devices with the ZnO films exhibited a pronounced resonance peak centred at 537 MHz with a k^2 coupling coefficient of 7 %. It found therefore that the impedance matching of the FBAR could be easily achieved simply by controlling the resonance the resonator.
Keywords: ZnO; FBAR; R.F sputtering magnetron; resonator.

1. Introduction

The upcoming needs for higher carrier frequencies in MEMS devices, open opportunities for bulk acoustic wave (BAW) technology based on piezoelectric thin films. In particular, the need for high perfomance filters has become increasingly apparent as spectrum crowding increases. Film Bulk Acoustic Resonator (FBAR) devices have become one of the most promising components, mainly due to their small size, high device perfomance and strong potential for the realization of microwave monolithic integrated circuits (MMIC). The most critical factor determining the resonance characteristics of FBAR devices is piezoelectric properties of the ZnO films, which is directly related to degree of the preferred oriention of the Zno crystal structure [1-2]. Considerable effort has been made to fabricate high quality ZnO films with a strongly preferred orientation. However, each approach has shown its own limitations such as the complexity of the fabrication methods and the high cost of process equipment. In FBAR devices, the ZnO film should exert a minimum stress on the underlying layer and also have a high piezoelectric constant.

This paper presents the fabrication and the analysis of ZnO based FBAR's that are centerd at frequencies ranging from 500 to 600 MHz. The texture of zno thin film was analyzed by X-ray diffraction and the electromechanical coupling coefficient k^2 was measured with Network analyzer. On the other hand the electrical properpies of the resonators were measured and are discussed as function of materials parameters and procesing conditions.

2. Zinc oxide thin films

Zinc oxide films were deposited by r.f magnetron sputtering using a zinc target (99,99%) with diameter of 51 mm and 6 mm thick. Substrate is p-type silicon with (100) orientation. The substrates were thoroughly cleaned with organic.

Magnetron sputtering was carried out in an oxygen and argon mixed gas atmosphere by supplying r.f power at a frequency of 13.56 MHz. The RF power was about 50 W. The flow rates of both the argon and oxygen were controlled by using flow meter (ASM, AF 2600). The sputtering pressure was maintained at $3.35.10^{-3}$ torr controlling by a Pirani gauge. Before deposition, the pressure of the sputtering system was under 4.10^{-6} torr for more than 12 h and were controlled by using an ion gauge controller (IGC – 16 F).

Thin films were deposited on silicon, substrate under conditions listed in Table 1 [3]. These deposition conditions were fixed in order to obtain the well-orientation zinc oxide films.

The presputtering occurred for 30 min to clean the target surface. Deposition rates covered the range from 0.35 to 0.53 μm/h. All films were annealed in an helium ambient at 650°C for 15 mn. In this study Pt was chosen as a bottom electrode material for the FBAR fabrication.

In order to investigate the crystallographic properties of the ZnO films, we carried out an X-ray diffraction (XRD) analysis using CuK_α (λ = 0,154054 nm) radiation. Figure 1 shows the diffractogram of a 5.7 μm ZnO thin film deposited on a platinized substrate. No other peak than the (002) one could be detected, indicating a very good c-axis texture. The dielectric properties of Zno films were measured with an impedance analyzer. Typical values for the relative permittivity and the dielectric losses were 8.5 and 0.002 respectively.

3. Resonator fabrication

ZnO based FBAR's were dessigned and fabricated on a 200 μm Si (100) wafer. ZnO and Si were chosen as high and low acoustic materials. The sputtering conditions had to be optimized so that the compressive stress of Zno would be compensated by the tensile stress of Si. This optimization is necessary to avoid cracking and delamination of the layers or a deformation of the substrate. A 80 nm Pt bottom electrode was deposited by evaporate. As next step the ZnO piezoelectric λ/2 film was deposited. The size of one 50 Ω resonator is 0.03 mm^2, including the contact pads.

4. Characterization

A network analyzer and and air coplanar probe were used to characterize these resonators (figure 2). The scattering parameter S_{11} was measured between 0.2 and 1 GHz and the admittance was calculed from these data. The resonance behavior of the FBAR device exhibits its characteristic impedance as a loop that is mostly located in the capacity part on the smith chart, as plotted in figure 3a. Alarge return loss of ≈ 50 dB was achieved at center frequency of 540 MHz (figure 3b). The Smith chart shows that the FBAR is already matched to 50 Ω impedance without any outer matching circuits.

The resonance frequency of the FBAR device is accepted to be f = v/2d where is wave and is ZnO film thickness. However, in reality, the bottom electrode reduces the resonance frequency by its presence as part of the acoustic path of the resonator [4-6]. The so-called mass loading effect is significantly more pronounced with the Pt electrode because of its low acoustic velocity. In FBAR fabrication, 5.7 μm thick ZnO films were deposited to obtain the resonance frequency of 555 MHz.

However, the measured resonance frequency was 537 MHz, which is 18 MHz lower than the expected value of 555 MHz. It was found that the resonance is determined to a large degree by the acoustic mass loading of the Pt bottom electrode. The performance of the resulting FBAR was evaluated using the following

$$k_{eff}^2 = \frac{\pi^2}{4}\frac{f_S}{f_p}\left(1 - \frac{f_S}{f_p}\right) \qquad (1)$$

k^2_{eff}, the effective electromechanical coupling coefficient, is a measure of the relative frequency spacing between the series resonance frequency (f_S) and parallel frequency (f_p) and also determines the maximum bandwidth that can be achieved with a filter. In general, two different definition have been used to find. One is the conventional definition of using the local extrema in the magnitude of the input admmittance (Y_{in}). The other is the empirical definition of using the local extrema in the slope of the input impedance phase. In this work, the empirical definition was used to calculate f_S and f_p from Figure 4. Where slope of Y_{in} was plotted as a function of frequency. As a result, f_S and f_p, were to be 520 MHz and 537 MHz respectively. From these findings, a coupling coefficient k^2 of 6.4 % was calculated using equation (1). This results depends on the crystallinity of Pt bottom electrode.

5. Conclusion

Very high quality r.f. magnetron sputtering deposited ZnO thin films have been shown the exhibit a S_{11} parameter of the FBAR device is accepted to be f = v/2d where is wave and is ZnO film thickness. The FBAR devices with the ZnO films exhibited a pronounced resonance peak centered at 537 MHz with a k^2 coupling coefficient of 7 %.

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Table 1. ZnO sputtering conditions

Sputtering pressure	3.35 x 10^{-3} Torr
Mixture gas	Ar + O_2 = 80 – 20 %
Power RF	50 W
Sputtering time	6 h
Substrate temperature	100 °C
Target-substrate distance	7 cm

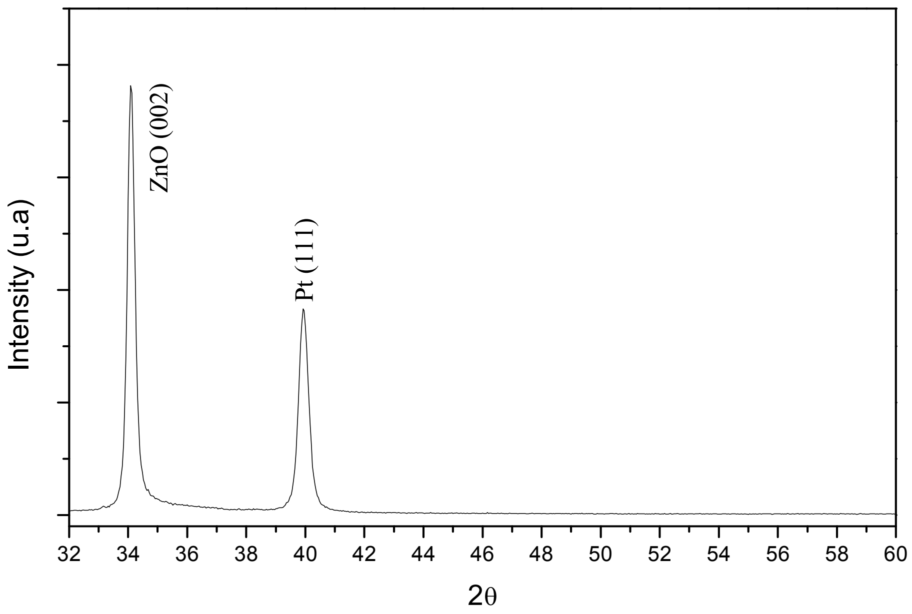

Figure 1. X-ray diffraction curves of ZnO thin films deposited on Pt bottom electrode.

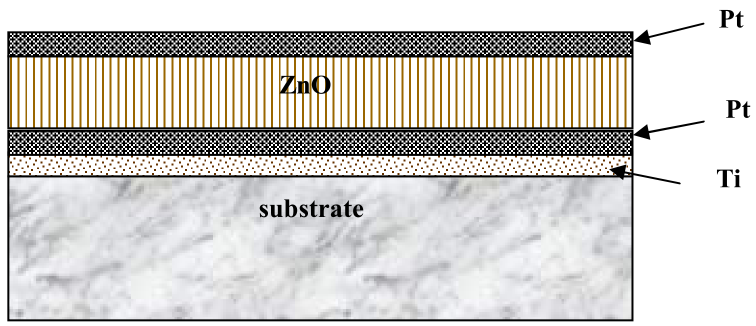

Figure 2. Schematic of FBAR device: cross-sectional view.

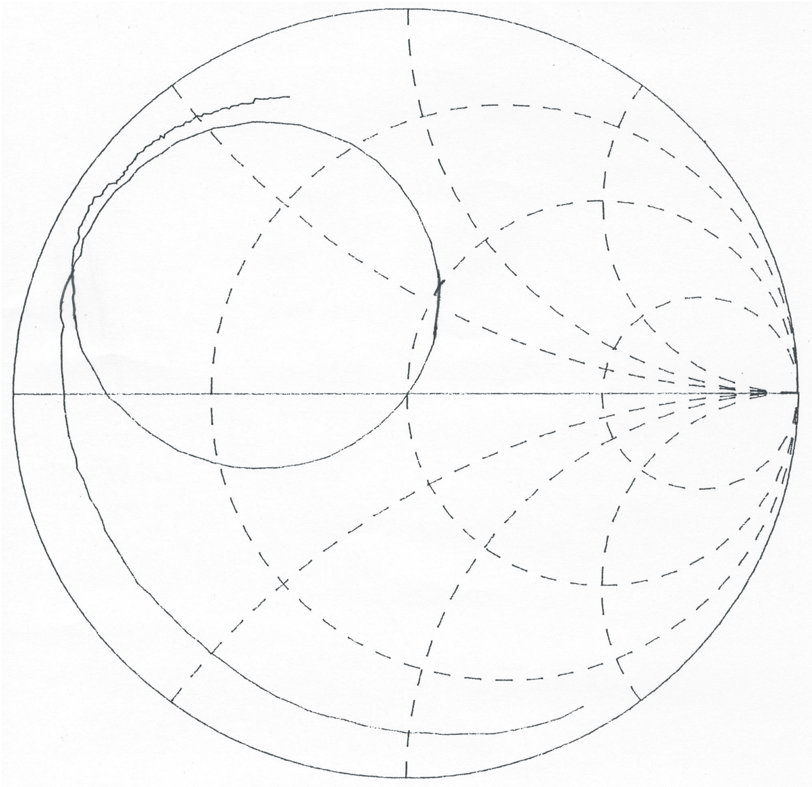

Figure 3. Characteristic of ZnO based FBAR: Smith chart

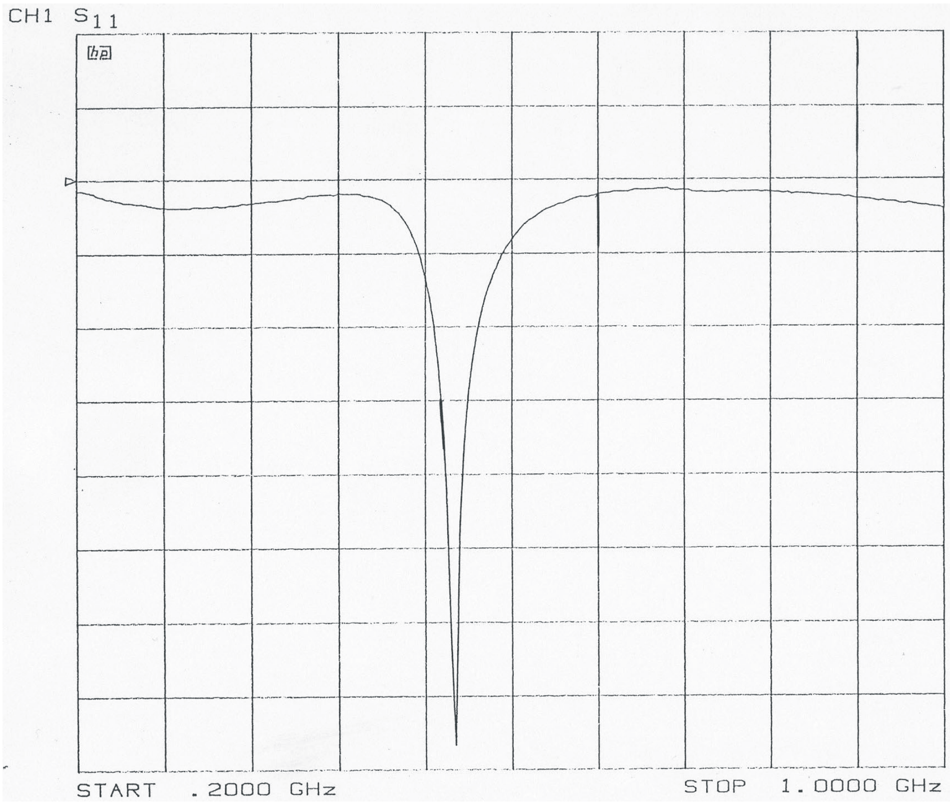

Figure 4. Characteristic of ZnO based FBAR: Return loss (S_{11}).

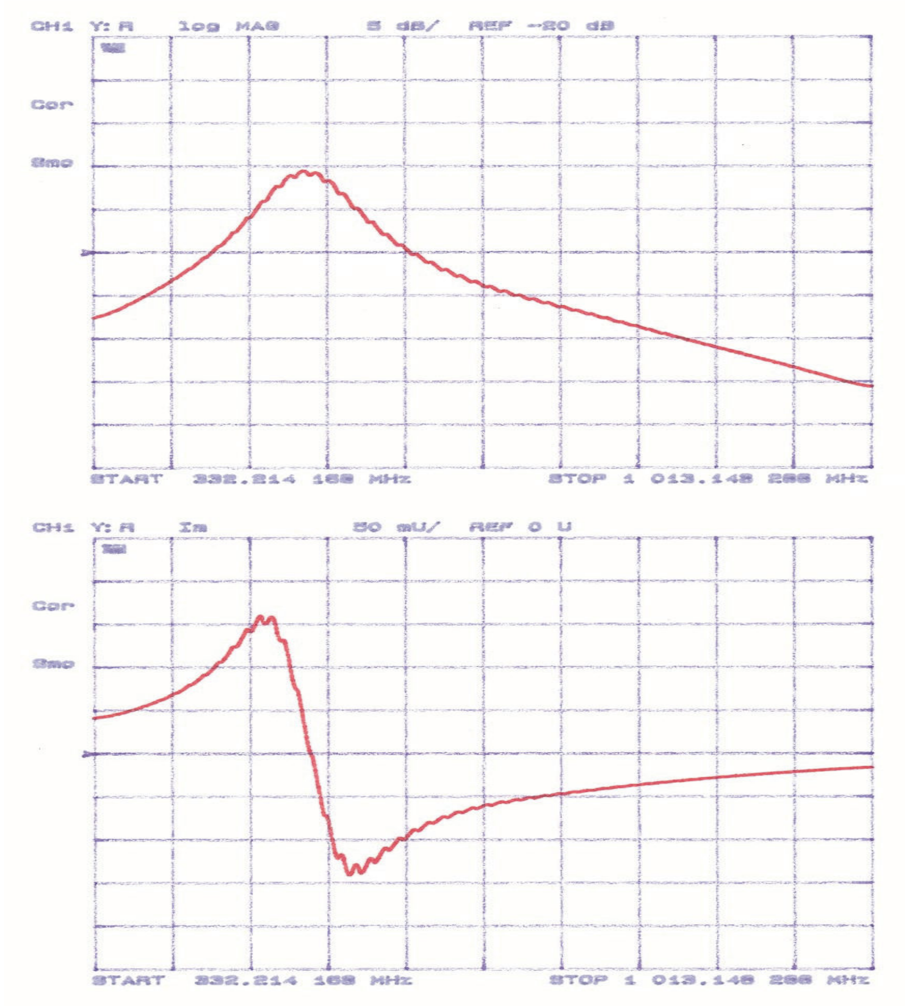

Figure 5. rms of Admittance curves measured on the ZnO based FBAR situated at the center of the wafer as function of frequency.