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Fabrication and analysis of ZnO thin film bulk acoustic resonators

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Abstract

This study employs RF magnetron sputter technique to deposit high *C*-axis preferred orientation ZnO thin film on silicon substrate, which is then used as the piezoelectric thin film for a thin film bulk acoustic resonator (FBAR). Electrical properties of the FBAR component were investigated by sputtering a ZnO thin film on various bottom electrode materials, as well as varying sputter power, sputter pressure, substrate temperature, argon and oxygen flow rate ratio, so that structural parameters of each layer were changed. The experimental results show that when sputter power is 200 W, sputter pressure is 10 mTorr, substrate temperature is 300 °C, and argon to oxygen ratio is 4:6, the ZnO thin film has high *C*-axis preferred orientation. The FBAR component made in this experiment show that different bottom electrode materials have great impact on components. In the experiment, the Pt bottom electrode resonant frequency was clearly lower than the Mo bottom electrode resonant frequency, because Pt has higher mass density and lower acoustic wave rate. The component resonant frequency will decrease as ZnO thin film thickness increases; when top electrode thickness is higher, its resonant frequency also drops, due to top electrode mass loading effect and increased acoustic wave path. Therefore, ZnO thin film and top/bottom electrode thickness can be fine-tuned according to the required resonant frequency.

Keywords: RF magnetron sputter; ZnO; Film bulk acoustic resonator

1. Introduction

The surface acoustic wave filter is the most widely used filter in current market, primarily because its area is small, so it can be produced at a large volume using technology similar to semiconductors and thus be less costly. It also has the advantages of low signal loss and low noise [1]. But in light of increasing jammed frequency band demand, since the applicable frequency of the surface acoustic wave filter is 10 MHz–3 GHz, demand for higher frequencies will encounter considerable manufacturing difficulty. Therefore, it cannot be integrated with an integrated circuit process, and can only be externally connected in the form of component to maintain high quality factor, which poses a different problem as future communication modules were towards the system on chip technology. Therefore, a kind of film bulk acoustic resonator (FBAR) micromechanical electronic component was developed in recent years as a high frequency filter to replace filters current on the market [2–4]. FBAR is smaller than logical circuit filters and dielectric ceramic filters and lower input loss than surface acoustic wave filter [5]. Previous studies on the structure of FBAR include the following. Lee et al. [6] deposited ZnO epitaxial film on p-InP (1 0 0) substrate for FBAR devices based on compound semiconductors substrates without metallic bottom electrode. Kim et al. [7] proposes a process for making an air-gap-type FBAR using the magnesium sacrificial layer. Weber et al. [8] used FBAR operating in shear mode for biosensing applications.

This study investigates the properties of high *C*-axis preferred orientation ZnO as a piezoelectric thin film for FBAR with a reactive RF magnetron sputter. The electrical properties of the FBAR component were investigated by sputtering a ZnO thin film on various bottom electrode materials, and varying the sputter conditions to change the structural parameters of each layer. In addition, to facilitate future integration, silicon is used as the substrate for the FBAR component.

2. Experiment

The main purpose of this experiment is to fabricate an FBAR thin film on a Si substrate, as shown in Fig. 1. Electrical

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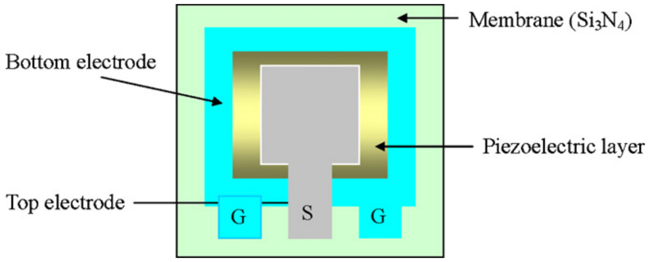

Fig. 1. The structure of FBAR designed.

properties of the FBAR component were studied by changing the parameters of various layers, such as electrode thickness, piezoelectric thin film thickness and area. The wafer adopted in this experiment is boron doped p-type single crystal silicon wafer, crystallographic direction is (1 0 0), thickness is 325 ± 25 μm, resistivity is 1–20 Ω cm. The experimental process is mainly divided into two main parts: sputtering of ZnO and component fabrication.

First conduct low-pressure chemical vapor deposition (LPCVD) of low-stress Si_3N_4 of thickness 0.2 μm (deposition under temperature 850 °C, process gas SiH_2Cl_2/NH_3, and working pressure 180 mTorr), and take it as a FBAR membrane; in this study, Si_3N_4 thin film material was chosen as etching hood and membrane. After cleaning, lithographic processes were employed to define the etching pattern and etch it by KOH and reactive ion etching (RIE), to make the acoustic wave cavity. After etching, the vacuum sputter metal bottom electrode, finally sputtered a ZnO thin film on the reverse side of the wafer as a piezoelectric thin film, with the Al electrode as the top electrode. Then the RIE was used to remove remaining silicon in the cavity to complete FBAR fabrication. The detailed fabrication process of the component in this experiment is stated below: (1) deposit Si_3N_4 as a membrane and etching hood; (2) apply a thick film photoresist and transfer the acoustic wave cavity etching pattern to photoresist; (3) exposure and developing; (4) etch off the acoustic wave cavity; (5) sputter the bottom electrode, ZnO thin film, and top electrode metal; and (6) remove rest remaining thickness of silicon in the cavity. A diagram of the fabrication process is shown in Fig. 2.

For the ceramic target this experiment used ZnO, with purity is 99.99%. The reaction gases were argon and oxygen, with

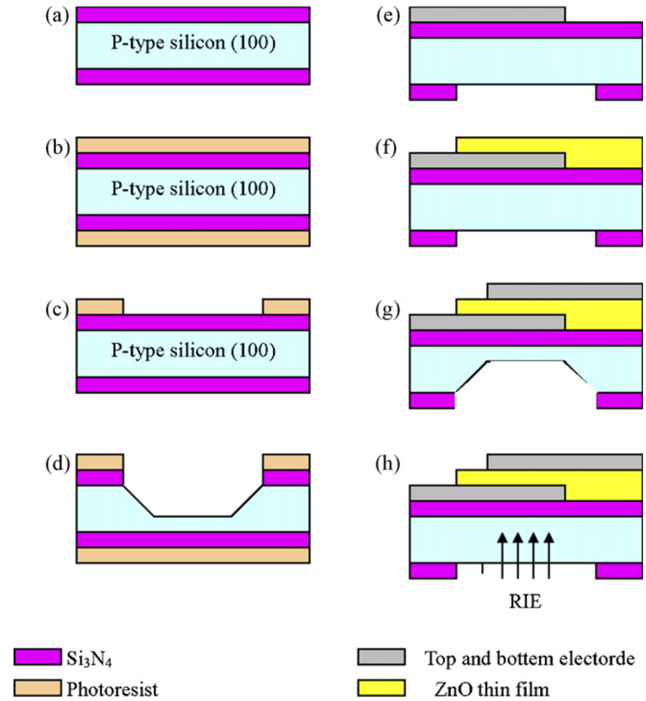

Fig. 2. Schematic the fabrication process of component.

purity of 5N (99.999%), the substrate was LPCVD-deposited low-stress Si_3N_4 on a single crystal silicon substrate and sputtered with Pt and Mo, size was a 1 cm × 1 cm coupon. The sputter background pressure was 5.0×10^{-6} Torr, work distance was fixed at 7 cm, total gas flow rate was 20 sccm, and various parameters were adjusted to perform thin film deposition. Parameter setting of this experiment was shown in Table 1.

In respect to thin film component analysis, a scanning electron microscope (JOEL, JSM-6360) was used to observe the section and measure deposition rate; an X-ray diffractometer (Rigaku d/max 2.b) was used to analyze lattice orientation of ZnO thin film, and a high frequency probe station with a network analyzer (HP8753ES) were used to measure the resonant frequencies of the fabricated device. The electromechanical coupling constant and quality factor were determined experimentally by following steps: first, measured the S parameter with a network analyzer, then, input S

Table 1
Parameters of growing ZnO thin film

Code	Working pressure (mTorr)	RF power (w)	Ratio of Ar/O_2	Heating temperature (°C)
A_1	10	200	8/2	100
A_2	10	200	8/2	200
A_3	10	200	8/2	300
B_1	5	200	8/2	300
B_2	10	200	8/2	300
B_3	15	200	8/2	300
C_1	10	150	8/2	300
C_2	10	200	8/2	300
C_3	10	250	8/2	300
D_1	10	200	8/2	300
D_2	10	200	6/4	300
D_3	10	200	4/6	300