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Surface micromachined AlN thin film 2 GHz resonator for CMOS integration

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Abstract

This paper describes the development of the aluminum nitride (AlN) thin film bulk acoustic resonator (FBAR) using noble MEMS techniques for CMOS integration. An air-gap was fabricated under the resonator for acoustic isolation. Germanium (Ge) was used as a sacrificial layer to make the air-gap. This technique gives high CMOS compatibility. The resonator achieved a Q factor of 780 and an effective electro-mechanical coupling constant (k_{eff}^2) of 5.36% at a resonant frequency of 2 GHz.

Keywords: FBAR; CMOS compatibility; Germanium; Sacrificial layer etching; Aluminum nitride

1. Introduction

A drastic growth of the mobile markets demands smaller and cheaper RF-systems. Consequently, a CMOS compatible resonator is actively researched and developed all over the world [1,2]. The CMOS compatible resonator will allow realizing a one-chip front-end circuit. A thin film bulk acoustic resonator (FBAR) is a leading candidate of CMOS compatible resonators [3–5].

The FBAR is a bulk acoustic wave (BAW) device like a quartz resonator. It simply consists of plate electrodes and a piezoelectric film. Since the FBAR does not require any sub-micron patterns such as a surface acoustic wave (SAW) device, it obtains wider process margin and higher electrical performances, which are low insertion loss and high power handling. The FBAR is fabricated on the substrate using conventional VLSI technologies. Therefore, it can be fabricated with the CMOS circuit on the same chip.

In order to obtain a high Q factor and reduce spurious responses, the FBAR has to be isolated acoustically from the substrate. Three techniques have been reported for the acoustic isolation as shown in Fig. 1. In the configuration of Fig. 1(a), the substrate beneath the resonator is thinned using a backside etching [3–5]. In the configuration of Fig. 1(b) and (c), an air-gap [6] and acoustic multi-reflectors [7] are fabricated between the resonator and the substrate, respectively. The air-gap type resonator (AGR) and the acoustic multi-reflectors type resonator, which is called solidity mounted type resonator (SMR) generally, are suitable for post CMOS process because they are fabricated by surface processing and do not need to machine the substrate. Especially, the AGR allows higher Q factor than the SMR because the air is ideal for acoustic isolator.

A sacrificial layer etching is used for a free-standing structure formation. However, phosphosilicate-glass (PSG), porous-Si and a metal such as Al or Cu, which are commonly used as sacrificial layers, are not appropriate for a post CMOS processing, since these materials are etched by HF or HCl based solution which causes a defect of the CMOS circuit. Contrarily, germanium (Ge) is dissolved easily by hydrogen peroxide (H_2O_2) and provides good process compatibility as a sacrificial layer [8,9].

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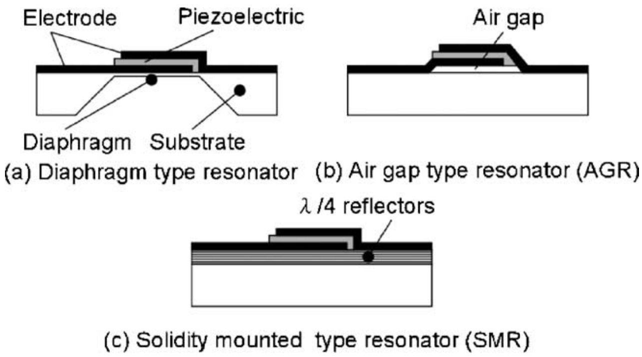

Fig. 1. Acoustic isolation structures.

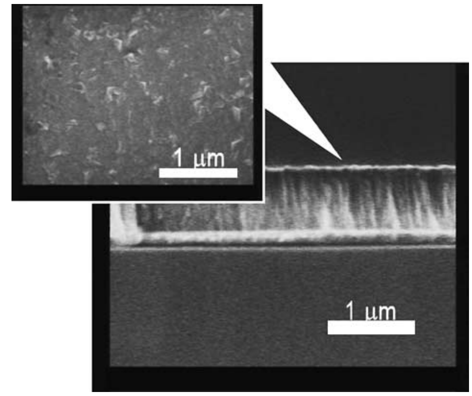

Fig. 2. SEM images of the reactively sputtered AlN film.

Both aluminum nitride (AlN) and zinc oxide (ZnO) are widely used for the FBAR as a piezoelectric layer, because those deposited films show high *c*-axis orientation, which is suitable for thickness extensional vibration. AlN, especially, does not have a metal which performs the recombination center of the carriers such as zinc of ZnO [10]. Hence, AlN is attractive for the CMOS integration. In addition, AlN film has several other advantages such as high breakdown voltages and low dielectric loss.

In this study, the air-gap type FBAR has been fabricated using the Ge sacrificial layer etching and AlN as a piezoelectric layer.

2. Fabrication

2.1. AlN deposition

It is widely accepted that (1 1 1) plane of fcc metals such as Al, Au or Pt has geometric matching to hexagonal (0 0 2) plane of AlN. Since Pt does not generate an oxide and an alloy, and obtains high (1 1 1) orientation easily when deposited [11,12], sputtered Pt was utilized as the base layer for AlN deposition. Various techniques have been reported for AlN deposition, which are, chemical vapor deposition (CVD) or electron cyclotron resonance (ECR) sputtering. In this study, RF magnetron reactive sputtering was used because this technique gives lower process temperature than CVD and has more simple system construction than ECR sputtering. The optimized condition is shown in Table 1. The process temperature is 250 °C, under which CMOS circuit is not damaged.

Table 1
RF reactive sputtering condition for the ALN deposition

Target	Al (99.999%), 2 in
Substrate	Pt(1 1 1)/Ti/Si
Back pressure	<5 × 10^{-8} Torr
RF power	200 W(10.2 W/cm^2)
Sputtering pressure	0.6 Pa
Substrate temperature	250 °C
Ar flow rate	6.3 sccm
N_2 flow rate	6.3 sccm
Deposition rate	20 nm/min

Scanning electron microscopy (SEM) images of deposited AlN film are shown in Fig. 2. The film revealed the evidences of zone-C-type morphology, that are columnar structure in cross section and grain facet on the surface [13]. An X-ray diffraction (XRD) pattern of the film clearly indicated AlN (0 0 2) peak as shown in Fig. 3(b). The rocking curve of the AlN (0 0 2) peak is shown in Fig. 3(a). Full width of half maximum intensity (FWHM) of 4° was achieved.

2.2. Characterization of Ge sacrificial etching

A sacrificial layer etching has been used to make a suspended structure. Ge was used as a sacrificial layer material in this study. Ge is dissolved easily in hydrogen peroxide (H_2O_2) and provides a good process compatibility with CMOS circuit.

The side etching rate was measured using the test sample as shown in Fig. 4. The test sample was fabricated in the following manner: Ge was sputtered on a Si substrate and patterned using a dry etcher. The pattern widths are 5 μm, 10 μm,

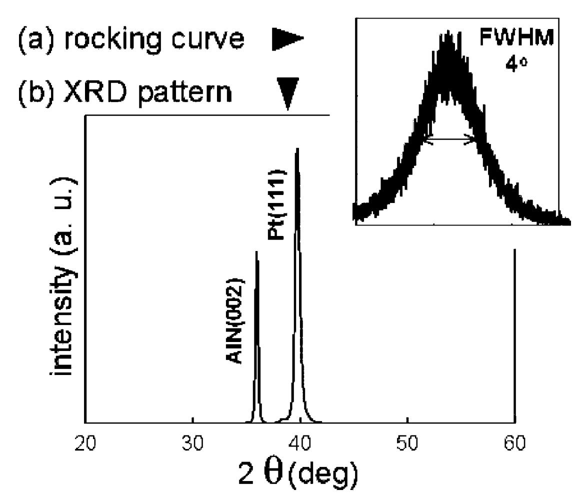

Fig. 3. XRD pattern of the reactively sputtered AlN film and rocking curve on the AlN (0 0 2) peak.