CMOS Integrated ZnO Thin Film Bulk Acoustic Resonator with Si3N4 Susceptor Layer for Improved IR Sensitivity

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Microelectromechanical sensors (MEMS) offer a new way of measuring temperature and infrared (IR) radiation, through measurements of total optical energy, overcoming the obstacles associated with narrow bandgap semiconductor detectors[1]. Specifically, Thin Film Bulk Acoustic Resonators (FBAR) offers a versatile MEMS technology based on resonant devices fabricated using piezoelectric materials [2]. With the addition of an absorbing susceptor and the use of zinc oxide (ZnO) as the piezoelectric it is possible to obtain a higher sensitivity device than previously demonstrated systems, taking advantage of ZnO's higher temperature coefficient of frequency (TCF) [3,4,5]. This work studies the improved sensing ability of an FBAR structure and ease of testing and superior parasitic performance provided in a package using an engineered high TCF FBAR in a monolithically integrated CMOS process.

These devices were fabricated both on glass and on a foundry-sourced CMOS IC with oscillator circuits for monolithic integration with the underlying circuitry. All of the layers, with the exception of nitride layers, were patterned using optical photolithography. Figure 1b shows a cross-section of the device. First, 1 um of PECVD deposited a-Si was deposited as a sacrificial layer. A thick layer (600nm) of strain-tuned Si3N4 was deposited using PECVD to support the highly compressive piezo film. The bottom electrode is patterned using optical photolithography and chrome/gold (Cr/Au) was deposited (5nm/100nm) via e-beam deposition. Au was the preferred bottom electrode for seeding a c-axis (002) oriented ZnO growth. ZnO, was grown using RF magnetron sputtering. To keep the temperature budget low enough for CMOS compatibility (<300C), the growth was performed at a temperature of 150C and constant pressure of ~2mTorr. A top electrode of Al was then deposited (100nm). The absorber layer (Si3N4) was deposited via PECVD (100nm). For the membrane's release, etch holes were opened with a Fluorine ICP and subsequently the a-Si was etched in XeF2. A micrograph of the finalized device can be seen in Figure 1a.

The device was tested by applying bias to the amplifying circuit and measuring the output of the oscillator circuit with a spectrum analyzer, as shown in figure 1c. The oscillation frequency of the demonstrated resonator is 1.5GHz. To demonstrate the improved IR sensitivity, the device was characterized as a temperature sensor using a controlled heated stage, yielding a TCF of -62ppm/C was extracted, shown in Figure 2a and 2b respectively. The limit of detection was also studied, by analyzing the noise at each temperature. A noise equivalent thermal difference (NETD) of ~6 KHz (4 ppm) or 66mK was obtained. A laser (650nm) was used to obtain a long wavelength optical response in the absorption region of the nitride absorber. The deposited nitride film absorbs 10-20% absorbance from ~600nm to 2.5um, spanning the long wavelength visible and near-IR (NIR)[4,5]. The incident power on the device was ~2uW, resulting in a 1.5MHz shift, as shown in Figures 3a and 3b. This shift translates into a sensitivity of 7.4KHz/(uW/mm^2).

By combining ZnO, a higher TCF piezoelectric, with a susceptor (Si3N4) for increased absorption and heat conversion we were able to demonstrate a high sensitivity sensor, which is also fully monolithic integrated with CMOS technology. This delivers a package that allows for simpler and faster detection response measurement [1,2,3,5]. These devices were not optimized for this application but show a lot of promise with numbers close to other similar structures that use Aluminum Nitride (which has half the TCF) and in some cases no absorber. By reducing the thermal conductivity of the tethers (size reduction) and designing a new CMOS chip that allows for differential measurements and digital outputs it is possible to obtain lower noise.

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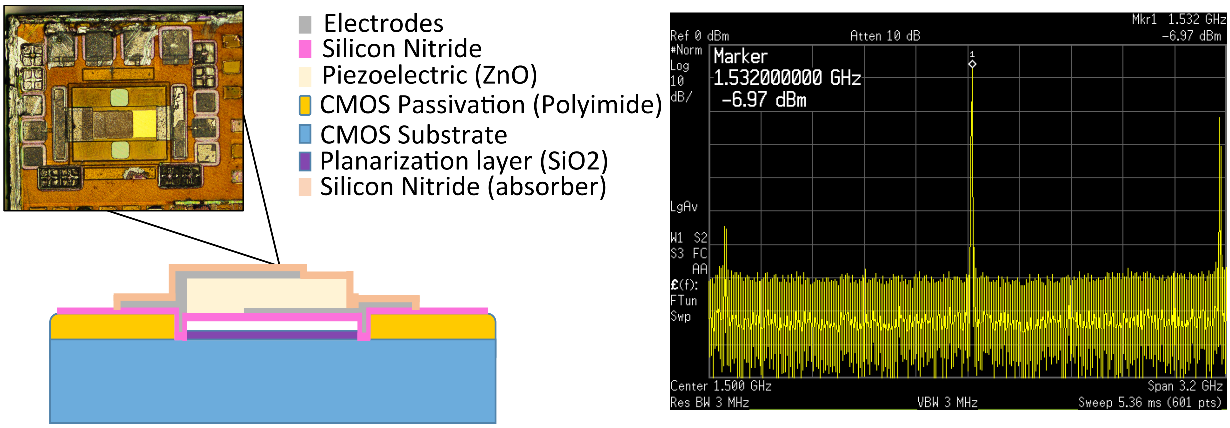

Figure 1 a) Micrograph of finished FBAR on CMOS b) FBAR structure c) FBAR frequency response

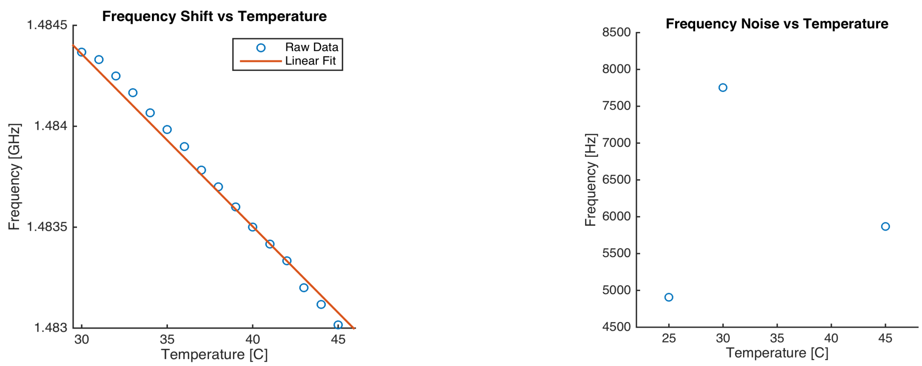

Figure 2. (a)FBAR response to temperature change (b) FBAR Noise measurement results

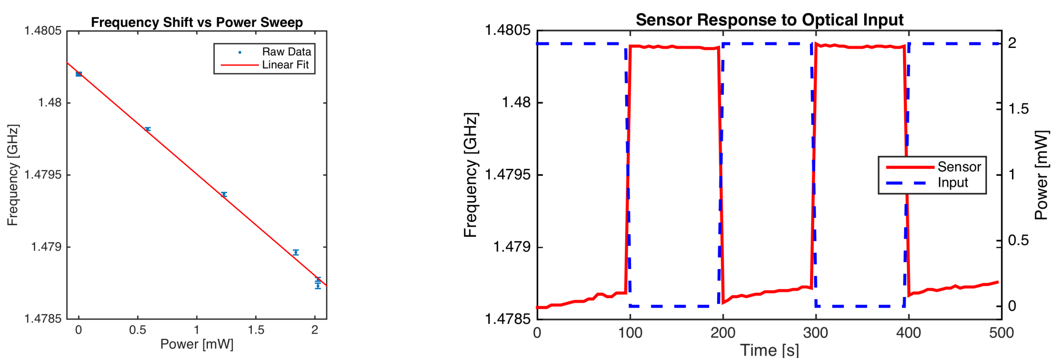

Figure 3. Frequency shift versus incidence power sweep (a) Low power laser (b) High power laser

Parameter	[5]	[6]	[3]	BOLOMETER[7]	This work
Piezoelectric	AlN	AlN	ZnO	-	ZnO
TCF [ppm/K]	-30	-27	-77	-	-62
NETD [mK]	50	-	-	30	66
Sensitivity [Khz/(uW/mm^2)]	-	-	13	-	7.4
Size	190umx128um	75umx200um	150umX150um	25um pitch	100umx100um
Operating Frequency [Hz]	116MHz	397MHz	1.8GHz	-	1.5GHz
CMOS	N	N	N	N	Y