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5 GHz band low phase noise Si-CMOS oscillator using FBAR

Shoichi Tanifuji[a)], **Tuan Thanh Ta, Suguru Kameda, Tadashi Takagi, and Kazuo Tsubouchi**

Research Institute of Electrical Communication, Tohoku University, 2–1–1 Katahira, Aoba-ku, Sendai, Miyagi, 980–8577 Japan

a) *tanifuji@riec.tohoku.ac.jp*

Abstract: In this paper, low phase noise 5 GHz oscillator is presented. This oscillators designed with 90 nm silicon complementary metal oxide semiconductor (Si-CMOS) process. To achieve low phase noise, we used high Q value film bulk acoustic resonator (FBAR) instead of conventional LC resonant circuit. This FBAR oscillator has phase noise of lower than -130 dBc/Hz at 1 MHz offset.

Keywords: film bulk acoustic resonator (FBAR), 5 GHz, 90 nm silicon complementary metal oxide semiconductor (Si-CMOS), low phase noise, oscillator

Classification: Electron devices, circuits, and systems

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1 Introduction

Low phase noise oscillators are one of the most important components of radio transceivers, since their performance set the limits on the dynamic range and jamming sensitivity of the transceivers. Recently, to create small and low cost transceivers, fully integrated oscillators using silicon complementary metal oxide semiconductor (Si-CMOS) process has been developed [1, 2, 3, 4]. But because of noisy Si-CMOS transistor and low Q value inductor due to lossy low resistivity Si substrate, Si-CMOS based oscillators have poorer phase noise characteristic than that of compound semiconductors based ones. It is necessary to lower phase noise of Si-CMOS oscillators. In this paper, to improve the phase noise of oscillators, we used film bulk acoustic resonator (FBAR) [5, 6, 7] instead of conventional LC resonant circuit. FBAR have great advantages of high Q value, low insertion loss and small size over 2 GHz. We have fabricated 5 GHz band FBAR using aluminium nitride (AlN) film. AlN has high acoustic velocity of 1.1×10^4 m/s and good temperature coefficient of frequency (TCF) of 25 ppm/°C [8]. Therefore, we can obtain low phase noise oscillator by high Q value FBAR, more over FBAR oscillator can be realized standard oscillator by good TCF. In this paper, we improved phase noise using FBAR.

2 Device Fabrication

(a) FBAR Fabrication

FBAR structure has piezoelectric film sandwiched between bottom and top electrodes. We used membrane structure of $Pt/ZrO_2/SiO_2/Si(100)$. Resistance of Si(100) was a high value of more than 1 kΩcm. SiO_2 was thermal oxidization method on Si(100) to stop Si etching. We have selected Pt/ZrO_2 structure for bottom electrodes of FBAR. Pt has suitable characteristics to obtain high oriented AlN film. Thin ZrO_2 layer was used as a bonding layer between $SiO_2/Si(100)$ substrate and Pt layer. ZrO_2 and Pt layers were deposited by RF magnetron sputtering method. Thickness of ZrO_2 and Pt were 10 nm and 50 nm, respectively.

We have successfully grown c-axis oriented AlN film deposited by electron cyclotron resonance (ECR) plasma sputter method on $Pt/ZrO_2/SiO_2/Si$ substrate. Full width at half maximum ($FWHM$) of AlN(0002) on Pt/ZrO_2

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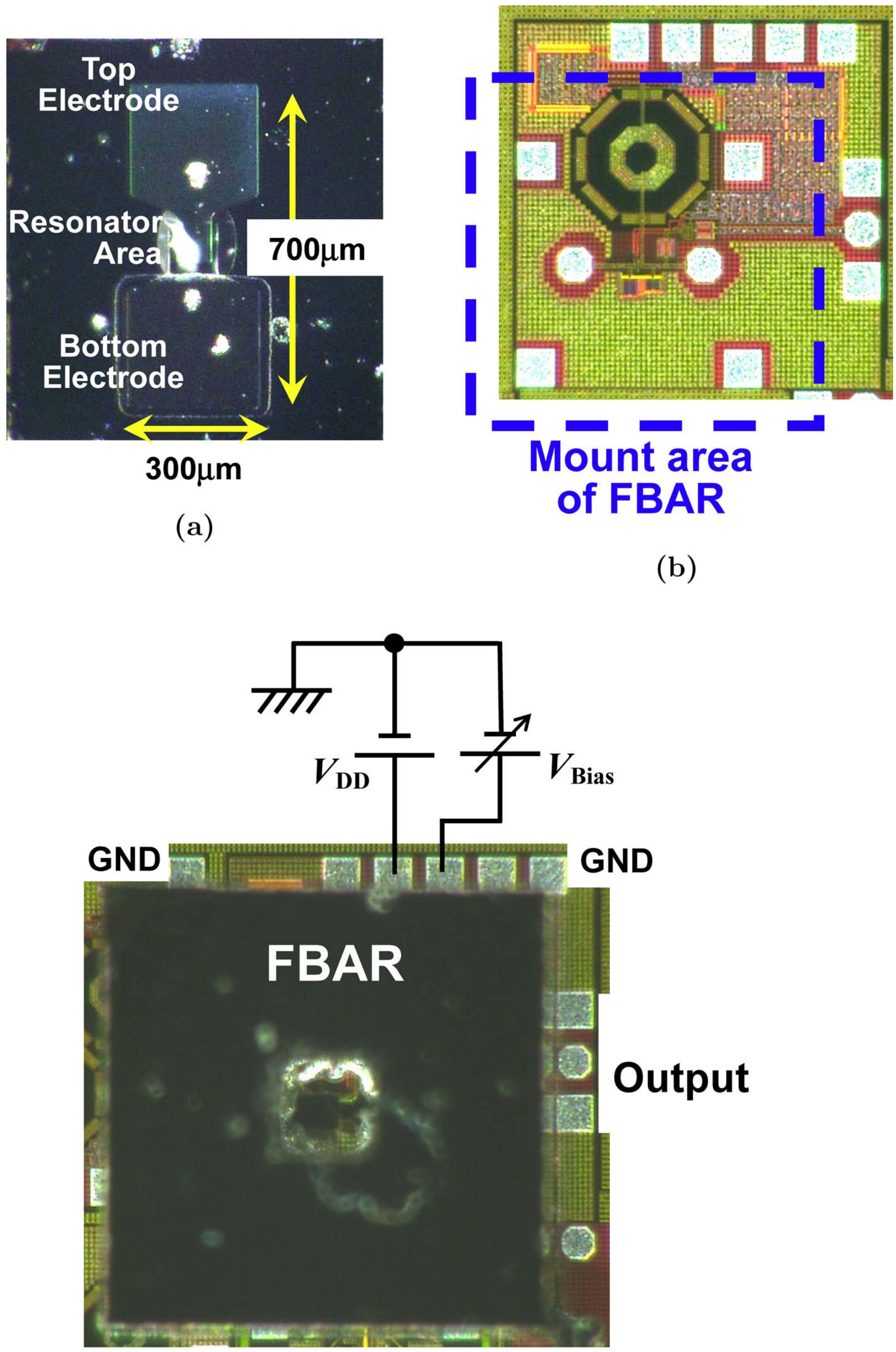

Fig. 1. Chip micrograph of (a) FBAR, (b) Oscillator circuit and (c) Oscillator chip mounted FBAR.

bottom electrode was excellent value of 1.3°. AlN thickness was 580 nm. Top electrode materials was Ag deposited by RF magnetron sputtering method. Ag thickness was 60 nm. Finally, we formed cavity under membrane structure used by deep-reactive ion etching (D-RIE) method.

(b) Oscillator design

Oscillator was basic colpitts circuit and it designed by using 90 nm Si-CMOS process of Taiwan Semiconductor Manufacturing Company, Limited

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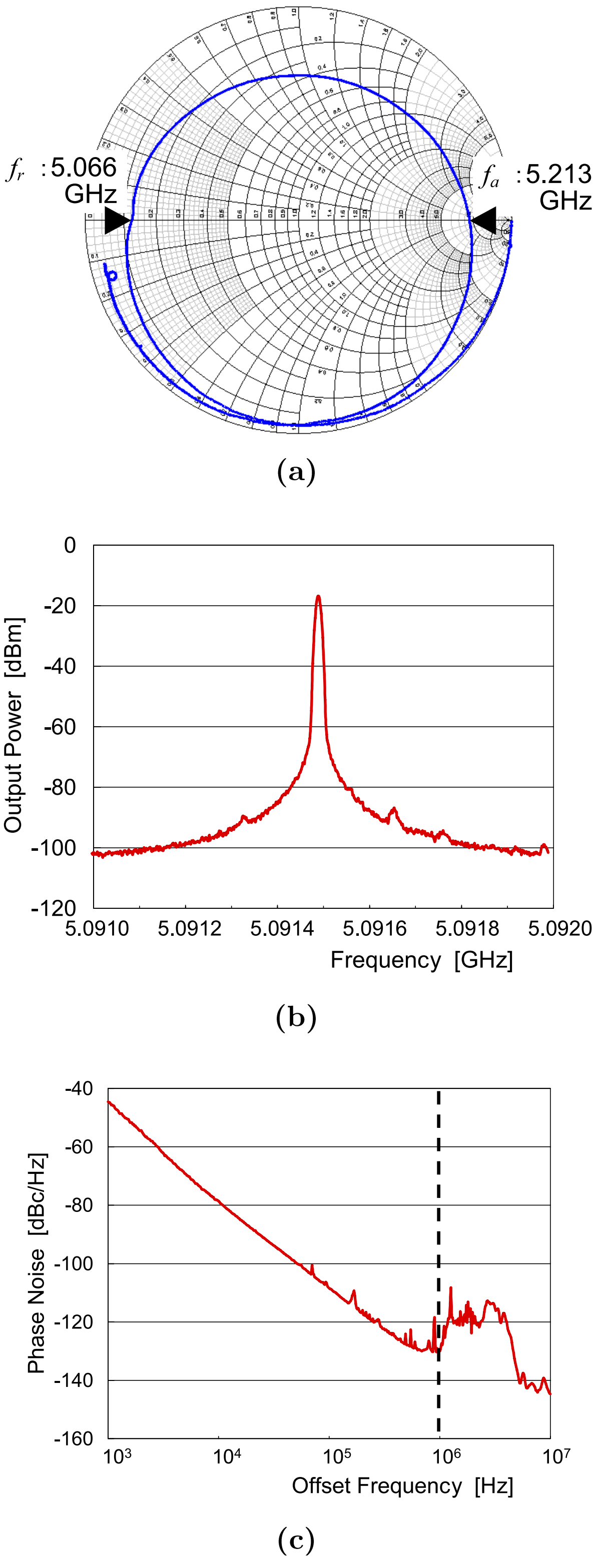

Fig. 2. Output characteristics of (a) FBAR resonant response (S_{11}), (b) Power spectrum and (c) Phase noise.

(TSMC). FBAR was mounted by flip-chip mounting using stud bump bonding (SBB) method on IC chip. Figure 1 shows Chip micrograph of FBAR and oscillator. The FBAR was die size of $1 \times 1\,\mathrm{mm}^2$. The oscillator circuit

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Table I. Performance summary and comparison with other works.

	This work	Ref. [9]	Ref. [10]
Oscillation Frequency	5 GHz	5 GHz	5.4 GHz
Process technology	90 nm Si-CMOS	Discrete BJT	0.35 μm SiGe BiCMOS BJT
Phase noise (@100 kHz)	−108.4 dBc/Hz	−109.5 dBc/Hz	−117.7 dBc/Hz

was also $1{\times}1\,\mathrm{mm}^2$.

3 Experimental Results

We measured oscillation frequency and output power on-wafer by using Series Spectrum Analyzer E4440A (Agilent Technologies, Inc.). Figure 2 (a) shows resonant characteristics of FBAR (S_{11}). Resonant frequency (f_r) was 5.066 GHz. Anti-resonant frequency (f_a) was 5.213 GHz. Q value and effective electromechanical coupling coefficient (k_{eff}^2) were 819 and 7.1%, respectively. Figure 2 (b) shows output characteristics of power spectrum. Horizontal axis is frequency and vertical axis is output power. Oscillating frequency was 5.0909 GHz, and it does not show any change during measurement. Figure 2 (c) shows phase noise characteristics measured by using Signal Source Analyzer E5052A (Agilent Technologies, Inc.). Horizontal axis is offset frequency and vertical axis is phase noise. Phase noise of designed FBAR oscillator is lower than −130 dBc/Hz at 1 MHz offset.

Table I shows performance summary and comparison with other works of FBAR oscillators. Their oscillator is using FBAR and oscillation frequency is 5 GHz band. Though, our work was Si-CMOS process with noisy transister, but we obtained near phase noise level of BiCMOS process. Those were results using nano fabrication technology of 90 nm process and high Q value FBAR.

4 Conclusion

Low phase noise oscillator was proposed by using film bulk acoustic resonator (FBAR). Oscillator chip was realized using 90 nm silicon complementary metal oxide semiconductor (Si-CMOS) process with small die size of $1{\times}1\,\mathrm{mm}^2$. FBAR was mounted by flip-chip mounting using stud bump bonding (SBB) method on oscillator IC chip. FBAR oscillator has low phase noise at 1 MHz offset of lower than −130 dBc/Hz at 5 GHz band.

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