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A Micromachined Air-Cavity Oscillator for 94 GHz Applications

Yumin Koh, Ungbi Son, Sangsub Song, and Kwang-Seok Seo

School of Electrical Engineering and Computer Science, Seoul National University,
San 56-1, Daehak-dong, Kwanak-gu, Seoul, 151-742, Republic of Korea

1. Introduction

For the modern RF and millimeter-wave communication systems, high-stable and low-phase-noise oscillators are required. Because an oscillator is a key component as signal source to be used for frequency translation, synchronization, or sampling [1]. Since the stability and phase-noise performance of an oscillator strongly relies on the quality factor of the loading circuits, these oscillators have been traditionally realized using dielectric resonators (DR's) with a high-Q factor [2]. However, DR's require sophisticated processing of dielectric pucks, a high-Q cavity and a planar resonator using micromachined technique can be a good alternative to DR's [3].

In this work, we have developed a micromachined cavity oscillator based on a thin-film substrate with a flip-chip interconnection for 94 GHz applications. This oscillator technology is an excellent candidate for low-cost mm-wave frequency sources with high performance.

2. Design and Fabrication

The circuit diagram of the developed oscillator is shown in Fig. 1, which largely consists of a micromachined cavity as the loading circuit and a PHEMT LNA as the gain block to generate negative resistance. A topology of the developed oscillator is a parallel-feedback configuration using the micromachined cavity as a parallel-feedback element, which enables a relatively straightforward oscillator design.

A micromachined air-cavity was designed for minimizing the coupling loss between the cavity and the external circuits. I/O ports of a cavity were located in the same side to shorten the feeding line coupled with external circuits [4]. In addition, the newly developed current probe scheme was applied, which can reduce the coupling loss by eliminating the transition loss between CPW and thin-film microstrip (TFMS) lines. To avoid an unwanted detuning effect, the cavity has groove structures for the TFMS I/O feeding lines. Full-wave simulation, which takes into account the current probes and the groove structure, was performed to predict a resonant frequency. The resonant frequency and the coupling level of the cavity were designed for 94 GHz and 5.5 dB, respectively and the cavity measures 2250×2246×280 micrometers.

The PHEMT gain block with two stages was implemented in WINSEM 0.15 μm PHEMT technology and occupied the area of 1060×850 micrometers. The output port of the gain block is connected to the micromachined cavity through the directional coupler, whose coupling level was designed to satisfy the oscillation condition that the loop gain is higher than 1 dB. Total length of the TFMS feeding lines was adjusted so that the phase of the loop including a micromachined cavity, a gain block, a directional coupler, and feeding lines made zero.

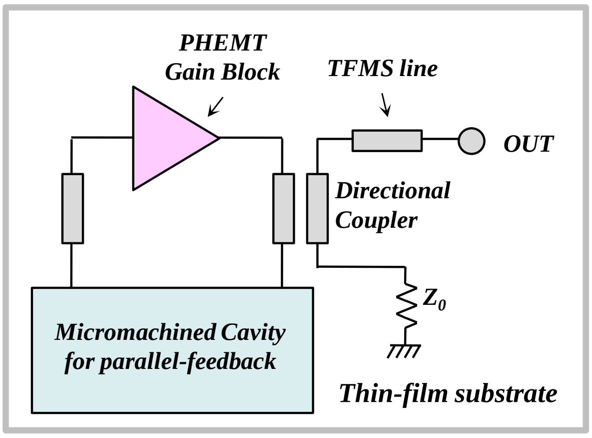

Fig. 1 Diagram of a micromachined air-cavity oscillator

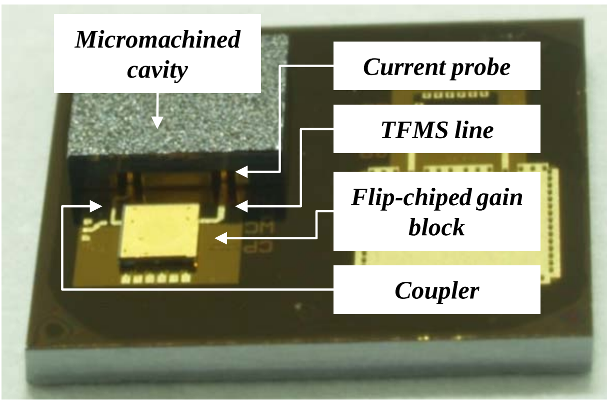

Fig. 2 Photograph of the developed 94 GHz micromachined air-cavity oscillator on a thin-film substrate

We fabricated the thin-film substrate which consists of Si-bumps, ground-bumps, and alternating thin-layers of benzocylobutene (BCB) dielectric and Au metal over the lossy silicon substrate [5]. Then, the cavity structure was fabricated by a silicon micromachining process. A silicon wafer was dry-etched using the Bosch process until a depth of 280 μm was achieved, and then the silicon cavity structure was electroplated with 5-μm thick gold. The current probes were simultaneously formed with the cavity etching process.

The fabricated cavity and PHEMT gain block were flip-chip mounted on a thin-film substrate with Au/Sn flip-chip bump. A bump height was about 20 μm after bonding, which was small enough to neglect the radiation loss through the gap between cavity and thin-film substrate. Figure 2 shows the photograph of the developed 94 GHz oscillator using a micromachined cavity integrated on a thin-film substrate with flip-chip interconnection.

3. Measurement results

The S-parameters of the micromachined cavity were measured using an HP8510C vector network analyzer over the frequencies of 90-98 GHz with a 50 MHz step. Shown in Fig. 3 is the measurement result of the cavity, which has the -6 dB coupling level at 93.7 GHz.

Figure 4 shows the measured output spectrum of the oscillator, where the oscillation frequency of 93.7 GHz was observed at a bias condition of V_{G1} = V_{G2} = -0.2 V, V_{D1} = V_{D2} = 3.5 V, I_{D1} = 35 mA, and I_{D2} = 32 mA. Considering the conversion loss of the harmonic mixer and other losses of measurement setup, the output power was estimated at 2 dBm. As illustrated in Fig. 5, the single-sideband phase noise (L_{SSB}) of - 99 dBc/Hz at 1 MHz offset was obtained at the same bias. This is the improved value of more than 23 dB compared with the fabricated free running oscillator.

4. Conclusions

A 94 GHz micromachined air-cavity oscillator has been successfully demonstrated. The developed oscillator consists of micromachined air-cavity and PHEMT gain block which were flip-chip mounted on a thin-film substrate. And the current probe scheme was applied to the micromachined air-cavity in order to reduce transition loss between cavity and I/O ports. These current probes were simultaneously formed with the cavity etching process so that this scheme can be easily applied. In measurement results, the fabricated oscillator has the comparatively large output power of 2 dBm and the low phase noise of -99 dBc/Hz at 1 MHz offset frequency. This result shows the micromachined air-cavity oscillator is useful to easily demonstrate the low-phase-noise mm-wave signal source.

Acknowledgements

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References

[1] C. T. C. Nguyen, L. P. B. Katehi, and G. M. Rebeiz: Proc. IEEE **86** (1998) 1756.

[2] A. M. Pavio and M. A. Smith: IEEE Trans. Microwave Theory Tech. **33** (1985) 1346.

[3] Y. Kwon, C. Cheon, N. Kim, C. Kim, I. Song, and C. Song: IEEE Microw. Guided Wave Lett. **9** (1999) 360.

[4] S. Song, Y. Kim, W. Choi, Y. Kwon, and K.-S. Seo: IEEE Microw. Guided Wave Lett. **19** (2009) 107.

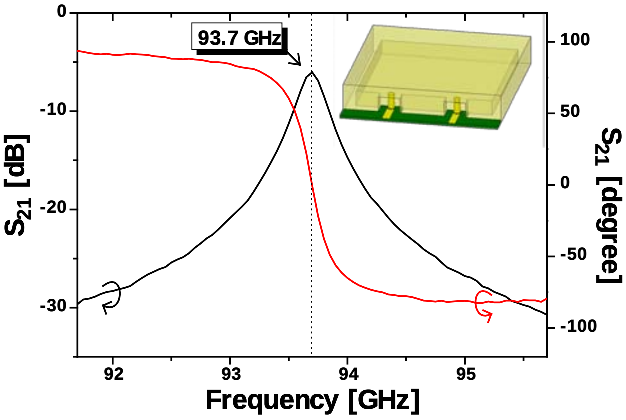

Fig. 3 Measured S_{21} and the structure of a micromachined air-cavity

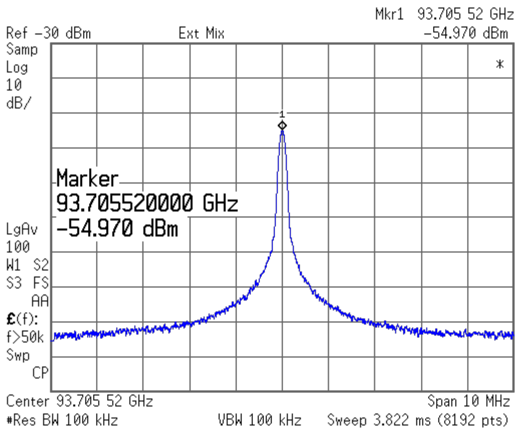

Fig. 4 Measured spectrum of the developed oscillator at the bias condition of V_{G1} = V_{G2} = -0.2 V, V_{D1} = V_{D2} = 3.5 V, I_{D1} = 35 mA, and I_{D2} = 32 mA.

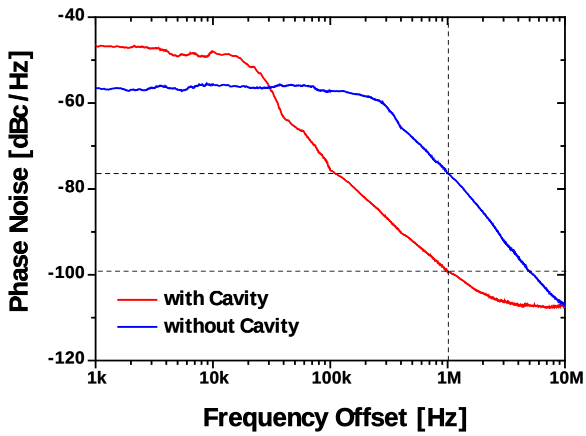

Fig. 5 Phase noise comparison between the developed oscillator and free running oscillator at the same bias condition as Fig.4.

[5] S. Song, Y. Kim, J. Maeng, H. Lee, Y. Kwon, and K.-S. Seo: IEEE Trans. Adv. Pack. **32** (2009) 101.