A suspension type spiral inductor for multi-GHz applications

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1. Introduction

Recently, there has been many researches performed on RF component especially for wireless RF communication[1-3]. The demands for multi-mode and multi-function in wireless communication require higher capacity, frequency and smaller size. RF MEMS technology has advantage of miniaturization, integration and high performance. A VCO (Voltage Controlled Oscillator) is one of a key component in wireless communication. The properties of VCO are depended on phase noise and they are greatly affected by Q factors of the inductor. Since the inductors fabricated by standard silicon process do not meet the requirement of RF systems, 3-D MEMS inductor that enables higher Q factor is needed. There have been several kinds of MEMS inductors that have been reported[4-6]. All of these inductors have low Q factor(< 20).

In this paper, we have fabricated high-performance suspension type spiral inductor on a various substrate materials using MEMS process. We also fabricated fully integrated VCO using MEMS suspension type inductor.

2. Fabrication

The fabrication process is a simple process using multi-layer photoresist. The substrate silicon wafer is prepared with 2000Å nitride layer for insulation(Fig. 1a). Next, Ti/Cu are deposited as seed layer(Fig. 1b). The thick copper bottom electrode is formed by electroplating with thick photoresist, patterned by UV exposure, as a mold(Fig. 1c). After removal of the mold by stripper, thick photoresist is coated again for post patterning (Fig. 1d). By copper electroplating, 20 um posts are formed(Fig. 1e). After hardening of the bottom photoresist, second Cu seed deposition is performed and the photoresist is patterned to make a mold for top spiral inductor(Fig. 1f). Top spiral inductor is electroplated to the height of 10 um to reduce ohmic loss and to gain high Q factors(Fig. 1g). Finally, the inductor is released by etching photoresist mold and seed metals(Fig. 1h).

3. Results

3.1 Inductors on various substrates

The inductors are fabricated on various substrates to figure out the effect of substrate loss on Q factor of inductor. Five kinds of substrates were selected. They were silicon with 2000Å nitride insulation layer, silicon with 5 um oxide insulation layer, HRS(over 10000 ohm*cm) with 2000Å nitride insulation layer, glass and quartz. Fig. 2 shows the SEM photograph of the fabricated inductor. The fabricated inductors were measured from 0.5 GHz to 20 GHz using HP network analyzer. Fig. 3 shows the characteristics of the fabricated inductor. The inductor on glass wafer has peak Q factor of 30 at 4 GHz with an inductance of 2.5 nH. However, the inductor on silicon wafer with 2000Å nitride insulation layer has peak Q factor of 15 at 1 GHz with an inductance of 2.4 nH. The Q factor of inductor on silicon wafer has lower value since it has greater substrate loss. Fig. 4 shows the loss of through line on silicon and glass wafer. The through line is a straight line on the substrate. One can clearly see that the loss of silicon substrate is much higher than loss of glass substrate.

The measured data was used to find out fitting parameters in equivalent circuit model. Fig. 5 shows the equivalent circuit of fabricated inductor and table I shows the fitted parameter values of silicon with 5um oxide insulation layer, HRS, glass and quartz. The measurements were performed with the samples with same dimensions. Thus C_f, R_s and L have similar values. The substrate with low C_{ox}, C_{sub} and high R_{sub} values shows better characteristics.

3.2 Integrated inductors

To fully use the advantages of RF MEMS, integration is an essential process. The fabricated inductor was integrated on a RFIC chip to make a VCO. The VCO circuit was designed and fabricated with Hynix 0.18 um process. The fabrication process of inductor integration is the same as fabricating single inductor. The only difference is the size of the substrate. The integration process was done on 4*4cm chip. Fig. 6 shows the SEM picture of integrated inductor on a chip.

4. Conclusions

The inductors have been fabricated on a various wafer to compare the different characteristics of inductors due to substrate loss. The feeding line, signal pad and ground line showed high loss for silicon substrate and caused degradation of Q factors. Nevertheless, with appropriate insulation layer, the performance of inductor ($Q > 20$) has been measured to satisfy requirement of RF systems. We have fabricated fully integrated VCO with MEMS inductor.

Acknowledgments

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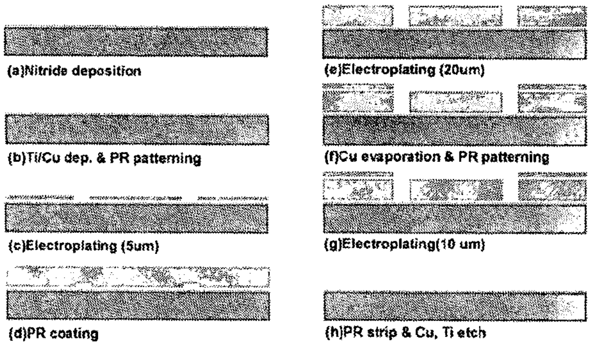


Fig 1(a)-(h) Process flow of inductor fabrication

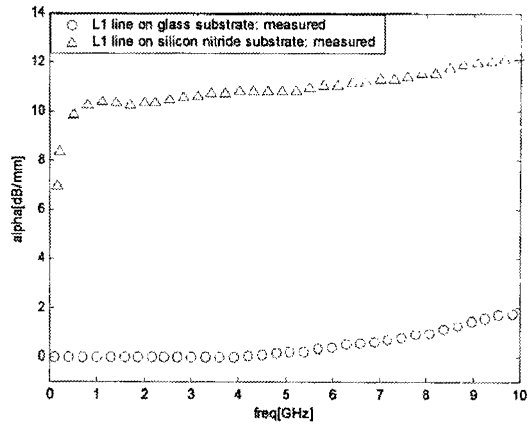
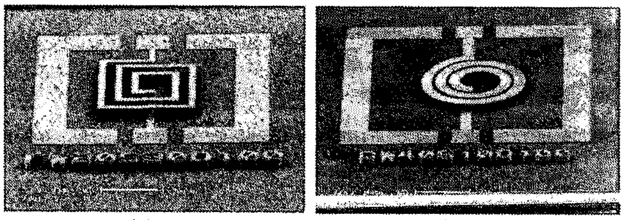


Fig.4 Loss on glass and silicon wafer



(a) (b)

Fig. 2(a),(b) SEM pictures of fabricated inductor

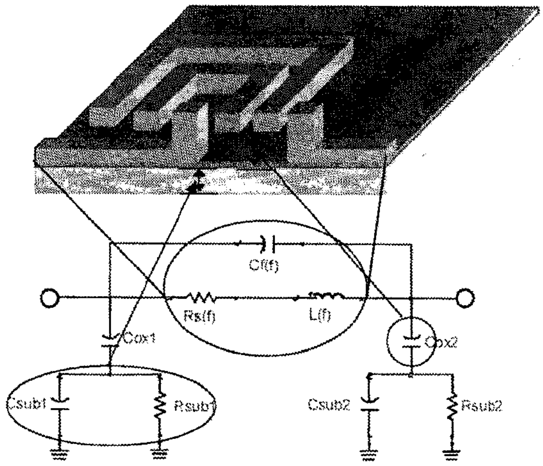


Fig. 5 Equivalent circuit of fabricate inductor

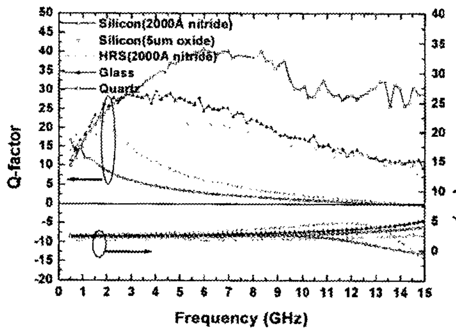


Fig 3. Characteristic graph of fabricated inductor

Table I. Fitted parameter values

	Cf (fF)	Rs (Ω)	L (nH)	Cox1 (fF)	Cox2 (fF)	Csub1 (fF)	Csub2 (fF)	Rsub1 (Ω)	Rsub2 (Ω)
5um Si sub.	1	1.3	2.2	103	107	75	80	200	205
HRS sub.	1	1.2	1.7	65	67	45	47	900	910
Glass sub.	1	1.2	2.1	73	75	55	60	1200	1235
Quartz sub.	1	1.2	2.1	65	67	42	43	3300	3400

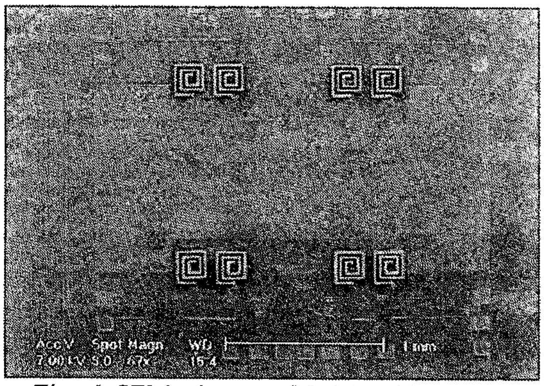


Fig. 6 SEM picture of VCO with integrated MEMS inductor