A Study on the Design and Characteristics of thin-film L-C Band Pass Filter

In-Sung Kim†, Jae-Sung Song*, Bok-Ki Min*, Won-Jae Lee* and Alexandru Muller**

Abstract - The increasing demand for high density packaging technologies and the evolution to mixed digital and analogue devices has been the on-set of increasing research in thin film multi-layer technologies such as the passive components integration technology. In this paper, Cu and TaO thin film with RF sputtering was deposited for spiral inductor and MOM capacitor on the SiO_2/Si(100) substrate. MOM capacitor and spiral inductor were fabricated for L-C band pass filter by sputtering and lift-off. We are analyzed and designed thin films L-C passive components for band pass filter at 900 MHz and 1.8 GHz, important devices for mobile communication system. Based on the high-Q values of passive components, MOM capacitor and spiral inductors for L-C band pass filter, a low insertion loss of L-C passive components can be realized with a minimized chip area. The insertion loss was 3 dB for a 1.8 GHz filter, and 5 dB for a 900 MHz filter. This paper also discusses a analysis and practical design to thin-film L-C band pass filter.

Keywords: Integrated passive component, thin-film L-C band pass filter, high-Q, MOM capacitor, spiral inductor

1. Introduction

Microwave circuit has played an important role in the mobile communication system. One challenge in the implementation of circuit integration is in the design of MOM(metal-oxide-metal) capacitor and spiral inductor with a high quality factor at micro wave frequency band. Typical Q-value required for RF circuit design at 900 MHz and 1.8 GHz are in the range of 5~10 for broad-band matching section, and may need to be higher than 30 in a narrow-band network, such as filters[1, 2, 3].

In this study, high-Q spiral inductors and MOM capacitor were designed and fabricated on SiO_2/silicon-p(100) substrate with a RF sputtering[4, 5]. In order to realize a thin-film L-C band pass filter on silicon substrate, passive components such as MOM capacitor and spiral inductor should be characterized first, and based on the equivalent circuit models of these components, a coupled resonation filter can be designed and fabricated. We particularly focused on the design of filters operating at 900 MHz and 1.8 GHz, which are the most frequently used in the commercial mobile system [4, 5].

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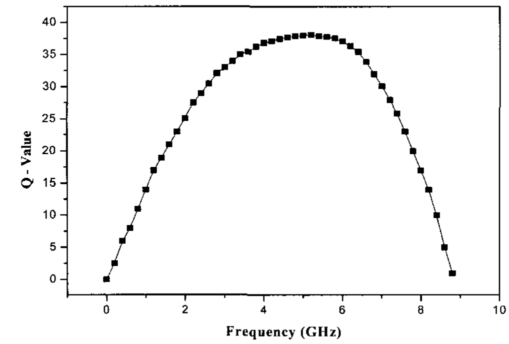
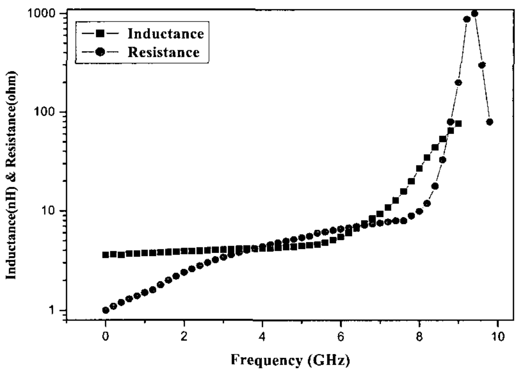
2. Characteristics and fabrication of thin film L-C components

MOM capacitor and spiral inductor were designed for direct two ports S-parameter evaluation. The two ports S-parameter were transferred into one-port S-parameter, and the subsequently the |Z|-parameters can be calculated. Based on real parts and imaginary parts of Z-parameter transferred from the direct two-ports S-parameter, the effective resistance (the real part) and the effective inductance (the imaginary part) versus frequency can be extracted. Fig. 1 (a), (b) show the Q-values, extracted inductance and resistance of the spiral inductor with 3.5 turn, while the metal width is 50 μm width a 20 μm spacing (Fig. 5-a). The Q-value were higher than 22.5~35.0 at 2.0 ~ 3.7 GHz with an inductance of 3.0 nH, and it's maximum Q-value was 37.1 at 4.95 GHz. Spiral inductors with various turns were all fabricated and characterized in order to cover all the necessary values for L-C networks. Spiral inductror is deposited with Cu on the silicon wafer by sputtering. The film thickness was controlled with the discharge time of sputtering. Measurement of the thickness of the spiral coil was done by surface profiler. The thicknesses of the fabricated films were 1.4 μm.

In addition, MOM capacitors fabricated on silicon substrates were also calibrated. A 1500 Å thick sputtered Ta_2O_5 thin film was used as a oxide layer(metal-oxide-metal), and the capacitance density is around 0.21 fF/μm^2. Based on the same evaluation, the Q-value for MOM

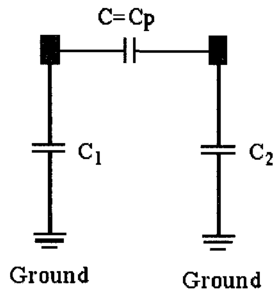


(a) Q-value of spiral inductors

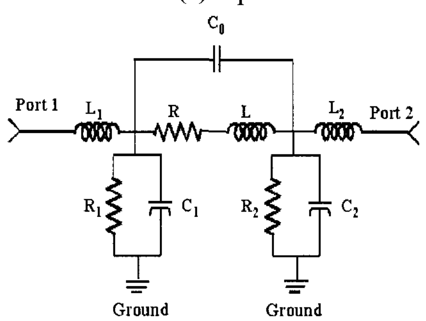


(b) Inductance-resistance of spiral inductor

Fig. 1 Q-value and Inductance-resistance of 3.5 turns spiral inductor with a 50 μm Cu width and 20 μm spacing



(a) capacitor



(b) spiral inductor

Fig. 2 Equivalent circuits of MOM capacitor (a) and spiral inductor (b)

capacitor reached 30 for the operating frequency below 2 GHz. Dielectrics were deposited with TaO on Cu thin film as a insulation layer.

3. Design of thin film L-C band pass filter

The equivalent circuit models of MOM capacitor and spiral inductor, shown in Fig. 2(a) and 2(b), were optimized by curve-fitting microwave S-parameter. Based on the extracted parameters of MOM capacitor and spiral inductor, a microwave band pass filter can therefore be designed. The schematic of this filter is shown in Fig. 3, which consists of a pair resonator divided by a coupling capacitor [6, 7]. This resonator is built by L-C tank circuit, and the parasitic capacitance of spiral inductor is also taken into account. These high-Q passive component can guarantee a low insertion loss and high return loss. Both input and out put capacitors are used for DC blocking and matching purpose.Fig. 5 (a), (b) shows the integrated 1.8 GHz thin film components and L-C band-pass filter on silicon substrates with a dimension of 1.5 X 1.5 mm.

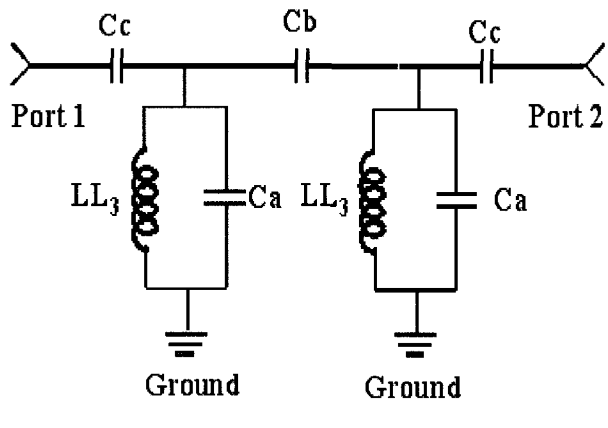
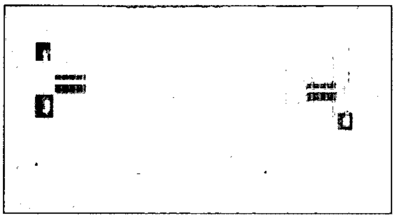


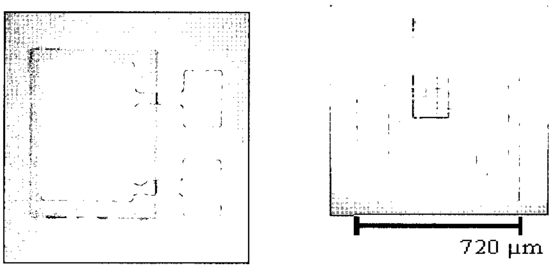
Fig. 3 Equivalent circuit of 2^{nd} order band pass filter

The characteristics of this 1.8 GHz band-pass filter evaluated by network analyzer S-parameter measurement are shown in Fig. 5 (a), (b). The central frequency was 1.58 GHz with a band width of 600 MHz.

The in-band insertion loss and off-band return loss were 2 dB and 15 dB respectively, which are sufficient for the applications in microwave integrated circuit (MIC). The measurement results are slightly shifted comparing with the simulation prediction. In addition, the return loss of upper band is degraded, which is due to the grounding problem, where the oxide layer technology is not included in our thin film technology.

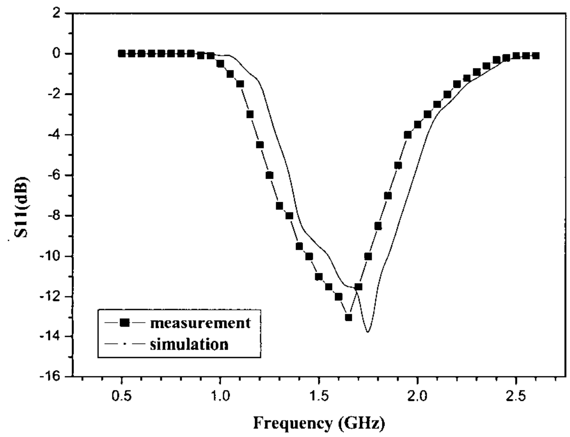


(a) integrated L-C thin film band pass filter

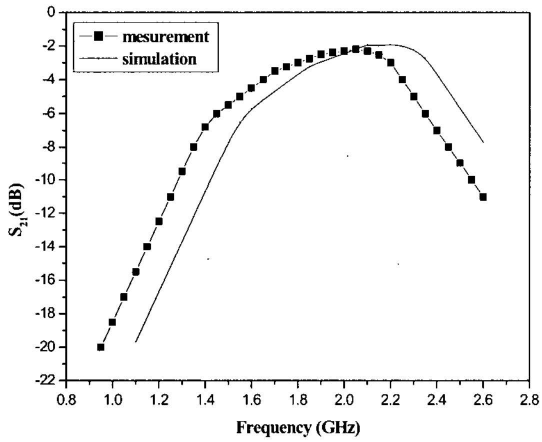


(b) MOM capacitor and spiral inductor

Fig. 4 The photograph of L-C band pass filter and passive components for microwave devices

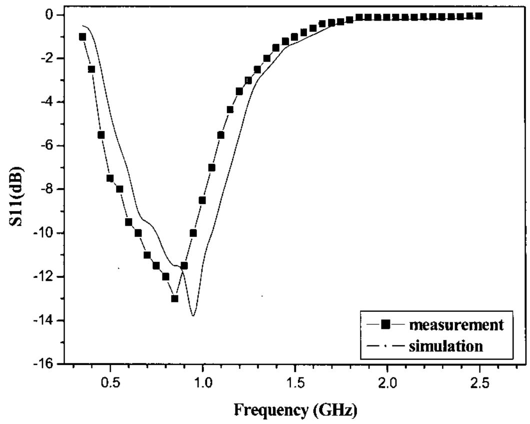


(a) reflection (S_{11})

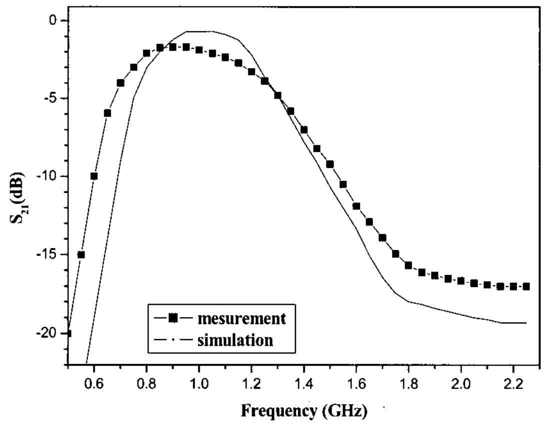


(b) transmission (S_{21})

Fig. 5 Simulated and measured microwave performance of 1.8 GHz thin film band pass filter



(a) reflection (S_{11})



(a) transmission (S_{21})

Fig. 6 Simulated and measured microwave performance of 900 MHz thin film band pass filter

As to the design of 900 MHz band pass filter, which requires a higher inductance value, the improvement of insertion loss is somewhat limited due to a higher parasitic resistance. Fig. 6 (a), (b) demonstrates the measurement results of this thin film band pass filter. The central frequency was slightly shifted to 870 MHz with a bandwidth of 270 MHz. The in-band insertion loss and off-band return loss were 5.3 dB and 8 dB respectively. Comparing with the 1.8 GHz one, the performance of 900 MHz band-pass filter is relatively poor, which may be due to the higher uncontrollable parastics effects [8].

4. Conclusion

The Both 900 MHz and 1.8 GHz thin film band pass filter were fabricated on silicon substrate. This technology provides a potential small physical dimension in the realization of microwave integrated circuits. The insertion loss of 3 dB and 5 dB were obtained for 1.8 GHz and 900 MHz thin film L-C band pass filter respectively.

Finally, different lumped passives component have been combined in an example which indicates the possibility of realising microwave passive filters.

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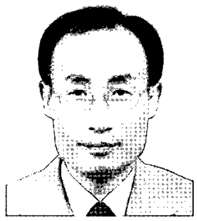

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