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MEMS-based Varactor Fabricated by Gold Electroplating for Tunable SAW Filter Application

可変 SAW フィルタ応用のための
金めっきによる MEMS 可変容量

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1. Introduction

A recent mobilephone has a quite complicated wireless front-end, which is composed of many filters, amplifiers, mixers etc. A mobilephone will become more complicated in the future, because new applications and services such as cognitive radio and body area network are expected to be commercialized. To make the wireless system more flexible and functionalized, a tunable or reconfigurable wireless front-end is a promising option. Among several kinds of components in the wireless front-end, filters are the most difficult ones to tune in frequency, because low insertion loss, sharp cut-off characteristics and small size are also required.

In the previous work[1], we demonstrated the preliminary operation of a tunable SAW filter with MEMS-based air gap varactors directly integrated. From design point of view, resuired capacitances are typically as largr as several to several ten pF, and thus the varactors is very large in size. The large air gap varactor is susceptible to film stress, which is often generated during the film deposition process. Another problem is time-consuming and often imcomplete removal of a sacrificial layer to make the air gap. This study addressed the above problems.

2. Design

Figure 1 is the circuit diagram of a ladder-type SAW filter. The varactors connected in parallel with the series SAW resonators (S2 and S3) change anti-resonance frequency to lower side. The varactor connected in series with the parallel SAW resonator (P2) changes resonance frequency to higher side. As a result, the passband moves within the original bandwidth, i.e. one without the varactors. To obtain a wider frequency tuning range, the original SAW filter must have a wide bandwidth, and thus Love wave on a 15 ° Y $LiNbO_3$ substrate, which has high electromechanical coupling coefficient, K^2, is used.

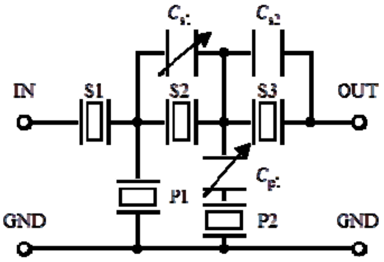

Fig. 1 Circuit diagram of the tunable SAW filter.

The characteristic impedance, Z_0, of a wireless system is generally 50 Ω, and the tunable filter fabricated in the previous study also had Z_0 of 50 Ω. On the other hand, the capacitance of the veractor is inversely proportional to Z_0, and higher Z_0 leads to smaller capacitance. To make the size of the varactors smaller, Z_0 of 200 Ω is selected in this study. Figure 2 and Table 1 show the layout and specifications of the tunable SAW filter, respectively.

The structure of the MEMS-based varactor is shown in Figure 3. The varactor is simply composed of an electrostatically-driven thin film bridge structure. The bridge structure is made of electroplated Au, while Ni was used in the previous study. This is because Au has smaller resistance than Ni. Also, smaller film stress is expected, because Au is softer than Ni. The initial air gap is 1.4 μm, and the theoretical pull-in voltage is 42 V for C_{s1} and 29 V for C_{p1}.

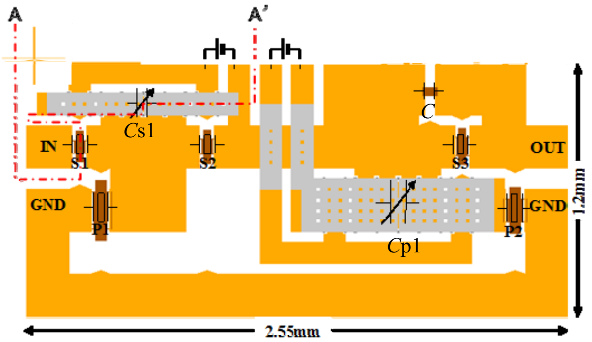

Fig. 2 Device layout of the tunable SAW filter.

Table. 1 Specifications of the tunable SAW filter.

	S1	S2	S3	P1	P2	C_{s2}
IDT pitch [μm]	2.8	2.8	2.8	3.6	3.6	4.4
Aperture [μm]	27.8	28.4	27.6	43.0	43.6	44.0
Number of IDT fingers	23	27	32	49	31	37
Number of reflectors	30	30	30	30	30	-

Varactor	C_{s1}	C_{p1}
Width [μm]	100	250
Length [μm]	840	840
Thickness [μm]	4	4
Capacitance [μm]	0.20〜0.71	0.50〜1.76

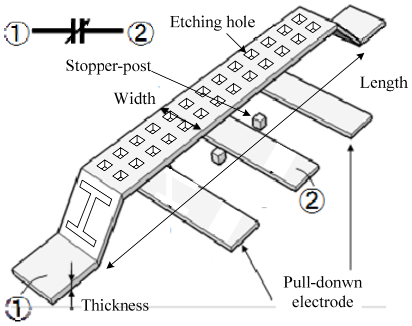

Fig. 3 Schematic structure of the MEMS-based varactor.

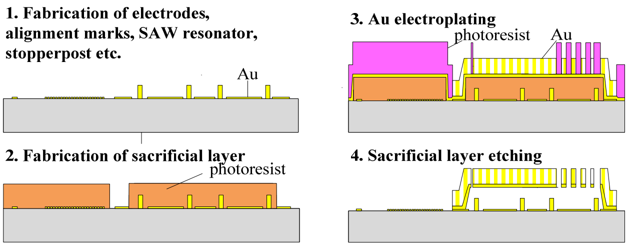

Fig. 4 Fabrication process of the tunable SAW filter.

3. Fabrication process

Figure 4 illustrates the simplified fabrication process. On a 15 ° Y $LiNbO_3$ substrate, Au/Cr electrodes and alignment marks are fabricated by lift-off technique. Subsequently, SAW resonators and fixed capacitors are fabricated by electron beam lithography and lift-off technique. The stopper posts on which the varactor bridge lands are made of 4.7 µm thick Au/Cr by lift-off technique again.

As a sacrificial layer for the capacitor air gap, a negative photoresist of 1.4 µm in thickness is patterned. On it, a Au/Cr seed layer is deposited, and then a 6 µm thick mold for Au electroplating is formed using a positive photoresist. 4 µm thick Au is electroplated in the mold. Finally, the mold, seed layer and sacrificial layer are removed step by step to release the bridge structures.

4. Result

For Au electroplating, a non-cyanide bath (Microfab Au310, EEJA) was used at 50 ºC. The bath was stirred with a paddle and air bubbling for uniform deposition. The current density was 0.4 A/dm^2.

The sacrificial layer was removed by either O_2 plasma ashing or O_3 water etching[2]. As shown in Figure 3, the bridge structure has the release holes from which the sacrificial layer is etched. The pitch of the release holes is 12 µm in this study. By O_2 plasma ashing, it took about 9 hours to remove the sacrificial layer. By O_3 water etching, the sacrificial layer was removed after 3 hours. By both methods, a small amount of residues were found below the bridge structure intentionally broken for observation. The residues looked different for the different etching methods, and further study is necessary for the complete removal of the sacrificial layer.

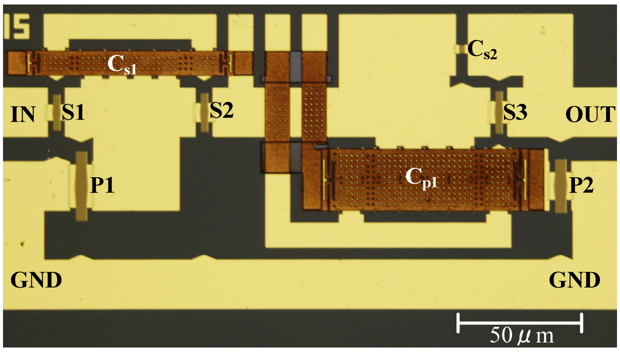

Fig. 5 Optical image of the fabricated tunable SAW filter.

Figure 5 shows the fabricated tunable filter. One of the problems which we found is filter performance degradation after the fabrication of the varactors. For example, the minimum insertion loss was −2.9 dB and −8.3 dB before and after the varactor process, respectively. This might be due to damage to the IDT and reflectors and the residues on the SAW resonators. Another important problem is the film stress of the electroplated Au. By the film stress, the bridge structure was distorted, leading to short circuit and/or too high pull-in voltage. These problems must be solved for the operation of the tunable SAW filter.

5. Conclusion

A 1 GHz tunable SAW filter with MEMS-based air gap varactors were designed and fabricated on a 15 ° Y $LiNbO_3$ substrate. The bridge structure of the varactor was made of electroplated Au and a sacrificial negative photoresist. The sacrificial layer was removed by either O_2 plasma ashing or O_3 water etching. We found important problems to be solved; damage to SAW resonators, residues after the sacrificial layer etching and the film stress of the electroplated Au.

Acknowledgement

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