A 60 GHz Tunable Filter Based on Polymer Cap Deflection

Seonho Seok, Janggil Kim, Nathalie Rolland, and Paul-Alain Rolland
IEMN/IRCICA CNRS 8520 Cité Scientifique-Avenue Poincare BP 60069 59652
Villeneuve d'Ascq Cedex, France

***Abstract*-This paper presents a novel tuning mechanism for millimeter-wave BPF based on the deflection of the BCB membrane. A 3-pole parallel-coupled microstrip filter was first fabricated and measured on a 30 µm-thick BCB polymer substrate and then it was packaged by BCB cap transfer technique. Actuation voltage is applied to capacitive actuators at both sides of the packaged planar filter. The implemented filter shows a 3 dB bandwidth of approximately 8 GHz, a passband insertion loss of 3.7 dB at center frequency of 65.5 GHz while its return loss is better than 10.8 dB at the whole passband. Also, the tuning range of the capped tuning filter was measured to be 750 MHz from 64.50 GHz to 63.75 GHz. instructions give you basic guidelines for preparing papers for conference proceedings.**

I. INTRODUCTION

For millimeter wave circuits, MEMS technology attracts much attention due to its merits as enabling technology by emerging novel circuits such as transmission lines with low loss and low dispersion, radio frequency (RF) filter, voltage controlled oscillator and phase shifters [1-3]. Although the mature micromachining technology makes it possible to implement microwave and millimeter-wave filters on dielectic membrane suitable to on-chip integration, it doesn't provide the solution of tuning components enough to be applicable to modern multi-band communication system. MEMS varactor is common to give a tuning capability to filter, but there still exist some barriers due to the reliability of MEMS and its packaging issues [4-6]. As an alternative way to realize a tunable filter at millimeter-wave frequency, dielectric actuation method is proposed because it changes the electromagnetic field distribution of filter resulting in its center frequency change. BCB dielectric cap will be placed above the filter like a package cap and it will be actuated by electrostatic force changing the air-gap between BCB cap and the filter element. Concerning the BCB polymer, it is chosen due to its excellent electrical and mechanical material properties; low dielectric constant, low tangent loss, and Young's modulus enough to form polymer cap. The BCB cap is transferred to the filter device by our wafer-level BCB thin-film cap transfer technique [7].

In this paper, 60 GHz-band tunable parallel-coupled BPF is presented using BCB cap actuation. In section II, the concept of the tunable filter is first described and then the parallel-coupled BPF design method will be presented with analytical calculation and electromagnetic simulation. In addition, the tunable characteristic will be also investigated as a function of air gap height between BCB cap and filter. The fabrication process for the designed filter will be explained in section III. In section IV, characterization and discussion will be presented.

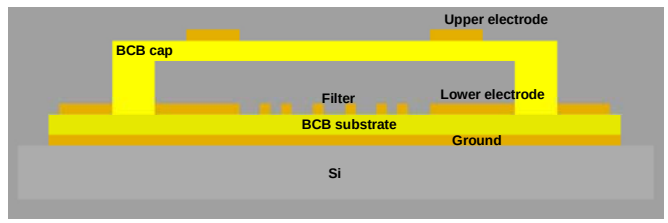


Figure 1. Concept of the proposed tunable bandpass filter

II. TUNABLE FILTER CONCEPT AND DESIGN

The concept of the proposed tunable bandpass filter (BPF) on BCB polymer covered with BCB polymer cap is shown in Fig. 1. The BCB cap has two functionalities of a package and an actuator for filter tuning. Electrostatic force applied to gold electrode on BCB cap moves it downward and hence the center frequency of the filter will be changed. Parallel-coupled, half-wavelength resonator filter shown in Fig. 2 was first designed following standard design procedure in Reference [8]. The 3-pole, 5 % bandwidth and 0.1 dB ripple at a midband f0 = 60 GHz were used to find g value for a low pass prototype. Firstly, even and odd mode impedances between the two resonators were analytically calculated as listed in Table 1 (a). Half of them are given due to the symmetry of this kind of filter. The next step is to find the actual dimensions of the coupled resonators corresponding to the desired even- and odd-mode impedance. The filter is implemented on BCB substrate with dielectric constant of 3 and thickness of 30 µm. Using design equations of the coupled resonators given in Chapter 4 of [8], the width and spacing for each pair of the resonator are found as Table 1 (b). Starting with these physical dimensions, electromagnetic simulation was performed to examine and optimize the frequency response of the filter.

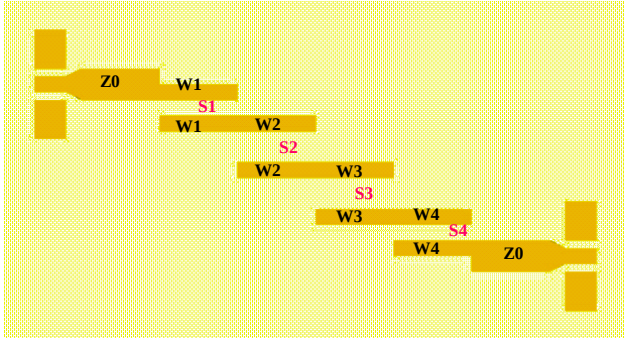


Figure 2. Parallel-coupled bandpass filter

TABLE I

DESIGN PARAMETERS OF THE MICROSTRIP FILTER

(a) Even- and odd-mode impedance of coupled microstrip lines

j	$(Z_{oe})_{j,j+1}$	$(Z_{oo})_{j,j+1}$
0	67.6	40
1	53.9	46.7

(b) Coupled microstrip dimensions of the filter

j	W_j (µm)	S_j (µm)
1 and 4	70	10
2 and 3	80	60

Repeating the EM simulations by tuning the significant parameters manually, the performance of the BPF was optimized referring to the center frequency and insertion loss and return loss at passband. The microstrip width was found 85 µm to have 50 ohms impedance for 30 µm BCB substrate when permittivity and tangent loss of BCB are 2.9 and 0.008 respectively. The optimized dimensions are S1=S4=10 µm, S2=S3=25 µm, W1=W4=70 µm, W2=W3=80 µm. In addition, tuning characteristic is also investigated using electromagnetic simulation as a function of air-gap height when 15 µm-thick BCB membrane is used. It shows maximum tuning range of 1 GHz from 15 µm to 5 µm air-gap height change as shown in Fig. 3. It is assumed that BCB membrane has no deformation. Also, the behaviour of BCB membrane is investigated as a function of actuation voltage. The dimension of DC electrode is 2760 µm (L) x 900 µm (W). The capacitive electrostatic actuator is modelled along with BCB cap structure using ANSYS simulator. The relationship between BCB cap deflection and DC actuation voltage is shown in Fig. 4. Center deflection of 9.5 µm is accomplished at 90 V.

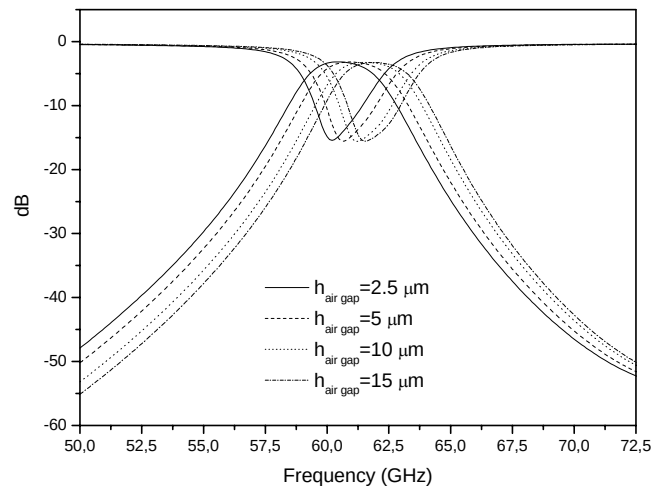


Figure 3. Filter tuning characteristic as a function of air-gap height

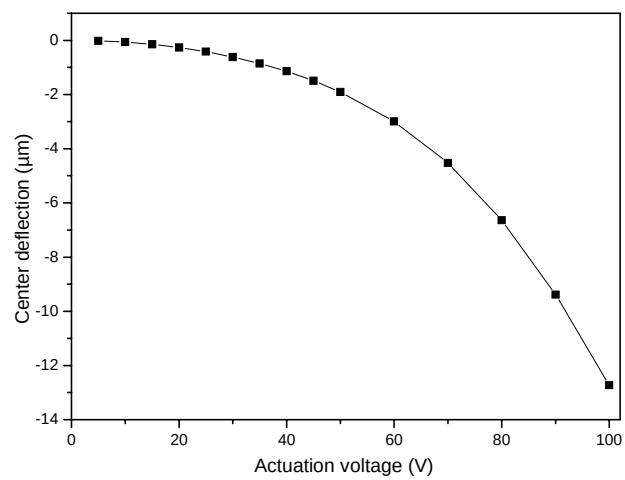
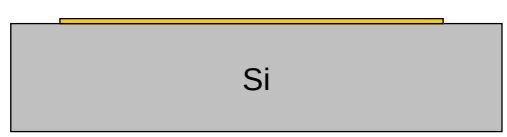


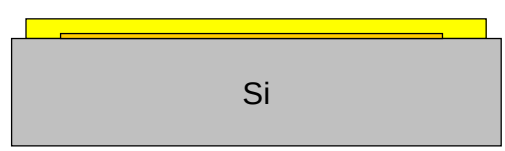
Figure 4. BCB cap deflection as a function of actuation voltage

III. FILTER FABRICATION

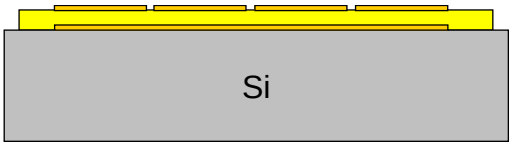
The fabrication process is depicted in Fig. 5. The process consists of two parts; parallel-coupled BPF on 30 µm-thick BCB substrate and BCB cap transfer to the implemented BPF using BCB thermo-compressive bonding.



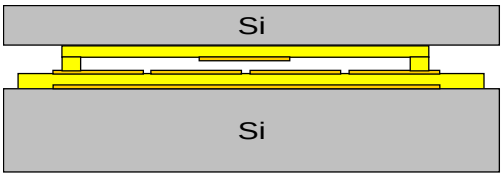
(a) Metallization for ground



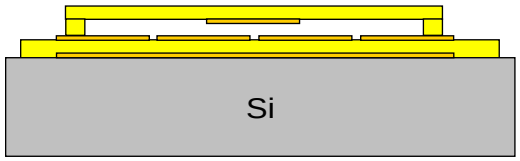
(b) BCB patterning



(c) Metallization for microstrip implementation



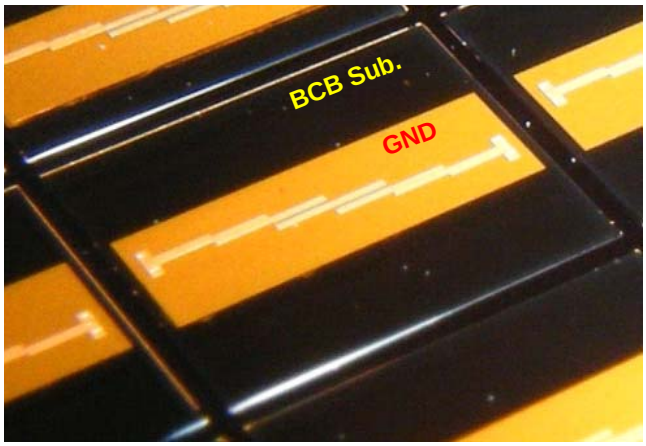
(d) BCB tuning cap transfer



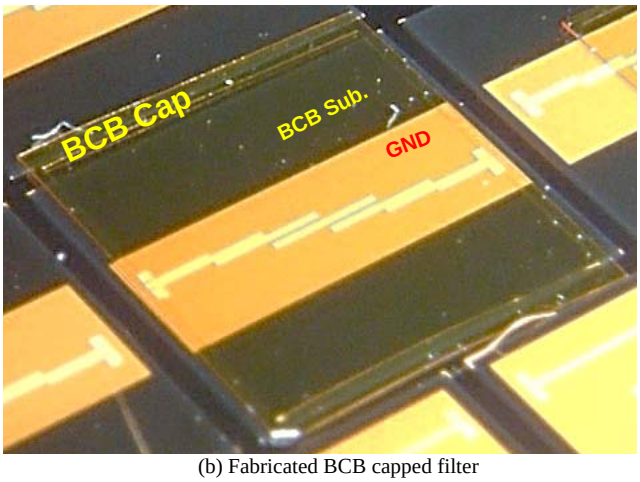
(e) Removal of Si carrier wafer

Figure 5. Process flow of the proposed tunable BPF

The process flow is described as follows; (a) Ti (100 nm)/ Au (400 nm) seed layers are deposited on Si substrate and then electroplating with AZ9260 mold is performed for bottom ground plane. (b) BCB patterning process is done to have the designed thickness for microstrip implementation. (c) Electroplating process of step (a) was repeated for the resonators on BCB substrate. Via metallization to the ground was performed simultaneously to have coplanar probe access for RF characterization. (d) BCB caps on Si carrier wafer are transferred to the filter wafer by wafer-to-wafer BCB bonding. Detailed process of BCB cap formation and its transfer technique were explained at Ref [7]. (e) Si carrier wafer was released using mechanical separation assisted by anti-adhesion layer [7].



(a) Fabricated filter on BCB substrate without BCB cap



(b) Fabricated BCB capped filter

Fig. 6 Fabrication results

The designed half-wavelength resonators are successfully implemented on BCB substrate as shown in Fig. 6 (a). The fabricated filter is BCB-capped as shown in Fig. 6 (b).

IV. FILTER CHARACTERIZATIONS

The manufactured BPF on BCB substrate without BCB cap is first characterized by HP8510C and probe system. The measured filter characteristic is shown in Fig. 7. The insertion loss is 3.7 dB at the center frequency of 65.5 GHz while the return loss is better than 10.8 dB including probe-to-probe loss at the whole passband. Also, it shows 3 dB bandwidth of approximately 8 GHz. The simulation result comes from ADS modelling with the same material parameters as those in the design section.

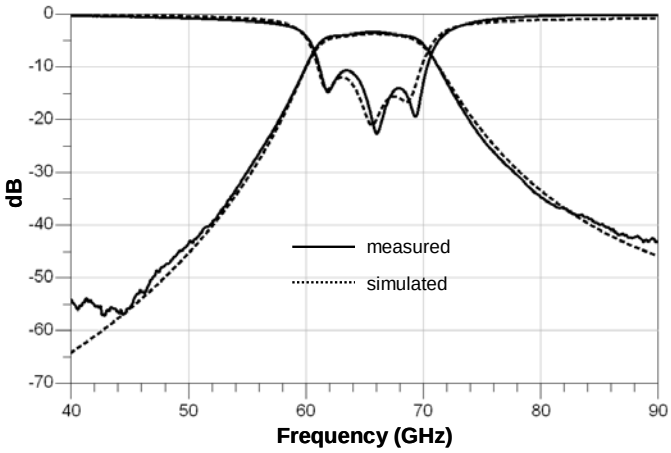


Figure 7. Measurement and simulation of the filter

The BCB capped filter is then measured to find its tuning characteristic. Fig. 8 shows the measured results. The achieved tuning range was 750 MHz from 64.50 GHz (cap up state) and 63.75 GHz (cap down state) and the associated insertion losses are 3.49 dB and 3.52 dB while the return losses are better than 11 dB. The center frequency of the capped filter is reduced from that of the filter without the cap because the cap increases the effective dielectric constant. In addition, the change of dielectric constant from the two states of the cap is estimated to be 0.08 through the ADS simulation.

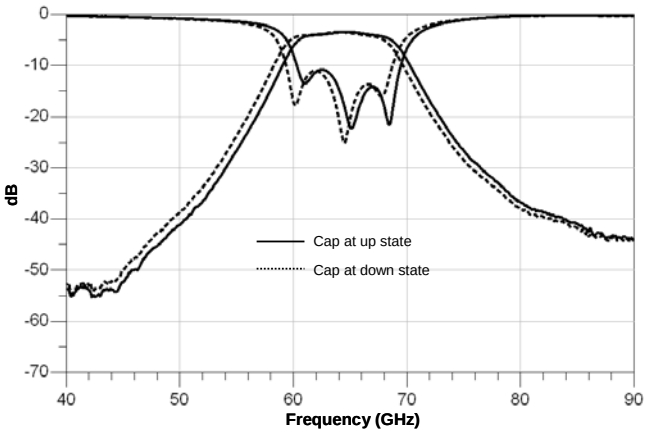


Figure 8. Measured tuning characteristic of the filter

V. Conclusion

For a tunable filter at millimeter-wave frequency, new dielectric cap actuation method is proposed as an alternative way of current MEMS varactor ones. Because the dielectric cap actuation changes the effective dielectric constant of the resonator of the filter, it can be used for filter tuning. To realize it, BCB polymer cap was bonded to the filter like a package cap and then metallization was performed on it to complete capacitive actuator for electrostatic actuation. Electrical model using HP ADS was obtained to optimize the filter performance comparing the measurement and the simulation. Also, the actual material properties of the BCB polymer were found through the extraction method of the S-parameter measurement of 50 ohm microstrip line at millimetre frequencies. The implemented tuning filter showed competent performance in terms of insertion loss, return loss, 3 dB bandwidth, and tuning range. Therefore, the proposed tunable filter can be a good candidate for wireless communication systems.

Acknowledgment

The authors wish to acknowledge the technical staffs of IEMN. This work was supported by European funding FEDER (Fonds Europeen de DEveloppement Regional).

References

[1] Baker N S and Rebeiz G M, “Distributed MEMS true-time delay phase shifters and wide-band switches”, IEEE Microwave Theory and Technique Symp. Digest, 1999, pp. 299–302.

[2] Weller T M, Katehi L P B and Rebeiz G M, “High performance microshield line components” , IEEE Microwave Theory and Technique Symp. Digest, 1995, pp. 534–543.

[3] Kudrle T D, Neves H P, Rodger D C and MacDonald N C, “A microactuated millimeter wave phase shifter”, Solid-State Sensor and Actuator Workshop, Digest Tech. Papers pp. 1276–9, 1999.

[4] S. Seok, N. Rolland and P. -A. Rolland, " A Novel Packaging Method using Wafer-Level BCB Polymer Bonding and Glass Wet-Etching for RF Applications", Sensors and ActuatorsA-Physical,Vol 147,Issue 2, Oct. 2008, pp.677-682.

[5] S. Seok, N. Rolland and P. -A. Rolland, "Packaging methodology for RF devices using a BCB membrane transfer technique", Journal of Micromechanics and Microengineering, Vol. 16, No. 11, Nov. 2006, pp.2384-2388.

[6] Ki-IL Kim, Jung-Mu Kim, Gun-Chul Hwang, Chang-Wook Baek and Yong-Kweon Kim,“Packaging for RF MEMS devices using LTCC substrate and BCB adhesive layer”, J. Micromech. Microeng, 16, No. 1, 2006, pp.150-156.

[7] J.Kim, S. Seok, N. Rolland, P.-A. Rolland, “A Novel Wafer Level Bonding/Debonding Technique Using an Anti-adhesion Layer for Polymer-based 0-level Packaging of RF device” The 60th Electronic Components and Technology Conference (ECTC 2010), June 2010, pp. 323 - 328.

[8] Jia-Sheng Hong, M. J. Lancaster, Microstrip Filters for RF/Microwave Applications. 2001 John Wiley & Sons, Inc.