A 12GHz Lumped-element Hybrid Fabricated on a Micromachined Dielectric-Air-Metal (DAM) Cavity

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Abstract — **A novel lumped-element hybrid is presented. The hybrid is disposed on a newly developed dielectric-air-metal (DAM) cavity, which consists of an SiN membrane above a metallized 30-um-deep cavity made by a micromachining process. This process enables to make every component be worked from one-side of a silicon (Si) substrate, and to leave back-side as a part of a package. This is indispensable to realize a very thin MEMS-packaged-device consisting of two wafers bonded. Also, patterned metal grounds can provide all kinds of lumped elements. Among those, series inductors are investigated in detail. A hybrid with series inductors and shunt capacitors is fabricated. Good agreement between the measured and simulated results was obtained to validate this structure for fabrication of micro-size microwave components on an Si substrate.**

I. INTRODUCTION

Micromachining technology has been developed well to be applied microwave components these days. Among variety of such components, inductors on a dielectric membrane, under which a part of a substrate has been removed by etching process from back-side, are expected to have high-Q and high-self-resonant-frequency. In addition to such advantages, the micromachining technology can provide possibility of wafer level package of those microwave devices as well.

For reliability, some structures that separate the micromachined devices completely from outer environments such as humidity are required. To package such devices, at least two more wafers were required [1][2], one is disposed on the front-side to cover the devices, and the other is disposed on the back-side to seal the etched cavity of the back-side. Otherwise, they gave up the membrane structure and used high resistivity Si substrate to reduce the total number of wafers to two [3][4][5].

In order to solve the problem mentioned above, a novel process is developed that enables a membrane on metallized cavity to be worked only from front-side. Therefore, the back-side can be used as a part of the package. Also, the process enables to pattern metals on the cavity to propose several kinds of elements on the cavity.

Four types of lumped element components are enumerated to be realized by the DAM process. Among those, series inductors are investigated by electromagnetic (EM) based simulation and are fitted to equivalent circuit models. Qs and self-resonant frequencies are derived for some dimensions.

A hybrid circuit operated at 12GHz was designed and fabricated by utilizing the lumped elements. The measured data agreed well with simulated one.

II. DAM PROCESS

Our proposing novel process to realize DAM cavity is explained as follows [6].

Fig. 1 shows our proposing novel DAM-cavity process. In step (a), the top oxide layer is patterned to be a mask for etching, and alkaline etching is performed to create 30-um-deep cavity. 1 um-thick Au is sputtered in step (b). If patterning of the Au is required, it can be performed in this step. Positive photoresist (AZ4330) is spin-coated in step (c) and cured at low temperature (110°C to 125°C). The overswelled resist is co-planarized with the Au by chemical mechanical polishing (CMP) as shown in step (d). In step (e), 1 um-thick SiN is sputtered to be a membrane. The contact holes for metal on the SiN to reach the metal under the SiN are etched. In step (f), 0.03/0.6-μm thick Cr/Au is sputtered onto the SiN and a CPW and other circuit patterns are formed by photolithography and ion beam etching. The holes for sacrificial etching are opened by reactive ion etching in step (g). Finally, the photoresist as a sacrificial material was removed by acetone or commercial resist stripper in the last step (h).

The features are that (1) all process are worked from front-side to leave back-side as a part of a package, and that (2) the ground metal on the surface of the cavity can be patterned to propose all kinds of lumped elements as

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well as to reduce parasitic capacitances to the ground metal.

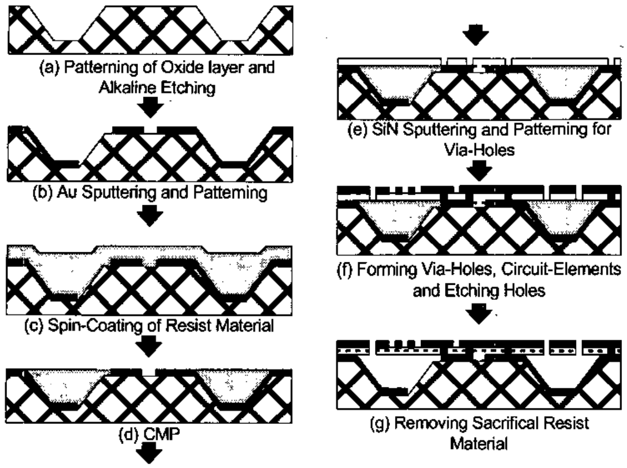

Fig.1: Process flow of the DAM cavity

III. LUMPED ELEMENTS

A. Structures of lumped elements

Micromachined lumped-elements have been reported by some papers. As an example, L. H. Lu introduced them by removing substrate material between spiral turns [7], and applied to hybrids [8].

In this paper, four types of lumped elements on the DAM cavity are proposed. Fig.2 shows series C, shunt C, series L and shunt L respectively.

Series C is realized by Au electrodes that sandwich 1 um SiN membrane as a dielectric layer. The Si substrate under the capacitance is left not to be etched for a platform that supports the membrane mechanically. Also, the lower electrode is isolated from the metal on the cavity by patterning it. This platform is not necessary if the size of the component is small.

Shunt C is realized by Au electrodes that sandwich 1-um SiN membrane as a dielectric layer as well as a series C does. The platform is necessary in this case.

Series L is realized by Au line that meanders on the SiN membrane. Depending on the operation frequency and inductance, the metal on the cavity is removed to reduce parasitic capacitance to the ground and to increase self-resonant-frequency.

Shunt L is realized by Au line that meanders or spirals on the SiN membrane. The end of the line goes down through the contact hole to reach the ground. The Si substrate under the inductor is left not to be etched to be the ground platform.

Among these four types of lumped elements, shunt C and series L are used in the following hybrid. The shunt C performance is easy to predict because of less parasitic elements. Therefore, the series L is investigated in this paper.

B. Series inductor

Fig.3 shows the pattern of the examined series meander inductor with the metal thickness of 0.6 um on a 30-um-depth DAM cavity, and the equivalent model of the inductor. Q of the structure is calculated by fitting the EM solution to the model. Fig.4 shows the relation of the cavity depth and the Q factor and the inductance of the inductor. The EM simulation was done by commercial software (EM sight by AWR). Since the skin depth of Au at 12GHz is greater than the metal thickness, the resistance at low frequency is used in this simulation. The left axis represents the ratio of the Q of the structure to the Q when the depth is 30 um at 12GHz. If the depth increases to 60 um, the Q could increase only to 11.6%. Hence, the conductor loss of the top metal of the inductor plays main role in degradation of the Q factor.

Fig.5 shows the relation of resonant frequency and cavity depth. When cavity becomes deep, the parasitic capacitance reduces, and resonant frequency increases. With the depth of 30 um, the resonant frequency becomes more than 45GHz. It seems to be enough to fabricate a hybrid at 12GHz.

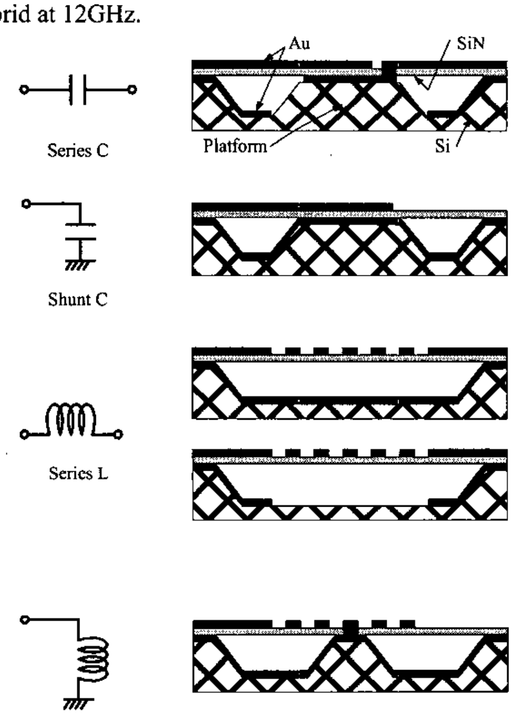

Fig.2: Structures of four types of lumped elements

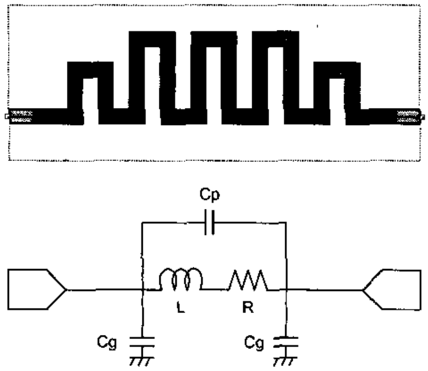

Fig.3: Pattern and model of examined meander inductor (size:710um x 180um)

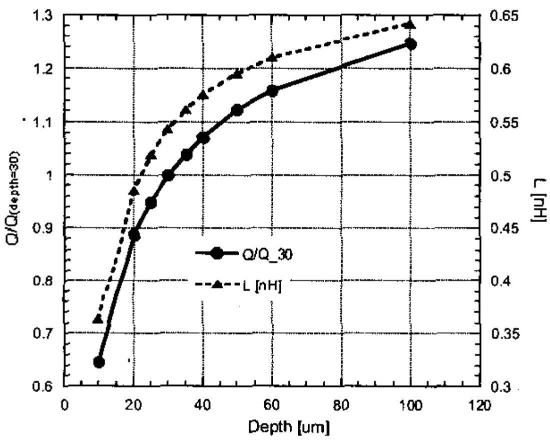

Fig.4: Q and L vs. depth of cavity

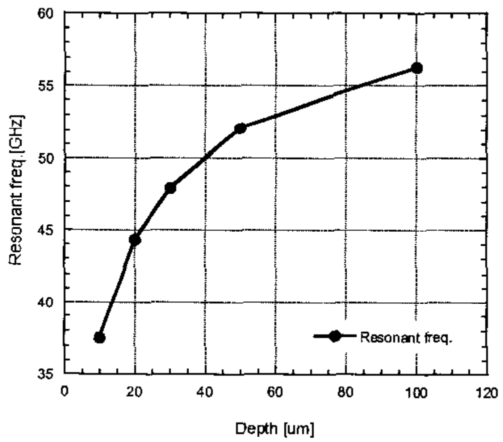

Fig.5: Resonant frequency vs. depth of cavity

III. DESIGN AND EXPERIMENT OF A HYBRID

Fig. 6 shows the lumped element circuit of the hybrid designed by a conventional way [9]. The dimensions of the each inductor are determined by iterating EM simulations and fitting the results to the model until the value of L becomes the desired one. The capacitance of the four-shunt capacitors is obtained by subtracting parasitic capacitances Cg of the adjacent two inductors from the designed 0.54 pF.

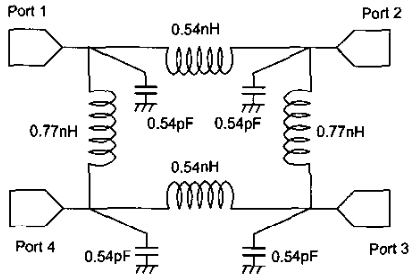

Fig.6: Lumped element circuit of the hybrid.

Fig.7 shows the schematic view of the hybrid fabricated on the DAM cavity. Four ports are disposed to different directions to be measured by micro-probe with the pitch of 150um. The optical micrograph and the SEM image of the hybrid are shown in Fig.8 and Fig.9, respectively. The size of the hybrid is 710um by 710um.

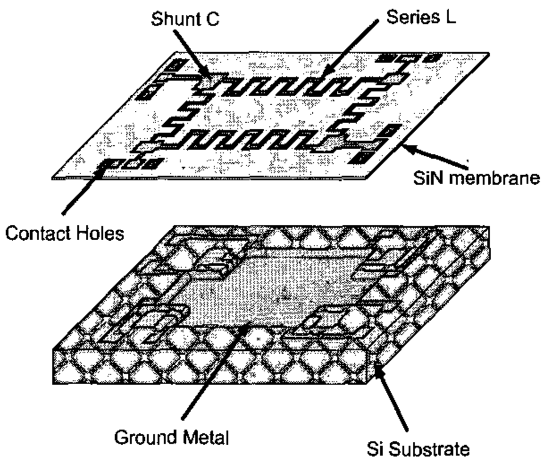

Fig.7: Schematic view of the hybrid on the DAM

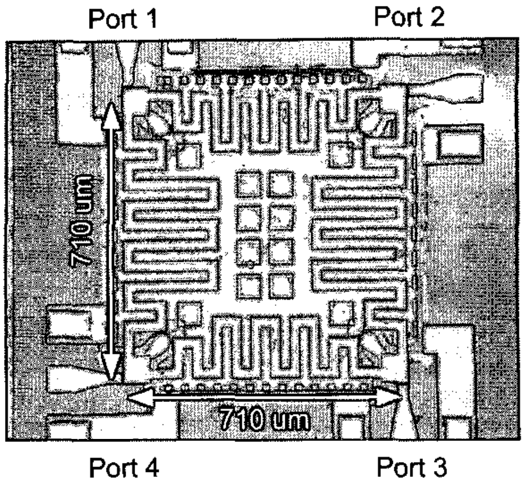

Fig.8: Optical micrograph of the hybrid

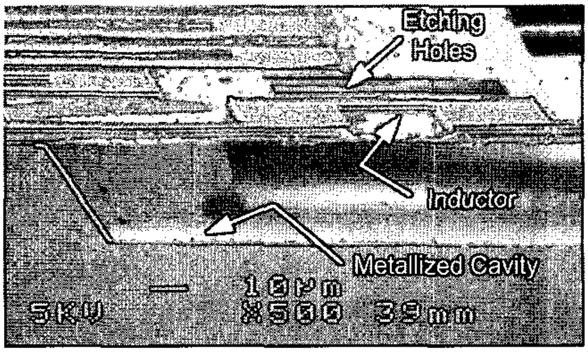

Fig.9: SEM image of the corner of the hybrid

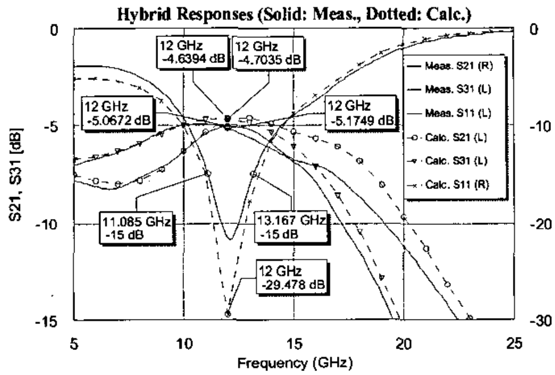

Fig.10: The simulated and measured results of the fabricated hybrid

Fig.10 shows the simulated and measured result. The insertion loss at the center frequency was 2.17 dB, and the bandwidth of 17.3% was achieved for -15dB reflection. The phase difference (S31/S21) was 88.9° at 12GHz. The EM simulation predicts the insertion loss to be reduced to 1.8dB if 1-um-thick metal would be used. While the measured result had additional 0.4dB, which came from the loss of interface structures such as pads, the frequency responces had good agreement.

IV. CONCLUSIONS

We have proposed a novel DAM cavity structure to achieve very thin and very compact devices. A hybrid was fabricated on the 30-um-deep cavity and showed good agreement with the simulated result. The investigations on series inductor were performed on Q-factor, self-resonant frequency and cavity-depth to show the depth of 30 um is reasonable choice of the DAM cavity for lumped elements at 12GHz.

REFERENCES

[1] S. V. Robertson, A. R. Brown, L. P. B. Katehi, and G. M. Rebeiz,, " A 10–60-GHz Micromachined Directional Coupler," IEEE Trans. MTT, Vol,46, No.11, 1998, pp1845-49

[2] A. R. Brown, and G. M. Rebeiz,, "Micromachined Micropackaged Filter Banks", IEEE microwave and guided wave letters, Vol. 8, No. 4, 1998, pp158-60

[3] R. M. Henderson, K. J. Herrick, T. M. Weller, S. V. Robertson, R. T. Kihm, and L. P. B. Katehi,, " Three-Dimensional High-Frequency Distribution Networks—Part II: Packaging and Integration," IEEE Trans. MTT, Vol. 48, No. 10, 2000, pp1643-51

[4] R.F.Drayton and L.P.B.Katehi, et al, "Development of self-packaged high frequency circuits using micromachining technology," IEEE Trans. MTT, Vol.43, No.9,1995, pp2073-80

[5] R. F. Drayton, R. M. Henderson, and L. P. B. Katehi,, "Monolithic Packaging Concepts for High Isolation in Circuits and Antennas," IEEE Trans. MTT, Vol. 46, No. 7, 1998, pp900-906

[6] Y. Yoshida, T. Nishino, J. Jiao, S. S. Lee, M. Kumagai, Y. Suehiro, K. Miyaguchi, and T. Fukami, "A Novel Grounded Coplanar Waveguide with Cavity Structure," IEEE MEMS Conference Proceedings., 2003

[7] L.H. Lu, J.-S. Rieh, P. Bahattacharya, and L.P.B.Katehi," K-band Si/SiGe HBT MMIC amplifiers using lumped passive components with a micromachined structure", IEEE RFIC symposium, 1998, pp17-20

[8] L.H. Lu, P. Bahattacharya, and L.P.B.Katehi," Design and implementation of micromachined lumped quadrature (90) hybrid", IEEE IMS, 2001, pp1285-88

[9] R.Moniga, I. Bahl and P. Bhartia, RF and Microwave Coupled-line Circuits, Artech Inc., 1999, pp225-260