High Performance Air Gap Transmission Lines for Millimeter Wave Applications

INHO JEONG, SEONG-HO SHIN*, JU-HYUN GO*, JOONG-SOO LEE, CHOONG-MO NAM, DONG-WOOK KIM, AND YOUNG-SE KWON*

Telephus Inc.

25-11 Jang-dong, Yuseong-gu, Taejeon, 305-343, Korea

* Dept. of EE, KAIST

373-1 Kusong-dong, Yuseong-gu, 305-701, Taejeon, Korea

***Abstract* - The air gap transmission lines are developed by new multi-layer process. The developed transmission lines are air gap coaxial line, air gap strip line and air gap BMSL (Buried MicroStrip Line). Air gap transmission lines show very low signal loss and very high isolation performances. The transmission line loss of the coaxial line is less than 0.08dB/mm up to 40GHz. Those of the strip line and the BMSL are about 0.15dB/mm and 0.13dB/mm, respectively. Reduction of the parasitic coupling between signal lines is very important in high-density MICs and MMICs. The isolation characteristics of the coaxial line and the BMSL are measured. In case of coaxial lines with 2mm coupling length and 60μm distance between signal lines, the coupling is less than -52dB up to 40GHz. Under same conditions, the coupling of the BMSL is less than -43dB. Therefore the air gap transmission lines are very suitable structures for high performance and high-density RF applications.**

I. INTRODUCTION

Recent developments of MMICs are placing increasing demand on circuit interconnection technique that high frequency signal can be propagated through interconnection line without sacrificing circuit performance. At present, the common interconnection line structures in monolithic integrated circuit technology are the microstrip line and coplanar waveguide configurations. The geometric structure of these interconnections can change the propagating field distribution that has a large impact on the performance of the circuits, and this field perturbation affects the loss and dispersion characteristics of the transmission lines over a semiconductor to degrade the high frequency signal performance.

For microwave and millimeter wave transmission lines, the air dielectric material was a good candidate to achieve low loss and high frequency devices [1-3,8]. In spite of these advantages, the air dielectric material was not used for transmission lines and other microwave devices because of complex process, reliability problem and package issue. Implementation of multi-layer air dielectric is very hard because it is difficult to remove the sacrificial layer and seed metals for electroplating process. On account of its poor surface roughness, it is very hard to achieve precision line and spacing, and to prevent electrical short.

In this paper, we use new process method to solve the above problems and fabricate three types of the transmission lines. They are air gap coaxial line, air gap strip line and air gap BMSL on thick oxide silicon substrate [10][11]. All the transmission lines can be made on a substrate simultaneously by same process.

II. AIR GAP COAXIAL LINE

The structure of air gap coaxial line is so simple that it can be fabricated just by lithography and Cu plating process. But there is one different point, compared to conventional process. In this work, we use Ti/Cu as seed metal for Cu electroplating. But the Cu seed metal is patterned before the plating process. This process method can provide fine pitch of line and spacing even if the surface roughness is very poor. And it also prevents to affect plated Cu metal during the process of seed metal removal.

The analysis of coaxial lines has been the subject of substantial researches, where they attempt to find a simple and precise expression for characteristic impedance in the rectangular coaxial configuration. In the reference [14], O.R. Cruzan describes that the characteristic impedance of the rectangular coaxial transmission line can be readily and accurately computed by a simple equation when the capacitance per unit length is known.

In this work, the air gap coaxial line was monolithically implemented using an air as a dielectric material. The coaxial line was designed for 50ohm characteristic impedance. Due to its closed structure and air characteristic, the coaxial line has low attenuation and high isolation compared to the conventional coplanar

0-7803-7239-5/02/$10.00 © 2002 IEEE

waveguides (0.3dB/mm attenuation at 10GHz, [10]) and the elevated coplanar waveguides (0.1dB/mm attenuation at 20GHz, [2]). Fig.1 shows the SEM photograph of the fabricated coaxial line by our advanced process. The width(w) of the signal line is 30μm. And the gap(g) between the signal line and the sidewall ground is 35μm. The thickness of signal line is 12μm. The gaps from signal line to top ground and bottom ground are also 12μm, respectively. The measured characteristics of the coaxial line are shown in fig.2.

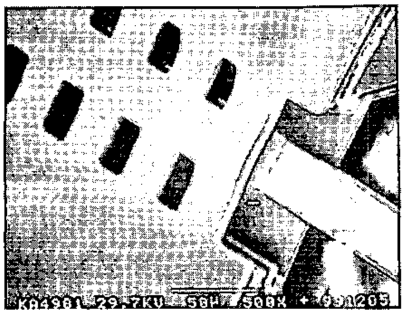

Fig. 1 The SEM photograph of the fabricated air gap rectangular coaxial line on thick oxide Si substrate

The attenuation level of the coaxial line is lower than 0.08dB/mm up to 40GHz. The return loss is less than -32dB (g=35μm). To investigate the cross-talk effect, which is important for high-density integration, we measured the coupling between the two 50ohm coaxial lines. The coupling length is 2mm and the line spacing, the distance between two signal lines, is 60μm. Fig. 7 shows the coupling between the coaxial lines versus frequency. The coupling is less than -52dB over the whole frequency range.

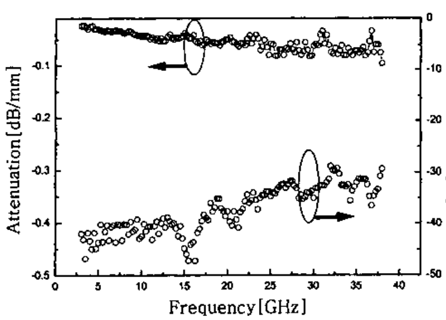

Fig.2 The measured attenuation and return loss of the air gap rectangular coaxial lines (w=30μm, g=35μm)

III. AIR GAP STRIP LINE

The proposed air gap strip line provides very low signal attenuation and good performance in high frequency region. Fig.3 shows the SEM photograph of the fabricated air gap strip line on thick oxide Si substrate using the same process steps as them of the air gap coaxial line. The width of signal line is 26μm and the thickness of the signal line is 12μm. The gap between signal line and ground is fixed to be 12μm. The center conductor is a metal air-bridge supported by several posts on thick oxide Si substrate. The pitch of posts is 700μm and their cross section area is 35×25μm. Every post is surrounded by ground plane with 20μm separation.

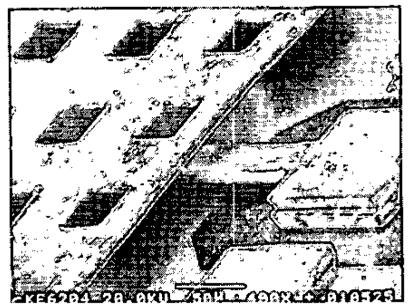

Fig. 3 The SEM photograph of the fabricated air gap strip line on thick oxide Si substrate

The signal line width (w) for 50ohm line impedance can be easily calculated with Agilent ADS (Advanced design system) software. The length of the fabricated air gap strip line is 2mm. According to the calculation results, 50ohms line width is 26μm. Fig.5 shows the measured attenuation and return loss of the strip line in dB/mm versus frequency.

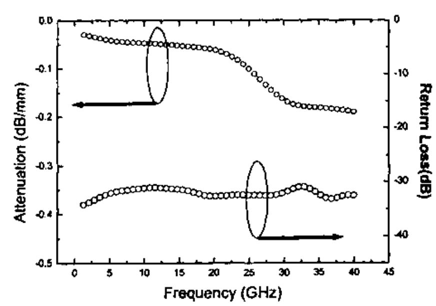

Fig.4 The measured results of the attenuation and return loss of the air gap strip line

As shown in fig. 4, the attenuation of the developed strip line is lower than 0.1dB/mm (w=26μm) over the frequency range (from 1GHz to 25GHz). The return loss of the 2mm-long strip line is less than –32dB (w=26μm). It shows that the characteristic impedance of the strip line is about 50ohms. It is very similar to the simulation result.

IV. BURIED MICROSTRIP LINE

Ishikawa et al. proposed buried microstrip line (BMSL) in 1996 [4,5]. In this section, we present newly developed BMSL process showing low loss and high isolation.

The air gap BMSL of our work has the properties of low coupling, high isolation and low loss because of its structure with air dielectric material. Fig.5 shows the SEM photograph of the air gap BMSL using the air multi-layer and the copper electroplating process. The width and the thickness of center conductor are 30μm and 12μm, respectively. The gap from side ground to the center conductor is 25μm. The height from bottom ground to the center conductor is fixed to be 12μm. The center conductor is a metal air-bridge supported by several posts, and the pitch of posts is 700μm. The thickness of side ground wall is 36μm, and is 12μm higher than the signal line. The process of the air gap BMSL is also very compatible with that of the air gap coaxial line.

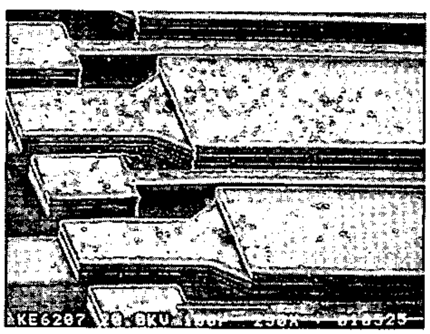

Fig. 5 The SEM photograph of the fabricated air gap BMSL on thick oxide Si substrate

Fig.6 shows the attenuation and return loss of the BMSL in dB/mm versus frequency. The effects of the dielectric and conductor losses were included. The attenuation of the BMSL is lower than 0.13dB/mm over the frequency range (from 1GHz to 40GHz). The return loss of the 2mm-long BMSL is less than –20dB. Like the air gap coaxial line, the air gap BMSL also shows the low signal propagation loss and high isolation even in several tens of GHz.

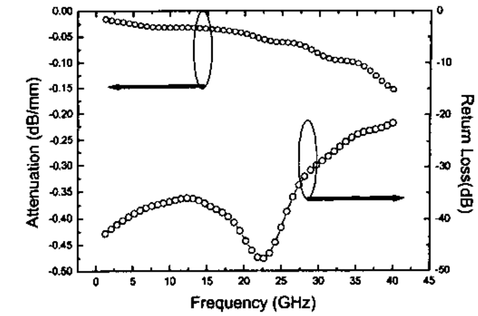

Fig.6 The measured attenuation and return loss of the air gap BMSL (w=30μm, g=25μm)

To measure the coupling characteristics, two BMSLs were fabricated. The coupling length is 2mm and the line spacing, the distance between the two signal lines, is 60μm. Fig.7 shows the measured coupling characteristics between the two BMSLs versus frequency. The coupling is lower than –43dB over the frequency range. But the coupling is slightly higher than the air gap coaxial line because its topside is opened, compared to the closed structure of the coaxial line.

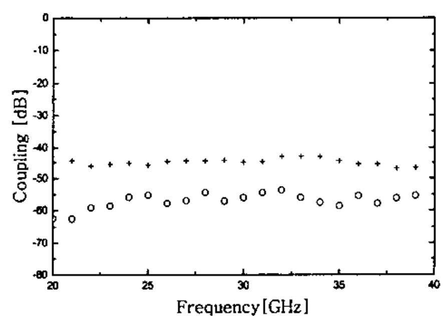

Fig.7 The measured isolation performances of the air gap coaxial and the air gap BMSL
+ : air gap BMSL o : air gap coaxial line

V. CONCLUSION

There have been many approaches to make high performance transmission lines for millimeter wave applications. The low loss and high isolation are required for higher frequency applications and high-density applications. Using the proposed structures and the developed process, we can fabricate the advanced transmission lines with high isolation and low loss up to millimeter wave range. Only the lithography and the copper plating process are applied to fabricate the air gap transmission lines.

The air gap coaxial line showed the low loss of 0.08dB/mm up to 40GHz, including the conductive metal loss. Besides, the coupling of 2mm coupled lines is less than –52dB at 60μm coupling gap.

The air gap strip line showed the loss of 0.1dB/mm up to 25GHz and the return loss is below –32dB at 2mm-long length. The attenuation of the air gap BMSL is less than 0.13dB/mm at 40GHz. And the coupling is less than –43dB in case of 2mm coupling length and 60μm coupling distance.

If the developed technologies are used, all the air gap transmission lines can be fabricated on same substrate simultaneously. Besides the fabrication cost is very low and the manufacturing process is very simple. The physical size of transmission line is very small, compared to other research results, such as microshield line, other BMSL and some other micromachined transmission lines.

These technologies will provide very good solution in next-generation digital wireless communication system requiring high frequency operation and high isolation performance and they will be widely utilized for low cost millimeter wave modules and systems.

REFERENCES

[1] G. H. Ryu, D. H. Kim, J. H. Lee and K. S. Seok, "A novel impedance line for MMIC using air gap stacked structure" MTT-Digest, pp.613-616, 2000.

[2] F. schnieder, R. Doerner, W. Heinrich, "High-impedance coplanar waveguides with low attenuation" IEEE Microwave and Guided Wave Lett., no. 3, vol. 6, pp.117-119, March, 1996

[3] T. M. Weller, L. P. Katehi, and G. M. Rebeiz, "High performance microshield line components" IEEE Trans. Microwave Theory Tech., vol. MTT-43, no. 3, pp.534-542, Mar., 1995.

[4] T. Ishikawa, and E. Yamashita, "Characterization of buried microstrip lines for constructing high-density microwave integrated circuits" IEEE Trans. Microwave Theory Tech., vol. MTT-44, no.6, pp.840-847, June 1996.

[5] T. Ishikawa, and E. Yamashita, "Experimental results on buried microstrip lines for constructing high-density microwave integrated circuits" IEEE Microwave Guided Wave Letters, vol. 5, no.12, pp.437-438, Dec. 1995.

[6] Theodore L. Willke and Steven S. Gearhart, "LIGA micromachined coplanar transmission lines and filters" IEEE Trans. Microwave Theory Tech., vol. MTT-45, no. 10, pp. 1681-11688, Oct., 1997

[7] N. I. Dib, W.P. Harokopus, L. P. B. Katehi, C. C. Ling and G. M. rebeiz, "A study of a novel planar transmission line" presented at the 1991 IEEE MTT-S International Symposium, Boston, MA, June 1991.

[8] Jeff C. P. Chuang and Samir M. El-Ghazaly, "Integration of air-gap transmission lines on doped silicon substrate using glass microbump bond techniques" IEEE Trans. Microwave Theory Tech., vol. MTT-46, no. 11, pp. 1850-1855, Nov., 1998.

[9] R. F. Drayton, R. M. Henderson, and L. P. Katehi, "Monolithic packaging concepts for high isolation in circuits and antennas" IEEE Trans. Microwave Theory Tech., vol. MTT-46, no. 7, pp. 900-906, July 1998.

[10] C. M. Nam, and Y. S. kwon, "Coplanar waveguides on silicon substrate with thick oxidized porous silicon (OPS) layer" IEEE Microwave and Guided Wave Lett., vol. 8, no. 11 pp.369-371, Nov., 1998.

[11] Choong-Mo Nam and Young-Se Kwon, " High Performance Planar Inductor on Oxidized Porous Silicon(OPS) Substrate," IEEE Microwave Guided Wave Letters, vol. 7, no. 8, pp. 236-238, 1997

[12] I. H. Jeong, B. J. Kim, Y. S. Kwon "Monolithic implementation of air-filled rectangular coaxial line" Electronics Letters, vol. 36, no. 3, pp. 228-230, Feb. 3, 2000.

[13] I. H. Jeong, Y. S. Kwon "Monolithic implementation of coaxial line on silicon substrate" IEEE Microwave Guided Wave Letters, vol. 10, no.10, pp. 406-408, Oct., 2000.

[14] O. R. Cruzan, and R. V. Garver, "Characteristic impedance of rectangular coaxial transmission lines" IEEE Trans. Microwave Theory Tech., vol. MTT-12, no. 7, pp. 488-495, Sept., 1964