MICROWAVE PROPERTIES OF COPLANAR TRANSMISSION LINES AND FILTERS ON DIAMOND FROM 1-120 GHz

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ABSTRACT

The properties of coplanar transmission lines (CPWs) and -filters on polycrystalline diamond substrates are investigated over the frequency range from 1-120 GHz.

Experimental results obtained for different geometries are in good agreement with theoretical predictions. Coplanar transmission line technology was applied to flip-chip diamond substrates for power amplifier MMICs.

I. INTRODUCTION

Diamond, because of its high thermal conductivity (≥ 20 W/cmK at 300 K), low dielectric loss and its great mechanical strength, is an excellent material for optoelectronic and microwave power applications. With the recent possibility of large area epitaxial growth, its use as a potentially low.- cost microwave substrate material has become very attractive. Little is known about the electrical properties of diamond wafers. Below, we shall present new data on the microwave properties of in - house grown diamond substrates over the frequency range 1-120 GHz.

II. TECHNOLOGY

The polycrystalline wafers, up to 6 inch diameter, are grown by a microwave plasma enhanced chemical vapour deposition technique [1]. The wafers are subsequently polished to their final thickness. A polished 2 inch wafer is illustrated in Fig. 1. The dielectric loss tanδ varies considerably, depending highly on growth parameters [2]. Measurements at 145 GHz on our wafers have shown tanδ values as low as $4x10^{-5}$ [2]. The dielectric constant of the wafers was found to be 5.7±0.05 [1].

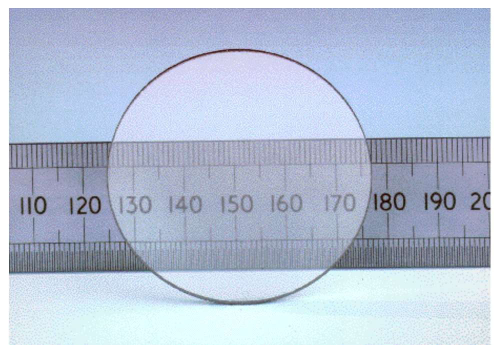


Fig. 1 Polished 2-inch diamond wafer.

III. COPLANAR TRANSMISSION LINES

We placed a number of CPWs, differing in impedance, length and ground-to-ground spacing on a 2 inch diameter wafer of 0.3 mm thickness. The metalization was plated gold of 3 µm thickness. The back side of the wafers was not metalized. Because of the low dielectric constant, the impedance range of practical coplanar lines on diamond is between 35 Ω and 130 Ω. In Fig. 2 the CPW characteristic impedance Z_0 is shown as a function of the ratio of center conductor width w to ground-to-ground spacing d. In comparison to CPWs on GaAs, substantially higher impedances can be achieved. Coplanar lines of 50, 70 and 100 Ω impedance are illustrated in Fig. 3, where the pattern of the metalization reflects the structure of the polycrystalline diamond surface. The gold surface roughness is below 100nm.

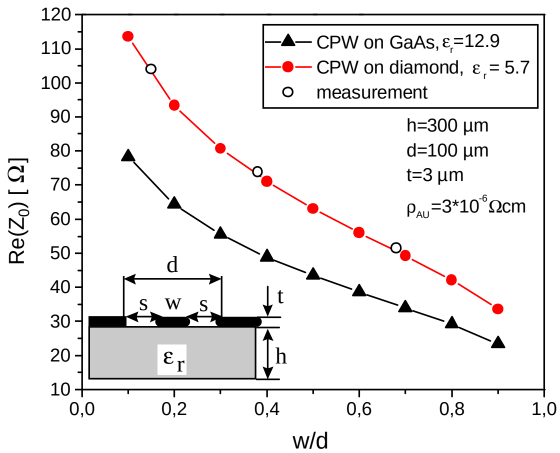


Fig. 2 Simulation of characteristic impedance as a function of CPW dimensions.

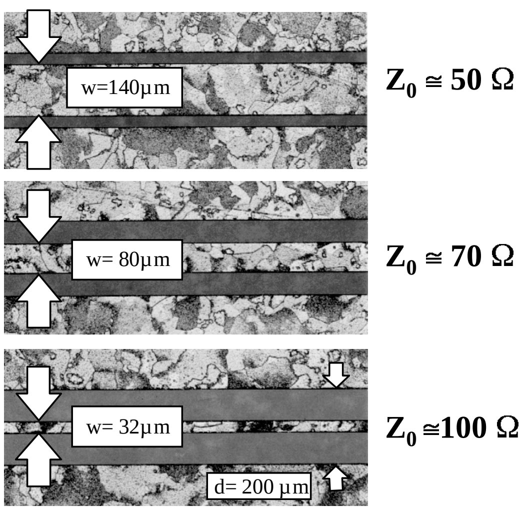


Fig. 3 CPWs of different impedances on diamond.

On-wafer S-parameter measurements were performed on a metal chuck. Typical results for the impedance and the attenuation of 200 µm wide CPWs are shown in Fig. 4. The CPW line parameters were calculated with the 3D EM simulator HP-HFSS, and compared with the extracted values from the on-wafer S-parameter measurements. The deviation of the characteristic impedances at high frequencies from their initial values is an indication of the existence of additional modes. No dispersion is observed in the effective dielectric constant ($\varepsilon_{r\ eff}$ ≈3.3).

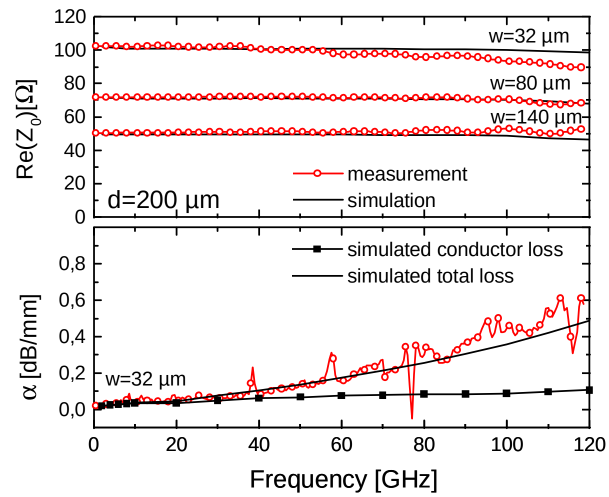


Fig. 4 Characteristic impedance and attenuation of CPWs on diamond.

The contribution of the conductor loss to the total attenuation α is less than 0.1 dB/mm, even above 100 GHz. The additional attenuation in Fig. 4 is due to power leakage into substrate modes. This leakage was calculated using standard spectral domain analysis [3], and is in good agreement with our measurement. Proper choice of diamond thickness and mounting configuration can reduce this effect considerably.

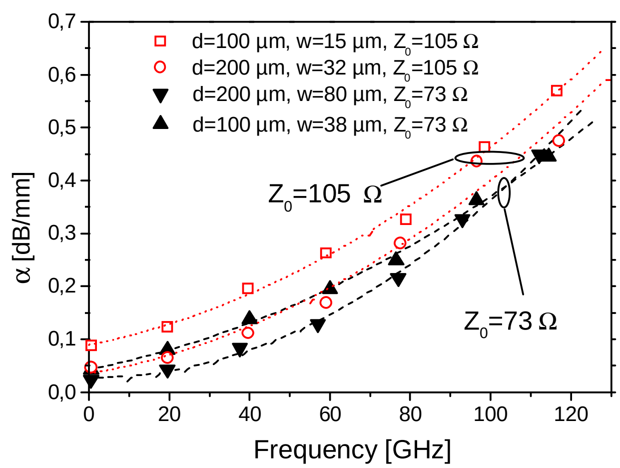


Fig. 5 Attenuation of high impedance lines for different CPW-dimensions

The attenuation of different high impedance lines is depicted in Fig. 5. The dimensions of the CPW distinctly influence the power leakage into surface modes. Large ground to ground spacings and small center conductor widths lead to additional attenuation [4]. No additional attenuation due to the polycrystalline nature of the diamond substrates was observed.

IV. COPLANAR FILTERS

We realized filters on diamond which take advantage of the CPWs distributed properties [5]. A low pass stepped impedance filter (Z_{01}=35 Ω, Z_{02}=130 Ω) with its measured S-parameters is depicted in Fig. 6. The 3 dB cutoff frequency is 63 GHz. The rejection reaches -40 dB at 80 GHz.

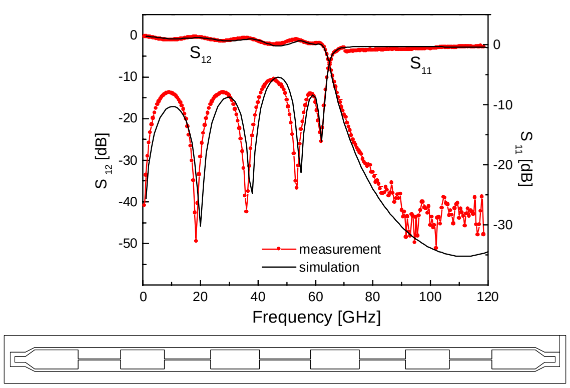


Fig. 6 S-parameter measurement and simulation of a stepped impedance low pass filter.

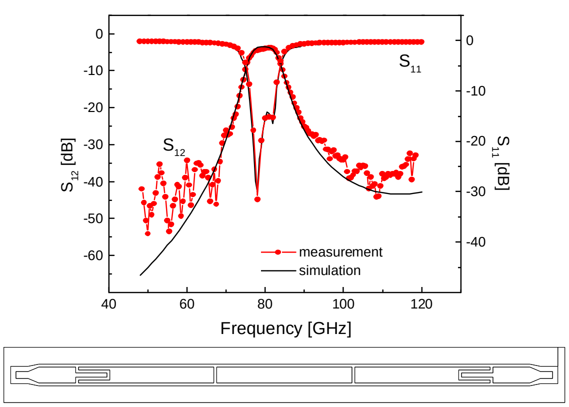


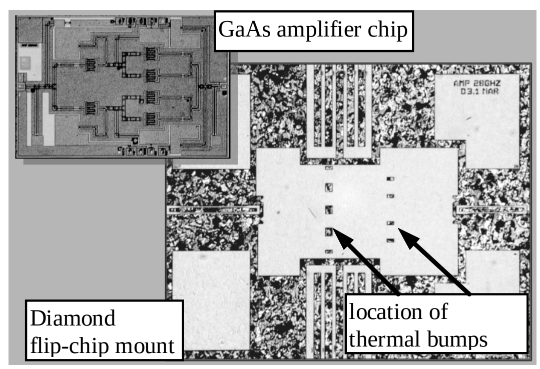
Fig. 7 S-parameter measurement and simulation of an interdigital band pass filter.

An interdigital band pass filter with its measured and simulated results is shown in Fig. 7. With line sections of 950 µm length and interdigitated capacitances of 17 fF and 5 fF, the filter had an insertion loss of 3.75 dB at the center frequency of 80 GHz. The measured filter characteristics were modelled with good agreement by means of our CPW models [6], implemented in the circuit simulator HP-MDS.

V. FLIP-CHIP MOUNTING

As an application of coplanar transmission lines on diamond we have investigated the flip-chip mounting of GaAs MMICs. Flip-chip mounting of power MMICs to diamond, with gold bumps very close to the active elements can provide effective heat sinking [7] without the need of substrate thinning.

a)



b)

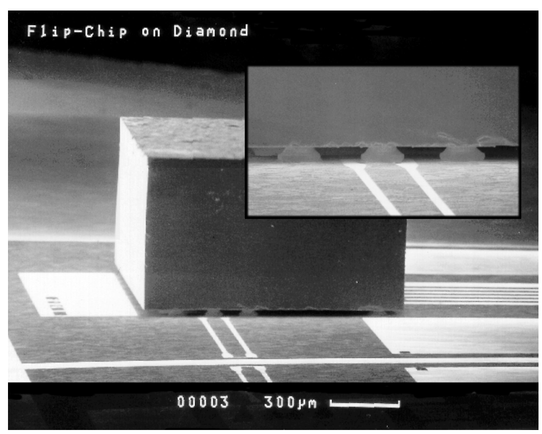


Fig. 8 a) Diamond flip-chip mount using CPW technology with 28GHz GaAs PHEMT power amplifier MMIC. b) mounted amplifier MMIC using ball bond technology

Fig. 8 a) shows a diamond flip-chip mount using CPW technology, together with the 28 GHz GaAs PHEMT power amplifier MMIC (2 stages, 6 PHEMTs with a total gatewidth of 3.6mm, P_{-1dB} = 26 dBm and 4.4 W DC power consumption). The amplifier was mounted using ball-bond flip-chip technology [8] as shown in Fig. 8 b).

Measurements of the small signal characteristics on chip and flip-chipped on diamond of the amplifier are depicted in Fig. 9. Flip-chip mounting did not alter the performance of the amplifier to a large extend.

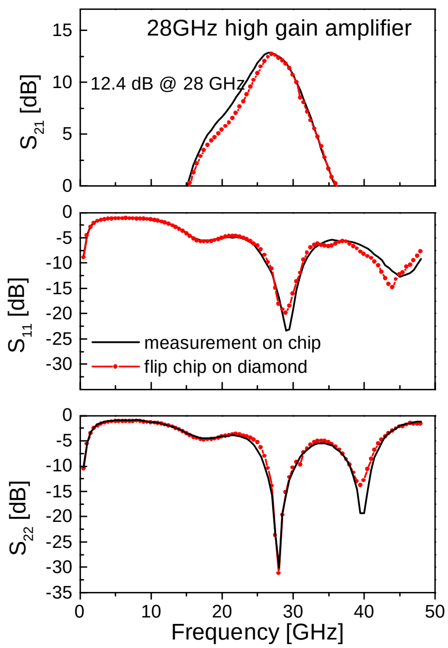


Fig. 9 Small signal characteristics of a 28 GHz PHEMT power amplifier measured on chip and after flip chip mounting on diamond

3D thermal simulation of the mounted device shows that the heat dissipation through the thermal bumps is not sufficient. Thus the temperature of the flip-chip mounted device is slightly increased compared to its face up on chuck performance. For efficient heat dissipation, the position of the bumps as well as the transistor layout has to be optimized.

In summary we report the excellent microwave properties of PECVD diamond wafers as a substrate material for coplanar transmission lines, filters and flip-chip mounting.

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REFERENCES

[1] M. Füner, C. Wild, P. Koidl, “Novel Microwave Plasma Reactor for the CVD of Large Area High Quality Diamond Wafers,“ Appl. Phys. Lett., in print.

[2] R. Heidinger, “Dielectric Properties Measured on CVD Diamond Grades for Advanced Gyrotron Windows,“ Proc. 19th Conf. On Infrared and Millimeter Waves, Orlando, 1996.

[3] T. Krems, W. H. Haydl, H. Massler, J. Rüdiger, “Advantages of Flip-Chip Technology in Millimeter-Wave Packaging,“ Proc. of IEEE MTT-Symposium Dig., Denver, pp. 987-990, 1997.

[4] J.-Y. Ke, I-S. Tsai, C. H. Chen, “Dispersion and leakage characteristics of coplanar waveguides,“ IEEE Trans. Microwave Theory Tech., vol. 40, pp. 1970-1973, 1992.

[5] G.L. Matthaei, L. Young, E. M. T. Jones, „Microwave Filters, Impedance Matching Networks and Coupling Structures,“ Artech house , Norwood, MA, pp. 651-723, 1980.

[6] W.H. Haydl, A. Tessmann, K. Züfle, H. Massler, T. Krems L. Verweyen, J. Schneider, “Models of coplanar lines and elements over the frequency range 0-120GHz,“ 26th EuMC Proc., pp. 996-1000, 1996.

[7] R. Sturdivant, C. Ly, J. Benson, J. Wooldridge, “Using MMIC Flip Chips and CVD Diamond For Improved Thermal Management Of Microwave Modules,“ Proc. IEEE MTT-Symp Dig., Denver, pp. 505-507. 1997.

[8] P. Heide, “Microwave and Millimeterwave Sensor Systems for CommercialApplications at 24, 61 and 77 GHz,“ MIOP 97, Proc. Workshop on Commercial Radio Sensor and Communication Techniques, Stuttgart, Germany, 1997