Millimeter-Waves Structures on Benzocyclobutene Dielectric Substrate

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Abstract. *The need of low-loss substrate materials with stable dielectric performances is a strong requirement when working at millimeter frequencies, where standard dielectrics exhibit prohibitive losses. In this paper, the authors focus their attention on a polymer material, the benzocyclobutene (BCB), having a low dielectric constant and a low loss tangent, with a stable behavior up to THz frequencies. A specific in-house manufacture technology is described to realize millimeter-wave structures on a BCB dielectric substrate. Experimental validations on BCB-based circuits and antennas prototypes are discussed.*

Keywords

Millimeter-wave, benzocyclobutene, low-loss materials.

1. Introduction

In recent years, strong research efforts have been devoted to the investigation of innovative materials and/or fabrication technologies for the realization of efficient low-loss circuits and antennas well working at millimeter frequencies but requiring a minimal increase in cost. To guarantee good performances as dielectric substrate at millimeter waves, the material should have low losses and a low dielectric constant, stable within the operating frequency range, so the values of material permittivity and dissipation factor should be accurately considered, but also the thermal stability of these parameters has a relevant role for a proper material selection, especially for space applications. Potential substrates with excellent performances extending throughout the millimeter-wave range can be found in the polymer category. Among different polymer materials, such as PDMS [1], Polymide [2], Parylene-N [3], whose electrical parameters are summarized and discussed in [4], our attention has been focused on BCB as giving low values of permittivity and loss tangent, together with a low coefficient of thermal expansion, thus guaranteeing a stronger dielectric stability versus temperature [4]. BCB has already been successfully applied in literature as a covering film for packaging and interconnections on a silicon substrate [5-9]. In this paper, the use of BCB as substrate material for planar microstrip structures is discussed in order to overcome difficulties related to the occurrence of large dielectric losses in the high microwave range. Furthermore, a low cost in-house fabrication technology is described to realize single-layer and multilayer substrates from a small quantity of BCB liquid material.

2. BCB Dielectric Properties

BCB is a promising organic material showing stable permittivity values and low losses over a broad frequency range. The producer [10] claims a dielectric constant ε_r = 2.65, with a few percent variations between 10 GHz and 1.5 THz, and a loss tangent between 0.0008 and 0.002 from 1 MHz to 10 GHz. Additional data are also available [10] in the frequency range between 400 GHz and 1500 GHz, which confirm a stable dielectric behavior of the BCB on a broad frequency range. However, no specific electrical values are provided in the middle microwave range, below 400 GHz. In order to guarantee the accurate design and performance level of BCB-based microstrip structures also in the uncovered frequency range, a broadband dielectric characterization has been performed by the authors up to 65 GHz [11]. A conductor-backed coplanar waveguide (CBCPW) has been adopted as test structure and the dielectric parameters of BCB have been extracted from on-wafer S-parameter measurements. As reported in Fig. 1, an approximately steady value near the manufacturer specification ε_r= 2.65 is obtained, and a close agreement with the simulation results can be observed within the measurement frequency range [11]. The extracted values of the loss tangent, reported in Fig. 2, show a variation between 0.001 and 0.009 in the measurement range between 11 GHz and 65 GHz [11].

3. Manufacturing Process of BCB-Based Microstrip Structures

The fabrication process for BCB-based microstrip structures is fully performed into the Microwave Laboratory at University of Calabria. A three steps procedure, essentially based on deposition, curing and etching, is adopted to realize single-layer or multi-layer structures, as described in the process flow-chart of Fig. 3. The BCB is first deposited on the copper ground plane, by using a spin coater at a speed of 1000 rpm, which gives a dielectric thickness equal to 26 µm. A soft-cure process is then applied in a convection oven under nitrogen at a temperature of 210°, to avoid polymer oxidation. The two processes of deposition and soft-curing are then repeated for all subsequent dielectric layers. In order to achieve a full 100% polymerization, a hard-cure process is applied in a convection oven under nitrogen at a temperature of 250°. The top copper layer is then deposited by a physical vapor deposition and the circuit pattern is finally etched by using a laser and photo-etching procedure.

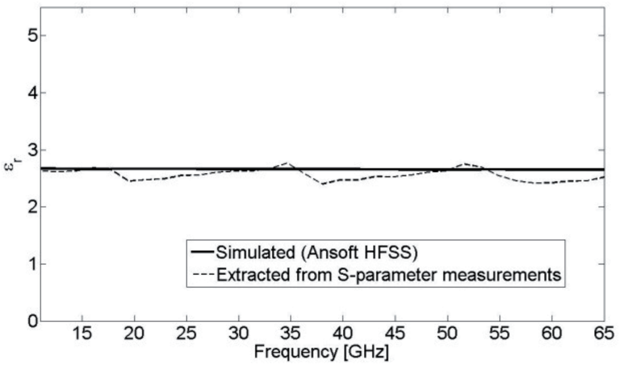

Fig. 1. Dielectric constant of BCB substrate [11].

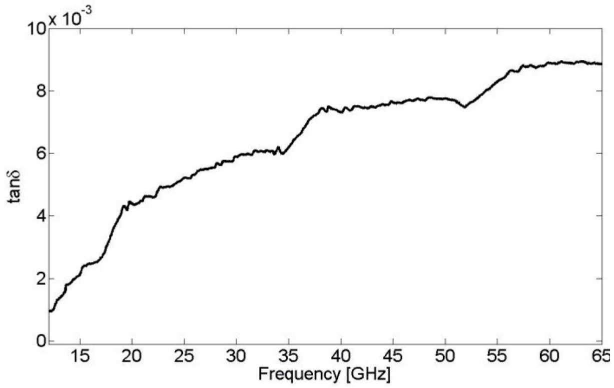

Fig. 2. Loss tangent of BCB substrate [11].

4. CBCPW on BCB Substrate

A first validation test of the manufacturing process for BCB-based microstrip structures has been performed on a CBCPW configuration. As a matter of fact, the coplanar structure is widely adopted at high frequencies in alternative to microstrip lines, because providing best features in terms of dispersion and radiation losses, and also for its easy fabrication and integration capability. To simplify the realization process, the value of BCB thickness is chosen equal to the maximum height for single coating (26 µm for the adopted Cyclotene series 3022 [10]).

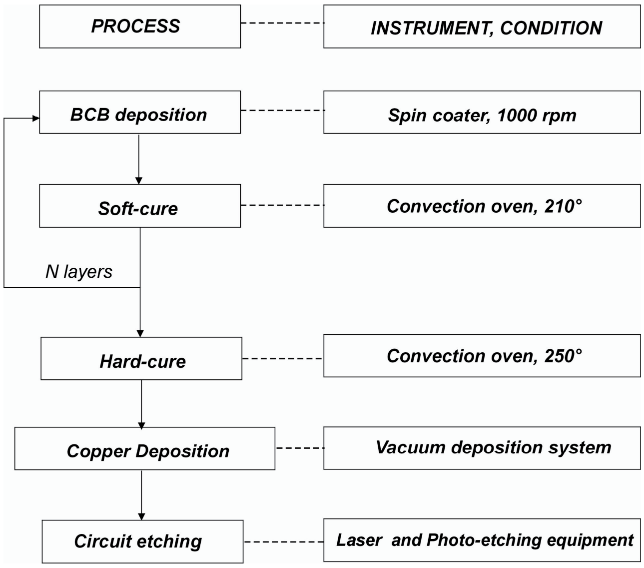

Fig. 3. Process sequence and conditions for BCB-based microstrip structures.

In this case, a hard-cure process is adopted which is typically carried out for realizing a single polymer layer, and leads to achieve 100% conversion from liquid to solid. The central conductor width W and the ground strip separation G are chosen by simulations on commercial Ansys software to match a 50 Ω characteristic impedance. The values of loss tangent previously determined (Fig. 2) are used for the accurate characterization in the simulation stage. A photograph of the realized 7 mm length CBCPW on BCB substrate is reported under Fig. 4. The experimental validation of the CBCPW prototype is performed by using a vector network analyzer Anritsu 37397B and a probe station fitted with 500 µm GGB GSG contact probes (Fig. 5).

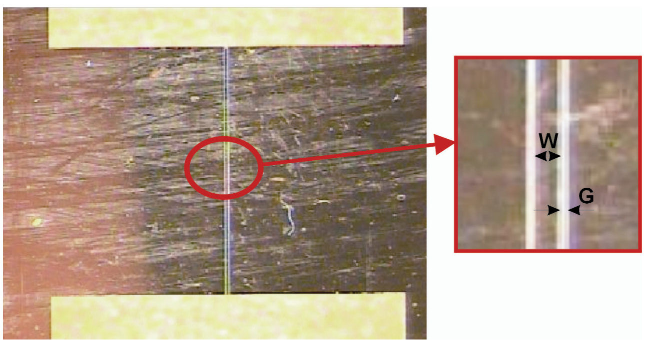

Fig. 4. Photograph of the realized CBCPW on BCB substrate (W = 70 µm, G = 30 µm).

The comparison between measured and simulated CBCPW insertion loss is illustrated in Fig. 6. The non-perfect agreement between them can probably be attributed to some non-calibrated measurement inaccuracies, primarily given by the probe contact and the positioning errors.

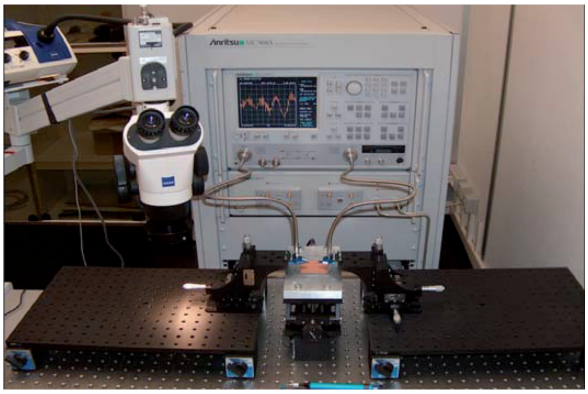

Fig. 5. Photograph of the test setup for the experimental validation of CBCPW on BCB substrate.

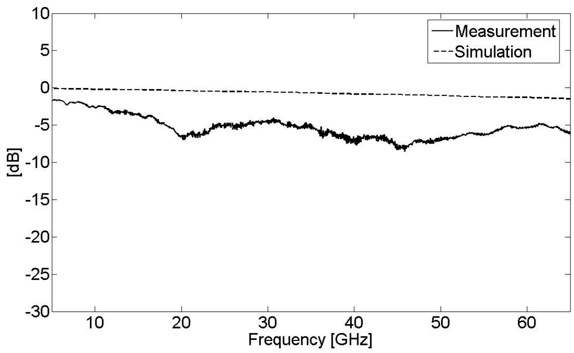

Fig. 6. Comparison between simulated and measured insertion loss of CBCPW on BCB substrate.

5. V-band Patch Antenna on BCB Substrate

As a further validation example, a V-band inset patch antenna has been designed on a BCB dielectric substrate. The layout of the antenna prototype, with the full indication of all dimensions, is reported in Fig. 7. In order to perform on-wafer measurements, a microstrip-to-coplanar waveguide transition is also included in the design, as illustrated in Fig. 7. The patch antenna is realized on a single layer of BCB, having thickness equal to 26 µm. The simulation characterization is performed by assuming the exact loss tangent at the design frequency as reported in Fig. 2, approximately equal to 0.009. In the realization stage, a 0.5 mm copper layer is first adopted as deposition support for the BCB dielectric layer. A hard-cure process is then applied to realize the BCB polymerization, and a 1µm copper layer is subsequently deposited by the vaporization procedure.

The antenna layout is finally etched by a laserwriter machine. A photograph of the realized V-band antenna prototype, with a particular showing the microstrip-to-coplanar waveguide transition, is reported in Fig. 8. The test setup adopted to perform on-wafer measurements is illustrated in Fig. 9, and the excellent comparison between the simulated and the measured return loss is reported in Fig. 10.

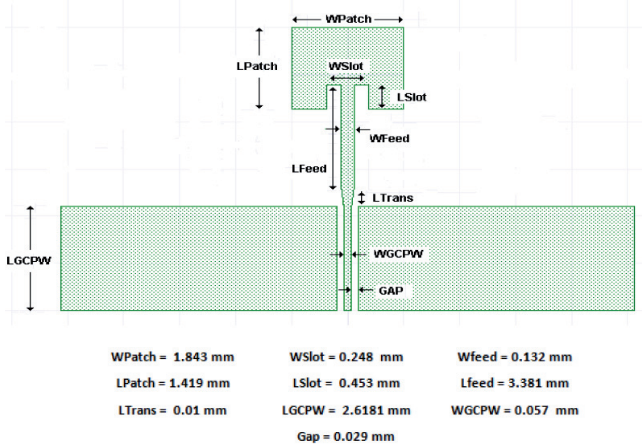

Fig. 7. Layout and dimensions of V-band patch antenna on BCB substrate.

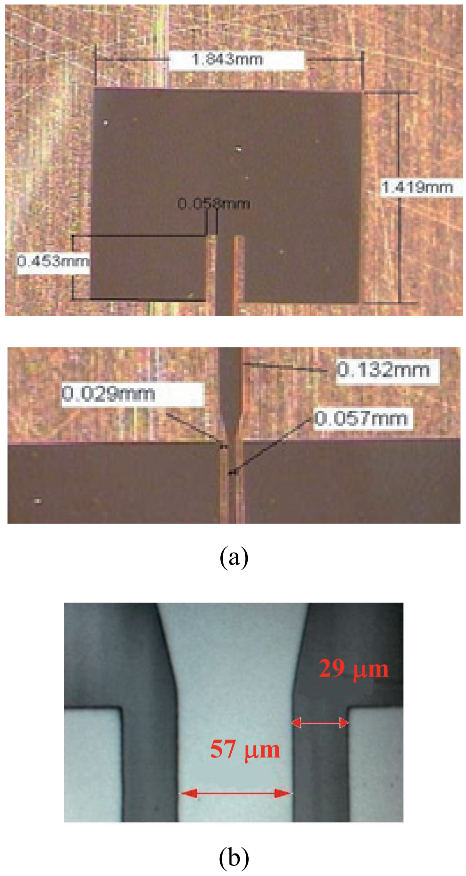

Fig. 8. (a) Photograph of the realized V-band patch antenna and (b) particular of the microstrip-to-coplanar waveguide.

6. Conclusion

The use of BCB polymer as dielectric substrate for millimeter-wave circuits and antennas has been discussed in this paper. A specific in-house manufacture technology has been developed to realize at low cost BCB-based microstrip structures of arbitrary thickness by polymerization of small quantities of liquid BCB. The effectiveness of the fabrication methodology has been successfully tested on millimeter-wave prototypes of coplanar waveguides and patch antennas.

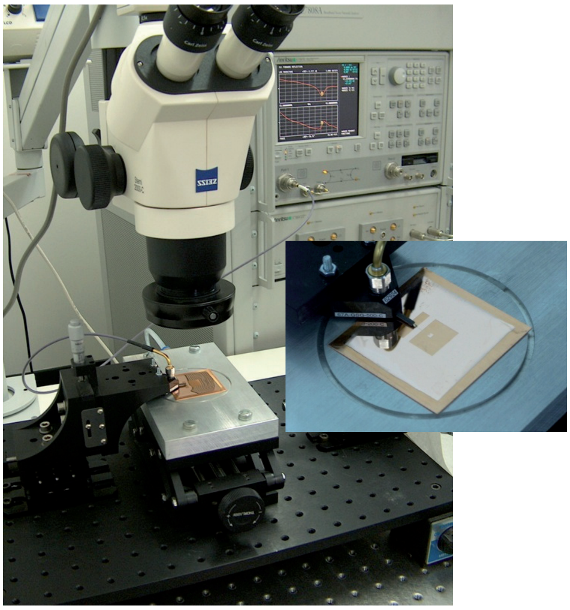

Fig. 9. Photograph of the test setup for the experimental characterization of V-band patch antenna on BCB substrate.

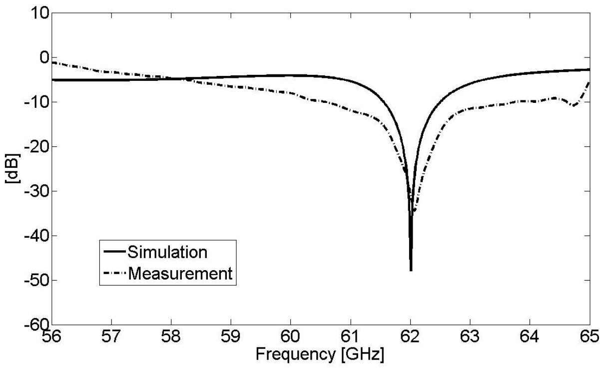

Fig. 10. Comparison between simulated and measured return loss of V-band patch antenna on BCB substrate.

References

[1] Dow Corning. *Sylgard 184 Silicone Elastomer*. [Online]. Available at: http://www.dowcorning.com.

[2] HD MicroSystems. *PI-2525, PI-2555, PI-2556 & PI-2574 Polymide*. [Online]. Available at: http://www2.dupont.com.

[3] Specialty Coating Systems. *SCS Parylene Properties*. [Online]. Available at: http://www.scscoatings.com.

[4] COSTANZO, S., VENNERI, F., BORGIA, A., VENNERI, I., DI MASSA, G. 60 GHz microstrip reflectarray on a benzocyclobutene dielectric substrate. *IET Science, Meas. Technology,* 2011, vol. 5, no. 4, p. 134 - 139.

[5] CARRILLO-RAMIREZ, R., JACKSON, R. W. A highly integrated millimeter-wave active antenna array using BCB and silicon substrate. *IEEE Trans. Microwave Theory and Tech.,* 2004, vol. 52, no. 6, p. 1648 - 1653.

[6] SEOK, S., ROLLAND, N., ROLLAND, P. Design, fabrication, and measurement of benzocyclobutene polymer zeo-level packaging for millimetre-wave applications. *IEEE Trans. Microwave Theory and Tech.,* 2007, vol. 55, no. 5, p. 1040 - 1045.

[7] GRZYB, J., RUIZ, I., COTTET, D., TROSTER, G. An investigation of the material and process parameters for thin-film MCM-D and MCM-L technologies up to 100 GHz. In *Proceedings of the 2003 Electronic Components and Technology Conf.*, 2003, p. 478 - 486.

[8] KRISHNAMURTHY, V. B., COLE, H. S., SITNIK-NIETERS, T. Use of BCB in gih-frequency MCM interconnects. *IEEE Trans. Comp., Packag., and Manufact. Tech. – Part B,* 1996, vol. 19, no. 1, p. 42 - 47.

[9] CHINOY, P. B., TAIADOD, J. Processing and microwave characterization of multilevel interconnects using benzocyclobutene dielectric. *IEEE Trans. Comp., Packag., and Manufact. Tech. – Part B,* 1993, vol. 16, no. 7, p. 714 - 719.

[10] Dow Chemical. *Cyclotene 3000 Series Advanced Electron Resins*. [Online]. Available at: http://www.dow.com/cyclotene.

[11] COSTANZO, S., VENNERI, I., DI MASSA, G., BORGIA, A. Benzocycloutene as substrate material for planar millimeter-wave structures: dielectric characterization and application. *Journal of Infrared, Millimeter and Terahertz Waves,* 2010, vol. 31, no. 1, p. 66 - 77.

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