Experimental Characterization of Interconnects and Discontinuities in Thin-Film Multichip Module Substrates

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ABSTRACT

Interconnects and discontinuities in a thin-film multichip module substrate are experimentally characterized, taking into account the effective dielectric loss attributed to dielectric anisotropy of the thin-film.

I INTRODUCTION

The design of controlled impedance interconnects in thin-film multichip modules (MCM-D's) and the subsequent circuit-level simulation of the package requires accurate models of microstrip and stripline transmission lines and discontinuities. Current practice is to use established planar transmission line models developed for conventional microwave circuit analysis. These models have been experimentally verified for various families of lines fabricated on ceramic (alumina) substrates. Ceramic substrates have an isotropic dielectric constant but in contrast thin-film substrates generally have in-plane/out-of-plane dielectric anisotropy. This is a consequence of the selective orientation of the long polymers when they are laid down by spinning. The overriding material-design consideration is to match the in-plane thermal coefficient of expansion of the material to that of the semiconductor to be bonded to it. The dielectric anisotropy of the material has a significant effect on signal propagation in that the quasi-TEM propagation mode is leaky. The purpose of this paper is to present experimental characterizations of interconnects and discontinuities which account for the large effective dielectric loss of thin-film interconnects due to this radiation.

II CHARACTERIZATION PROCEDURE

Signal propagation on a transmission line is fully described by the propagation constant, γ, and characteristic impedance, Z_0, or by per unit R, L, G and C parameters. Here the propagation constant, γ, of a line is found as a by-product of a conventional TRL procedure. While of interest in its own right, determination of Z_0 is an essential step in removing the effect of fixturing in the TRL method used here. It can be determined with γ and two of the R, L, G and C parameters known.

In this work C is measured directly at 1 MHz and is assumed to be independent of frequency. Often G is assumed to be zero, but here R was analytically determined using the combined finite-element/integral equation method described in [1] and so it is possible to solve for G [2].

III INTERCONNECT CHARACTERISTICS

The structures considered here are aluminum embedded microstrip transmission lines built on a silicon-substrate MCM using Hitachi PIX-L112 polyimide dielectric. The MCM contains both first (FLM) and second (SLM) layer metal lines with cross section shown in Fig. 1. The 10, 16, and 32 μm nominal width lines are designated A, B, and C with a preceding numeral indicating whether the line is FLM or SLM. A finite-element/integral equation analysis [1] was performed to calculate the variation of R with frequency for the FLM lines leading to G as plotted in Fig. 2, indicating an effective loss tangent of 0.022. Plots of $\alpha_C = \frac{1}{2}R\sqrt{C/L}$ and $\alpha_D = \frac{1}{2}G\sqrt{L/C}$ ($\alpha = \alpha_C + \alpha_D$) for the FLM lines are shown in Fig. 3 and the derived Z_0 in Fig. 4. These Z_0's were used in the TRL calibration procedure in determining the parameters of interconnects over gridded ground planes as shown in Figs. 5 and 6.

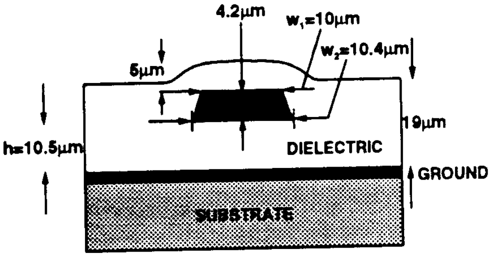

Figure 1: Cross-section of a 10 μm SLM line. The distance between the ground and the FLM is 5μm.

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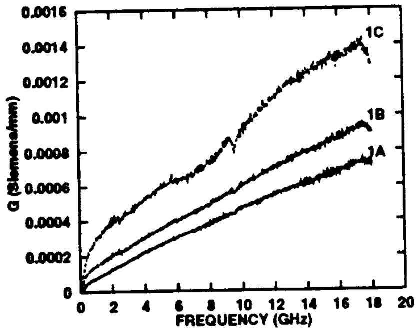

Figure 2: *G* versus frequency.

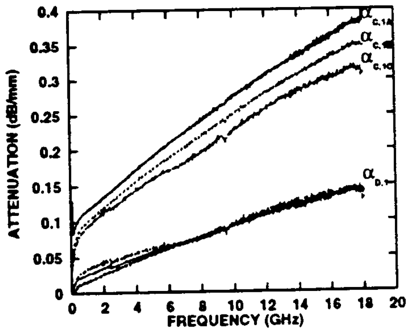

Figure 3: Attenuation constants for first layer metal lines: $\alpha_{C,1A}$, $\alpha_{C,1B}$ and $\alpha_{C,1C}$ are the conductive part and $\alpha_{D,1}$ is the dielectric part.

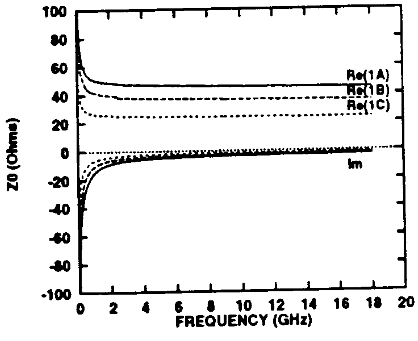

Figure 4: Characteristic impedance of the FLM interconnects

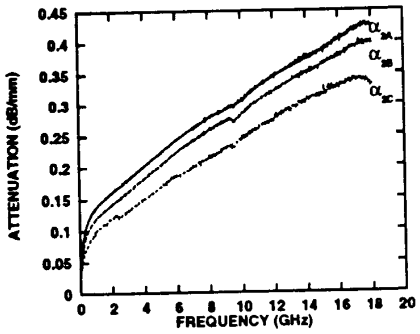

Figure 5: Attenuation of interconnects over a 20 μm pitch gridded ground plane with 10 μm × 10 μm openings. The gridded ground was fabricated using FLM and the interconnect using SLM.

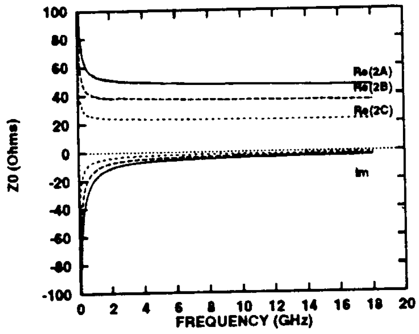

Figure 6: Characteristic impedance of interconnects over the gridded ground plane.

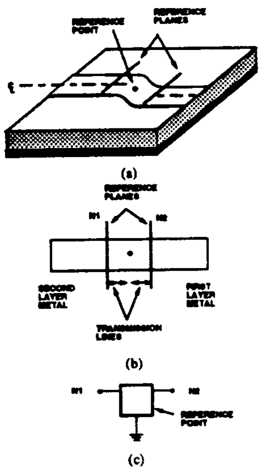

Figure 7: A conformal via discontinuity: (a) view of measurement structure showing via reference planes for a model of the via; (b) conventional via model; and (c) point discontinuity model.

IV DISCONTINUITY CHARACTERIZATION

Discontinuities in nets generally appear as localised discontinuities with connecting transmission lines. Using the via of Fig. 7a as an example, the conventional CAD model includes sections of the connecting transmission lines (Fig. 7b) in which the ends account for most of the effect of a CAD via model. Including the transmission line sections guarantees good agreement between measured and calculated results. In layout extraction the concept of a net incorporating a via is to route from point A to point B, change metallisation layers at point B, and then to route to point C. The conceptualization is not to route a line from point A to the reference plane of the via, then insert a spatially distributed element, and then continue routing from the other reference plane of the via. In a standard measurement set the parameters of a point discontinuity are measured anyway. It is far more reasonable to model the structure as a point discontinuity as in Fig. 7c. An example of point discontinuity results for a via are shown in Fig. 8.

V CONCLUSION

The in-plane and out-of-plane dielectric characteristics of thin-films are difficult to measure except using optical techniques. For these reasons and because of dimensional variations, CAD models of interconnects on thin-films must be calibrated by measurements.

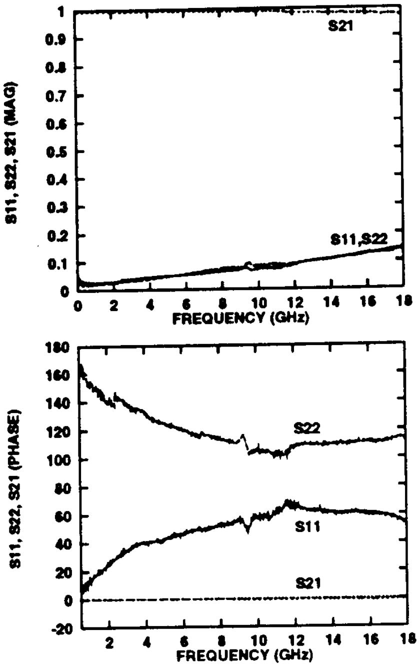

Figure 8: Experimentally derived via S parameters.

ACKNOWLEDGEMENT

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[2] S. Lipa, M.B. Steer, A.C. Cangellaris and P.D. Franson, "Experimental characterisation of transmission lines in thin-film multichip modules," *Unpublished*.