Dispersion Characteristics of Microstrip Transmission Line on Glass Microwave IC's

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***Abstract*—Measurement of the effective dielectric constant of microstrip transmission line on glass for the frequency range of 5–35 GHz are presented. These measurements indicate that there is very little dispersion in 200-μm-thick glass for frequencies up to 35 GHz. Further, electromagnetic analysis shows that the dielectric constant of glass changes from 4.05 to 4.00 when the frequency varies from 5 to 35 GHz, somewhat compensating for the dispersion.**

I. Introduction

GLASS [1]–[3] is increasingly being used for many microwave and millimeter-wave applications. Since many of these applications require accurate modeling, there is a need to evaluate the dielectric constant of wafer-processed glass versus frequency more accurately than previously reported [4]. Microstrip resonator measurements have been widely used to measure effective dielectric constant [5], [6]. York and Compton [7] have carried out extensive measurement of straight gap-coupled resonators and have described two analytical models which are most accurate for CAD applications. However, their measurements were confined to frequencies below 18 GHz.

This letter provides dispersion characteristics of 200-μm-thick glass for frequencies up to 35 GHz. Additionally, EM simulations, using Maxwell SI Eminence,[1] are used to model and deduce the dielectric constant of glass from the measured effective dielectric constant.

II. Theory

For any low-loss medium such as microstrip on low-loss dielectric, transmission line resonance can be represented by a simple one-pole circuit and a loss mechanism. Under this assumption, the phase and magnitude of S_{21} varies sharply at resonance. Since the phase is a monotonically varying function, it is much easier to fit than the magnitude of S_{21} and, therefore, in this letter the phase is used to extract the resonance accurately.

Fig. 1 shows a typical measured and least squares fitted phase of S_{21}. The end points which were used for extracting the phase are circled and the solid curve represents the fitting function. By restricting the fitted frequency range to be near the resonant frequency, the region of fast phase change, interaction with other terms are avoided. Typically, Q's are greater than 100 for frequencies higher than 5 GHz, and the fitted frequency range is less than 1% of the resonant frequency.

A typical measurement of symmetrical straight gap-coupled resonator, shown in Fig. 2(a), involved two resonant lines nominally having fundamental resonance at f_0 and $2f_0$ [9]. The effective dielectric constant is given by

$$\varepsilon_{\text{eff}} = \frac{c^2(m_1 f_2 - m_2 f_1)^2}{4(l_1 - l_2)^2 \cdot (f_1 f_2)^2} \quad (1)$$

where f_1 and f_2 are the resonant frequencies of the resonators, m_1 and m_2 are the resonant mode numbers, and l_1 and l_2 are the line lengths. Besides the straight resonators, we also measured ring resonators [8, p. 246]. The curvature effects were included by using the roots of Bessel functions as outlined by Owens [9]. Other effects such as field interaction across the ring and resonance splitting due to nonuniformity around the ring [8] are minimal for the geometry and photolithography control of the resonator used in this work. Additionally, the coupling capacitance is assumed to be small and ignored.

III. Measurements

Fig. 2(a) shows the layout of the gap-coupled symmetrical straight resonator together with the dimensions and Fig. 2(b) shows the layout of the ring resonator. The straight resonators had line widths of 25, 100, and 400 μm on 7070 corning glass of 200-μm nominal thickness corresponding to a nominal impedances of 150, 100, and 50 Ω, respectively. The ring resonators had line widths of 100 and 400 μm. These structures were manufactured on glass using a lift-off process. The effective metal conductivity, approximately calculated as the thickness weighted sum of sheet conductivity of each layer divided by total thickness, is about 3.5×10^7 Siemens/m, while the measured metal thickness is between 3.5–3.6 μm. Four wafers were processed in a single batch run and these are labeled wafers A, B, C, and D.

Fig. 3 shows the extracted effective dielectric constant of glass versus frequency for the three set of transmission lines using the straight resonators with on-wafer measurement. Also plotted on the graph is the effective dielectric constant of glass as obtained from a ports' only solutions with an finite-element method-based EM simulator, Ansoft's Maxwell SI Eminence [8]. To ensure accuracy, the simulations included the metallic losses. The figure indicates that to simultaneously fit the effective dielectric constant of 50-, 100-, and 150-Ω transmission lines, the glass dielectric constant has to change with frequency. There are two sources for error in the EM simulations—first, the line parameters, particularly the metal

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[1] Maxwell SI Eminence, Trademark of Ansoft Corporation, Four Station Square, Suite 660, Pittsburg, PA, USA.

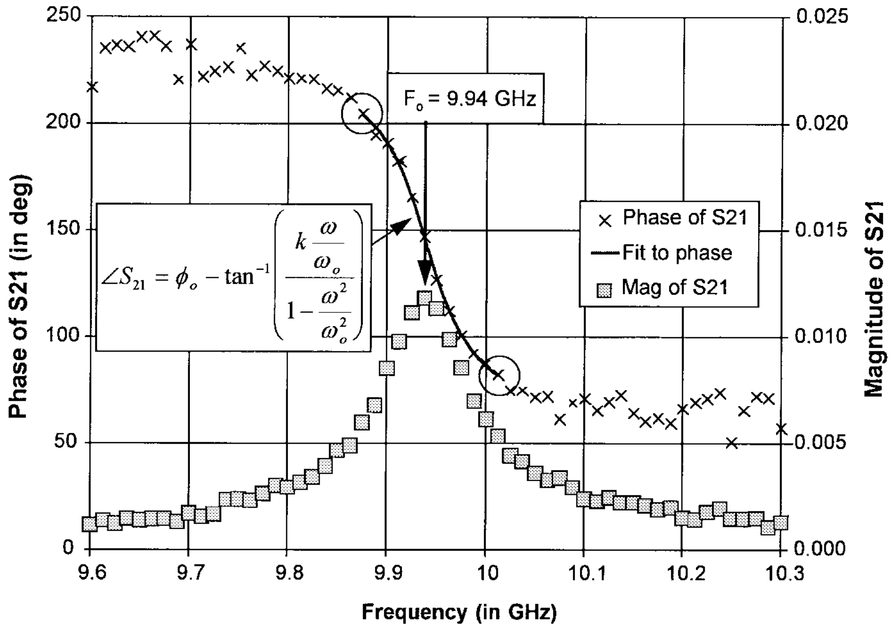
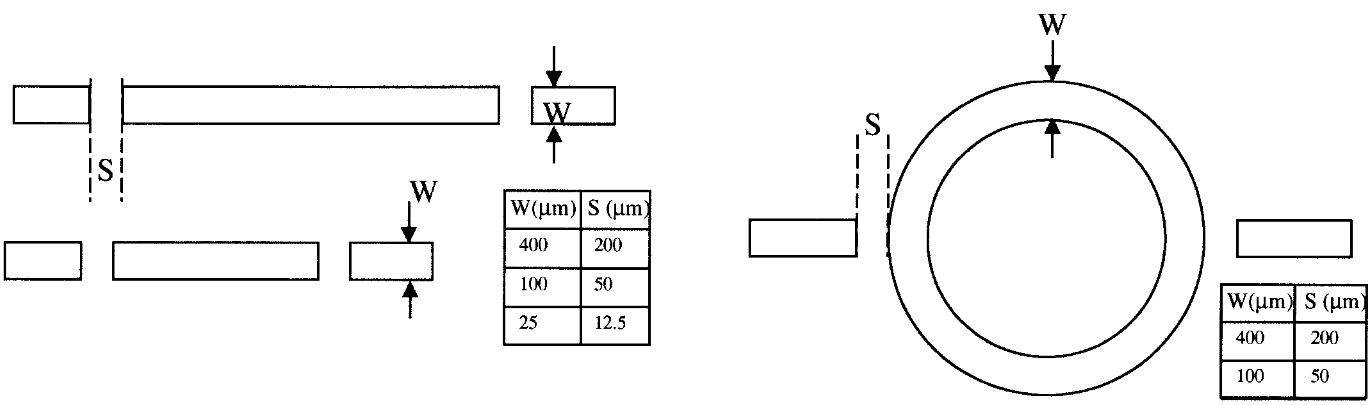


Fig. 1. Measured and fitted phase of S_{21}. Also shown is the magnitude of S_{21}.



(a) (b)

Fig. 2. The geometry of the measured structures. (a) Gap-coupled symmetric straight resonator. (b) Ring resonator.

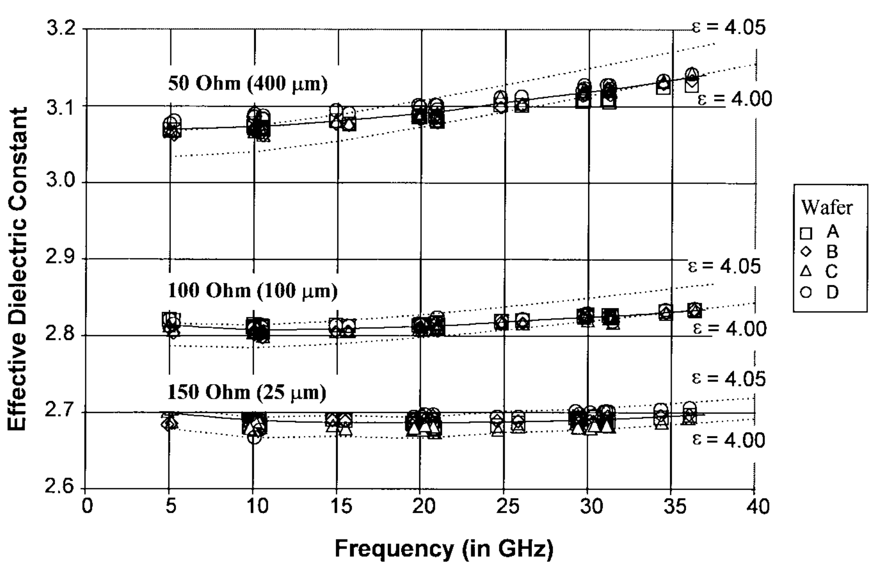


Fig. 3. Measured effective dielectric constant of glass for 50-, 100-, and 150-Ω microstrip lines on four wafers using gap-coupled symmetric straight resonators. The solid curve represents a least square spline fit through the data, while the dotted curves represent EM simulations for the lines assuming glass dielectric of 4.05 and 4.00.

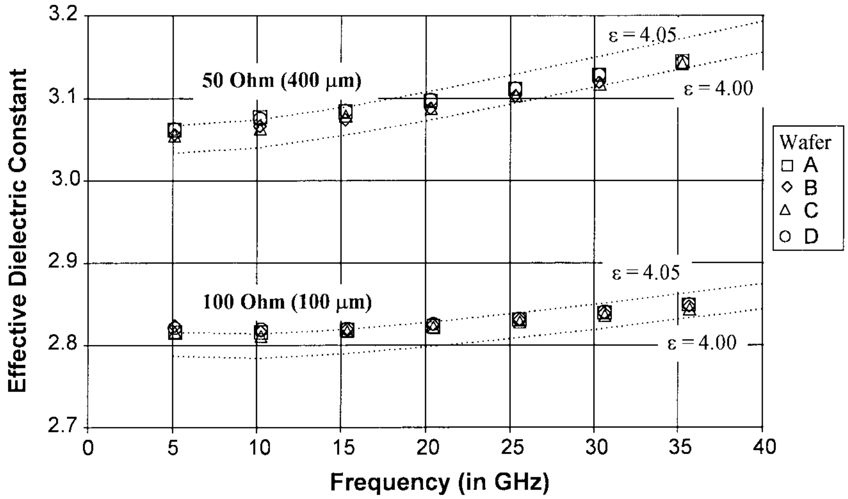


Fig. 4. Measured effective dielectric constant of glass for 50- and 100-Ω microstrip lines on four wafers using ring resonators. The dotted curve are EM simulations for the effective dielectric constant of the lines assuming glass dielectric of 4.05 and 4.00.

TABLE I
THE GLASS PERMITTIVITY REQUIRED IN LINECALC TO RESULT IN THE MEASURED EFFECTIVE DIELECTRIC CONSTANT FOR 400-μm (50-Ω) WIDE LINE

Frequency (GHz)	Measured Effective Dielectric Constant (50 Ω line)	Implied Linecalc Dielectric Constant
5	3.070	4.04
10	3.073	4.03
15	3.081	4.02
20	3.091	4.01
25	3.105	4.01
30	3.119	4.00
35	3.134	4.00

loss and metal shape, are not known to have high accuracy, and second, the surface boundary conditions on the metal and the box enclosure can influence the finite-element method (FEM)-based calculations. These errors are more significant for narrow lines.

Table I shows the dielectric constant of glass required to fit the measured effective dielectric constant for the 400-μm-wide line in LineCalcLineCalc.[2] Both EM simulations and Linecalc indicate that the glass dielectric constant changes from 4.05 to 4.00 as the frequency is increased from 5 to 35 GHz. Note that the frequency dispersion characteristics of the glass microstrip transmission line are s compensated by the dielectric constant decrease of glass.

Fig. 4 shows the effective dielectric constant of glass as derived from the ring resonators. The loading effect of the coupling capacitor will result in a slightly larger extracted effective dielectric constant of glass as confirmed in Fig. 4.

The error in the measurements are expected to be small as the lines were defined photolithographically and the fitting algorithm is automated and consistent, thus self correcting to some extent. The worst case standard deviation of the data from the spline fitted curve in Fig. 3 is less than 0.008 (0.3%) across different wafers, clearly indicating consistency in the data and lot repeatability.

[2] Trademark of HP-EEsof, 5601 Lindero Canyon Rd., Westlake Village, CA, USA.

IV. CONCLUSION

Gap-coupled symmetrical straight resonators using on-wafer testing have been found to provide accurate effective dielectric constants for microstrip transmission lines on glass. The standard deviation of the measured data from a spline fit is less than 0.3% indicating good process uniformity. Additionally, the measurements presented here indicate that the effective dielectric constant of glass changes from 4.05 to 4.00 as the frequency is increased from 5 to 35 GHz. Both LineCalc and EM simulations can accurately predict the effective dielectric constant of glass for wide lines; however, EM simulations are more useful for narrow lines.

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