V-1 HIGH DIELECTRIC SUBSTRATES FOR MICROWAVE HYBRID INTEGRATED CIRCUITRY

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Microstrip transmission-line components are finding wide application in microwave integrated circuits. Properties of the microstrip structure have previously been investigated for semiconductor dielectrics,[1] low-dielectric ($k < 10$) ceramics,[2] sapphire,[3] and Polyguide.[3] This paper will present the properties of high-dielectric ($k > 10$) substrates in the microstrip configuration.

All of the data were taken from the A1SiMag temperature-compensating series No. T96 manufactured by American Lava Corporation. The dielectric constant of this material is in the range of 25-100. The material consists of titanium dioxide with additions of magnesium and titanium to provide a minimum change of capacitance as a function of temperature.

The primary virtue of high-dielectric substrates for microwave circuits is reduced size. By increasing the substrate dielectric constant from 10 to 100 the guide wavelength of a 50-ohm microstrip line can be reduced by a factor of 0.35. Since the high-dielectric microstrip lines also have low loss and a useful range of impedances, this class of circuits will undoubtedly find wide applications in microwave integrated circuitry.

Three properties are required in characterizing microstrip lines: wavelength, characteristic impedance, and attenuation. The wavelength in the microstrip line has been measured by two methods. Using the first method, the line is operated as a half-wavelength filter which is loosely coupled and open-circuited at both ends. By measuring the resonant frequencies of the filter the wavelength in the microstrip line may be simply calculated.

An alternative method consists of short-circuiting the transmission line and searching for the frequencies where the VSWR minimum positions are identical with those of a short-circuited air line. At these resonant frequencies the line is once again a half-wavelength filter. Better measurement accuracy seems to be obtained from the second method, although both methods give the same value of guide wavelength.

Characteristic impedance may be simply determined from time-domain reflectometer measurements. With the line terminated in 50 ohms, the reflection coefficient is measured for a transmission line which is sufficiently long for transitions at the end of the line to have a negligible effect.

The attenuation of the line may be determined by measuring the loss tangent of the short-circuited resonant line. This loss may be expressed in dB/cm or dB/λ_g. Using the latter units, the advantages of high-dielectric substrates will become more apparent.

The measured and calculated ratio of free-space wavelength to microstrip wavelength is plotted in Figure 1 as a function of dielectric constant and geometry. This ratio has been computed from a conformal mapping solution given by Wheeler.[4] $\lambda_o/\lambda_g = \sqrt{k'}$ (1) $k' = 1 + q(k-1)$ (2)

where

k' is the effective dielectric constant;

k is the substrate dielectric constant;

q is the effective filling fraction.

The measured and calculated characteristic impedance is plotted in Figure 2 as a function of geometry and dielectric constant. The calculated impedance is based on the conformal mapping solution given by Wheeler.[4] Notice that the high-dielectric substrates require smaller values of w/h for high-impedance levels because of the higher transmission-line capacitance. Since line width is restricted by thin-film-technology limitations, thicker substrates will be required for high-dielectric microstrip circuits.

From measuring the total loss tangent, the attenuation constant is given by

$$\alpha = 27.3 \tan \delta \qquad \text{(units are dB/}\lambda_g\text{)} \qquad (3)$$

where $\tan \delta$ includes both dielectric and conductor loss.

The theoretical attenuation may be computed for a TEM wave. The attenuation constant is the sum of the dielectric losses and the conductor losses.

$$\alpha = \alpha_d + \alpha_c \qquad (4)$$

Dielectric losses must include the effective dielectric constant.[5] At low frequencies, where ohmic losses dominate, the dielectric attenuation constant becomes

$$\alpha_d \cong \frac{\omega}{2} (\mu\, k)^{1/2} \tan \delta_k \left(\frac{k}{k'}\right)^{1/2} q \qquad \text{(units are nepers/meter)} \qquad (5)$$

Conductor losses may be approximately calculated by assuming a uniform current across the width of the conductor and also assuming that the ground-plane current is distributed uniformly under the conductor.

When the conductor thickness is greater than the skin depth, the conductor attenuation becomes

$$\alpha_c \cong \frac{\sqrt{\pi f \mu \rho}}{Z_o w} \qquad \text{(units are nepers/meter)} \qquad (6)$$

where

ρ is the conductor resistivity;

f is the frequency;

μ is the magnetic permeability.

Using the relations above, the theoretical attenuation constant and measured values have been plotted in Figure 3 as a function of frequency and geometry.

Conclusions

High-dielectric substrates consisting of a temperature-compensated titanium dioxide homogeneous mixture have been shown to have the properties required for reduced-size microwave integrated circuits. The variations of microstrip wavelength, characteristic impedance, and attenuation with geometry and dielectric constant are in good agreement with the theory. The low values of attenuation and guide wavelength make this material particularly attractive for low-loss microwave circuitry.

1. T.M. Hyltin, "Microstrip Transmission on Semiconductor Dielectrics," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-13, November 1965, p. 777.
2. B.T. Vincent, Jr., "Ceramic Microstrip for Microwave Hybrid Integrated Circuitry," 1966 G-MTT Symposium, May 1966.

3. M. Caulton, J.J. Hughes, and H. Sobol, "Measurements on the Properties of Microstrip Transmission Lines for Microwave Integrated Circuits," RCA Review, September 1966, p. 377.
4. H.A. Wheeler, "Transmission-line Properties of Parallel Strips Separated by a Dielectric Sheet," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-13, March 1965, p. 172.
5. J.D. Welch and H.J. Pratt, "Losses in Microstrip Transmission Systems for Integrated Microwave Circuits," 1966 NEREM Record.

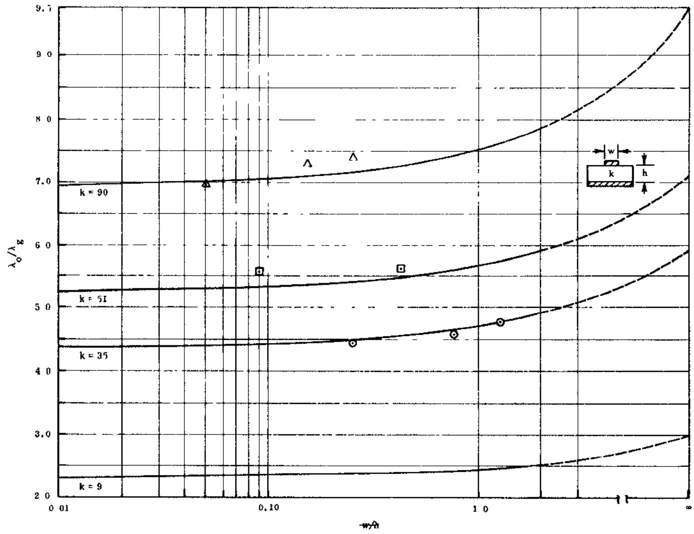

FIG. 1 - λ_o/λ_g versus Dielectric Constant and Geometry

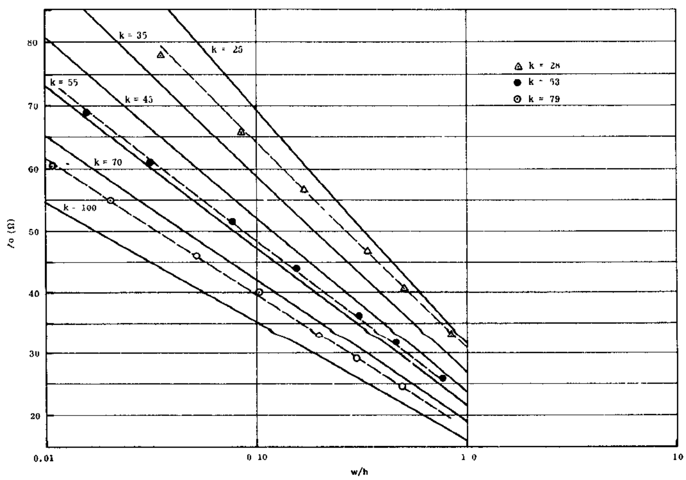

FIG. 2 - Characteristic Impedance versus Dielectric Constant and Geometry

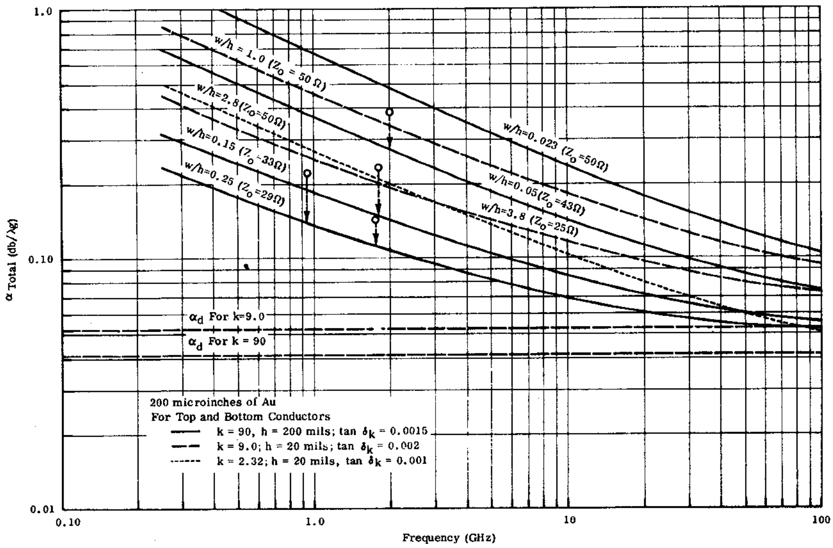

FIG. 3 - Attenuation Constant versus Frequency and Geometry

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