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INSULATED NONRADIATIVE DIELECTRIC WAVEGUIDE FOR MILLIMETER-WAVE INTEGRATED CIRCUITS

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An improved version of the nonradiative dielectric waveguide(NRD-guide), called an insulated nonradiative dielectric waveguide, is proposed for millimeter-wave integrated ciruits. This dielectric waveguide can overcome some difficulties which arise when high dielectric material is used in the NRD-guide. Guide wavelengths and transmission losses were measured at 50 GHz and compared with theory.

Introduction

The nonradiative dielectric waveguide(NRD-guide) has been proposed for millimeter-wave integrated circuits[1] and studied continuously using polystyrene dielectric exclusively[2,3]. Though high dielectric materials such as Stycast(trade name) and alumina are preferable in view of the small circuit size, their use in NRD-guide fabrication entails some difficulties. First of all, the dielectric strips must be unusually wide in one dimension of the cross section and thin in the other. The transverse dimensions of a typical Stycast strip are 2.7 mmx0.86 mm at 50 GHz. Such a flat strip wastes more material than necessary and is difficult to fabricate with reasonable accuracy. Another disadvantage of using high dielectric strips in the NRD-guide is a narrow frequency band of single mode operation limited by the presence of the extra E^x_{12} mode(named according to image guide convention). In order to overcome these difficulties and at the same to attain some reduction in transmission losses, an insulated nonradiative dielectric waveguide will be proposed in this paper.

In the insulated NRD-guide, the high dielectric strips are sandwiched between the low dielectric overlays on the conducting plates just as in the insulated image guide. The conducting plate separation, of course, is smaller than half a wavelength to suppress undesirable radiation. This improved scheme can successfully eliminate most difficulties associated with the high dielectric NRD-guide without spoiling the nonradiative nature of the waveguide at all, as will be explained later.

The insulated NRD-guide were fabricated using Stycast and alumina to measure guide wavelengths and transmission losses at 50 GHz. Since the materials were selected only from a standpoint of high dielectric constant and ease of fabrication, their loss tangents were not necessarily very small, and hence the transmission losses were unexpectedly large. But, the theory predicts that it is not difficult to reduce the transmission loss of the insulated NRD-guide to a level below 2.5 dB/m, if high quality alumina with a loss tangent as small as 10^{-4} is used.

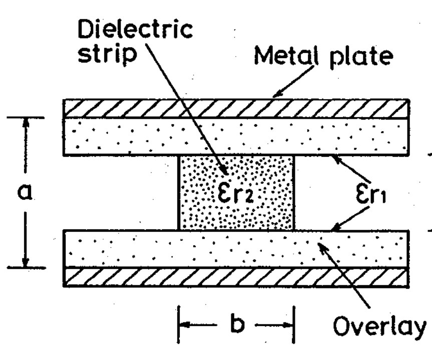


Fig.1 Cross section of insuated NRD-guide

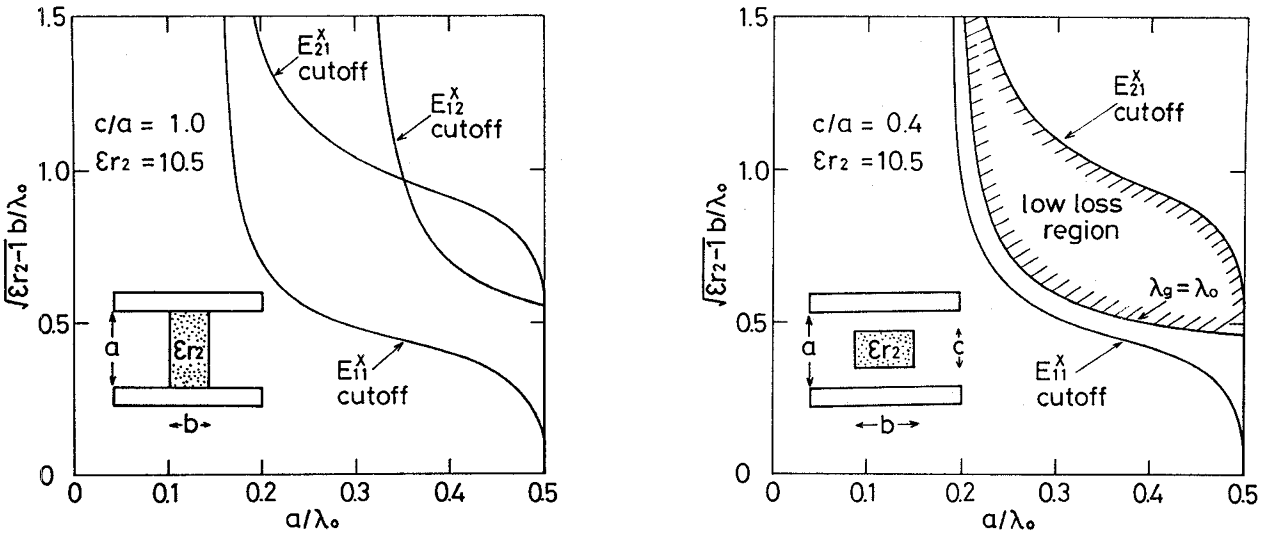
Operation Diagram

Fig.1 shows the cross sectional view of the insulated NRD-guide. The top and bottom plate separation is a, the transverse dimensions of the dielectric strip are bxc, and the high and low dielectric constants are ε_{r2} and ε_{r1}, respectively. The dielectric constnat ε_{r1} can be unity in the special case where the low dielectric overlays are replaced with air. Only this case will be considered below.

In order to analyze the insulated NRD-guide, the effective dielectric constant(EDC) method will be used. In the presence of the conductive boundaries, however, different sequences of applying the EDC method often cause a substantial difference in the final results[4]. In this paper, the EDC method is applied in the direction parallel to the conducting plates first, and then a hypothetical three layered slab sandwiched between the conducting plates is solved exactly to obtain the propagation constant of the original waveguide in Fig.1. The reversed sequence is traced in the analysis of the trapped image guide to obtain a good agreement with measurements[4]. But, the present approach may also be justified by the fact that it yields the exact solution when the low dielectric overlays tend to zero in thickness(NRD-guide).

In the beginning, an operation diagrams for the NRD-guide(c/a = 1.0) and the insulated NRD-guide(c/a = 0.4) are prepared on the basis of the EDC method and presented in Figs.2(a) and (b), respectively. The dielectric material in both the figures is assumed to be Stycast(ε_{r2} = 10.5). The operation diagram is drawn in such a way that the modes are above cutoff in the upper parts of the corresponding curves and below cutoff in the lower parts. Therefore, only the E^x_{11} mode can exist in the region bounded by the critical curves of all the relevant modes. As manifested in Fig.2(a), a considerable area is cut away by the critical curve of the E^x_{12} mode. This results in a substantial reduction of the frequency band of single mode operation. In the insulasted NRD-guide, however, such a reduction of the frequency band never arises as seen in Fig.2(b). Thus, one of the disadvantages of the high dielectric NRD-guide is removed.

Typical dimensions of the Stycast NRD-guide can be determined from the operation diagram as a = c = 2.7 mm and b = 0.86 mm, while those of the insulated NRD-guide are a = 2.7 mm, b = 1.45 mm and c = 1.08 mm. It can be seen that the dielectric strip in the insulated NRD-guide is more compact in the cross section and hence less wasteful of material and easier to fabricate than that in the NRD-guide. This overcomes another disadvantage of the high dielectric



(a) NRD-guide (b) Insulated NRD-guide

Fig.2 Operation diagrams of NRD-guide and insulated NRD-guide

NRD-guide.

Furthermore, if the guide wavelength of the E^x_{11} mode is made smaller than the wavelength of the plane wave in the low dielectric medium, the fields decay toward the conducting plates in the exponential manner so that a reduction of the conduction loss can be expected. This condition is fulfilled in the hatched low loss region in Fig.2(b).

Measurements

By using Stycast and alumina, insulated NRD-guides were fabricated to measure guide wavelength and transmission losses at 50 GHz. By preliminary measurements of the NRD-guides and the rod guides, the material constants of Stycast and alumina were estimated to be $\varepsilon_{r2} = 10.5$, $\tan\delta = 3.8\text{x}10^{-3}$ and $\varepsilon_{r2} = 8.5$, $\tan\delta = 10^{-3}$, respectively. Considering these values, the materials are not necessarily satisfactory for millimeter-wave applications, but they may still be helpful for examining basic properties of the insulated NRD-guide.

Transition A transition from a metal waveguide and an insulated NRD-guide was constructed in the configuration as shown in Fig.3. To facilitate fabrication, no tapers were provided at the ends of the strip. For support within metal waveguides, the dielectric strip was anchored in a hole drilled in a Teflon piece, 3.1 mm in length, which was backed by a similar Teflon piece of 1.1 mm in length. Since these Teflon pieces serve as impedance transformers as well, their lengths had to be carefully adjusted. The waveguide was provided with two rectangular metal fins, 5 mm in length and 2.7 mm in width, which was attached to the middle of the edges of the broad walls, flared out by about 30° and inserted between the conducting plates to precisely maintain the separation. Though the structure is simple, this transition worked very well, and the return loss was measured to be in excess of 14 dB, at least over the frequency band of a manual tuning klystron oscillator.

Guide Wavelength In the measurement of guide wavelengths, the insulated NRD-guide was terminated by a metal waveguide short by way of the transition to create clear standing wave patterns along the dielectric strip. The electric field was probed by an electrically small unipole antenna consisting of the inner conductor of a semi-rigid cable of 0.8 mm in diameter. The outer surface of the cable was coated with a very thin lossy material to suppress unexpected interferences. The dimensions of the tested guides were a = 2.7 mm, b = 1.45 mm and c = 1.08 mm for Stycast and a = 2.7 mm, b = 1.5 mm and c = 1.0 mm for alumina. The measured results are summarized in fig.4 as a function of frequency. Solid curves represent theoretical values caluculated by the EDC method. Agreement between theory and measurements is excellent within practical accuracy. The measurements revealed that the guide wavelength of the insulated NRD-guide is not much different from that of the rod guide so long as the same dielectric strip is used. This is quite in contrast to the NRD-guide.

Transmission Loss Transmission losses were measured by comparing transmission coefficients of two insulated NRD-guides of different lengths, 40 mm and 70 mm. Measured data of the transmission coefficients for insulated NRD-guides are shown in Figs.5(a) and (b) together with those for the metal waveguide, 40 mm in length. The obtained transmission loss for the

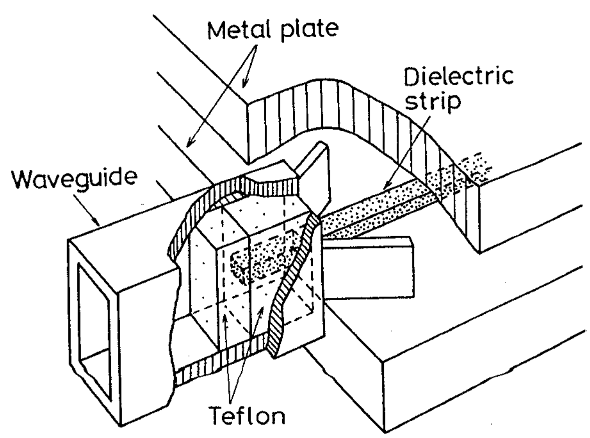


Fig.3 Transition from metal waveguide to insulated NRD-guide

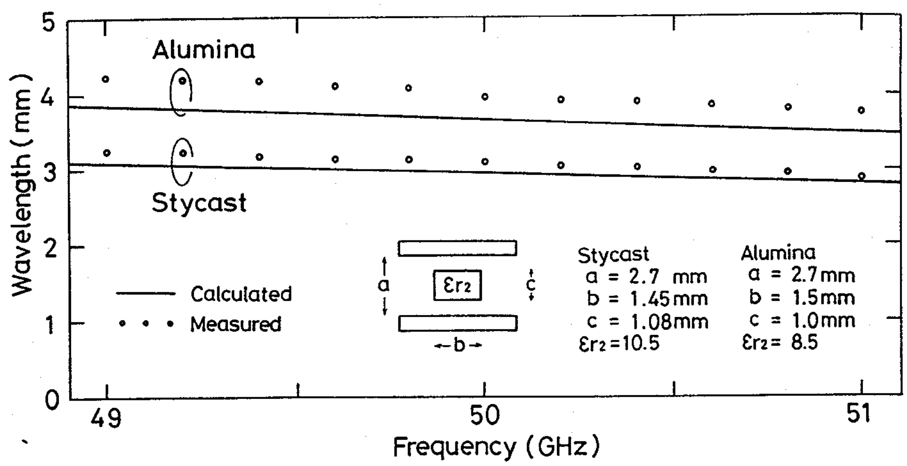
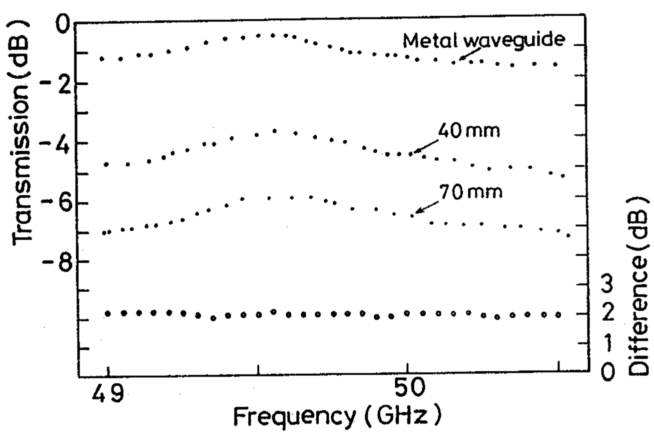
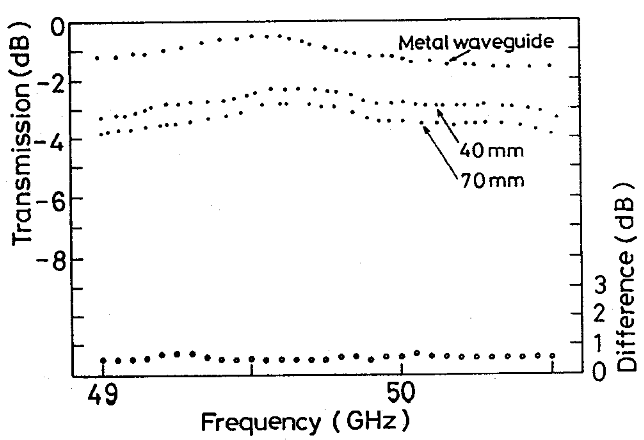


Fig.4 Theoretical and measured values of guide wavelength of Stycast and alumina insulated NRD-guides



(a) Stycast insulated NRD-guide



(b) Alumina insulated NRD-guide

Fig.5 Measured values of transmission coefficients of insulated NRD-guide having different lengths of 40 mm and 70 mm

Stycast guide was 69 dB/m. The corresponding theoretical value is calculated to be 69.9 dB/m, assuming the conducting plates to be brass($\sigma = 1.7\text{x}10^7$ S/m). This value consists of 69.4 dB/m dielectric loss and 0.5 dB/m conduction loss. Therefore, if less lossy material is used, a reduction of the transmission loss will be attained. In fact, this can be understood by examining data for the alumina strip in Fig.5(b). The transmission loss was estimated to be 19 dB/m in this case. The theoretical value is 17.2 dB/m, which includes 16.3 dB/m dielectric loss and 0.9 dB/m conduction loss. Since the dielectric loss is proportional to the loss tangent of the material, the transmission loss can be expected to further reduce to a level less than 2.5 dB/m, if high quality alumina whose loss tangent is as small as 10^{-4} is used.

Conclusions

An improved type of the NRD-guide, called an insulated NRD-guide, is proposed to overcome some difficulties which arise when high dielectric strips are used in the NRD-guide. Guide wavelengths and transmission losses of the proposed guide were measured at 50 GHz and compared with the theoretical values calculated by the EDC method. The theory suggests that one order of magnitude less transmission loss than that obtained here can be attained since high quality alumina with a loss tangent of approximately 10^{-4} is currently available.

References

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