5.3: LAYERED MEDIA AS HIGH POWER MICROWAVE ABSORBERS

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Materials for high power attenuator or matched load applications should present a wave impedance of several hundred ohms for maximum absorption and at the same time should be capable of large heat dissipation. These requirements are generally mutually exclusive, since for conductors thermal conductivity is proportional to electrical conductivity. One way to circumvent this is to use an anisotropic material which can conduct heat easily in the direction perpendicular to the electric field orientation.

Since no known material possesses the desired properties it is proposed to synthesize an artificial medium constructed of alternating layers of an absorber and an insulator. Boron nitride and graphite are isomorphous with nearly identical lattice parameters. The crystal spacings of hexagonal boron nitride has been reported by Pease [1] as a = 2.5040 Å and c = 6.6612 Å, while the corresponding parameters of graphite are a = 2.464 and c = 6.736. Thus, under appropriate conditions, epitaxial growth of each of the materials on the other is feasible, and a laminate may be constructed by crystal growth techniques such as vapor deposition.

To minimize mechanical strain the thermal expansion characteristics of the materials should be very similar. Pease determined the thermal coefficient alpha a = 2.3×10^{-6} and alpha c = 44.1×10^{-6} per degree centigrade for boron nitride. The corresponding coefficients for graphite are alpha a = 1.3×10^{-6} and alpha c = 17.2×10^{-6} per degree centigrade.

Pyrolytically deposited graphite has very anisotropic electrical properties, with an electrical conductivity of 10^4 mhos per centimeter in the easy direction, and a conductivity of one mho per centimeter in the hard direction. Boron nitride is an insulator. Both materials when deposited pyrolytically display anisotropic thermal conductivities. In the plane parallel to the surface, that is, normal to the c-direction of the deposit, the thermal conductivity of the deposit approaches that of copper. The resulting composite when properly oriented should therefore possess the desired high heat dissipation characteristics, and should be a good high power absorber if it can be made to have the right sort of impedance.

This problem has been considered theoretically. The determinantal equation was derived for a plane wave propagating in the z-direction in a semi-infinite media, as shown in Figure 1. In the limit of very thin layers the propagation constant is given by

$$\gamma^2 = \frac{j\omega \mu_o \sigma_x (1 + t_d/t_M)}{1 + \dfrac{\sigma_x t_d}{j\omega\varepsilon_x t_M}} \tag{1}$$

where σ_x is the x-directed conductivity of the graphite and ε_x is the x-directed permittivity of the insulator. This expression is valid only when the thickness of the graphite is small compared to the skin depth associated with the largest conductivity.

In order to determine the effectiveness of the layered material scheme, the reflection of a plane wave normally incident on a semi-infinite composite was examined. The percentage of the incident power absorbed by the laminate is strongly dependent on the relative thicknesses of the insulator and the graphite as may be seen in Figure 2. It should be noted that while relatively large values of t_d/t_m give the largest absorption, the penetration depths are correspondingly large. The frequency dependence of the penetration depth is illustrated in Figures 3 and 4. The power absorption is relatively frequency insensitive as is shown in Figure 5. Extension of the theory to the more difficult cases in which the thicknesses are not small compared to a skin depth has not been attempted since it involves a matching of all the modes in the composite to the incoming plane wave.

Because of the expense and difficulty of fabricating boron nitride-graphite sandwiches by thermal deposition, it seemed desirable first to test some samples which, hopefully, would be electrically similar to those thermally grown, but which could be more readily made. Accordingly, specimens have been constructed of pyrolytically deposited

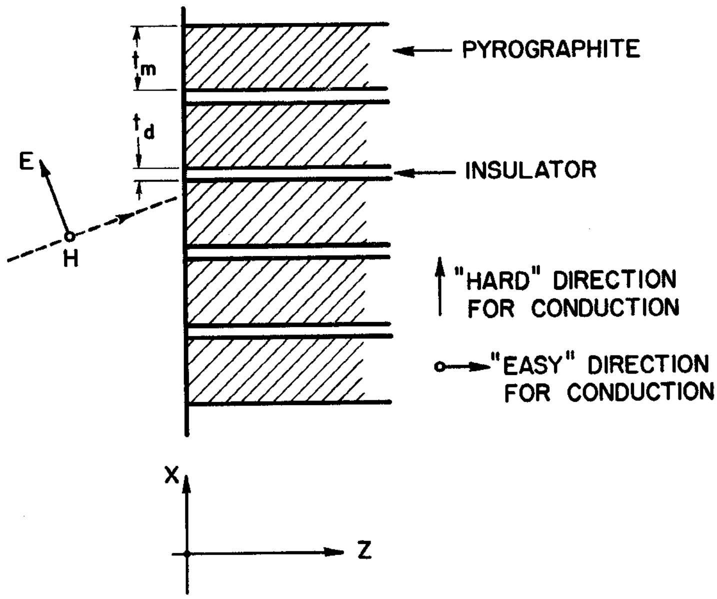

Fig. 1. Diagramatic representation of layered composite of pyrolytic graphic and boron nitride.

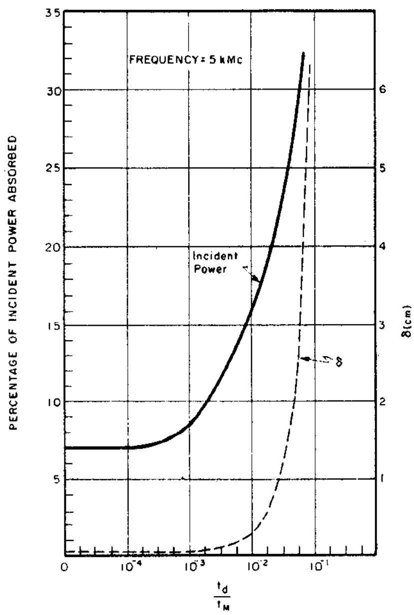

Fig. 2. The dependence of incident power absorbed and penetration on the relative thicknesses of insulator and metal layers.

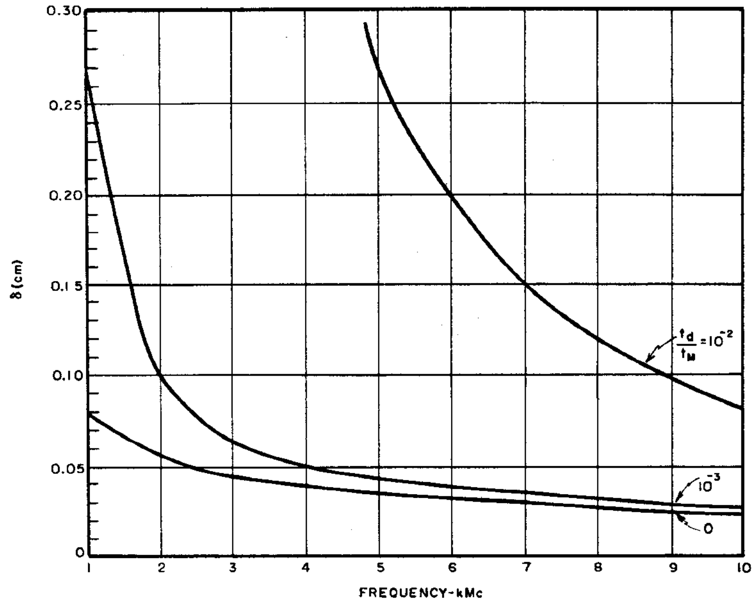

Fig. 3. The frequency dependence of penetration in a laminate for thin insulating layers.

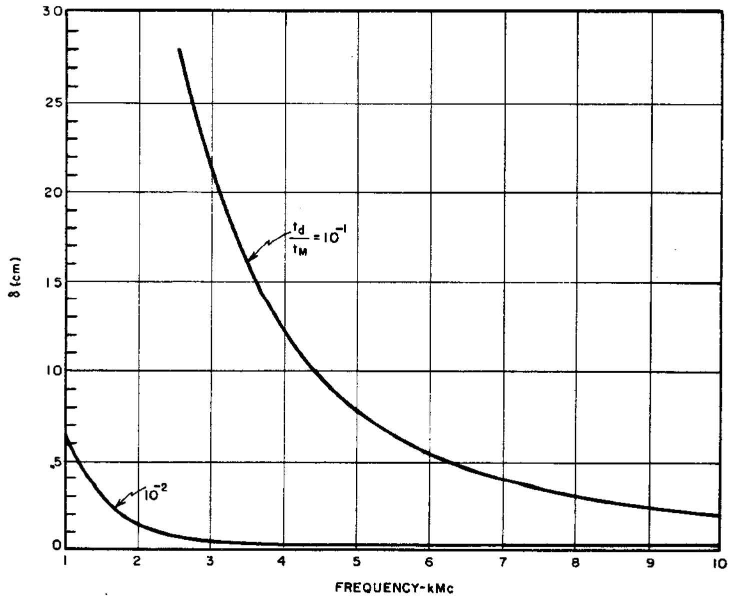

Fig. 4. The frequency dependence of penetration in a laminate for thin insulating layers.

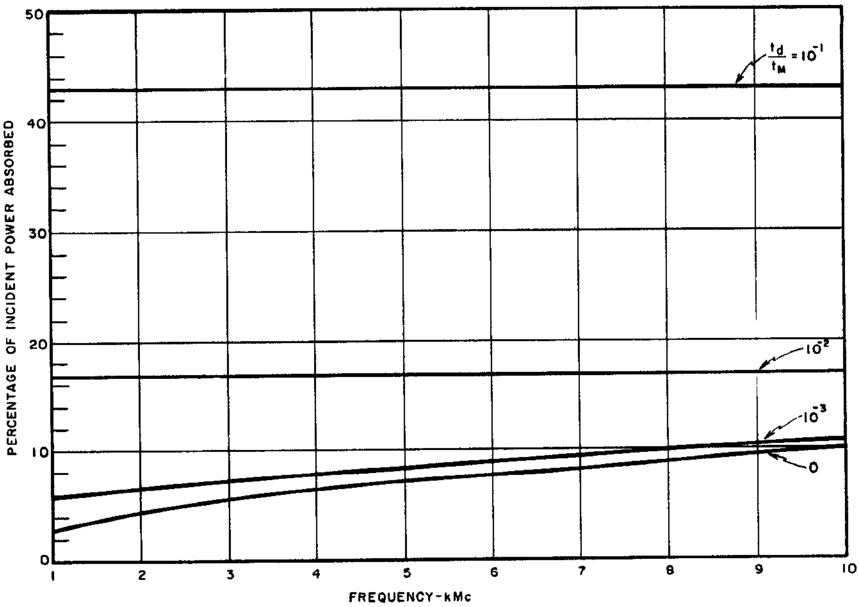

Fig. 5. The frequency dependence of incident power absorbed for various insulator thicknesses.

graphite layers approximately five millimeters thick alternating with dielectric sheets about twenty-five microns thick. Since the skin depth associated with the greater conductivity is on the order of one hundredth of a millimeter the previous theoretical results do not apply to these samples. For ease of fabrication, polystyrene was used as the dielectric in place of boron nitride.

These samples were inserted in a wave guide with the laminations parallel to the broad face of the guide. The insertion loss and reflection coefficients have been determined over a range of frequencies and sample lengths. The power absorbed by a sample 1.3 centimeters long is shown in Figure 6. In this experiment the penetration depth in the sample was smaller than its length. These results are in rough agreement with the predictions of the thin-layer theory. Experiments performed on a sample one-half the previous length gave entirely different results. Many sharp fluctuations in the VSWR with frequency were observed, probably due to the fact that the sample was behaving more as an artificial dielectric than an attenuator. These resonances are highly undesirable and provide additional impetus for going to very thin samples.

In order to obtain an experimental confirmation of the theoretical treatment, samples have been constructed in which the skin depth is large compared to a layer thickness. Germanium is being used in order to allow layer thicknesses which are physically large enough to be readily fabricated. However, it also seems perfectly feasible to construct

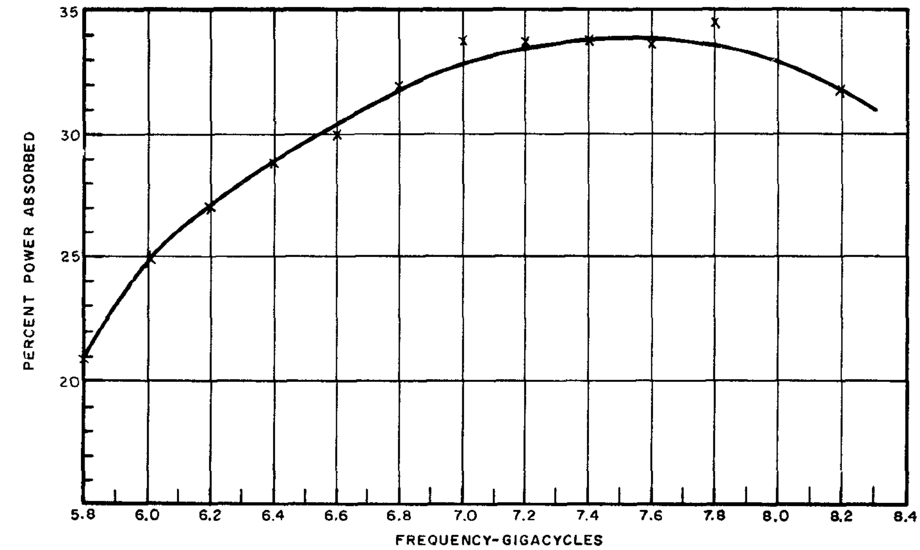

Fig. 6. Percentage of the incident power absorbed by the composite—as determined by experiment.

specimens of thermally deposited boron nitride-graphite in which the layer thicknesses approximate the case analyzed theoretically. Experiments of this sort are in progress.

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1. R. S. Pease, "X-Ray Study of Boron Nitride," Acta Cryst. 5, 356 (1952).