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Temperature Dependent Performance of Coplanar Waveguide (CPW) on Substrates of Various Materials

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TEMPERATURE DEPENDENT PERFORMANCE OF COPLANAR WAVEGUIDE (CPW) ON SUBSTRATES OF VARIOUS MATERIALS

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ABSTRACT

This paper presents the attenuation (α) and effective dielectric constant (ε_{eff}) of Coplanar Waveguide (CPW) transmission lines on high-resistivity silicon and diamond substrates as a function of both temperature and frequency. The technique used to obtain the values for α and ε_{eff} involves the use of a unique cryogenic probe station designed and build by NASA. Attenuation of gold CPW lines on diamond substrates is compared with that of superconducting CPW lines.

INTRODUCTION

Materials such as: gallium arsenide(GaAs), alumina and RT Duroid have traditionally been the substrates of choice for microwave and RF applications because of their low loss. However, there are many applications where these materials are not suitable. Power amplifiers and some optical applications, for instance require substrates capable of removing large amounts of heat. Large scale commercial applications, such as cellular communications require substrates that are low-cost, easy to manufacture and capable of being integrated with digital technology. Although silicon is a very mature technology, it has not been used as a microwave substrate because of its extremely high dielectric loss. It has been shown both theoretically (1) and experimentally (2) that the dielectric losses associated with silicon substrates become negligible when the resistivity of the silicon is at least 2500 Ω-cm. Another substrate that is not typically used for microwave applications is diamond. It wasn't until recently that diamond substrates became commercially available at a reasonable cost. Since diamond has the highest known thermal conductivity of any material (up to 1800 W/m-K available commercially) and ε_r of 5.7, it is an ideal substrate for microwave power applications.

This paper examines the characteristics of Coplanar Waveguide (CPW) transmission lines on high resistivity silicon and diamond substrates. Attenuation (α) and effective dielectric constant (ε_{eff}) are reported as a function of frequency, temperature and CPW geometry.

EXPERIMENTAL RESULTS

CPW lines were fabricated, in gold, on a high-resistivity silicon (HRS) substrate with the following characteristics: $\rho > 30{,}000$ Ω-cm, substrate thickness (d) = 0.2 mm, and gold thickness (t) = 2.5 μm. A set of lines with a characteristic impedance of 50 Ω was fabricated. The strip (S) and slot (W) widths of the set was: S = 50 μm, W = 25 μm. CPW lines were fabricated also, in gold, on a diamond substrate with t = 2.4 μm and d = 0.35 mm. The substrate was grown by Diamonex. Two sets of 50 Ω lines were fabricated with S = 125 μm, W = 25 μm and S = 250 μm, W = 50 μm.

The lines were measured using an Hewlett-Packard 8510C Automatic Network Analyzer and a custom cryogenic probe station. α and ε_{eff} were calculated from the measured S-parameter data using a TRL calibration routine called DEEMBED developed by NIST (3). α and ε_{eff} of the CPW lines at both room temperature and 77 K as a function of frequency are shown in figures 1 and 2, respectively. The attenuation was calculated over the entire range, no interpolation was used. The discontinuities in curves A and D are due to bad data points which were omitted. Attenuation improves with temperature, with a greater improvement seen at higher frequencies. In the case of the HRS substrate, ε_{eff} becomes lower at 77 K and is dependant on the S and W of the CPW line. Where, as in the case of the diamond substrate, there is almost no change in ε_{eff} with temperature or CPW geometry. This is partially due to the fact that the diamond substrate is almost twice as thick as the HRS substrate. The α of the larger geometry CPW line on diamond has extremely low loss at 77 K. Figure 3 shows an expanded version of this curve along with values of α for superconducting CPW lines [4]. This shows that gold CPW lines on diamond at cryogenic temperatures have an α very close to (and in some cases, perhaps better than) those lines made of high-Tc superconducting materials.

CONCLUSIONS

Values for α and ε_{eff} for CPW lines are given as a function of frequency and temperature. The lines were fabricated on both HRS and diamond substrates. This is the first presentation of microwave transmission line data on diamond. ε_{eff} was shown to decrease with temperature for lines on HRS substrates but remains relatively constant for those on diamond substrates. Attenuation improved, for both substrates, as a function of temperature. CPW lines on diamond showed superior performance, comparable with that of superconducting CPW lines.

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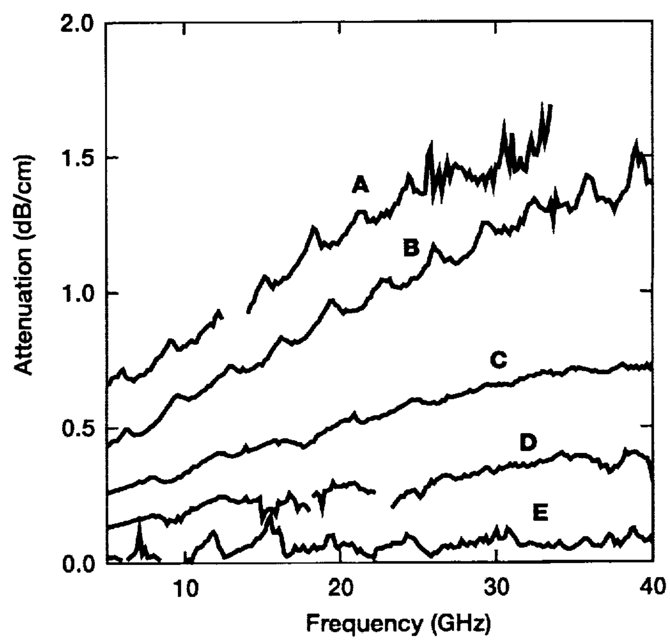

Figure 1.–Attenuation of CPW lines on:
A: High resistivity silicon, S=50 μm, W=25 μm, at 293 K
B: High resistivity silicon, S=50 μm, W=25 μm, at 77 K
C: Diamond, S=125 μm, W=25 μm, at 293 K
D: Diamond, S=125 μm, W=25 μm, at 77 K
E: Diamond, S=250 μm, W=50 μm, at 77 K

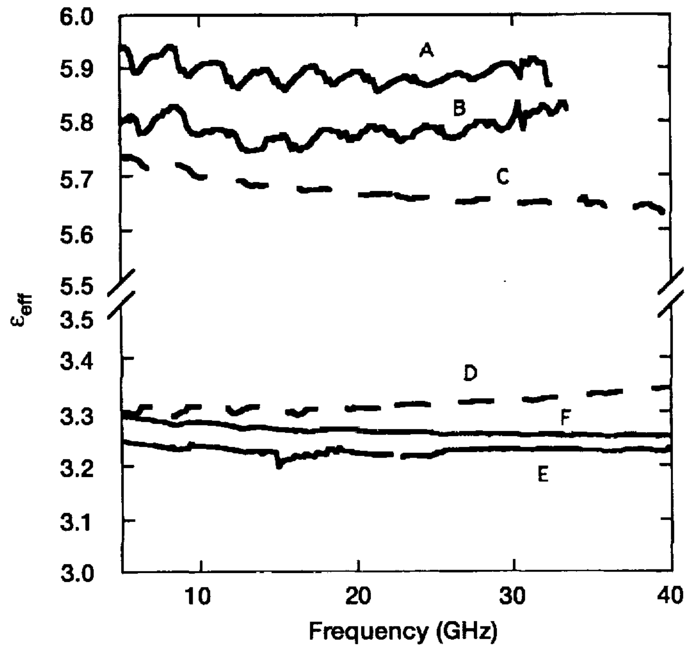

Figure 2.–Effective Dielectric constant of CPW lines on:
A: High resistivity silicon, S=100 μm, W=50 μm, at 77 K
B: High resistivity silicon, S=100 μm, W=50 μm, at 293 K
C: High resistivity silicon, S=50 μm, W=25 μm, at 293 K
D: Diamond, S=250 μm, W=50 μm, at 77 K
E: Diamond, S=250 μm, W=50 μm, at 293 K
F: Diamond, S=125 μm, W=25 μm, at 77 K

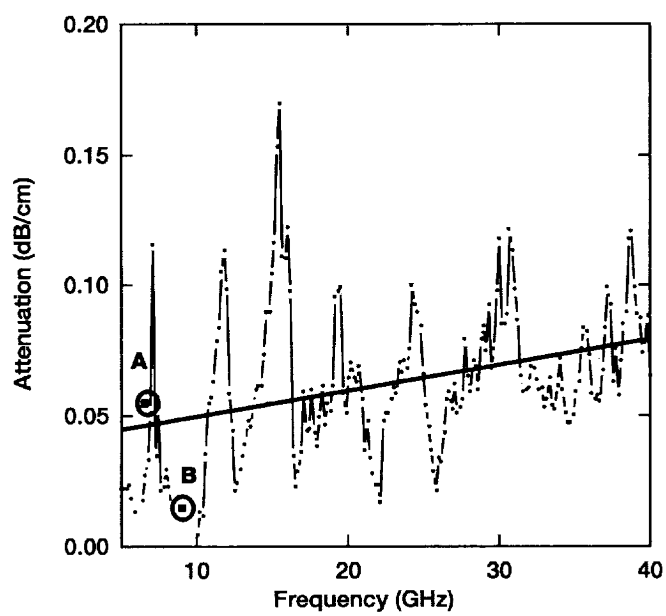

Figure 3.–Attenuation of gold CPW lines on Diamond (S=250 μm, W=50 μm) and $YBa_2Cu_3O_{7-x}$ CPW lines at 77K on A: $LaAlO_3$ and B: MgO.

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