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Abstract:

In multi-layer circuits, the reduction of the dielectric constant in substrate materials is becoming increasingly important, as the heat emission of the circuits increases with an increasing number of layers. One way to achieve a lower dielectric constant is to create porosity in the material. In this project, two types of substrate samples were made with coin-shaped porosity. One had holes of 8.0mm in diameter, and the other had holes of 2.5mm in diameter. The total vacuum area was 250mm^2, or 7.7% of the total area, in either case. It was hoped to discover a relationship between aspect ratio and the effectiveness of dielectric constant reduction. But due to problems with measurements and sample size, trends were not clear, although it could be tentatively stated that the smaller porosity gave less reduction.

Introduction:

The manipulation of a material's dielectric constant through the mixing of different materials has been a subject of research for a long time. For the multi-layer substrate application, a low dielectric constant is desired as a way of increasing thermal conductivity. The effectiveness of mixing porosity with material on dielectric constant reduction was studied in this project, as well as the impact aspect ratio has on the reduction.

Procedure:

1. Punch out 7 circles (diameter=64.4mm) of the dielectric tape using a cutter and a hydraulic press.

2. Punch out circles (diameter=8.0mm or diameter=2.5mm) in a regular, radially distributed pattern on 3 of these circles using brass tubings.

3. The 7 layers of tape are stacked together, alternating the ones with holes and the ones without, and are laminated at 70°C and 1000psi for 7min.

4. The laminated tape is placed on a piece of alumina substrate, which is already dusted with a layer of alumina powder, for heat treatment.

5. The heating cycle: 10°C/min to 350°C for 1.5 hr of burnout, 10°C/min to 850°C for 15min of sintering, 10°C/min cooling rate to room temperature.

6. Aluminum foil is glued on the sintered tape using vaseline gel.

7. Capacitance measurements are made at frequencies from 75kHz to 12MHz.

Data Analysis:

The following formula was used to find the dielectric constant:

$K = (t)(C)/(A)(e_o)$,

where K=dielectric constant,

t=thickness of the substrate,

C=Capacitance,

A=area of the substrate,

e_o=permittivity of free space.

The results of the calculations, as well as the collected data, are presented in Table 1. Seven layers of solid tape were sintered in a stack to serve as a standard. Its dielectric constant was found to be 6.2. Out of the six samples with the 8.0mm holes, two had dielectric constants in the range of 4.8 to 4.9, and three had dielectric constants in the range of 7.5 to

8.0. The remaining sample had a short and gave a dielectric constant of 0. One of the 2.5mm samples had a dielectric constant of 4.9, and the other had a dielectric constant of 2.4. All the dielectric constants reported above were taken at 75kHz.

Three of the 8.0mm samples had an increase in dielectric constant, implying either the solid sample gave too low a reading or these measurements were wrong. An actual increase in dielectric constant is ruled out because that violates physical laws. Although the data for the other 8.0mm samples showed a decrease in dielectric constant, within a fairly tight range, it cannot be interpreted as factual either since it was observed in a minority number of cases. A similar problem exists in analyzing the 2.5mm data. Although both showed a reduction, the small sample size makes it impossible to judge the accuracy of the measurement. And the problem is made worse by the spread in the data.

A number of factors could have contributed to errors in the measurements. First of all, very small holes and cracks might have appeared during sintering due to poor thermoexpansion characteristics or poor sintering techniques. Two, the bond between the layers in a substrate might not have been tight. Three, aluminum foil might not be the best contact to use. Lastly, any warping of the tape caused by sintering would have thrown off the capacitance measurements.

Conclusion:

This project was unsuccessful in determining the effect of porosity on dielectric constant and also the aspect ratio effect. The problems were in the small sample size and in poor sample making techniques. Four more 2.5mm samples were made, but because an available furnace could not be found within a few days, the already laminated samples disintegrated. Many more samples would need to be made before any meaningful conclusion can be drawn.

References:

1. Mitoff, S.P. "Properties Calculation for Heterogeneous Systems," Advances in Materials Research, Vol 3, Herbert Herman (editor), Interscience Publishers, New York, 1968.

2. Polder D. and Van Santen J.H. "The Effective Permeability of Mixtures of Solids," Physica XII, No 5, North-Holland, August 1946.

TABLE 1. CAPACITANCE MEASUREMENTS AND DIELECTRIC CONSTANT CALCULATIONS

SAMPLE TYPE	FREQUENCY (HZ)	THICKNESS (MM)	CAPACITANCE (F)	D	DIELECTRIC
LARGE	75000	1.21	1.35043E-10	0.002496	7.50
	150000	1.21	1.34919E-10	0.002367	7.49
	500000	1.21	1.34723E-10	0.002565	7.48
	750000	1.21	1.34667E-10	0.002694	7.48
	1000000	1.21	1.34651E-10	0.002787	7.47
	2000000	1.21	1.34749E-10	0.003473	7.48
	4000000	1.21	1.35496E-10	0.005637	7.52
	8000000	1.21	1.36238E-10	0.042928	7.56
	10000000	1.21	1.37111E-10	0.055731	7.61
	12000000	1.21	1.38044E-10	0.068833	7.66
SMALL	75000	1.2	8.85813E-11	0.003333	4.88
	150000	1.2	8.84925E-11	0.003757	4.87
	500000	1.2	8.8311E-11	0.006813	4.86
	750000	1.2	8.82638E-11	0.008778	4.86
	1000000	1.2	8.82276E-11	0.01072	4.86
	2000000	1.2	8.81887E-11	0.018119	4.86
	4000000	1.2	8.84669E-11	0.032695	4.87
	8000000	1.2	8.8651E-11	0.103837	4.88
	10000000	1.2	8.69593E-11	0.133058	4.79
	12000000	1.2	8.68228E-11	0.146305	4.78
LARGE	75000	1.16	8.96401E-11	0.002294	4.77
	150000	1.16	8.95752E-11	0.001969	4.77
	500000	1.16	8.94637E-11	0.001962	4.76
	750000	1.16	8.94467E-11	0.002001	4.76
	1000000	1.16	8.94406E-11	0.002078	4.76
	2000000	1.16	8.94773E-11	0.00251	4.76
	4000000	1.16	8.9816E-11	0.003364	4.78
	8000000	1.16	8.9917E-11	0.035067	4.79
	10000000	1.16	9.03505E-11	0.044312	4.81
	12000000	1.16	9.08531E-11	0.054061	4.84
SOLID	75000	0.96	1.41783E-10	0.003255	6.24
	150000	0.96	1.41644E-10	0.002753	6.24
	500000	0.96	1.41416E-10	0.002674	6.23
	750000	0.96	1.41361E-10	0.002701	6.23
	1000000	0.96	1.41338E-10	0.002777	6.23
	2000000	0.96	1.41414E-10	0.00327	6.23
	4000000	0.96	1.42061E-10	0.004645	6.26
	8000000	0.96	1.42655E-10	0.037736	6.28
	10000000	0.96	1.43695E-10	0.047874	6.33
	12000000	0.96	1.44908E-10	0.058679	6.38

SAMPLE TYPE	FREQUENCY (HZ)	THICKNESS (MM)	CAPACITANCE (F)	D	DIELECTRIC
SMALL	75000	0.96	5.4473E-11	0.020274	2.40
	150000	0.96	5.43104E-11	0.028381	2.39
	500000	0.96	5.35966E-11	0.06245	2.36
	750000	0.96	5.31919E-11	0.087121	2.34
	1000000	0.96	5.27742E-11	0.109514	2.32
	2000000	0.96	5.07176E-11	0.192738	2.23
	4000000	0.96	4.57819E-11	0.342836	2.02
	8000000	0.96	3.45779E-11	0.632443	1.52
	10000000	0.96	3.01983E-11	0.748172	1.33
	12000000	0.96	2.65758E-11	0.850501	1.17
LARGE	75000	1.75	1.43961E-16	-2.21383	0.00
	150000	1.75	-3.18544E-16	-1.90225	-0.00
	500000	1.75	-8.5475E-17	-19.9073	-0.00
	750000	1.75	-5.4769E-17	-46.4402	-0.00
	1000000	1.75	-1.55561E-16	-21.4519	-0.00
	2000000	1.75	-2.18363E-16	-31.6686	-0.00
	4000000	1.75	-1.54358E-15	-8.87215	-0.00
	8000000	1.75	3.19878E-15	-9.43421	0.00
	10000000	1.75	2.73562E-15	-12.8204	0.00
	12000000	1.75	-6.40647E-18	-6380.92	-0.00
LARGE	75000	1.25	1.33654E-10	0.002477	7.66
	150000	1.25	1.33532E-10	0.002307	7.66
	500000	1.25	1.33336E-10	0.002421	7.65
	750000	1.25	1.33296E-10	0.002481	7.64
	1000000	1.25	1.33269E-10	0.002575	7.64
	2000000	1.25	1.3337E-10	0.003129	7.65
	4000000	1.25	1.34058E-10	0.005	7.69
	8000000	1.25	1.34531E-10	0.040632	7.72
	10000000	1.25	1.35298E-10	0.051739	7.76
	12000000	1.25	1.36192E-10	0.063001	7.81
LARGE	75000	1.3	1.34095E-10	0.003483	8.00
	150000	1.3	1.33954E-10	0.003972	7.99
	500000	1.3	1.33664E-10	0.006751	7.97
	750000	1.3	1.33569E-10	0.008636	7.97
	1000000	1.3	1.33507E-10	0.010386	7.96
	2000000	1.3	1.33439E-10	0.017361	7.96
	4000000	1.3	1.33568E-10	0.034738	7.97
	8000000	1.3	1.33183E-10	0.095064	7.94
	10000000	1.3	1.3358E-10	0.118905	7.97
	12000000	1.3	1.34039E-10	0.143581	7.99

SAMPLE TYPE	FREQUENCY (HZ)	THICKNESS (MM)	CAPACITANC (F)	D	DIELECTRIC
LARGE	75000	1.53	6.96384E-11	0.033625	4.89
	150000	1.53	6.91342E-11	0.047725	4.85
	500000	1.53	6.71676E-11	0.108184	4.71
	750000	1.53	6.57265E-11	0.149249	4.61
	1000000	1.53	6.43896E-11	0.187057	4.52
	2000000	1.53	5.84458E-11	0.325301	4.10
	4000000	1.53	4.63824E-11	0.560263	3.26
	8000000	1.53	2.8626E-11	0.945817	2.01
	10000000	1.53	2.3674E-11	1.07496	1.66
	12000000	1.53	2.019E-11	1.17355	1.42