Concentric In-Plane Method for Thermal Diffusivity Testing

The measurement of thermal diffusivity using the flash-method is based on determining a characteristic time-temperature relationship (thermogram) on one side of a solid, opaque sample following the pulse striking it on the opposite side. The basic analysis, described first by Parker [1] expresses thermal diffusivity, α, in terms of the time it takes for this rear face temperature excursion to reach 50 % of its maximum value, $t_{1/2}$, for a sample of thickness, d:

$$\alpha = 0.1388 \frac{d^2}{t_{1/2}} \tag{1}$$

Other solutions, using different points on the thermogram are very similar in nature to the above, and are equally subject to the same limitations. The experimental limitations become more clear when the equation is rearranged, and $t_{1/2}$ is expressed as multiples of the average width of the energy pulse, nominally 400 μs for the DLF System, and 500 μs for the DXF System. Picking an arbitrary level of minimum 1 % time resolution Equation 1 yields:

$$0.30\alpha \leq d^2 \tag{2}$$

Equation 2 allows to readily determine a minimum sample thickness for a material based on its known (or expected) thermal diffusivity. Thinner samples will begin to introduce errors above the 1% level. For example a material like copper (α~1 cm^2/s) is advisable to have about 0.53 cm thickness. Arguably, with great care and fast data recording, (such as in the Discovery Laser and Xenon Flash Systems), it is possible to measure even 3 mm thick copper with reasonable accuracy. This is, however, rapidly reaching limiting values beyond which a methodology different than the one dimensional through the plane testing has to offer.

One such method was introduced some time ago for testing thin samples of highly conductive materials for cases when the sample could not be made thicker. It was commonly referred to as an "offset" or "in-plane" method, and it is based on depositing the energy on one spot on one surface, and generating the thermogram from information obtained from a spot on the other side, "offset" by a known distance from the first. Undoubtedly this generates a complex heat flow pattern, that gives rise to a variety of possible errors due to leakages, etc. Never-the-less its value was demonstrated by years of use to measure materials like Aluminum Nitride (α~0.8 cm^2/s) ceramic substrates only 0.05 mm thick. The accuracy, however, suffers greatly and 8-10 % error is considered normal. Most of our competitors are using this "offset" form of the in-plane method.

To improve on the accuracy of measuring thin, highly conductive samples, Anter has undertaken the development of an improved method in which the heat flow follows in a fully symmetrical, self guarding circular/cylindrical path (Patent Pending). The pulse is deposited in a ring shaped area and the measurement is made on the opposite side at the center of the ring. This pattern forces the heat flow to penetrate the thickness below the ring and then progress radially in the cylindrical volume of material toward the center. Due to the quasi focusing of the heat wave on the center point, the signal is made stronger than it would be in a linear heat path. The heat flow away from the outer perimeter of the ring acts as a "guard" and diminishes outside effects area of interest. As a result, the performance of the

"concentric in-plane" solution is demonstrably superior to the earlier, linear "offset" methods.

Experimental proof of this improved performance is presented below. Three samples were fabricated from the same block of aluminum alloy, having thicknesses of 3.8 mm, 0.72 mm, and 0.33 mm. The thick sample (A) was tested in the standard, straight through mode, while the two thin ones (B and C) with the in-plane offset method. If the analytical solution for the **"concentric in-plane"** method is valid, the results should be essentially identical.

The actual test data listed below proves this to be true.

Sample	**Thermal Diffusivity (cm^2/s)**				Spread
	Test 1	Test 2	Test 3	Average	(%)
A	0.778	0.751	0.759	0.763	± 1.8
B	0.827	0.783	0.799	0.803	± 2.7
C	0.807	0.770	0.773	0.783	± 2.4

The standard deviation of the mean for the entire group is 0.8 %, which indicates that the **concentric in-plane method produces excellent results, reliably, even for very thin, highly conductive samples.**

References

Parker, W. J., R. J. Jenkins, C. P. Butter, and G. L. Abbott, "Flash Method of Determining Thermal Diffusivity, Heat Capacity and Thermal Conductivity", *J. Appl. Phys.* **32**, p. 1679 (1961).

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