Chapter 3

Thermal characterization of ceramic tapes

Abstract

Thermal characterization of ceramic tapes is presented in this chapter. The evaluation is carried out using photoacoustic technique. Transmission mode geometry is employed for the measurement of thermal diffusivity and reflection mode geometry is used for the measurement of thermal effusivity. In both these geometries, same open photoacoustic cell is used. From the measured values of thermal diffusivity and thermal effusivity, thermal conductivity value has also been evaluated. Investigations carried out on seven different materials and the results obtained are presented.
3.1. Introduction

During the last decade, several methods have been developed for the non-destructive characterization of thermal, optical and structural properties of materials (1-8). The laser induced photoacoustic (PA) method has gained more popularity due to its simple, elegant experimental scheme as well as due to its versatility in employing different configurations to measure the required thermo-physical parameters with great accuracy (9-11). The principle of the effect is that a sample in a closed cell illuminated by modulated light at audio frequencies produces an acoustic signal.

Photoacoustic technique has been made use of by many scientists for the measurement of thermal parameters of thin films and solid samples (12-21). In the heat transmission configuration of PA cell geometry, when the sample is illuminated with the chopped light beam, heat oscillations generated at the illuminated surface, facing the ambient, propagate through the sample to the sample-air boundary in the microphone chamber of the cell. Pressure oscillations of the same frequency are induced in the air chamber by the temperature variations at the surface interface between the sample and the air and a microphone can detect them. The photoacoustic signals obtained have a certain phase shift relative to the signal detected in the case of reflection geometry. Since the phase shift of the signal does not depend on the optical properties of the sample, it is simpler to extract information on the thermal diffusivity from the experimental results. Phase measurements are most suitable for determining the thermal parameters of the material.

Ceramics are considered to be one of the most suitable components for the fabrication of many of the devices used in electronic and optoelectronic
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industry. In the case of ceramics, thermal accumulation causes thermally induced stresses in the sample, which in turn causes failure and deterioration in ceramic-based devices. Since ceramic tapes are used for microelectronic device fabrication, a thorough knowledge of the thermal parameters is essential.

3.2. Ceramics

Ceramics, one of the three major material families, are crystalline compounds of metallic and nonmetallic elements. The ceramic family is large and varied, and includes such materials as refractories, glass, brick, cement and plaster, abrasives, ferroelectrics, ferrites, dielectric insulators etc (22, 23). Even though ceramics are crystalline materials like metals, they have little or essentially no electrical conductivity at room temperature because of fewer free electrons. They have high stability and, on an average, higher melting points and greater chemical resistance than metals and organic materials. These materials typically exhibit excellent corrosion resistance, high hardness, good wear resistance and low thermal conductivity. Ceramic materials find applications in electronics and optical hardware. They are used as substrates for fiber optic waveguides in integrated optics and for the manufacture of components in microelectronics.

3.2.1. Ceramic processing

Ceramic processing is the sequence of operations that purposely and systematically change the chemical and physical aspects of the structure. The processing commonly begins with one or more ceramic materials, liquids, and special additives called processing aids (24). The forming technique used will
depend on the consistency (slurry, paste, plastic body or granular material) of the system and will produce a particular un-fired shape with a particular composition and microstructure. The finished material is then commonly heat-treated to produce a sintered microstructure. The sintered product may have a single component or a multicomponent composite structure.

In processing ceramic materials, several processing additives must be incorporated in a batch to produce the flow behavior and properties requisite for forming. Although most of these substances are added in relatively small amounts and some may be eliminated at a later stage of processing and do not appear in the final product, they are essential materials for processing. Polymer molecules and coagulated colloidal particles that are absorbed and bridge between ceramic particles may provide inter-particle flocculation, and are commonly called flocculants or binders. In condensed systems, such as cast bodies and unfired ceramic coatings, the binder may improve the plasticity green strength. Different types of binders are needed for different processes. In tape casting it is necessary for the binder to be a film former as it comes out of solution. Decomposition of the binder during firing commonly produces gas and pores, which are eliminated during sintering to obtain dense ceramic. In addition to the binders, a plasticizer is also added to modify the viscoelastic properties of a condensed binder-phase film on the particles. Binders used in ceramic processing must be plasticized to produce a moldable composition. Casting processes are used to produce a self-supporting shape called a cast from specially formulated slurry. Tape casting process is employed for the preparation of thin ceramic tiles that are used in the fabrication of microelectronic components.
3.2.2. Tape casting

Doctor-blade processing or tape casting is a specialized method of producing thin, flat uniform strip, which can subsequently be cut into rectangular tiles. This process is a low cost process for the manufacture of large areas of thin ceramic sheets of controlled thickness and high quality (25-28). In this process inorganic powders are mixed with a solvent and dispersant in a ball mill. A binder and plasticizer are added to the suspension in a second milling step. The homogeneous, well-dispersed and concentrated slurry is degassed and spread on a flat moving carrier surface using the doctor blade process. A thin sheet of high uniformity is formed. The solvents are evaporated leaving the dried tape with sufficient strength and flexibility to be cut to the proper shape.

The thickness of the tape is a function of the height of the blade, the viscosity of the slurry, the speed of the carrier film and the drying shrinkage. The casting speed is dependent on the thickness of the tape, the evaporation rate and the length of the machine, all of which control the drying time. In the first stage of the firing process the binder and other organic additives are burned out carefully and the resulting inorganic structure is sintered at higher temperatures to a dense thin ceramic product with the desired properties. Green sheets can be laminated to create multilayer systems that are transformed to a monolithic structure by firing. The method is used almost exclusively for the production of thin electronic substrates where the control of surface finish and flatness is of overriding importance (29, 30). These include multilayer ceramic electronic packaging, multiyear titanate capacitors, piezoelectric devices, thick and thin insulators, ferrite memories and catalyst supports. In producing
3. Electronic packaging, metal circuit patterns and film resistors are commonly printed on the green sheet and co-fired.

3.3 Significance of thermal parameters

3.3.1 Thermal diffusivity

Centuries before, Jean Fourier (1768-1830) derived a basic law defining the propagation of heat in a one-dimensional homogeneous solid as (31-33)

$$\frac{\partial Q}{\partial t} = -kA \frac{\partial T}{\partial x}$$

(1)

The above equation is known as Fourier equation. Equation (1) implies that the quantity of heat $dQ$ conducted in the $x$-direction of a uniform solid in time $dt$ is equal to the product of the conducting area $A$ normal to the flow path, the temperature gradient $dT/dx$ along this path, and the thermal conductivity $k$ of the conducting material. Formal definition of thermal diffusivity arises when deriving an expression for a transient temperature field in a conducting solid from the Fourier equation. The equation describing the temperature field in a homogeneous, linear conducting solid with no internal heat source is,

$$\nabla^2 T = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

(2)

where the thermal diffusivity $\alpha$ is given by

$$\alpha = \frac{k}{\rho C}$$

(3)
where $k$ is the thermal conductivity, $\rho$ is the density and $C$ is the specific heat capacity of the material. The thermal diffusivity $\alpha$ is usually expressed in m$^2$/s. Thermal diffusivity is thus an important thermo physical parameter, which essentially determines the diffusion of heat through a sample. The inverse of thermal diffusivity is a measure of time required to establish thermal equilibrium in a system for which a transient temperature change has occurred (34, 35).

3.3.2. Thermal effusivity

Another important and unique thermal parameter, thermal effusivity, measures the thermal impedance of the material. It is the ability of the sample to exchange heat with the environment and hence it is an important parameter for surface heating and cooling processes. The major difference between thermal diffusivity and thermal effusivity is that diffusivity is a bulk property of the sample whereas the effusivity is a surface property. The thermal effusivity is defined as $e_s = \sqrt{k\rho C}$ with dimension W s$^{1/2}$ cm$^{-2}$ K$^{-1}$, where $k$ is the thermal conductivity, $\rho$ is the density and $C$ is the specific heat capacity. Knowing the values of thermal diffusivity ($\alpha$) and thermal effusivity, thermal conductivity ($k$) value can be evaluated. The feasibility of photoacoustic technique for the simultaneous measurement of thermal conductivity and heat capacity has already been established (36). Thermal effusivity value of ceramic tapes has great importance when they are used for microelectronic device fabrication or used as thermal barriers in integrated optics.
3.4. Theoretical background

3.4.1. Thermal diffusivity measurement

The heat transmission configuration is depicted in figure 1. For an optically opaque solid, the entire light is absorbed by the sample at x = 0 and the periodic heat is generated at the same place. Assuming that the heat flow into the air (ambient) in contact with the front surface of the solid is negligibly small, the thermal waves generated at x = 0 will penetrate through the sample to its rear surface. The heat thus reaching the sample-air interface at x = -l_s will get attenuated after traveling a very small distance called the first thermal diffusion length in air. Thermal diffusion length is given by $\mu = \left( \frac{2\alpha}{\omega} \right)^{1/2}$, where $\alpha$ and $\omega$ are the thermal diffusivity of air and modulation frequency of the incident light respectively. Consequently, this periodic heating process arising as a result of the periodic absorption of light at the interface at x = 0 results in an acoustic piston effect in the air column in between the sample and the microphone.

According to the one-dimensional heat flow model of Rosencwaig and Gersho, for the arrangement schematically shown in figure 1, the pressure fluctuation in the air inside the chamber is given by (37-40),

$$Q = \frac{\gamma P_0 I_0 (\alpha_c \alpha_s)^{1/2}}{(2\pi) l_s T_0 k_s f \sinh (l_s \sigma_s)} e^{j(\omega t - \pi/2)}$$

where $\gamma$ is the ratio of specific heat capacities of air, $P_0$ and $T_0$ are the ambient pressure and temperature, $I_0$ is the radiation intensity, $f$ is the modulation frequency, and $l_s$, $k_s$, and $\alpha_s$ are the length, thermal conductivity and the thermal
diffusivity of the medium. \( i = g \) refers to the air and \( i = s \) refers to the solid sample. Also \( \sigma_i = (1 + j) \alpha_i \) where \( \alpha_i = (\pi f / \alpha_i)^{1/2} \) is the thermal diffusion coefficient of the medium \( i \). In arriving at the above expression it is assumed that the sample is optically opaque.

![Figure 1. Schematic representation of the open cell geometry](image)

For thermally thin sample (i.e. \( l_s a_s << 1 \)), the expression for \( Q \) reduces to

\[
Q = \frac{\mathcal{N}_0 l_0 \alpha g \frac{1}{2} \alpha_s e^{j(\omega t - 3\pi/4)}}{(2\pi)^{3/2} T_0 l_g l_s k_s f^{3/2}}
\]

Above expression implies that the PA signal amplitude from a thermally thin sample under the heat transmission configuration varies as \( f^{3/2} \) and the phase is insensitive to the variation in the modulation frequency.

When the sample is thermally thick (i.e. \( l_s a_s >> 1 \)), the expression for \( Q \) becomes
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\[ Q = \frac{\gamma P_0 I_0 (\alpha - \alpha_s)^{1/2} \exp \left[ -l_s (\pi f / \alpha_s)^{1/2} \right]}{\pi T_0 \gamma g_s k_s f} e^{j(\omega t - \pi/2 - l_s \alpha_s)} \]

The amplitude of the PA signal decreases with the modulation frequency as 

\[ R = \left( \frac{1}{\sqrt{f}} \right) \exp \left( -b \sqrt{f} \right) \] with \( b = l_s \sqrt{\pi/\alpha_s} \), while the phase \( \phi \) decreases linearly with \( b \sqrt{f} \). Hence, the thermal diffusivity \( \alpha_s \) can be evaluated either from the amplitude data or from the phase data, provided the sample is optically opaque and thermally thick in the frequency region of interest. Though the phase and amplitude of the PA signal contains clear signature of the thermal properties of the specimen, phase data is more reliable for open cell configuration since the amplitude data depends on many external parameters such as sample surface quality and detector response at different wavelengths. Experimental results reported here are derived from the phase data.

3.4.2 Thermal effusivity measurement.

According to Rosencwaig and Gersho theory (37,38) for the heat reflection configuration, when the sample is kept in contact with a thermally thin absorbing layer, the acoustic pressure in the microphone chamber is given by the equation,

\[ Q_1 = \frac{\gamma P_0 I_0 (\alpha - \alpha_s)^{1/2}}{(2\pi)l_g T_0 k_s f} e^{j(\omega t - \pi/2)} \]
where $k$, and $\alpha_i$ are the thermal conductivity and thermal diffusivity. $i = s$ corresponds to the sample, $i = 0$ corresponds to the absorbing layer and $i = g$ corresponds to the air in the microphone chamber. $\gamma$ is the ratio of specific heats for air, $P_o$ is the pressure, $I_0$ is the incident intensity, $l_g$ is the length of the gas column in the cavity, $T_0$ is the temperature of the gas inside the chamber. Here, $\omega = 2\pi f$ and $b = \left(\frac{k_s \sigma_s}{k_0 \sigma_0}\right)$. The acoustic signal varies as $\frac{1}{f}$ and is proportional to the ratio $\frac{\sqrt{\alpha_s}}{k_s}$, the inverse of the thermal effusivity of the sample.

In the absence of the sample (i.e., only the absorbing layer is present) the pressure fluctuation inside the cavity is given by,

$$\delta P_2 = \frac{n^3 l_0 \alpha g^{1/2}}{(2\pi)^{3/2} \alpha_0 k_0} e^{j(\omega t - 3\pi/4)}$$

The PA signal varies as $f^{-3/2}$ and depends on the ratio $\frac{\alpha_0}{k_0}$.

Now,

$$\frac{\delta Q_1}{\delta Q_2} \propto \frac{l_0 k_0 \sqrt{\alpha_s}}{\alpha_0 k_s} f^{1/2}$$

Thermal effusivity of the sample ($\epsilon_s = k_s/\sqrt{\alpha_s}$) can be evaluated by measuring the signal amplitude as a function of modulation frequency from the
absorbing layer-sample composite and that from the absorbing layer alone, provided the thickness, density and specific heat capacity of thin absorbing layer are known.

3.5 Experimental details

3.5.1 Experimental setup

The experimental setup consists of an Argon ion laser (Liconix 5000 series), a mechanical chopper (Stanford Research Systems SR540) and the open photoacoustic cell. The schematic of the experimental set-up is given in figure 2. The open photoacoustic cell (figure 3) has provisions for both rear side and front side illumination.

The intensity modulated optical radiation from the Argon ion laser is allowed to fall on the sample kept inside the open photoacoustic cell. The PA signal generated in the cell is detected using a sensitive electret microphone (BT 1834) and is amplified using a lock-in amplifier. The phase and amplitude of the PA signal are recorded using a digital lock-in amplifier SR 830. Samples in the form of free-standing ceramic tapes are pasted on aluminium foils using thermal paste to avoid mechanical vibrations of the samples due to its periodic dilation (drum effect) during irradiation (41).
3.5.2 Open photoacoustic cell

The major building block of the cell is an acrylic (perspex) disk of thickness 1cm and diameter 5.5cm. The acoustic chamber is made by drilling a bore of diameter 3mm across the thickness at the centre of the disk. One end of this cylindrical hole is closed with an optical quality glass slide of thickness 1.4mm and the other end is kept open. Another fine bore of diameter 1.5mm pierced at the middle of the main chamber and perpendicular to it serves as the acoustic coupler between the main chamber and the microphone. At a distance of 8mm from the main chamber the microphone is firmly glued to the orifice of the side tube. Shielded wires are used to take the electrical connections directly from the microphone. Entire system is then fixed inside a cylindrical hollow block of aluminium, leaving half the thickness of the acrylic disk outside the aluminium holder. Solid samples having uniform surface quality can be easily stuck at the top of the sample chamber (open end) by using vacuum grease. On
the other hand, if the sample is very thin and requires more tight contact, then another identical acrylic disk with a 3mm hole at the centre can be used to press the sample in between the two disks.

3.5.3 Sample specifications

The investigations are carried out on green ceramic tapes obtained from CMET, Trichur. All the samples have a uniform thickness of 70μm. The green tapes contain a polymer network in which ceramic particles are embedded. Therefore no porosity is expected at green stage. Only after binder (polymer) burns out, porosity will appear. Specifications of the samples are given in table1.
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### Table 1

<table>
<thead>
<tr>
<th></th>
<th>SiC</th>
<th>PMN-PT</th>
<th>PZT</th>
<th>Al₂O₃/ZrO₂</th>
<th>ZrO₂</th>
<th>Barium titanate</th>
<th>Barium titanate</th>
</tr>
</thead>
<tbody>
<tr>
<td>% ceramic</td>
<td>61.65</td>
<td>74.78</td>
<td>77.42</td>
<td>36.41</td>
<td>57.71</td>
<td>66.61</td>
<td>66.63</td>
</tr>
<tr>
<td>% binder (polyvinyl butyral-PVB)</td>
<td>2.57</td>
<td>1.62</td>
<td>1.37</td>
<td>21.5</td>
<td>3.09</td>
<td>2.00</td>
<td>2.45</td>
</tr>
<tr>
<td>% of plasticizer (Phthalates and Glycols)</td>
<td>2.8</td>
<td>2.17</td>
<td>1.78</td>
<td>3.33</td>
<td>4.11</td>
<td>3.18</td>
<td>3.55</td>
</tr>
<tr>
<td>%solvents</td>
<td>32.98</td>
<td>21.43</td>
<td>19.43</td>
<td>38.76</td>
<td>35.09</td>
<td>28.21</td>
<td>27.37</td>
</tr>
</tbody>
</table>

In the case of Al₂O₃/ZrO₂ (Alumina-zirconia) the solvent is water and binder is polyvinyl alcohol (PVA).

3.5.4. Thermal diffusivity measurements

The theory involved in the measurement of thermal diffusivity is given in section 3.3. The rear side illumination or the so-called heat transmission configuration is used for the present investigations. The ceramic tape sample is pasted on thermally thin aluminium foil using a thermal paste and is fixed to the top of the open photoacoustic cell (OPC) using vacuum grease at the edges. The cell is arranged such that the modulated laser beam falls on the aluminium foil. Photoacoustic signal phase is measured as a function of modulation frequency. The same experiment is repeated with aluminium foil alone.
Difference in phase readings of the two observations gives the phase for the sample under investigation corresponding to a modulation frequency.

Figure 4. Cross sectional view of OPC geometry for the measurement of thermal diffusivity

Since the phase of PA signal changes linearly with $b \sqrt{f}$, where $b = l_s \frac{\pi}{\sqrt{\alpha_s}}$, slope of phase difference vs square root of frequency plot gives the value of $'b'$.

Knowing sample thickness $l_s$, thermal diffusivity ($\alpha_s$) is calculated from the slope.
3.5.5. Thermal effusivity measurements

Same ceramic tape samples and the same open photoacoustic cell are used for thermal effusivity measurements. In this investigation the reflection mode geometry is employed. Sample is pasted on to aluminium foil and the sample aluminium foil combination is mounted on the PA cell so that the free surface of the sample faces the ambient. Irradiation is made through the front glass window and thermal waves are generated from the aluminium-gas interface.

Figure 5. Cross sectional view of OPC geometry for the measurement of thermal effusivity
Thermal effusivity is evaluated from the slope of the signal amplitude ratio (ratio of amplitudes corresponding to aluminium foil alone and sample+aluminium foil combination) vs square root of frequency plot.

3.6. Results and discussion

The variation of phase difference in the photoacoustic signal (difference in the phases corresponding to aluminium foil alone and ceramic tape pasted on aluminium foil) as a function of modulation frequency under the heat transmission configuration for the samples under investigation is shown in figures 6 to 12.

Figure 6. Variation of PAS phase difference as a function of modulation frequency for alumina-zirconia sample.
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Figure 7. Variation of PAS phase difference as a function of modulation frequency for zirconia sample.

Figure 8. Variation of PAS phase difference as a function of modulation frequency for Silicon carbide sample.
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Figure 9. Variation of PAS phase difference as a function of modulation frequency for lead zirconate titanate (PZT) sample.

Figure 10. Variation of PAS phase difference as a function of modulation frequency for lead magnesium niobate titanate (PMNPT) sample.
Figure 11. Variation of PAS phase difference as a function of modulation frequency for Barium Titanate sample

Figure 12. Variation of PAS phase difference as a function of modulation frequency for Barium Tin Titanate sample
Thermal diffusivities of the samples are calculated from the slopes of the straight-line graphs and are tabulated in table 2. Literature values (42-47) of the thermal diffusivities of pure ceramics and ceramic films are also included for comparison. Since tape casting is a batch process, there may be changes in the thermal parameters from batch to batch and will depend on the presence of additives and binders, which are added during the tape casting process. Values of thermal parameters of ceramic tapes are not available. However, it is seen from the table that the thermal diffusivity values calculated using the photoacoustic technique are of the same order of magnitude as that of the literature values. It is found that addition of certain materials changes the thermal diffusivity of the compound. Alumina has a higher thermal diffusivity compared to zirconia (~0.1 cm²/s). Thermal diffusivity of alumina-zirconia compound is greater than that corresponding to zirconia. The enhancement in thermal diffusion of the compound sample will be due to the presence of alumina. The same effect has been observed in the case of tin doped barium titanate also. Thermal diffusivity of barium tin titanate is found to be higher than that of barium titanate. The enhancement in thermal diffusivity might be due to the presence of tin in the compound. This shows that ceramic tapes with required intermediate values of thermal parameters can be prepared by mixing appropriate amounts of different materials. Difference in actual value can be attributed to the presence of materials other than ceramics.

Figures 13-19 show the variation of ratio of photoacoustic signal amplitude between sample attached to aluminum foil and aluminum foil alone as a function of modulation frequency. Thermal effusivities are calculated from the slopes of the straight line fits.
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Figure 13. Variation of ratio of PAS amplitudes as a function of modulation frequency for zirconia sample.

Figure 14. Variation of ratio of PAS amplitudes as a function of modulation frequency for Alumina-zirconia sample.
Figure 15. Variation of ratio of PAS amplitude as a function of modulation frequency for Silicon carbide sample

Figure 16. Variation of ratio of PAS amplitudes as a function of modulation frequency for lead zirconate titanate (PZT) sample
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Figure 17. Variation of ratio of PAS amplitude as a function of modulation frequency for lead magnesium niobate titanate (PMNPT)

Figure 18. Variation of ratio of PAS amplitude as a function of modulation frequency for Barium Titanate sample
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Figure 19. Variation of ratio of PAS amplitude as a function of modulation frequency for Barium Tin Titanate sample

Calculated values of thermal diffusivity, thermal effusivity and thermal conductivity values are tabulated in table 2. As a laser operating in the light mode is used for irradiation, the incident power is stable. Uncertainty of $\pm 0.0005$ can be expected in the calculations because of the variations that may occur in tape thickness from the expected value.
## Table 2: Sample Thermal Characterization

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thermal diffusivity of tapes (cm²/s)</th>
<th>Thermal conductivity of tapes (W/cmK)</th>
<th>Effusivity of tapes (W²/1/2/cm²K)</th>
<th>Thermal diffusivity of thin films (literature)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia</td>
<td>0.0044</td>
<td>0.049</td>
<td>0.74</td>
<td>0.002- 0.005</td>
</tr>
<tr>
<td>Alumina-Zirconia</td>
<td>0.055</td>
<td>0.061</td>
<td>0.26</td>
<td>Between 0.1 &amp; 0.002</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>0.076</td>
<td>0.039</td>
<td>0.15</td>
<td>0.08</td>
</tr>
<tr>
<td>Lead Zirconate Titanate(PZT)</td>
<td>0.0078</td>
<td>0.011</td>
<td>0.12</td>
<td>Of the order of 10⁻³</td>
</tr>
<tr>
<td>PMNPT (lead magnesium niobate titanate)</td>
<td>0.029</td>
<td>0.017</td>
<td>0.1</td>
<td>Not available</td>
</tr>
<tr>
<td>Barium Titanate</td>
<td>0.0016</td>
<td>0.00941</td>
<td>0.24</td>
<td>0.0015</td>
</tr>
<tr>
<td>Barium Tin Titanate</td>
<td>0.0066</td>
<td>0.048</td>
<td>0.6</td>
<td>Not available</td>
</tr>
</tbody>
</table>

Table 2
3.7. Conclusions

The present study clearly shows that the photoacoustic technique is an effective tool for the thermal characterization of ceramic samples. Details of investigations carried out on the thermal parameters of seven different ceramic (green) tape samples and the results obtained are presented. Analysis of results shows that the thermal diffusivity values depend on the constituents of the medium. Mixing one ceramic with another changes the effective thermal parameters of the sample. In general, addition of plasticizers and binders is found to change the thermal diffusivity values of ceramic tapes compared to pure thin film samples.

References

25. A. Roosen, Basic requirements for tape casting of ceramic powders.
3. Thermal characterization.

44. National Physical Lab. TPAC News 7
45. Microstructure develop. and thermal parameters (internet)
46. G.E. Young wood et al, Pacific North west national Lab (Internet)