# Determination of thermal conductivity of epoxy resin with metallic load

# Determinação da condutividade térmica de resina epóxi com carga metálica

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**ABSTRACT**
With the increase of technology in the electronics industry, new methods have emerged, resulting in smaller components and higher processing capacity. In contrast, problems related to rate of heat transfer of these components have been increasing and with this reduction in size, the temperature began to be an important variable to be observed in equipment. Normally, performance improvements, such as computers or racks of telephone exchanges, translate directly into greater heat dissipation of electronic devices that make up the device, and consequently, high rates of heat transfer. Thus, the cooling of electronic equipment gained paramount importance as the effect of increased power densities in micro-electronic equipment made available by advances in semiconductor technology. Because of this, whenever we face interesting challenges in finding a technique of removing heat more effectively for these high-tech applications, is one of those challenges, which underpin this research is to determine the properties of the constituent components of a new system cooling is a heat exchanger based on phase change of a fluid inert. There are a few examples: automotive radiator and air conditioning, cooling and optoelectronic LEDs. A heat exchanger is physically designed to enhance and to improve the surface in contact with the cooling fluid around it, like air. Approach air velocity, choice of material and surface treatment are some of the factors that influence the thermal resistance and thermal performance of these components. In this research, the epoxy resin with metallic charge, has lower thermal conductivity than aluminum, for example, however, it does not conduct electricity, getting great importance of electronic devices nowadays.

**Keywords**: conductivity, experimental, photoacoustic, emissivity, epoxy resin.

**RESUMO**
Com o aumento da tecnologia na indústria eletrônica, novos métodos surgiram, resultando em componentes menores e maior capacidade de processamento. Em contrapartida, os problemas relacionados à taxa de transferência de calor desses componentes vêm aumentando e com essa redução no tamanho, a temperatura passou a ser uma variável importante a ser observada nos equipamentos. Normalmente, melhorias de desempenho, como computadores ou racks de centrais telefônicas, se traduzem diretamente em maior dissipação de calor dos dispositivos eletrônicos que compõem o dispositivo e, consequentemente, altas taxas de transferência de calor. Dessa forma, o resfriamento de equipamentos eletrônicos ganhou importância primordial como efeito do aumento das densidades de potência em equipamentos microeletrônicos disponibilizados pelos avanços na tecnologia de semicondutores. Por conta disso, sempre que nos deparamos com desafios interessantes em encontrar uma técnica de remoção de calor de forma mais eficaz para essas aplicações de alta tecnologia, é um desses desafios, que sustentam esta pesquisa é determinar as propriedades dos componentes constituintes de um novo sistema de resfriamento é um trocador de calor com base na mudança de fase de um fluido inerte. Existem alguns exemplos: radiador automotivo e ar condicionado, refrigeração e LEDs optoeletrônicos. Um trocador de calor é fisicamente projetado para aumentar e melhorar a superfície de contato com o fluido de resfriamento ao seu redor, como o ar. A velocidade de aproximação do ar, a escolha do material e o tratamento da superfície são alguns dos fatores que influenciam a resistência térmica e o desempenho térmico desses componentes. Nesta pesquisa, a resina epóxi com carga metálica, possui menor condutividade térmica que o alumínio, por exemplo, porém, não conduz eletricidade, adquirindo grande importância dos dispositivos eletrônicos nos dias de hoje.

**Palavras-chave:** condutividade, experimental, fotoacústica, emissividade, resina epóxi.

## 1 INTRODUCTION

With the growth of the electronics industry, along with the field of telecommunications, new technologies have emerged through the requirement of customers and struggle to stay in the market. Since then, these industries started looking for smaller components and better and better, generating more phone functions in a rack, for example. With the increase in technology, the components are decreasing and at the same time, the problems increase. The temperature began to be an important variable to be observed in electronic equipment, because with the reduction of the components there was an increase in the rate of heat dissipation. Normally, performance improvements, such as computers or backstage of telephone exchanges, translate directly into greater heat dissipation of electronic devices that make up the equipment, and consequently, high rates of heat transfer.

Thus, the cooling of electronic equipment has gained considerable importance as a result of increased power densities in micro-electronic equipment made available by advances in semiconductor technology (Bar-Cohen, 1992).

Because of this, we always come across interesting challenges in finding a technique of removing heat more effectively for these high-tech applications.

One of these challenges, which is based this research consisted in determining the properties of the constituent component of a new cooling system, which is a latent heat exchanger of an inert fluid.

Examples of heat exchangers are: air conditioning and radiator inside a vehicle, cooling optoelectronic, electronic devices such as high-power lasers and light emitting diodes (LEDs).

A heat exchanger is physically designed to increase and improve the surface in contact with the cooling fluid around it, like air. Approach air velocity, choice of material and surface treatment are some of the factors that influence the thermal resistance and thermal performance of these components.

In this research, the heat exchanger was composed of an epoxy resin with metal loading, which has considerable thermal conductivity, however, does not conduct electricity, so far, a fact unprecedented in the market.

The fact that the resin is an innovative material made this research much more motivating, knowing also the great importance of electronic devices today, and the many applications that have cooling techniques.

## 2 OBJECTIVE

Determining the thermal conductivity of an epoxy resin with metallic filler by the method of photoacoustic effect.

## 3 THE MATERIALS AND EXPERIMENTAL TECHNIQUE

To perform the measurements by photoacoustic effect, we used the method of open cell. The following materials were used in this project:

- Pre microphone amplifier type Tube Ultragain MIC100 Behringer;
- Electret microphone;
- Power Laser - He-Ne 8 mW of power;
- Amplifier tuned type Lock-in, (SRS 530);
- Mechanical light modulator "Chopper" Thorlabs;
- Photoacoustic cell configuration type open (OPC);
- Tektronix Oscilloscope.

In addition, we used a resin from a polyester adhesive that had as constituents, polyacids, drying agents, glycols and solvents, with it, the base resin for the manufacture of epoxy resin to metal loading.

The preparation of the resin was made towards a viable production scale if it were implemented in the industry. After the resin is mixed with the metal charge, the compound was subjected to intense agitation to ensure sample homogeneity. Furthermore, to ensure the concentration and composition of the metallic charge of the resin before performing the measurement tests, it was subjected to metallographic analysis (Fig. 6) by means of optical microscopes with viewing screens graduated in the Laboratory of microstructural characterization of block M1 of the Department of Mechanical Engineering.

Initially was used a charge of metallic copper powder with a density of 3g/cm$^3$ and then with a density of 2.7 g/cm$^3$. This material was provided without cost, as material for study and research by the company Metalpó Indústria e Comércio Ltda.

The determination of thermal properties of the resin compositions was carried out similar to the metallic charge and the resin and two different grain sizes (different thickness) of the metal used and the procedure carried out in non-controlled temperature of approximately 30 ° C.

Now, as a method to obtain the thermal properties of the sample, was used the photoacoustic, because the photothermal techniques, in particular the photoacoustic have shown to be extremely useful as methods of analysis of virtually any type of material with a very characteristic important: they are non-destructive techniques.

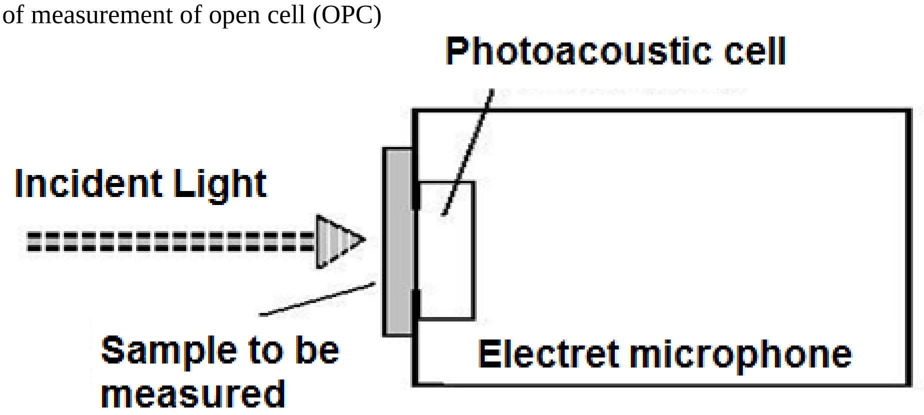
They bring together a large group of experimental methods based on the conversion of light energy into heat. In this technique, the light energy falls transiently or periodically on the investigated material (epoxy resin with metal loading), being part of this energy, absorbed and partly transformed into heat as a result of processes without excitation of atomic energy levels and molecular .

The temperature of the material varies with the same frequency as the incident radiation, leading to variation in parameters such as sample refractive index, thermal conductivity and thermal diffusivity. The diffusivity (thermal conductivity as well) is a parameter that gives a measure of how heat propagates into the sample and has a unique value for each material, hence its importance (Olenka, 2003).

From the absorption of radiation by the material, a specific sensor detects the change in the behavior of this material, where many different effects can occur in the sample or in their neighborhoods.

In the different methods of measuring the properties by the photoacoustic effect, the experiment can be prepared to obtain a thermal property: $\alpha_s$, thermal diffusivity, k, the thermal conductivity and heat capacity per unit volume $\rho C_p$. For review one of these properties is considered that there is a dependence of photoacoustic signal with the modulation frequency of the light falling on the sample. In the method of open, cell can be monitored the dependence when the sample passes from a thermally thin regime to a thermally thick. In Figure 1 we have a scheme of this method.

Figure1. Method of measurement of open cell (OPC)




The theory of the photoacoustic effect provides the dependence of the signal amplitude and its phase depending on the modulation frequency. Insofar as the modulation frequency is increased the thermal diffusion length (μ) decreases, because of this, the sample passes from thermally thin regime ($\mu_s >> l_s$) to a thermally thick ($\mu_s << l_s$) and $l_s$ is the thickness of the sample (Olenka, 2003). We can observe that the dependence on thermally thin regime ($\mu_s >> l_s$) for optically opaque samples, the amplitude of the photoacoustic signal has the functional dependency on frequency in order:

$$S \propto f^{\left(-\frac{3}{2}\right)} \quad (1)$$

For a thermally thick sample the amplitude of the photoacoustic signal has a functional dependence on frequency in order:

$$S \propto \frac{1}{f} e^{-b\sqrt{f}} \quad (2)$$

with:

$$b = l_s \left(\frac{\pi}{\alpha_s}\right)^{\frac{1}{2}} \quad (3)$$

Of parameter *b* and knowing the thickness of the sample $l_s$ we evaluate the thermal diffusivity of the material. In dependence of the transition between these two regimes, have a value at which the thermal diffusion length equals the thickness of the sample $\mu_s = l_s$. This occurs at a certain frequency. In this case the parameter of thermal diffusivity can be evaluated in light of this frequency $f_c$ at the transition point by the relation:

$$\alpha_s = \pi f_c \, l_s{}^2 \quad (4)$$

## 4 METHOD OF MEASURING

For this method a sample is considered optically opaque wherein the periodic heating by light incident on the sample is performed in the sample-air interface resulting acoustic effect piston. The sample was placed directly on the microphone. To ensure the coupling microphone-sample, was passed up a thin layer of silicone grease on the surface of the microphone, which in addition to helping the coupling function is to isolate the chamber air photoacoustic that the external environment. Before the start of the experiments, some standard procedures in the measurement equipment were taken. First, the set light of He-Ne laser for focussing it at right angles on the sample surface towards the bore and the microphone, as can be seen in Fig. 2 and Fig. 3. Furthermore, it is necessary that the sample surface has low reflectance, as this measurement process is by absorption of light and heat generation, resulting that the larger the absorption, the greater the amplitude of the photoacoustic signal. Because the surface material has a high degree of reflectivity (very common in metals), it was necessary the deposition of a thin layer of black ink. The adopted to carry out the measurements, all samples had their surfaces on the side of excitation, covered by a thin layer of black ink for better heat absorption.

Figure 2. Experimental apparatus off.

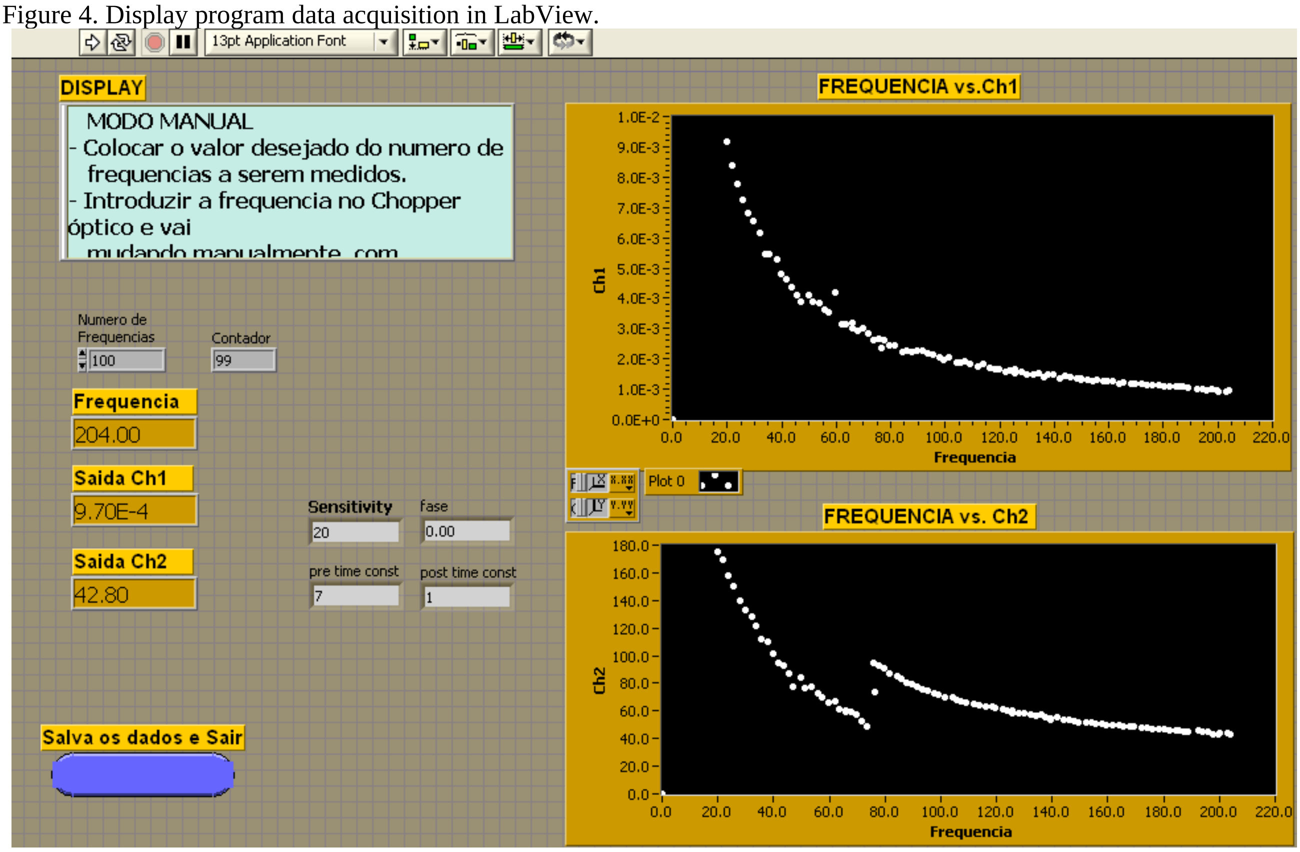
Figure 3. Experimental apparatus on.

When starting the measurements, was waited for the stabilization of the amplitude and phase of the photoacoustic signal. The phase of the photoacoustic signal was then adjusted in the lock-in to 180 °. This is done so that there is no phase inversion (-180 ° to 180 °) in the course of action and that a standardization in measurements can be made.

Subsequently set up a frequency modulation initial 20Hz from which we made a sweep from 20Hz to 300Hz. After, the filters were activated until the frequency of 60Hz and then reactivated at a frequency of 120Hz, which are the first two harmonics of the frequency range analyzed.

To perform these measurements, was developed an program for data acquisition in LabView ® platform as shown in Fig. 4. With this program, as there is a variation in the frequency manually, the program stores the generated points and automatically generates a curve of the photoacoustic signal by frequency modulation.

Figure 4. Display program data acquisition in LabView.




Finally, after detection and storage of components of intensity and phase of the photoacoustic signal in their respective frequencies, these data were analyzed (Prandel, 2009).

## 5 RESULTS AND DISCUSSION

First, to check the response of the microphone was carried out a scan on a sample of carbon paper, which is known and depends on the inverse of the modulation frequency. The result was satisfactory. After this check, was given start measurements on the first sample that was a resin which had copper powder density 3g/cm$^3$.

Then with the calibrated microphone, can be traced the graph of intensity's logarithm against the frequency's logarithm, allowing indicate the frequency region in which there is a predominance of diffusion behavior thermally thick. Applying the logarithm function in both members of Eq. (5) is obtained from the linear Eq. (6) for adjusting the amplitude and phase of the photoacoustic signal:

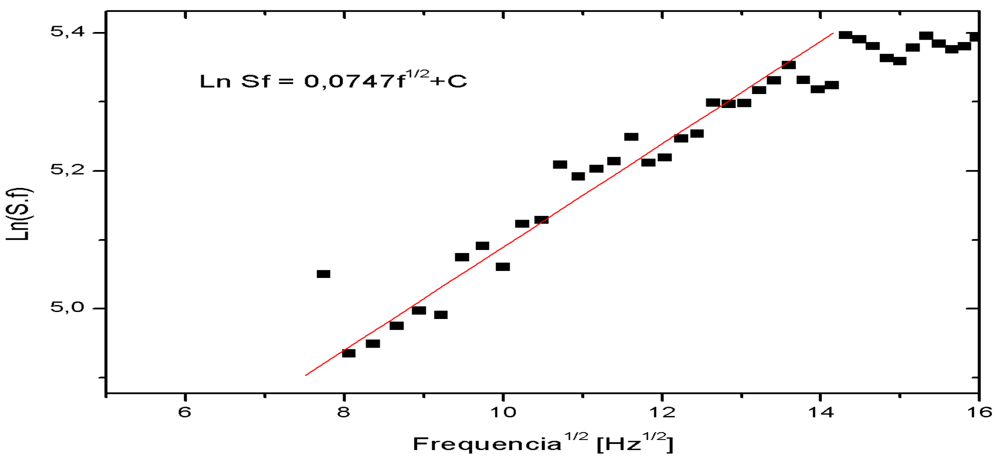
$$S.f = e^{b\sqrt{f}} + C \quad (5)$$

$$Ln(S.f) = b\sqrt{f} + C \quad (6)$$

In order that the coefficients "C" (constant) and "b" were obtained in the experimental graph of Ln(S.f) versus $f^{\frac{1}{2}}$, and S is the signal and f the frequency (Fig. 5). Knowing the sample thickness ($l_s$), the thermal diffusivity of the sample $\alpha_s$ was obtained by the equation (7):

$$b = l_s\left(\frac{\pi}{\alpha_s}\right)^{\frac{1}{2}} \quad (7)$$

Figure 5. Ln (S.f) versus $f^{\frac{1}{2}}$ for the first sample.



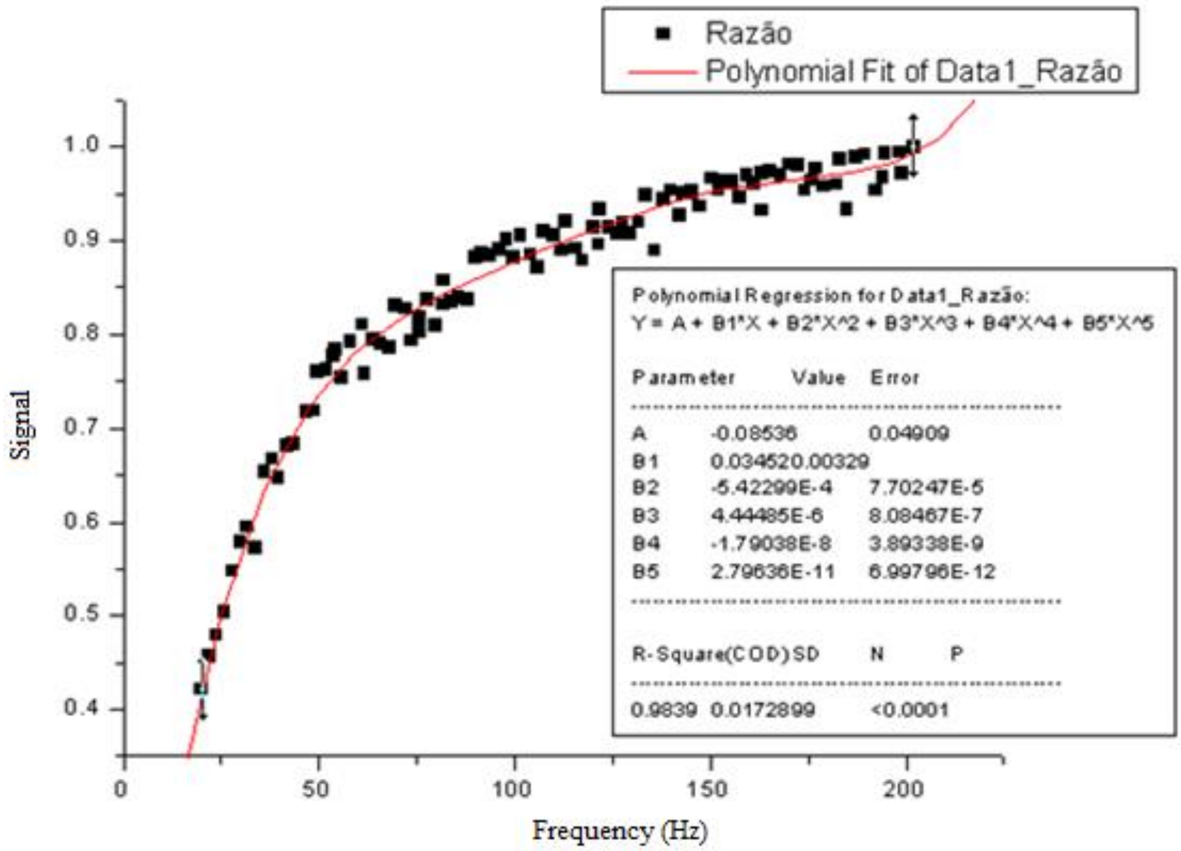
Thus, the values of the thickness of the sample ($l_s$ = 0.3 x$10^{-3}$ m), and the b value found from the graph, there was obtained a value of diffusivity equal to 0.5 x$10^{-4}$ $m^2$/s. With this value according to Eq. (8) was obtained value of thermal conductivity for the sample:

$$k = \rho\alpha C_p \tag{8}$$

The value of k = 69,75$\frac{W}{mK}$ was obtained for a value of $\rho C_p$ equal to 1395x103J/$m^3$k obtained experimentally according to the hot wire (Fukushima, 2011).

For the second sample that was a resin which had copper powder density 2.73 g/$cm^3$, the initial calibration was carried into the microphone using an aluminum sample of the same dimensions of the sample of resin (0.2 x $10^{-3}$m). The calibration curve is shown in Fig. 6.

Figure 6. Calibration curve of the microphone for the sample of aluminum.

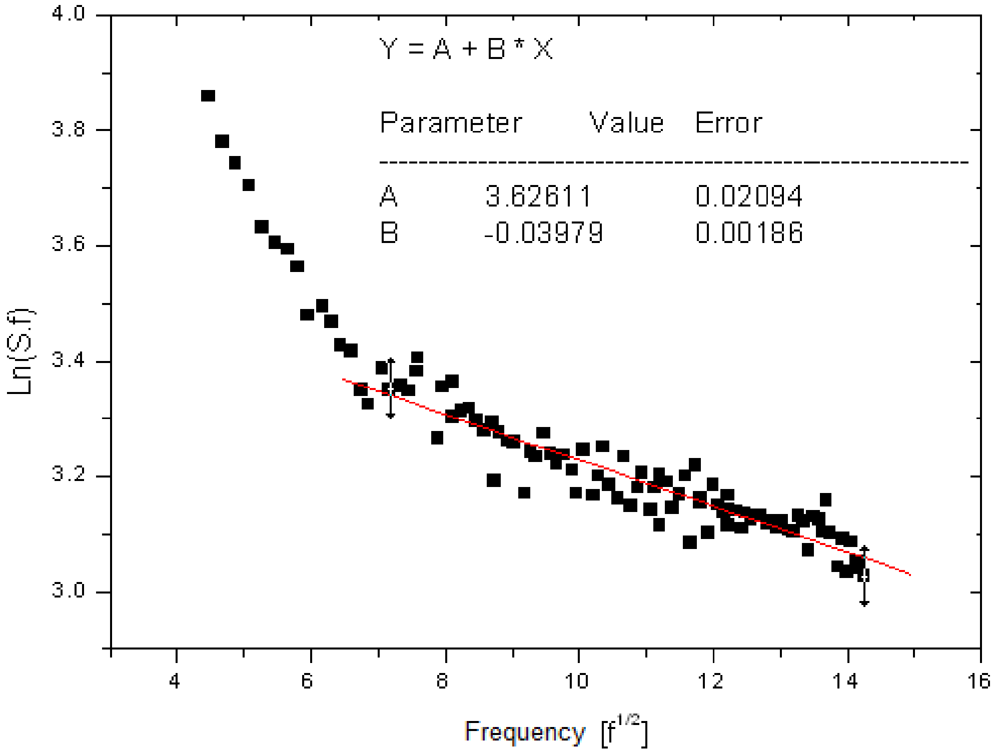



Then, with the calibrated microphone, was repeated the same procedure performed in sample 1. Thus, it can be traced the graph of intensity's logarithm against the frequency's logarithm, allowing indicate the frequency region in which there is a predominance of diffusion behavior thermally thick.

Applying the logarithm function in both members of Eq. (5) is obtained from the linear Eq. (6) for adjusting the amplitude and phase of the photoacoustic signal.

In order that the coefficients C (constant) and b were obtained in the experimental graph of ln (S.f) versus $f^{\frac{1}{2}}$ (Fig. 7). Knowing the sample thickness ($l_s$), the thermal diffusivity of the sample $\alpha_s$ was obtained again by using Eq. (7).

Figure 7. Graph of Ln (S.f) versus $f^{\frac{1}{2}}$ for the first sample.

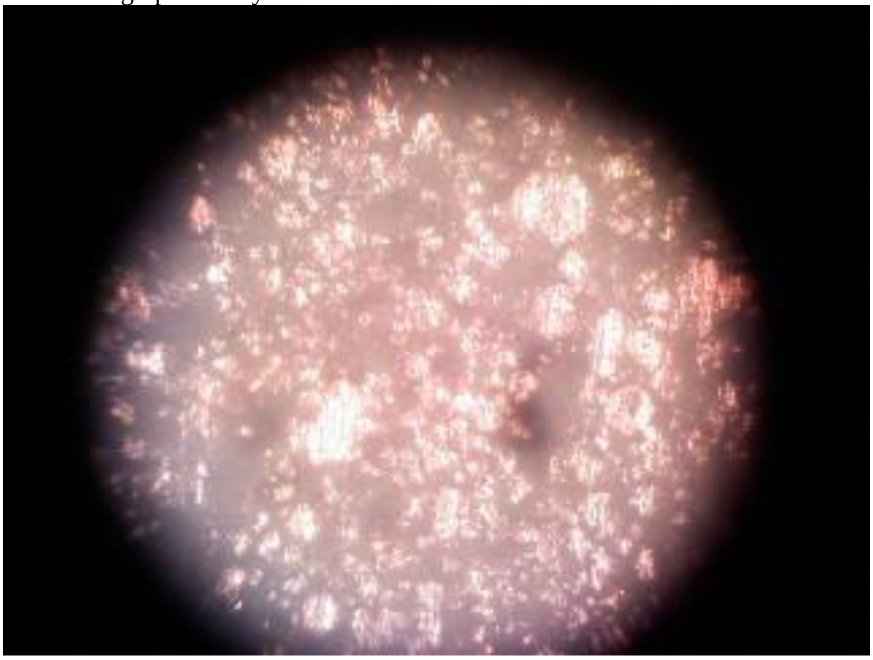



With thickness values of sample 2 ($l_s$ = 0.2 x $10^{-3}$ m), and found the value of b in the graph, gave a diffusivity value of 0.79 x $10^{-4}$ $m^2$ / s. With this value according to Eq. (8), the value of thermal conductivity for the sample was obtained.

Thus, the value of k = 110,3 W/mK was obtained for the second sample with a value equal to 1390x$10^3$ J/$m^3$k to $\rho C_p$, obtained experimentally according to the hot wire (Fukushima, 2011).

Furthermore, it is also known that the porosity, size, shape and particle size distribution affect the physical and mechanical properties of the materials in its manufacture (Prandel, 2009). In the case of such resin predominates to the metallic charge, it only being coated with a polymeric layer as shown in Fig. 8.

Figure 8. Epoxy Resin in micrographic analysis.



## 6 CONCLUSIONS

The photothermal techniques, in particular the photoacoustic, have proved extremely useful as methods of analysis of virtually any type of material. One of the important features of this technique is that they are non-destructive.

The temperature of the material varies with the same frequency as the incident radiation, leading to variation in parameters such as sample refractive index, thermal conductivity and thermal diffusivity. The diffusivity and thermal conductivity is a parameter that allows a measure of how heat propagates into the sample and has a unique value for each material, hence its importance (Olenka, 2003).

The data acquisition was done using a program developed in Labview platform and with the data obtained, was possible to build graphs with the help of software Origin ® [6] and thus was possible to determine their characteristic equations and analyze the behavior of the samples in ambient conditions, and finally possible to find conductivity values for each resin sample type.

The values found were satisfactory compared to the values found in the literature (Araujo and Rosenbenrg, 1976) and (Konzelmann *et al.*, 2008) since the resin does not conduct electricity and to which the resin had copper powder density of 3g/cm3 was obtained a thermal conductivity of 69.75W/mK and the resin which had copper powder density of 2.7 g/cm$^3$ and a thickness of 0.2 x10$^{-3}$m was obtained a thermal conductivity of 110.3 W/mK.

This is due to the fact that the resin present in the metal charge is surrounded by a polymeric layer as shown in Fig. 8. This feature prevents the passage of electric current, however, does not prevent the transfer of heat, being beneficial in cooling applications of electronic and telecommunications equipment requiring heat exchangers which are only electrical insulators.

This electrical insulating property can be proven in the lab after lab tests are performed with an electrometer, which was obtained by an electrical resistance of approximately 39GigaOhm.

Furthermore, the results are reliable because the parameters were calculated by means of the acquisition of data demonstrated error 0,186%, which proves that the method used OPC was useful and effective.

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