Nigerian Journal of Physics (NJP)
ISSN online: 3027-0936
ISSN print: 1595-0611
DOI: https://doi.org/10.62292/njp.v34i3.2025.442
Volume 34(3), September 2025

Thermo-Physical Properties of Different Sizes of Particulate Wood Materials for Optoelectronics Device Applications

***[1]Aramide, T. M., [2]Oluyamo, S. S., [2]Odusote, Y. A., [2]Olusola, O. I. and [1]Adeyemi, I. A.**

[1]Department of Physical Sciences, Oduduwa University Ipetumodu, Osun State, Nigeria
[2]Department of Physics, Condensed Matter and Statistical Physics Research UnitFederal University of Technology, Akure, Ondo State

*Corresponding Author's Email: temitopearamide2@gmail.com

ABSTRACT
In this research, thermo-physical properties of different sizes of particulate materials for optoelectronic devices applications were investigated. Five different wood species of the family of *Sterculiaceae*, *Moraceae*, and *Ulmaceae* were used in the study. The wood materials were pulverised into particles using a pulverizing machine and were sieved into different maximum particle sizes; 106 µm, 300 µm, 425 µm, 850 µm and 1180 µm with appropriate mesh. The wood samples were oven-dried at 50°C for 30 minutes to avoid redistribution of moisture under the influence of temperature. The basic apparatus that was used to determine the thermal properties was a Differential Thermal Analyser. The result of the thermal conductivity ranged from 0.0100 to 0.0492 $Wm^{-1} K^{-1}$. It was observed from the result that thermal conductivity of wood materials is dependent of particle sizes. This indicates that the performance of the material could be influenced by particle size. It has also been noted from the results obtained that almost all the samples considered at some sizes have their thermal conductivity similar to that of polystyrene whose potency in optoelectronics devices has been confirmed.

Keywords:
Particle wood,
Optoelectronic devices,
Differential Thermal Analysis,
Thermal conductivity,
Thermal diffusivity,
Thermal effusivity,
Hardness.

INTRODUCTION

In nearly all engineering industries, the choice, cost and availability of the materials to be used are very important (Ayugi *et al*. 2011; Hongli Zhu *et. al* 2016). It is of necessity to study and understand the properties of a material which will determine its reaction or response to a given situation (Ogunleye and Awogbemi, 2007). Much effort had been put together to understand the fundamental physical and chemical properties of optoelectronic devices to optimize their efficiency. Physical properties are very important characteristics of any material. Physical properties of materials; conductivity, diffusivity, effusivity and specific heat capacity are very important properties that characterize the thermal behaviour of a material, including wood (Suleiman *et al*., 1999; Olek *et al*., 2003; Sonderegger *et al*., 2011; Oluyamo *et al.,* 2017). They are also very important tools used to examine the electronic properties of wooding materials (Craig Dixon *et al*., 2000).

Wood is a complex biological structure, a composite of many cells acting together to serve the needs of a living plant. Information on the thermal conductivity of wood and its relationship to other wood properties is of interest from the standpoint of thermal insulation, drying, plasticizing, preservation, gluing of wood, and where heat resistance of wood is a major consideration in its application (Şahin, 2010). Several researches had been carried out on thermos-physical properties of materials most especially wood at different stages and results had also shown that different wood species do not have the same thermos-physical properties. Samuel *et al.* (2016) investigated the thermal properties of some selected tropical hard wood species and discovered that their thermal conductivities varied depending on the species. Adekoya *et al.* (2020) also studied the thermal properties of two wood species and observed that there was variation in thermal properties of the two wood species. Çavuş *et al.* (2019) investigated thermal properties of some wood species obtained from Turkey and observed that they had different thermal properties. Monika *et al.* (2002) investigated thermal properties of wood and wood composites made from wood waste and discovered that their thermal conductivity varied. Etuk *et al.* (2009) carried out research on the investigation of thermal properties of naturally seasoned dry *macaranga barteri* timber board and concluded that dry African thorn tree timber is a good thermal insulator and can be used as insulating board for self-cooled building in areas of severe or harsh climatic condition. Oluyamo and Bello (2014) studied the particle sizes and thermal insulation properties of some selected wood materials for solar device applications. This research revealed that, particle sizes consideration can be of great importance in improving the insulation properties of wood materials. Oluyamo *et al* (2017) investigated the variation of bulk and particle thermal properties of some selected wood materials for solar device applications. The result of the analysis revealed that the thermal conductivity of sawdust samples of the same wood material considered is lower compared with their bulk wood materials and values obtained for all the particle sizes fall within the range of thermal conductivities of materials used as thermal insulators in solar cell development and applications. In addition, some of the species considered showed very important uniqueness, most especially *Celtis phillipensis* where research had discovered that it has its grain aligned (Ken, 2014). Hence, the need to further research on the thermos-physical properties of this material and its applications in Optoelectronics devices.

Physical properties of particular interest are thermos-physical properties, which define characteristics of heat transport and heat storage in a material. Knowledge of the properties depends on adequate data produced from experiment. Light is emitted from a material when it is stimulated by the incident energy. If the energy is in the form of photons, photoluminescence is produced (Mohan, 2003). Materials which exhibit highly nonlinear optical characteristics of doubling or tripling the frequency of incident light are currently of great scientific and technological interest for use in the area of optoelectronics such as optical telecommunications, optical signal processing and, ultimately, the construction of optical computers. Nonlinear optics (NLO) is concerned with the interactions of electromagnetic fields in various media to produce new fields, which may be altered in phase, frequency or amplitude. Such media and their physical properties as well as their nonlinear optical properties have been of great interest in the field. Formerly, inorganic materials, such as KH2, PO4, LiNbO3 or InSb, were used as NLO materials, and are currently being replaced by materials based upon conjugated pi electron organic chromophores, which promise superior performance and adaptability to the desired chemical functions (Sureshkumar *et al.*, 2007). Organic nonlinear optical materials characteristically have large non-resonant susceptibilities, ultrafast response times, low di-electric constants, high-damage thresholds and intrinsic tailorability. The nonlinear optical response exhibited by organic materials with large delocalized pi electron systems in many cases found to perform much better than that shown by prior inorganic materials (Sureshkumar *et al.*, 2007).

There exists today a plethora of optoelectronic devices that are used in a multitude of applications. These devices include sources such as light-emitting diodes (LEDs) and laser diodes, photodetectors, optical amplifiers, and optical modulators. With such devices, one can generate, modulate, detect, and switch photons in an analogous way to electrons in an electrical circuit. They utilize energy in the visible and infrared regions of the electromagnetic spectrum. Solid state devices like sensors, IR emitters, and laser emitters are also used for optoelectronic applications. Organic materials have attracted much attention for applications in electronic and optoelectronic devices, such as organic transistors, organic solar cells and organic light-emitting devices. The organic light-emitting diode (OLED) is one of the most promising technologies for display and lighting applications. Compared with existing liquid crystal display (LCD) technology, OLED exhibits the advantages of self-emission, wide viewing angle, fast response time, simple structure, and low driving voltage. Optoelectronic devices can be classified into photoconductive and photovoltaic devices. Photoconductive devices such as photo resistors are widely used in counting systems, twilight switches, house security systems, etc. These detect variations in the light intensities and activate or deactivate electronic circuits. Photodiodes and phototransistors also fall in this category. These utilize the reverse biased junctions for generating current when illuminated. Photovoltaic devices produce a voltage when these are exposed to light. The light energy produces a potential difference across the p-n junction depending on the intensity of the incident light. Solar cells and photovoltaic cells are widely used in various applications to generate electricity.

Optoelectronics is one of the two major technologies driving the revolution in communications, which will not only have profound effects on the economy but on social and political structures as well. The other technology, optical fibers, is already beginning to mature, but optoelectronics is rapidly catching up, enabling the acceleration of the information age. Optoelectronic devices are basically electronic devices involving light. They have found their way into many different aspects of modern life whether it be the ubiquitous indicator LEDs on hi-fi systems, televisions, computers, solid-state lighting and countless other items or in the bar-code scanning systems at the supermarket, compact disk (CD), digital versatile disk (DVD) and blue-ray systems at home, the laser printer in the office, or when using a telephone or watching cable television. They are also found in many optoelectronics applications like military services, telecommunication, automatic access control system and medical equipment.

MATERIALS AND METHODS

Sample Preparation and Experimental Method

The materials that were used in the study include five different types of wood species of the families of *Sterculiaceae*, *Moraceae* and *Ulmaceae* found in the rainforest region, South Western Nigeria. These wood species are *Celtis Phillipensis*, *Milicia excelsa, Pterygota macrocarpa, Antiaris africana and Guaraea cedrata*. Based on previous research, these species of wood had revealed significant variation in their thermal conductivity values and unique property most especially *Celtis Phillipensis* that has its grains interlocked (Oluyamo et al., 2017). It is however, believed that further research into these wood species at different sizes could reveal more useful information apart from the previous one which will enhance its applications in industries rather than constituting menace into to the environment. The wood samples were collected from different sawmills in Akure South Local Government Area of Ondo State, South Western Nigeria. Samples were pulverized and oven-dried at 50°C for 40minutes to avoid redistribution of water under the influence of temperature. A mechanical test sieve shaker was used to sieve the particles using different mesh sizes: 106 µm, 300 µm, 425 µm, 850 µm and 1180 µm respectively.

Several techniques can be used to measure the thermal conductivity of wood: the guarded hot plate method, the transient plate technique (Shekhawat *et al*., 2013), the modified fitch-type apparatus, the heat flux meter technique (Cavus *et al*., 2019), the hot wire method and recently the parallel hot wire method. Most of these techniques are impractical for the thermal characterization of pure particle wood as the sample will be needed to be bonded with other material convenience sake. Since it is always difficult to account for the effect of binder on the thermal properties of the original sample, hence, the need for a differential thermal analyser which is able to determine the thermal properties of particulate wood materials in their form. The differential thermal analyser which measures the temperature, the direction and the magnitude of thermal transitions induced by heating or cooling a material in a controlled way was used. DTA measures these properties by comparing the temperature of the sample and that of a reference material, which is inert under similar conditions. This temperature difference is measured as a function of time or temperature under a controlled atmosphere and it provides useful information about the transition temperature but also about its thermodynamics and kinetics. To determining the thermal conductivity of the samples, each of them was placed inside the sample holder and put in a controlled source of heat (furnace) with a regulated temperature. The two thermocouples junction beads were inserted through the holes drilled by the sides of crucibles so as to measure the temperature of the sample and that of reference material. At the beginning of each determination, the power from a stabilized dc was turned on full until the temperature of the sample and reference material reached the desired value. This took several hours, throughout which time readings were taken by the automated machine. The details of the experimental procedure can be found in the literature (Boettinger *et al*, 2007; Jaroslav Sestak and Pavel Holba, 2013). The thermal properties determined are thermal conductivity, thermal diffusivity and thermal effusivity.

Thermal conductivity is a measure of the rate of heat flow through one unit thickness of a material subject to a temperature gradient. Thermal conductivity determines to a reasonable extent ability of a material to transport heat or resist heat. The value for the thermal conductivity (k) of each sample was estimated using the relation.

$$K = \frac{q\Delta_x}{A\Delta T} \quad (1)$$

where q is the heat flow, ΔT is the temperature difference across the crucibles, Δ_x is the sample size and A is the cross-sectional area.

Thermal diffusivity is the thermal conductivity divided by the density and specific heat capacity at constant pressure. It measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy. The thermal diffusivity of the samples were determined using the relation;

$$\lambda = \frac{k}{\rho c} \quad (2)$$

where;

λ is the thermal diffusivity, k the thermal conductivity, ρ the density and c is the specific heat capacity.

Thermal effusivity is a measure of the ability of a body to exchange thermal energy with its surrounding. The thermal effusivity of the samples were also determined using;

$$e = \sqrt{\lambda}\rho c \quad (3)$$

where

λ is the thermal diffusivity, ρ is the density and c is the specific heat capacity.

RESULTS AND DISCUSSION

The results of the analysis are presented in table 1 to 3. The thermal conductivities, diffusivities and effusivities of the sample for all the wood species considered are plotted against particle sizes in figure 1 to 3. Significant variation in thermal conductivity value of the same wood species as the particle sizes changed was noticed in the study.

Table 1: Thermal conductivity ($Wm^{-1}K^{-1}$) values of wood samples for different particle sizes

Sizes	*Milicia excelsa*	*Celtis phillipensis*	*Pterygota macrocarpa*	*Antiaris africana*	*Guarea cedrata*
106 µm	0.0274	0.0492	0.0283	0.0316	0.0271
300 µm	0.0222	0.0417	0.0250	0.0309	0.0247
425 µm	0.0203	0.0271	0.0240	0.0293	0.0190
850 µm	0.0200	0.0249	0.0223	0.0273	0.0121
1180 µm	0.0192	0.0134	0.0164	0.0181	0.0100

Table 1 above contains the values of thermal conductivity of all the samples. The values ranged between 0.0100 $Wm^{-1}K^{-1}$ and 0.0492 $Wm^{-1}K^{-1}$ which agrees with previous research (Ayugi *et al* 2011: Oluyamo *et al.* 2017). All the samples also have their highest thermal conductivity at 106 µm with *Celtis phllipensis* recording the highest thermal conductivity value of 0.0492 $Wm^{-1}K^{-1}$ and *Guarea cedrata* having the least thermal conductivity value of 0.0271 $Wm^{-1}K^{-1}$. At 1180 µm, *Guarea cedrata* has the least thermal conductivity value of 0.0100 $Wm^{-1}K^{-1}$. This is an indication that *Celtis phllipensis* is a better material in transporting heat energy due its high thermal conductivity (Tritt, 2004). However, this does not imply that other wood materials do not transport heat energy.

Also, almost all the thermal conductivity values obtained for all the particle sizes considered fall within the range of that of polystyrene whose efficiency in optoelectronics devices has been established (Sureshkumar *et al*., 2007; Sureshkumar *et al.*, 2008; Negi *et al.*, 2005; Sureshkumar *et al.*, 2004; Sureshkumar and Negi, 2005; Lindholf, 1996).

Table 2: Thermal diffusivity ($10^{-6} \times m^2s^{-1}$) values of wood samples for different particle sizes

Sizes	*Milicia excelsa*	*Celtis phillipensis*	*Pterygota macrocarpa*	*Antiaris africana*	*Guarea cedrata*
106 µm	6.69	8.90	3.80	2.10	5.40
300 µm	4.90	2.40	2.20	2.00	2.70
425 µm	2.90	2.00	1.80	1.80	1.70
850 µm	1.60	1.70	1.60	1.50	1.14
1180 µm	1.17	1.50	1.50	1.50	1.00

Table 2 above, showed thermal diffusivity of wood samples ranged between $8.90\times10^{-6}m^2s^{-1}$ and $1.00\times10^{-6}m^2s^{-1}$. *Milicia excelsa* has thermal diffusivity of 1.17 $^{6}m^2s^{-1}$ to 6.69 $^{6}m^2s^{-1}$, *Celtis phillipensis* has 1.50 $^{6}m^2s^{-1}$ to 8.90 $^{6}m^2s^{-1}$, *Pterygota macrocarpa* has 1.50 $^{6}m^2s^{-1}$ to 3.80 $^{6}m^2s^{-1}$, *Antiaris africana* has 1.50 $^{6}m^2s^{-1}$ to 2.10 $^{6}m^2s^{-1}$ and *Guarea cedrata* has 1.00 $^{6}m^2s^{-}1$ to 5.40 $^{6}m^2s^{-1}$ .Thermal diffusivity increases with decrease in particle sizes but at 106 µm, *Celtis phillipensis* was observed to have the highest thermal diffusivity value. This actually agrees with previous researches and from this observation, it implies that *Celtis phillipensis* has better ability to transport heat than other wood of the same species.

Table 3: Thermal effusivity ($Ws^{1/2}/m^2K$) values of wood samples for different particle sizes

Sizes	*Milicia excelsa*	*Celtis phillipensis*	*Pterygota macrocarpa*	*Antiaris africana*	*Guarea cedrata*
106 µm	9.360	9.958	7.028	7.842	11.47
300 µm	7.418	9.290	5.840	7.651	10.27
425 µm	5.844	6.476	4.691	6.884	10.07
850 µm	5.528	6.338	4.012	6.121	6.410
1180 µm	3.309	4.489	3.895	5.891	3.819

Table 3 revealed the thermal effusivity of all the samples to be between 3.309 $Ws^{1/2}/m^2K$ and 11.426 $Ws^{1/2}/m^2K$. *Milicia excelsa* has thermal effusivity 3.309 $Ws^{1/2}/m^2K$ to 9.360 $Ws^{1/2}/m^2K$, *Celtis phillipensis* has 4.489 $Ws^{1/2}/m^2K$ to 9.958 $Ws^{1/2}/m^2K$, *Pterygota macrocarpa* has 3.895 $Ws^{1/2}/m^2K$ to 7.028 $Ws^{1/2}/m^2K$, *Antiaris africana* has thermal effusivity 5.891 $Ws^{1/2}/m^2K$ to 7.842 $Ws^{1/2}/m^2K$ and *Guarea cederata* has thermal effusivity 3.819 $Ws^{1/2}/m^2K$ to 11.246 $Ws^{1/2}/m^2K$. The results above also showed that *Guarea cedrata* at 106 µm has the highest thermal effusivity compared with other woods. This connotes that the smaller the particle, the higher the ability of that wood to exchange heat with its surrounding. Also, based on this research, *Guarea cedrata* seems to be the best wood in exchanging heat with its surrounding.

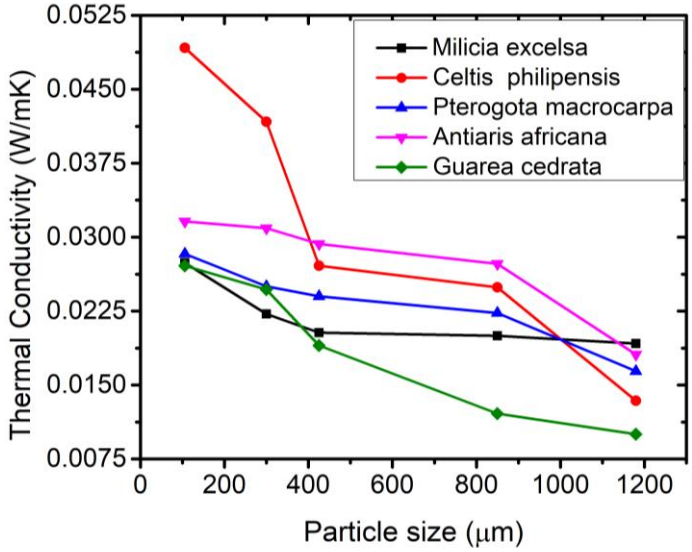

Figure 1: Thermal conductivity of the wood materials a function of particle sizes

Figure 1 revealed that among the particle sizes, 106 μm has the highest thermal conductivity value 0.0492 $Wm^{-1}K^{-1}$ compared with other particle sizes which is in conformity with previous research (Oluyamo and Adekoya, 2015, Oluyamo *et al.* 2017). This was as a result of reduction in porosity. As sample particle size decreased, thermal conductivities increased as a result of the reduction in the intermolecular distance between the grains in wood samples. This agrees with previous researches (Ayugi *et al* 2011; Oluyamo and Adekoya, 2015, Oluyamo *et al.* 2017).

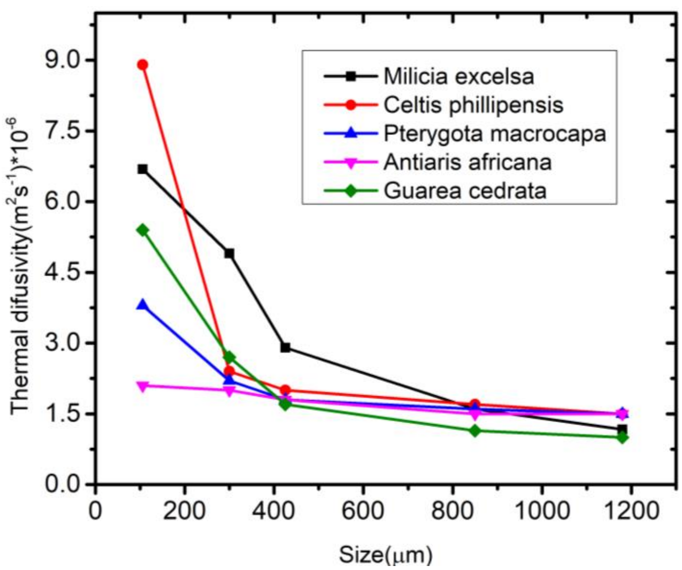

Figure 2: Thermal diffusivity of the wood materials as a function of particle size

Figure 2, showed thermal diffusivity of wood samples ranged between $8.90\times10^{-6}m^2s^{-1}$ and $1.00\times10^{-6}m^2s^{-1}$. Thermal diffusivity decreases with increase in particle sizes. At 016 μm, *Celtis phllipensis* exhibited a unique behavior in the sense that it recorded the highest value compare with other wood material. This was attributed to the fact that *celtis* family usually have their grains aligned and interlocked and the smaller the particles the more aligned and interlocked the grains (Ken, 2014). This makes it a better material for transporting heat.

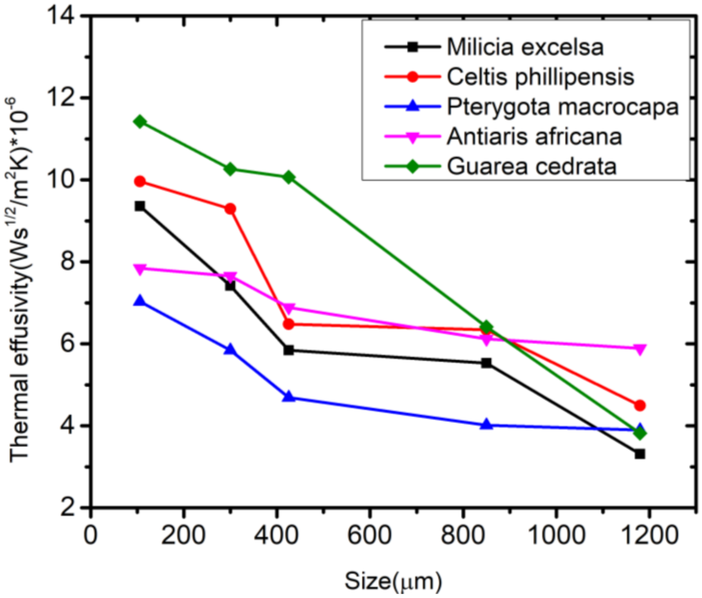

Figure 3: Thermal effusivity of the wood materials as a function of Particle size

In figure 3 above, thermal effusivity was plotted against particle sizes so as to see the effect of particle size on the thermal effusivity and it was discovered that based he research, particle size has significant effect on thermal effusivity of wood. The figure indicates that as particle size decreases, thermal effusivity increases which could be due to the fact that the more the particle size reduces, the closer the particle becomes which definitely cause reduction in porosity.

Also, comparing the results in this study with the thermal insulation property of some commonly used materials for flat plate solar collector which ranges between 0.0245-0.1202 $Wm^{-1}K^{-1}$, some of the values obtained in this research fall within the range of already established flat plate solar collectors (Young, 1992; Ziman, 1967).

CONCLUSION

It was established in the research that the thermal conductivity of wood materials ranged between 0.0492 Wm^{-1} K^{-1} to 0.0100 $Wm^{-1}K^{-1}$ for all the samples considered. The thermal conductivity of wood samples increases as particle size decreases which was attributed to decrease in porosity and reduction in the intermolecular distance between the grains in the samples. The wood samples considered at specific particle sizes, exhibit low thermal conductivity that is comparable with materials used as industrial insulators. Almost all the values obtained for all the particle sizes considered fall within the range of that of polystyrene which research had shown to have great potential application in optoelectronic devices if doped with optical chromophore. This connotes that; wood particles at some sizes would also have great potential application in optoelectronic devices if well harnessed.

REFERENCES

Adekoya, M. A., Adelakun A. O., Faremi, A. A. and Oluyamo S. S (2020). *Thermal Response at Room Temperature and Device Applications of Two Wood Species in Akure, South Western Nigeria.* Nigeria Journal of Pure and Applied Physics Vol. 10(1), 12 – 15, 2020. https://doi.org/10.4314/nipap.v10i1.3.

Ayugi, G., Banda, E. J. K. and D'Ujanga, F. M. (2011). *Local Thermal Insulating Materials for Thermal Energy Storage Department of Physics.* Makerere Thermal Response at Room Temperature and Device Applications of Two Wood Species in Akure, South Western Nigeria University, Kampala, Uganda, Rwanda Journal, 23:21-29.

Boettinger W. J., Kattner U. R. and Moon K. W. (2007). *DTA and Heat-flux DSC Measurements of Alloy Melting and Freezing*. Materials Science and Engineering Laboratory, National Institute of Standards and Technology. https://doi.org/10.1016/B978-008044629-5/50005-7

Çavuş, V., Şahin, S., Esteves, B., and Ayata, U. (2019). *Determination of thermal conductivity properties in some wood species obtained from Turkey.* BIORES. 14(3), 6709-6715. https://doi.org/10.15376

Craig Dixon., Michael R. Strong and S. Mark Zhang (2000). *Transient Plane Source Technique for Measuring Thermal Properties of Silicone Materials Used in Electronic Assemblies.* The International Journal of Microcircuits and Electronic Packaging, Volume 23, Number 4, Fourth Quarter, 2000 (ISSN 1063-1674). https://doi.org/10.13140/RG.2.2.27069.56803

Etuk S. S., Eno E. E. and Akpabio L. E. (2009). "*Investigation of thermal properties of naturally seasoned dry macaranga barteri timber board*". FUTY Journal of the environment, Vol. 4, No 1

Jaroslav Sestak and Pavel Holba (2013). *Theory of DTA and the anticipated role of heat inertia.* Journal of Thermal Analysis and Calorimetry.

Hongli Zhu., Wei Luo., Peter N. Ciesielski., Zhiqiang Fang., J. Y. Zhu., Gunnar Henriksson., Michael E. Himmel and Liangbing Hu (2016). *Wood-Derived Materials for Green Electronics, Biological Devices, and Energy Applications*. Journal of American Chemical Society, 116:9305−9374. https://doi.org/10.1021/acs.chemrev.6b00225

Ken, F. (2014). Useful Tropical Plants. Database web interface.

Lindhof, W. (1996) "*Properties and Uses of Recycled, Expanded Polystyrene in Recycling and Recovery of plastics".* Edited by: J. Brandrup, M. Bittner, W. Michaeli and G. Mengs, P. 631-49, © Carl Hanser Verlag, Munich.

Mohan, D. (2003). "*Optoelectronic Devices & Their Applications".* Electronics for you, Government Victoria College, Palakkad, Kerala.

Monika, B., Petr, K., Matus, B., Lubomir, K., Zuzna, H. and Peter, H (2021). *Thermal properties of wood and wood composites made from wood waste.* International Journal of Agrophysics. 35(3): 251-256. https://doi.org/10.31545/intagr/142472

Negi Y.S., Sureshkumar M.S., Goyal R. K., Islam M. and Aiyer R.C. (2005). "*Proc. National Conference on Microwaves and Optoelectronics".* NCMO'04, held in June 29-30, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, India, *In* Microwaves and Optoelectronics, Edited By: M.D. Shirsat, V.V. Nawarkhele, G.S. Raju and P.W. Khirade, © Anamaya Publishers / Anshan Publishing Co. Pvt. Ltd., UK First edition, 397.

Ogunleye I.O and Awogbemi, O. (2007). Thermo-physical properties of eight varieties of sawdust. Journal of Research in Engineering, 4: 9-11.

Olek, W., Weres, J., Guzenda, R. (2003) Effects of thermal conductivity data on accuracy of modeling heat transfer in wood. Holzforschung 57:317 – 325.

Oluyamo S. S., Aramide, T. M., Adekoya, M. A. and Famutimi, O. F. (2017) "Variation of Bulk and Particle Thermal Properties of Some Selected Wood Materials for Solar Device Applications". Volume 9, Pp 14-17, ISSN 2278s-4861. International Organization of Scientific Research Journal of Applied Physics. https://doi.org/10.9790/4861-0903011417

Oluyamo, S. S. and Adekoya, M. A. (2015). Effect of Dynamic Compression on Thermal Properties of Selected Wood Products of Different Particle Sizes. International Research Journal of Pure and Applied Physics Vol. 3, No. 1, Pp 22-29.

Şahin, Kol, H., Uysal, B., Kurt, Ş. and Ozcan, C. (2010).*Thermal conductivity of oak impregnated with some chemicals and finished*, Bioresources Technology, 5(2), 545-555.

Samuel Aggrey-Smith., Kwasi Preko., and Francis Wilson Owusu (2016). *Study of Thermal Properties of Some Selected Tropical Hard Wood Species*. International Journal of Materials Science and Applications. Vol. 5, No. 3, 2016, pp. 143-150. https://doi.org/10.11648/j.ijmsa.20160503.15

Shekhawat, M. S., Tak, S. K. and Manga, R. (2013). *The Transient Plane Source Technique to Measure Thermal Conductivity of Clays of Bikaner Region.* International Journal of Modern Physics: Conference Series Vol. 22, Pp 42–50. https://doi.org/10.1142/S2010194513009914

Sonderegger, W., Hering, S., Niemz, P. (2011) Thermal behavior of Norway spruce and European beech in and between the principal anatomical directions. Holzforschung 65: 369 – 375.

Suleiman, B.M., Larfeldt, J., Leckner, B., Gustavsson, M. (1999) Thermal conductivity and diffusivity of wood. Wood Sci. Technol. 33:465 – 473.

Sureshkumar M.S., Goyal R.K., Negi Y.S., Dadge J.V., Islam M. and Aiyer R.C. (2004). "*Second Harmonic Generation in NLO Active meta-Nitroaniline/ Recycled Polystyrene System".* Proc. International Conference *on Advances in Polymer Technologies*-MACRO'04, held at Regional Research Laboratory, Thiruvananthapuram, India, P. 244, Dec.15-17, PC.8/1-PC.8/4 Publisher: Society for Polymer Science, India, Thiruvananthapuram, India.

Sureshkumar, M. S. and Negi, Y. S. (2005). *Nitroaniline Doped Recycled Polystyrene Film for Optoelectronics Applications*", M. Phil., Thesis, Proc. *4th DAE-BRNS National LaserSymposium*-NLS-4, held at Bhaba Atomic Research Center, Mumbai, India, P. 507 – 511.

Sureshkumar M.S., Goyal R.K., Negi Y.S., Pratheepkumar A., Raghunatha Reddy K., Singh, R. P., Dadge J.W. and Aiyer R.C. (2007) "*Studies on the feasibility of recycled polystyrene doped with meta-nitroaniline for optoelectronics applications"*, Poly. Eng Sci., Vol. XX, (In Press)

Sureshkumar M. S., Goyal R. K. and Negi Y. S. (2008). "*Potential Applications of Polystyrene in Optoelectronics*". Progress in Rubber, Plastics and Recycling Technology, 24(1):53-71. Vol. 24, No. 1. https://doi.org/10.1177/147776060802400105

Tritt, T. M. (2004). *Thermal Conductivity: Theory, Properties, and Applications.* Kluwer Academic/Plenum Publishers. New York, 2004.

Young, H. D. (1992). University Physics. (7th Edition), Addeson, Wesley UK.

Ziman, J. (1967). *The thermal Properties of Materials*. Scientific American, Chapter 17, Page 251 USA. https://doi.org/10.1038/scientificamerican0967-180