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ELECTRICAL PROPERTIES OF INDONESIAN HARDWOOD CASE STUDY: *ACACIA MANGIUM, SWIETENIA MACROPHYLLA* AND *MAESOPSIS EMINII*

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ABSTRACT

Wood is considered as a complexity matter that had multi-purpose functions. The aims of this investigation was to reveal the electrical properties of wood and its potency as semiconductor. Wood samples used in this study is consist by three hardwood species. The measurement process with frequencies: 10, 100, 10^3, 10^4, 2.10^4, 4.10^4, 6.10^4, 8.10^4, and 10^5 Hz respectively.

Result shows there were various values of electrical conductivity and impedance toward the frequency which applied. The three types of wood used in this study are *Acacia mangium* Willd., *Swietenia macrophylla* King. and *Maesopsis eminii* Engler. We assume that this three type of wood have semiconductor properties. It is necessary to characterize other characteristic like absorbance, band gap, and current voltage. *S. macrophylla* has the highest value conductivity than others. Generally, these variations was influenced by wood properties and its anatomical structure in the wood, such as parenchyma, ray cell, vessel cell and fiber cell.

KEYWORDS: Semiconductor, electrical properties, vessel, fiber, parenchyma.

INTRODUCTION

Wood is a very complex material, anisotrophy, unsymmetric molecules, and heterogeneous structure (James 1975, Haygreen and Bowyer 1996). It can be seen from its structure and composition. All of the components in woods gives great contribution to wood functions and services (Becker et al. 2009). Each species or even in the same species has different cells and structures. Those cases, hereafter will be establish its function as well as appropriation in further used. Wood utilization closely intertwined by its properties as well as has to be cautiously considered due to its possess hygroscopic characteristic which of relate closely to the surrounding environmental (Antony et al. 2009). For practical purposes, the influences of the anisotropy of wood, the fiber orientation in respect to the electric field, must be considered also (Resch 2006). The optimum field orientation in an application may be deduced from the ε"*eff* versus moisture content curves as losses are higher for the field orientation parallel to the grain, which is characteristic of wood and paper products (James and Hamill 1965). That is way, in using it required specific comprehension particularly as electrical material purposed.

One of the basic properties which have to be known were whole materials as dielectric, solid, liquid or even gases possess ability to storage electrical energy. Wood was considered as solid materials which have plenty of benefit to be an electrical material. The thermal properties of wood are closely related to the fire performance of thick timber (FPL 2009). Although wood is a combustible material, there are several ways in which it outperforms fireproof metal in fire (Siau 1995). When wood is placed in an electric field, the current-carrying properties of the wood are governed by certain properties, such as moisture content, density, grain direction, temperature; and by certain components such as cellulose, hemicelluloses, and the lignin of wood. They also vary in an extremely complicated (Kabir 2001).

This investigation is aimed to reveal the electrical properties of several Indonesian hardwoods and its potency as semiconductor matter which deals with based on three differently wood sections.

Conductance measurement

Electrical properties of wood material are recommended urgently for study owing to it has a potency to be developed as a semiconductor material. Accurately measurements of this material can provide preliminary information to establish further unitization of wood. The electrical conductance is the ability of a material to conduct an electric current (a flow of electrons). It is the reciprocal of electrical resistance (Irzaman et al. 2011). It is a property attributable to the ions in material. Electrical current is transported through material via movement of ions, and conductance rise as increases as ion concentration. Because of the relatively simple measurement of conductance together with advanced mathematical modeling, it is often a good approach in purity assessment of wood material. This measurement is in a rapid mode, non destructive, and in-situ. It is based on electromagnetic energy, ultrasonic technique, and resonance. Measurement is developed that conduct interaction wood with electromagnetic wave. The conductance of a material is measured between two spatially fixed inert electrodes of known surface area. These electrodes are positioned parallel to and facing one another, separated by a gap of fixed dimensions. Conductance part of dielectric properties is an interaction electromagnetic field with a low conductor material. Dielectric properties of material are influence frequency, temperature, water content, density, composition and material structure. Wood has dielectric properties and non ideal polarization conduct dissipation phenomena, energy adsorption, and damages that influence dielectric constant (Irzaman et al. 2011).

MATERIAL AND METHODS

Wood preparation

Using of wood as samples in this experiment was consist of three hardwood species, *M. eminii* (*Maesopsis eminii*), *A. mangium* (*A. mangium mangium*) dan *S. macrophylla* (*Swietenia mahagoni*). The according electrodes tools namely 2 x 1 x 0.5 cm for each species. In this phase also those samples established intentionally for three surface i.e. tangential, radial and cross-section. Thus, total samples used in this experiment were 3 (tangential, radial and cross-section) x 3 (wood species). After that, those undergoes dried process used oven drying to reach appropriate wood moisture content (MC) that is around 10-15 %. Fig. 1 below shows three principal basic plane in wood (Hanson 2007).

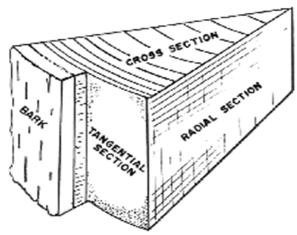

Fig. 1: Three basic plane in wood.

Electrical properties measurement

Electrical properties (conductivity, dielectric, and impedance) were measured using 3532-50 LCR HiTESTER (Hioki) that covers the range from 42 Hz to 5 MHz. Measurement get in room temperature (26-27°C) and frequencies: 10, 100, 10^3, 10^4, 2.10^4, 4.10^4, 6.10^4, 8.10^4 and 10^5 Hz. Conductance was measured in nano Siemens (nS) (Irzaman et al. 2011).

RESULTS AND DISCUSSION

Electrical conductivity of wood

Radial section

Electrical conductivity is the ability of material to conduct the electrical current which is shown by the magnitude (Kizito et al. 2008). Electrical conductivity is strongly influenced by moisture content, density, and structure of the wood (Irzaman et al. 2011; Hanson 2007). In wood, the rate depends on the direction of heat flow with respect to the grain orientation, that is have a relation with wood properties is an anisotropic material. Electrical conductivity obtained from the three types of wood on the radial section ranged between 0.35-1141 x 10^{-8} $S.cm^{-1}$.

Electrical conductivity in radial section increased along with the increasing frequency. *S. macrophylla* has the highest value and *A. mangium* has the lower value. It was occurred because the variation of anatomical structure in wood species (Daian et al. 2006). Rays cell of *S. macrophylla* is wider than *M. eminii* and *A. mangium* (Ani and Aminah 2006, Pandit and Kurniawan 2008). In the other hand, *S. macrophylla* have 3-4 series, *M. eminii* have 2 series, and *A. mangium* have 1 series of rays cell (Pandit and Kurniawan 2008). It affected the electrical conductivity value of *S. macrophylla*, so it has the higest electrical conductivity value than the others.

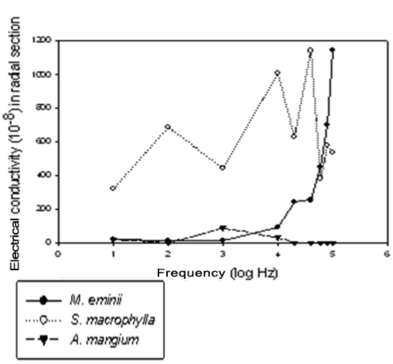

Fig. 2: The relationship between frequency and electrical conductivity in radial section from three Indonesian hardwood species.

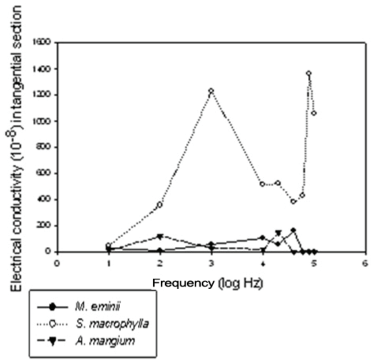

Fig. 3: The relationship between frequency and electrical conductivity in tangential section from three Indonesian hardwood species.

Tangential section

Electrical conductivity in tangential section is also increasing along with the higher frequency. In the tangential section the electrical conductivity value varied from 0.35-1385.5 x 10^{-8} S.cm^{-1}. The highest value is reached by *S. macrophylla* and the lowest by *A. mangium*. Electrical conductivity of both *M. eminii* and is under 200 x 100^{-8} S cm^{-1}.

One of the anatomical structures that give influence is the type of parenchyma. *S. macrophylla* wood has apotracheal and paratracheal parenchyma, while *M. eminii* and *A. mangium* just have paratracheal type. Consequently, *S. macrophylla* has the highest electrical conductivity value of than other woods. Electrical conductivity value was influenced by variation of anatomical structure among species (Daian et al. 2006).

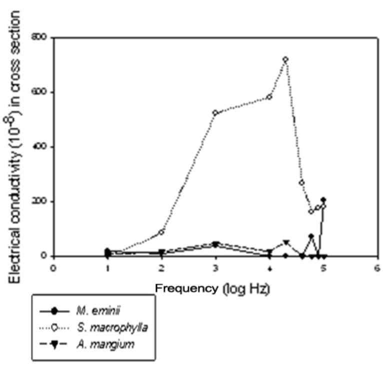

Fig. 4: The relationship between frequency and electrical conductivity in cross section from three Indonesian hardwood species.

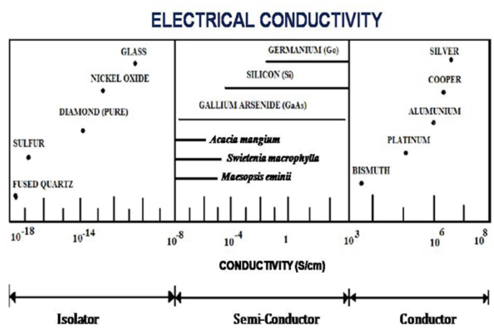

Fig. 5: Electrical conductivity of A. mangium mangium, Swietenia mahagony, and Maeopsis emini.

Cross section

Cross section plane structure in wood composed from cells which related one and other vertically and has a primary function for propping up standing tree (Yuniarti and Pandit 2010). In the cross section the electrical conductivity value varied from 0-720.63 x 10^{-8} $S.cm^{-1}$. The highest value is reached by *S. macrophylla* and the lowest by *A. mangium*. The electrical conductivity for each type of wood is proportional to the conductance, this can be seen in Figs. 2, 3 and 4. *S. macrophylla* reached the highest electrical conductivity in the three section is in while the lowest electrical conductivity found in *A. mangium*. This happened because, the wooden structures that make up each type of wood is varies one to another (Daian et al. 2006).

Electrical conductivity value in cross section was influenced by the anatomical structure, especially fiber and vessel. Fibers of *S. macrophylla* (1000 µm) is lower than fibers of *A. mangium* (1300 µm), and *M. eminii* (1500 µm) but (Pandit and Kurniawan 2008, Ani and Aminah 2006, Honjo et al. 2005). In other hand, *S. macrophylla* has pattern of spread semi-ring porous wood (coherent), while *M. eminii* and *A. mangium* have pattern of spread diffuse porous (inherent) (Pandit and Kurniawan 2008).

Type of electrical conductivity is divided into isolator, semiconductor, and conductor. Result in Fig. 5 shows that *A. mangium*, *S. macrophylla* and *M. eminii* can be assumed as semiconductor. Other characteristic like absorbance, band gap, and current voltage still have to be observed. *S. macrophylla* has the higest value in conductivity among the others. Conductivity value of *S. macrophylla* was effected by different anatomical structure of *S. macrophylla* than the others. *S. macrophylla* have pattern of spread semi-ring porous wood (coherent), while *M. eminii* and *A. mangium* have pattern of spread diffuse porous (inherent). Fiber length of *S. macrophylla* wood (1000 µm) is lower than fibers of *A. mangium* (1300 µm) and *M. eminii* (1500 µm). Rays cell of *S. macrophylla* (3-4 seriate) is wider than *M. eminii* (2 seriate) and *A. mangium* (1 seriate) (Ani and Aminah 2006; Pandit and Kurniawan 2008; Honjo et al. 2005). *S. macrophylla* wood have apotracheal and paratracheal parenchyma, while *M. eminii* and *A. mangium* just have paratracheal type. Wood is a multi complex material owing to composed of wide range of cell types. Therefore these properties are further determined the quality and properties. Besides, wood contained lots of material as composed which merged as one unity (Hidayat and Simpson 1994)

Impedance properties of wood

Electrical conductivity and impedance have a strong relation. Impedance is appeared from resistance value (Z) / electrical conductivity (G), capacitive reactance (Xc), and inductive reactance (XL) that form Fasor diagram. So, this make electrical conductivity and impedance have complex relation. In this research we also characterize impedance to support characterization of electrical conductivity.

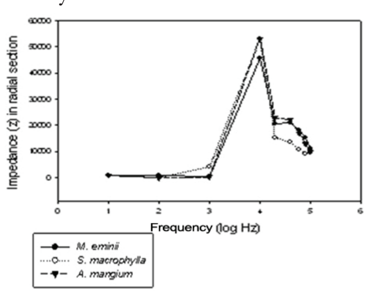

Fig. 6: The relationship between frequency and impedance in radial section from three Indonesian hardwood species.

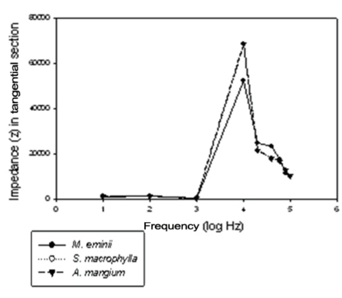

Fig. 7: The relationship between frequency and impedance in tangential section from three Indonesian hardwood species.

Radial section

The result in Fig. 6 showed that the impedance value of *S. macrophylla* and *A. mangium* achieve the same maximum value, which is 53129 ohm at frequency 10^4 Hz. On the other hand, *M. eminii* reaches the highest impedance at a frequency of 10^4 Hz with a value of 45681 ohm. Impedance values fluctuate. Impedance of *M. eminii* varies at frequency of 10 Hz to 10 Hz^2 and increased from 845 to 1040 ohm, then at a frequency of 10^3 the impedance value decreased to 426 ohm. At frequency of 10^4 the maximum value is reached then decreased to 20621 ohm at $2x10^4$ Hz frequency and increased again at a frequency of $4x10^4$ Hz to 20973 ohms. At frequencies $6x10^4$ Hz to 10^5 Hz impedance values continue to decline and eventually reach a value of 10934 ohms. It can be concluded that the *S. macrophylla* and *A. mangium* has a higher resistance than the *M. eminii*.

Tangential section

Fig. 7 showed that wood impedance in the tangential section ranged 310−68575 ohm. The highest impedance value for three samples can be seen at the 10^4 Hz of frequency then tend to decrease at $2x10^4$ Hz, afterward smooth decreased until 10^5 Hz. The graph also broadly indicated that at 10 to 10^3 Hz showed polarized consistent in low value, ranged between 310-1539 which of these numbers obtained from three wood samples. In tangential plane the result of impedance value for *S. macrophylla* wood reciprocal with conductivity value at same frequencys. At below 10^4 Hz the ability of a wood to conduct an electric current (a flow of electrons) is height and barrier properties of *S. macrophylla* wood reducted. According to Rout et al. 2009, that impedance decreases with increase in frequency.

In the other hand, the results impedance properties of *M. eminii, A. mangium*, and *S. macrophylla* showed in Fig. 7. This results can be explained by considering of wood based properties, namely fibers, resin content and wood density. Based on research of Rout et al. (2009) the magnitude of impedance decrease with increase that frequency also the temperature. As showed in Fig. 7, impedance of three wood constant until frequency 10^3 Hz, then it increase at 10^4 Hz, however the value of impedance become decrease with increase the frequency after 10^4 Hz.

Cross section

The results of measurements of impedance are three types of wood from Indonesia in the axial plane shows that *M. eminii* wood, *A. mangium* wood and *S. macrophylla* had impedance values with the highest frequency of 10^4 Hz. In addition, there is a tendency to fluctuate impedance 10-10^3 Hz frequency levels and decreased levels at frequencies above 10^4 Hz (Fig. 8). The fall in the value of the impedance at the frequency of 10^4 Hz is consistent with (Rout et al. 2009). The higher the impedance value of the material tested is a type of material that is blocking the flow of electricity, otherwise if the value of the lower impedance then the material is more easily transform and also conduct electricity (Rout et al. 2009).

Wood *M. eminii* has the lowest impedance value of the three tested types of wood, whereas *S. macrophylla* and *A. mangium* relative impedance value is almost the same. In granting the axial direction frequency impedance value obtained is influenced by the anatomical properties of wood, including: pores, fiber length and cell radii on wood (Daian et al. 2006). Besides wood also has some unique properties such as anisotropic, hygroscopic and has a very heterogeneous structure (James 1975).

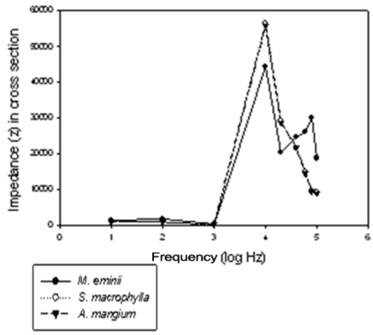

Fig. 8: The relationship between frequency and impedance in cross section from three Indonesian hardwood species.

Figs. 6, 7 and 8 showed impedance value from all of wood almost similar in frequency 10-10^3 Hz, increasing value occured in frequency 10^3-10^4 Hz and decreasing value occured after frequency 10^4 Hz. At low frequency (< 10^3 Hz) minority content was not vibrate so its indicated that the impedance value was low, while in frequency 10^4 Hz minority content was vibrate so its indicated that the impedance value was high. In higher frequency (>10^4 Hz) impedance value was increase with vibrate influence of minority content.

CONCLUSIONS

This three type of wood is assumed have semiconductor properties. *S. macrophylla* has the highest value in conductivity than others. In general, these variations are influenced by wood properties and its anatomical structure, such as parenchyma, ray cell, vessel cell, and fiber cell.

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