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Development of Pin Trapezium Hybrid Fins Heat Sink LED Bulb

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Abstract
The power sector in Nigeria and other developing countries is under severe stress because of generation supply deficits and high fuel costs. The electricity supply–demand gap in most developing countries is increasing rapidly as a result of the fast growing demand for electricity to meet economic growth, increasing urbanization, generation capacity deficits, high costs of new generation capacity, and fuel supply issues. From a menu of demand-side energy-efficiency measures, energy-efficient lighting technologies offer one of the most promising solutions to help bridge the supply-demand gap in many developing countries. The incandescent lamps have been found to consume much energy compared to fluorescence bulbs. Recently attention has shifted to Light Emitting Diodes (LED) for their advantage of using small electrical energy to deliver luminous lights. As enormous as the advantages of LED bulbs are over the incandescent bulbs and Compact fluorescence bulbs, the problem of heat dissipation in LED's drastically reduce their efficiency and in some cases damage the bulb before one quarter of their expected life. One factor that makes it easy or difficult for generated heat to disperse from the source of generation is the temperature of the surrounding air and adjacent materials to the heat source. Nigeria lies in the equatorial zone registering high temperatures throughout the year. Many imported LED bulbs have been found to fail, shortly after installation. A number of reasons have been adduced for such failures but the fact is that the foreign manufacturers have not taken cognizance of Nigerian peculiar conditions in the design and production of the LEDs heat sinks. The survival of LED bulbs in Nigeria would largely depend on how well heat dissipation in Nigerian customized bulbs is designed and produced. This invention addresses this problem by ensuring large surface areas for convective heat transfer away from the chip junction, through the installation of a hybrid pin and trapezium fin aluminum heat sink.
Key Words: *Light, LED, efficiency, heat, sink, pin, trapezium, fin*

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I. Introduction

Access to energy is the dividing line between the poor countries and the rich countries. This explains why the developed countries of the world have and consume far more energy than the developing and underdeveloped countries. If any country must tackle the problem of poverty, the country will need to provide energy for her citizens. Energy efficiency does not mean that we should not use energy, but we should use energy in a manner that will minimize the amount of energy needed to provide services. This is possible if we improve in practices and products that we use. If we use energy efficient appliances, it will help to reduce the energy necessary to provide services like lighting, cooling, heating, manufacturing, cooking, transport, entertainment etc. Hence, energy efficiency products essentially help to do more work with less energy. For instance, to light a room with an incandescent light bulb of 60 W for one hour requires 60 W/h (that is 60 watts per hour). A compact fluorescent light bulb would provide the same or better light at 11 W and only use 11 W/h. This means that 49 W (82% of energy) is saved for each hour the light is turned on (Uyigue et al, 2009). A LED bulb would achieve the same luminosity with 2-5 watts.

Experts have asserted that Nigeria can save up to half of the energy currently consumed in the country if energy is efficiently utilized. The major challenge has been that energy policy in Nigeria has undermined the importance and gains of energy efficiency to the environment and economic growth. In the midst of the prevailing energy crisis in Nigeria, energy efficiency will play a pivotal role in ensuring access to energy. Efficiency is not only cheaper than all other options; it also leads to growth in jobs and personal income. By reducing energy bills, it frees up money that can be spent elsewhere in the economy (Uyigue et al, 2009). The new generation green solid-state light source, LED has been widely regarded due to its distinctive advantages such as high luminous efficiency, energy saving, long lifetime, and being environment-friendly. It is being developed for solid-state lighting (SSL) for general illumination in commercial and household applications while offering up to 75% savings in electric power consumption over conventional lighting systems (Fengze et al, 2011).

Compact fluorescence energy saving lamps (CFESL) has been the most common energy saving lamp in Nigeria. This has so far imposed some challenges which led to the thought of making moves for the provision of alternatives. According to Ordinioha (2012), CFESL contains varying quantity of mercury that can easily contaminate the environment. Mercury is a neuro-toxin, but damages have been reported in the kidney, skin and the cardiovascular system. Hence, there is the need to switch over to better alternatives. The use of light emitting diodes (LEDs) could act as an alternative. LEDs are known to be efficient and are loved for being tiny. But they are only really tiny as long as heat management is not involved. Incandescent light sources work with temperatures up to 2.500°C. LEDs are much colder and many people stumble upon the fact that heat is such an issue. Being relatively cold LEDs still do produce heat which is not yet a problem. But they are based on semiconductors which, roughly speaking, simply allow temperatures below 100°C. According to the law of energy conservation the thermal energy must be transferred to the surrounding area. The LED can only use a small temperature gap between 100°C of the hot spot and 25°C ambience temperature; offering just 75 Kelvin. Consequently a larger surface and powerful thermal management are needed (Veitl, 2009).

The generation of power and its efficient utilization has been a matter of concern to both government and the public sector in advanced countries. In Nigeria, it appears there is no coordinated policy or effort by government and various stakeholders to generate solutions to the situation. Solutions proffered and generated by foreign countries have been imported into the country without considering Nigeria's prevailing conditions of general hotness emanating both from the weather conditions and from lack of power and infrastructure for air conditioning of the rooms and buildings where these bulbs are installed. This work is a research outcome of Electronics Development Institute (ELDI), Awka and Department of Electrical Engineering, Bayero University, Kano aimed at achieving an appropriate LED for Nigeria weather conditions. It is contrived to very easily survive the country's ambient conditions leading to better performance and longer life.

II. Problem Statement

The introduction of the first practical visible solid state LED occurred in 1962, and was invented by Nick Holonyak of the General Electric Company. It was discovered that the wavelength of an infrared GaAs diode could be shifted to the visible spectrum by the introduction of phosphate dopants. The introduction of a compatible large band gap material raises the overall band gap thus shifting emission into the visible spectrum. White LEDs can exhibit exceptional lifetimes, exceeding 50000 hrs, when operated under ideal conditions. Unlike an incandescent bulb filament operating at over 1000 °C, an LED device junction temperature should be kept under 120 °C. In order to meet this requirement the package and system materials and thermal design become crucial. Unlike traditional 5 mm devices with a package thermal resistance of 300-400 K/W, a power LED package resistance needs to be less than 20 K/W. At elevated temperatures the lumen depreciation with time is enhanced and performance is degraded (Arika et al, 2004).

High-power LEDs are becoming popular in recent years. Normally, about twenty percent of power input to LED is converted into the light energy and the remaining eighty percent of energy converted into heat, so it is important to dissipate the generated heat. The higher the power, the more the heat is produced. If the heat could not be dissipated immediately, it will concentrate on the tiny LED chip and cause the junction temperature of the chip to rise to a harmful level. It has been experimentally demonstrated that the life of LED decreases with increasing junction temperature in an exponential manner. Therefore, low junction temperature is essential for LED performance, which is a distinguishing feature of LED lamp versus traditional lighting. Since the market requires that LEDs have high power and packaging density, it poses a contradiction between the power density and the operation temperature, especially when LEDs are operated at a normal or higher driver current to obtain the desired lumen output. So heat dissipation becomes a key issue in the application of high-power LED (Xiaogai et al 2011).

Traditional incandescent lambs are energy consuming devices with high heat emitting rate. For a 100W incandescent lamb, 12% consumed energy is converted into heat, 83% energy becomes infrared radiation, and only 5% turns to visible light. In contrast, for a light-emitting diode, so called LED, 15% to 30% consumed energy is converted into visible light, and the rest becomes heat. In recent years, due to the rising awareness of environmental issue, the high luminous efficiency LED, contributed by low power consumption and long life time, has great potential for lighting application. A higher power LED produces relatively more heat, which makes heat dissipation become very important (Li-Ming Chu et al, 2015). This work provides the solution to LED bulb short life emanating from poor heat dissipation at the hot spot through the installation of a hybrid pin and trapezium fin aluminum heat sink. The larger heat dissipation rate capacity engendered by the hybrid heat sink installation leads to better lighting efficiency and consequent durability of the bulbs.

III. Objective

The objective of this work is to develop and incorporate a hybrid heat sink in LED bulbs production, for quick heat dissipation from the hot spot; leading to prolonged bulb life thereby saving money from the enhancement of the bulbs operational lives.

IV. Methodology

The work includes the assessment of failure modes of conventional LEDs followed by heat sink surface area configuration analysis and the determination of hybrid heat sink structure for enhanced capacity heat dissipation from the hot spot. The designed structure was effectively modeled and manufactured. Finite Element Analysis (FEA) approach was used to execute thermal modeling and analysis of all models with SolidWorks Simulation Premium 2014. Tetrahedral element was used in meshing. DIRECT SPARSE algorithm was used by solver. The methodology is known for high accuracy for conductivity gradient and also incorporates fluid mechanics.

V. Conventional LED bulbs

Certain elements found in the middle of the periodic table (the orderly grouping of chemical elements) are normally insulators, but they can be turned into conductors with a chemical process called doping and are then called semiconductors. Neither pure silicon (Si) nor germanium (Ge) is great conductors. They form a crystal lattice by having each atom share all of its 4 valence electrons with neighbouring atoms. The total of eight electrons cannot easily be jiggled out of place by an incoming current. If, however, the crystalline array is "doped" (mixed with an impurity) with arsenic which has five valence electrons, the behaviour of the lattice will change. Four bonds will still be made but there will be a leftover electron that can wander through the crystal. This is called an n-type semiconductor. Boron can also be used to dope a pure crystal of silicon. But since boron only offers 3 of the four electrons that a silicon atom needs, each silicon center is left with a hole. Semiconductors made in this manner are called p-type.

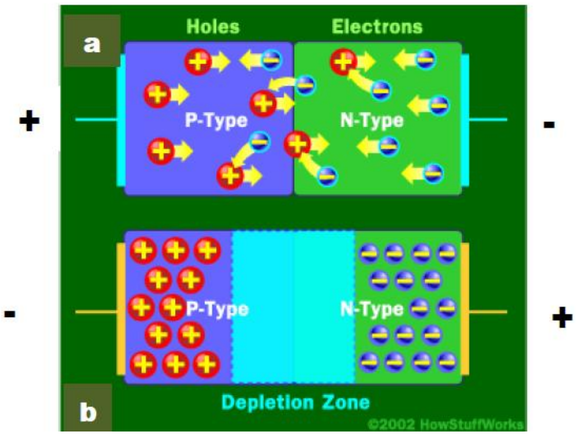

Figure 1 (a) and (b): P-N Junction

Semiconductors arranged with p type and n type having a junction as shown in (figure 1 (a) at the top of the diagram) above are called diodes. Diodes only allow electricity to flow in one direction through them. In figure 1(a), we see that if the negative end of the battery is attached to the n-type side of the diode, incoming electrons will dislodge the crystal's extra electrons towards the junction between the p-type and type materials. Meanwhile, as the electrons from the p type material move towards the positive end of the battery, they leave a trail of positive holes. At any given moment, at the junction we now have electrons on the n-side, and holes on the p-side. Electricity will flow. If we reverse the polarity (see bottom part of diagram), the holes will be "moving "towards the negative (-) end of the battery as the electrons move towards the junction. Meanwhile, the extra electrons from the n-material will move towards the positive (+) end of the battery. A depletion zone is created at the junction, and the diode will not conduct. When an electric charge passes through this diode, it activates the flow of electrons from the negative to the positive layer. Those excited electrons emit light as they flow into the positively charged holes. This application of diodes is referred to as Light Emitting Diodes (LED). The LED structure for lighting is shown in figure 2.

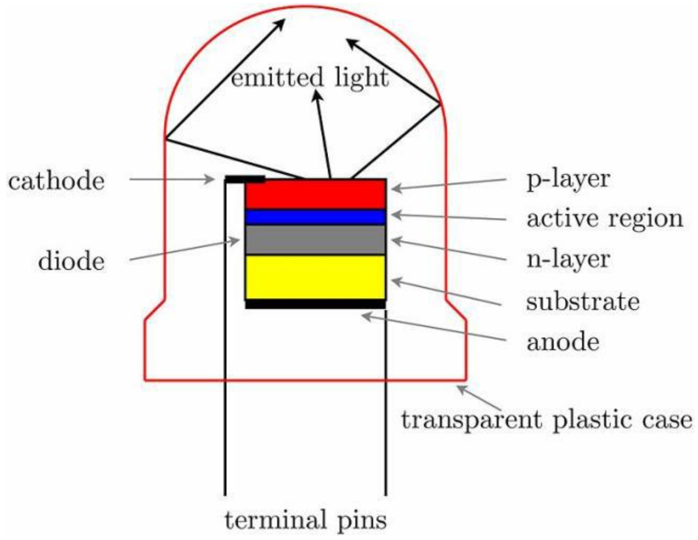

Figure 2: LED Structure

An LED lamp contains power conversion electronics (AC/DC), driver IC for the LEDs, a heat sink for thermal management and optics to optimize light quality. Since LED bulbs are intended to be form factor-compatible with current incandescent and CFL bulbs, they will have an AC/DC power supply circuit so they can operate from standard bulb "sockets." A schematic diagram of LED bulb is shown in figure 3.

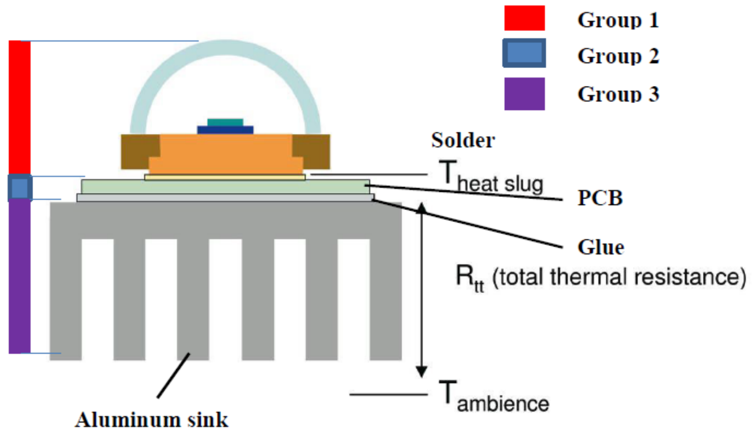

Figure 3: Schematic diagram of LED bulb structure

Group 1 is the LED itself and mainly remains untouchable. Its centre is a die and a heat slug, a copper part, which connects the die with the bottom of the LED. Group 2 is the heat sink, transmitting energy from a heat source to a heat drain. This is usually the surrounding air either with free or forced convection. The heat sink is usually made with aluminum flat fins. In-between group one and two is Group 3 providing mechanical connection, electrical isolation and thermal transmittance. That seems contradictory since most materials with good thermal conductivity conduct as well electricity. Vice versa almost every electrical isolation material translates into a thermal barrier. The best compromise is soldering the LED to a PCB which is glued on the metal heat sink (Veitl, 2009). At the solder the highest temperature T_{heat} plug is registered. It is then transferred through the Printed Circuit Board (PCB) and glued to the heat sink which dissipates the heat to the surroundings. If the heat is not dissipated quickly and efficiently the temperature at the Solder point would rise beyond acceptable value and damage the lamp. It is thus obvious that the predominantly hot climate of Nigeria requires an optimum heat dissipating heat sink for its LEDs. Most of the electricity in LEDs becomes heat rather than light. Removing heat from LEDs is therefore considered to be the key to enhancing their efficiency and lifetime. One of the most important issues for good thermal management of LEDs is the design of heat sinks of which shape, surface finish and material directly affect the heat transfer. Aluminum is light with excellent castability and formability and is one of the higher thermal conductivity values at 235 W/mK (Cho, 2015).

VI. Heat Sink

There are two ways for the cooling of the heat sink: passive cooling and active cooling. However, the fan for active cooling will cause some problems, such as noise and short lifetime, thus normally active cooling is not suitable for LED lamps. The heat is dissipated mainly by natural convection of the lighting body itself. The design of the lighting body with the function of heat sink is playing an important role in LED product today. There are many factors we need to consider in order to design an LED lamp with a good cooling system, such as structure, shape of the lamp, and material characteristic (Xiaogai et al, 2011). Usually powerful LEDs are mounted on a metal core PCB (MCPCB) that is attached to the heat sink. Thus heat release from the junction of the LED passes through the MCPCB board, which has good thermal conductivity and reaches the heat sink by conduction. While the heat transfer from the heat sink to the ambient is done by free convection (Andonova and Vakrilov, 2014).

There are many popular heat dissipating devices, such as heat pipe, heat sink, and fan. To most LED devices, heat sink is favored. The cooling fins design of heat sink will affect the LED luminous efficiency. This study developed a technology to design high efficiency heat sink for LED desk lamp. Light-emitting diode (LED) is a modern lighting device. If the heat dissipating mechanism of LED desk lamp is not well designed, the induced high temperature will cause the reduction of illumination and life time of lamp. Therefore, the heat sink design becomes a key technology for LED lighting device (Li-Ming Chu et al, 2015). Common shapes of conventional heat sinks are shown in Plates 1 -3, below.

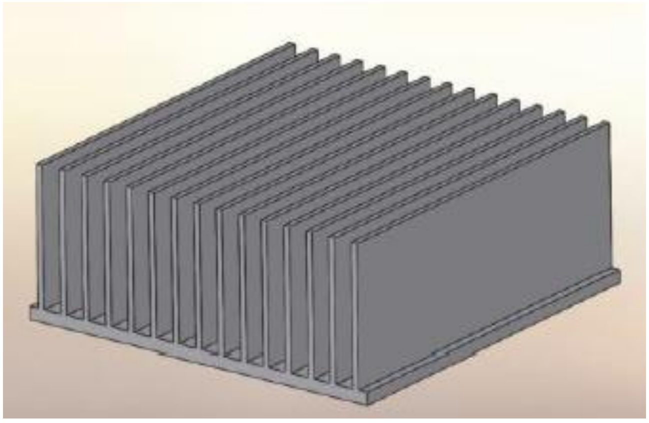

Plate 1: Rectangular fin heat sink for LEDs

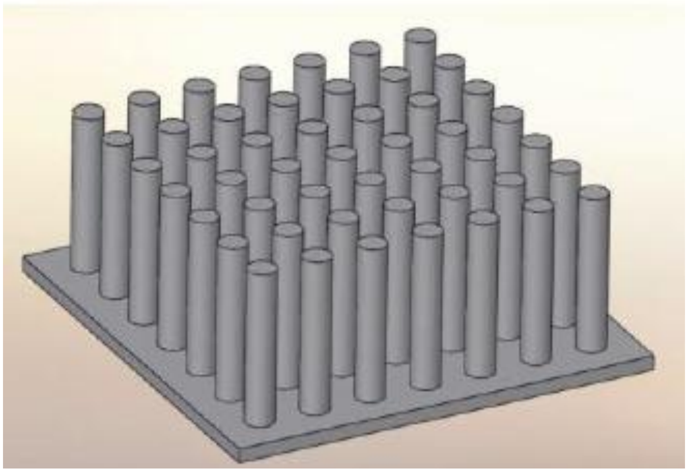

Plate 2: Pin fin heat sink for LEDs

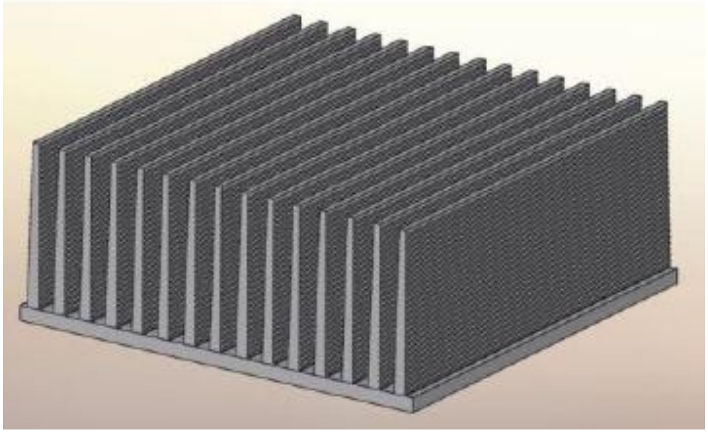

Plate 3: Trapezoidal scaled fin heat sink for LEDs

Conventional heat sinks are made of aluminum material. The most common LED applications use heat sinks from aluminum and copper. In most cases the use of aluminum heat sinks is preferred, because they are easily handled and have low weight. Pure aluminum heat sink shows temperatures very close to those of the copper heat sink. It has a high thermal conductivity and is easily handled and has a cost lower than that of copper, which makes it an optimal choice for material for the heat sink (Andonova and Vakrilov, 2014). Most heat sinks are of rectangular or square shape (Plate 1). The pin fin (Plate 2) is a recent introduction which performance runs closely to that of the square or rectangular sink. The rate of heat dissipation has been found to vary with shapes since it is dependent on the surface areas of the sink. It is observed that thermal mass, exposed surface area and geometric placement of fins plays a key role in deciding performance of fins and Heat Sink (Pal, 2014).

A comparative thermal simulation results presented on basic rectangular fins, pin fins and trapezoidal scaled tapered fins using SolidWorks Thermal Simulation by Pal (2014), shows the least case temperature is recorded for trapezoidal scaled fin heat sink at 440 C. (Pal, 2014).Trapezoidal scaled fins generated the highest surface area on the same 150mm x 150mm base area. Furthering thermal investigations with different shapes of varying surface areas; the new Pin-trapezium fin was invented leading to the emergence of this novel Brand of LEDs.

VII. Pin Trapezium Hybrid Fins Heat Sink LED Bulb

Figure 4 and 5 depict the orthographic and isometric views of the novel pin-trapezium fins heat sink. Pin Trapezium Hybrid Fins Heat Sink LED Bulbs are light emitting diodes with case temperature below or equal to 42.5630C. This value is optimal compared to case temperatures of 46.480C, 51.4130C, and 44.8620C for the conventional square or rectangular pin and trapezoidal scaled fins respectively; reported by Pal (2014).

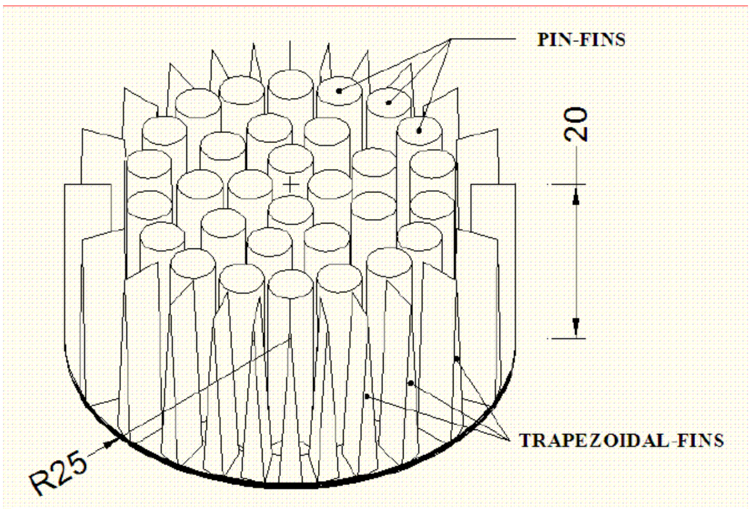

Figure 5: Isometric view of NASENI-ELDI (Pin-Trapezium Hybrid Heat Sink) LED Bulb

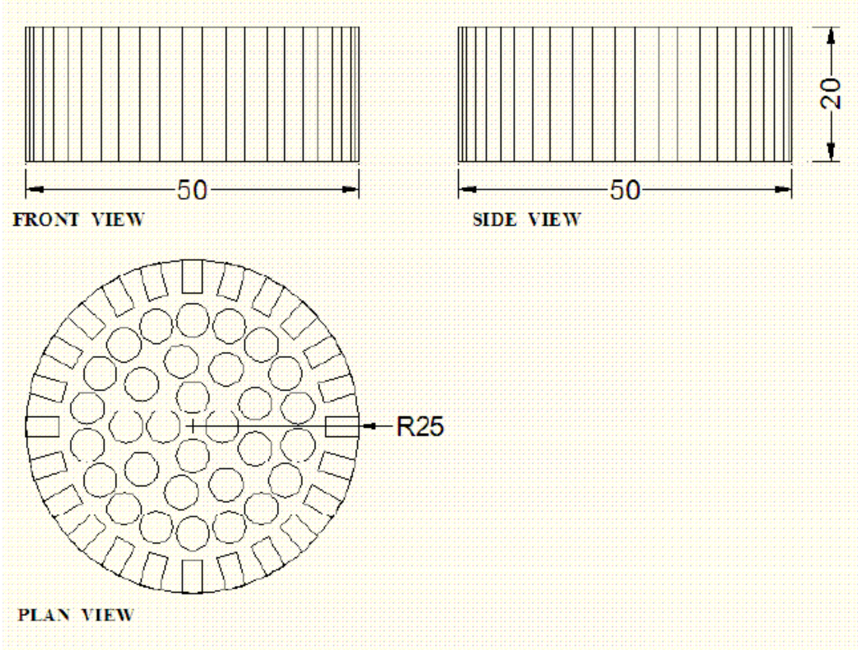

Figure 4: Orthographic view of
NASENI-ELDI (Pin-Trapezium Hybrid Heat Sink) LED Bulb

Finite Element Analysis (FEA) approach was used to execute thermal modeling and analysis of all models with SolidWorks Simulation Premium 2014. Tetrahedral element was used in meshing. DIRECT SPARSE algorithm was used by solver. The methodology is known for high accuracy for conductivity gradient and also incorporates fluid mechanics. The lowest case temperature obtained was occasioned by the systematic and iterative design of Pin and Trapezium Hybrid heat sink of aluminum material. Ambient was assumed as 250C. . Further simulation experimentations carried out on pin-rectangular hybrid and trapezium-rectangular hybrid fins yielded case temperatures lower than the 44.8620 C presently achieved case temperature of sole trapezium heat sink fins. The case temperature is however higher than the pin-trapezium fin configuration by about 2.50C. Plate 4 is a labeled picture of the components of the developed pin-trapezium hybrid fins heat sink LED bulb, emphasizing the heat sink. The block diagram, LED Arrangement and circuit diagram for 220V, 12W model of the novel LED bulb are depicted in figures 6, 7 and 8.

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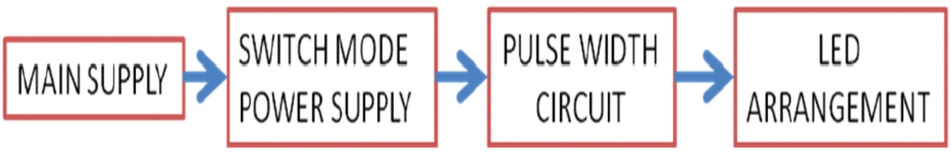

Figure 6: The Block Diagram

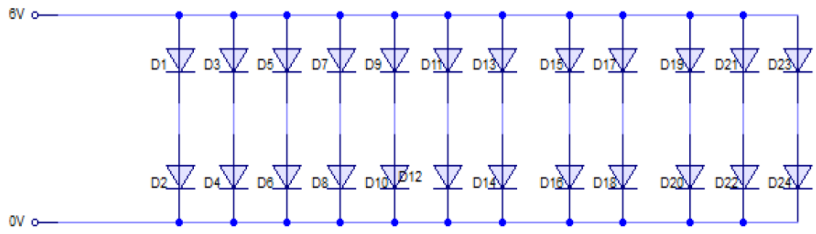

Figure 7: LED Arraignment

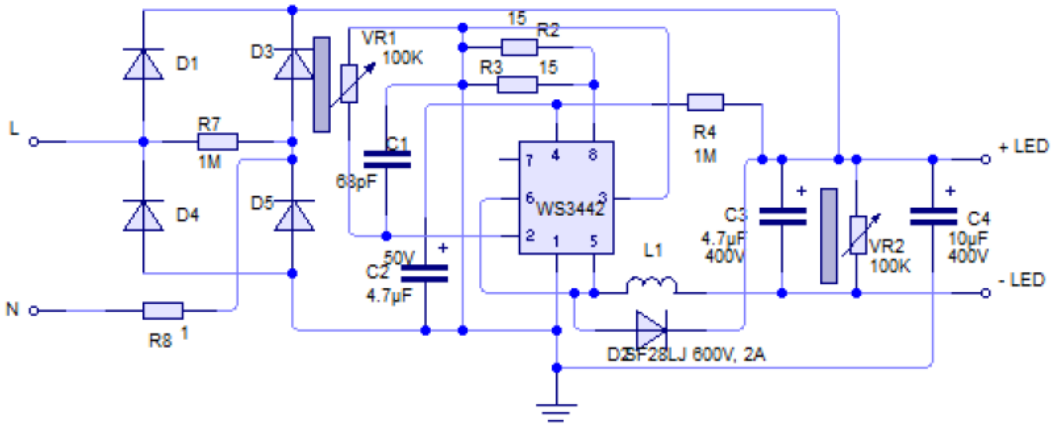

Figure 8: Circuit diagram

VIII. Conclusion

The novel Pin Trapezium Hybrid Fins Heat Sink LED Bulb (Plate 4), was developed at the Electronics Development Institute (ELDI), Awka, Anambra state, in collaboration with the National Board fpr Technology Incubation (NBTI) and Electrical Engineering Department of the Faculty of Engineering, Bayero University, Kano. It was patented in Nigeria in 2016 and has been found to last longer than other conventional LED bulbs.

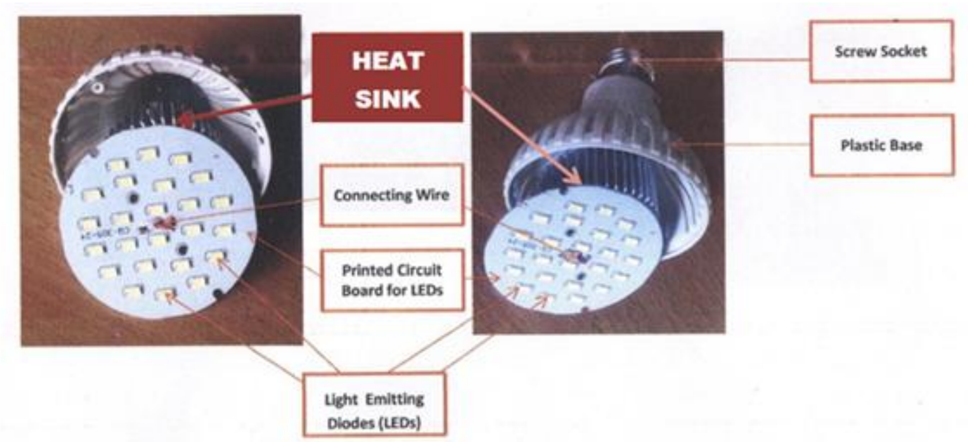

Plate 4: Novel Pin-Trapezium hybrid heat sink LED bulb

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