Evaluation of the Boosting Effect of Black Silicon Molecules in Mimosa Pudica Leaf Extracts on Solar Energy Transformation Efficiency

J. A. Nwaoga

Department of Pharmaceutical & Medicinal Chemistry, University of Nigeria, Nsukka, Nigeria

justusnwaoga@yahoo.com

***Abstract*-Mimosa pudica is now found to be a raw material for making photovoltaic cells capable of transforming solar radiation (energy) into electrical energy. Mimosa pudica is a medicinal plant of African origin. A local weed grows and thrives in the tropics. This plant belongs to the family: Fabacae, Genus: mimosa, Species: pudica, common name: mimosa, sensitive plant. It has physical features characterized by its ability to close the leaves when touched, the leaves open at sunrise, and then fold at sunset. The obvious control by the sun and photovoltaic response by the live Mimosa stimulated the interest to embark on the research. The Mimosa pudica solar cell electricity generation booster has been isolated using a profiled component leaf extract. This was done by using electrolytic process to separate the black silicon identified in the phytochemical analysis of the mimosa leaf extract. The isolates identified as black silicon, the thiosulfate and chloroplast as a composite is placed on a thin film PVC substrate. This produced a profound synergistic action in solar electricity generation. The addition of the crystalline black silicon to the composite slightly increased the transformation efficiency of the solar energy conversion. The microwave oven assisted the acid digestion of Mimosa pudica leaves with the resultant extraction of silica deposits. When the black silicon was added to the thiosulfate and chloroplast moieties, result showed graded shift in the transformation from 2-5%, thus raising the transformation efficiency from the usual current output of 250milliamps to 500milliamps, 6V DC output. The renewal time in the thin film coating was remarkable due to Nano particles of the black silicon providing increased surface area and the leaching effect of the thiosulfate which lead to expanded absorption spectra for solar activity. The finding is an improvement on the earlier demonstrated chlorophyll, thio-sulfate oxidation-reduction action resulting in electricity generation by Mimosa pudica solar cell accumulators.**

Keywords- Solar Energy; Electricity; Black Silicon; Photovoltaic Cell; Mimosa Pudica; Transformation; Efficiency

I. INTRODUCTION

Mimosa pudica is now found to be a reliable raw material for making photovoltaic cells capable of transforming solar radiation (energy) into electrical energy. Mimosa pudica is a medicinal plant of African origin. A local weed grows and thrives in the tropics. It belongs to the family: Fabacae, Genus: mimosa, Species: pudica, common name: mimosa, sensitive plant. It has physical features characterized by its ability to close the leaves when touched, the leaves open at sunrise, see Fig. 1, and then fold at sunset in Fig. 2. The obvious control by the sun and photovoltaic response by the live Mimosa plant stimulated the interest to embark on the research. The Mimosa pudica solar cell electricity generation booster has been isolated using a profiled component leaf extract. This was done by using electrolytic process to separate the black silicon identified in the phytochemical analysis of the mimosa leaf extract. The black silicon, thiosulfate and chloroplast make the composite for the thin film solar cell.

Fig. 1 Mimosa at sunrise

Fig. 2 Mimosa at sunset

Nanotechnology has contributed immensely to the scaling up of solar energy conversion to electricity for several applications [1]. Tremendous research efforts are put in place worldwide to explore the best options to follow in the quest to reduce the emission of greenhouse gases into the atmosphere while generating electricity. Such efforts are channeled into 4 areas:

1) Making current technologies in solar cell production cheaper;

2) Making energy transformation in the solar cells more efficient;

3) Developing new technologies and architectural designs for the solar cells;

4) Developing new energy carrier molecules that will serve as better light absorbers and more efficient energy converters [2].

Solar cells are designed to trap sunlight, like plant cells which store up solar energy inside micro photovoltaic structures where the photons they produce bounce around until they are converted into electrons. Given the large amount of energy in solar radiation (estimate suggest that it is the largest energy flow into the terrestrial ecosystem), its potential as rich resources and a crucial part of the renewable energy development is well known. Incident solar radiation is biologically and chemically converted to chemical energy (i.e. food) which is later transformed into electric energy [3], drew the attention of the scientific community that in plants, specifically Mimosa pudica the biomolecules that make up chemical energy is largely transformed into electric energy. He used the leaf extracts of the plants to develop bio-accumulators which are the building blocks of the photovoltaic cells from plant materials [3].

In similar studies, in solar energy elsewhere in the world, certain organic and inorganic substances play crucial roles in the noted energy transformation. Prominent among these are Cadmium, Selenium, Zinc, Silica, and their various combinations and have been found to serve as energy carrier molecules. Some elements like silicon have been ascribed with energy transformation and several other functions such as triggering natural defenses and participating in the different ways in which abiotic toxicities are alleviated. Silicon for example, is also known to be in chemically combined forms, a very ubiquitous element found in every part of many plants. Most importantly it was noted by botanists and material scientists that plants deprived of silicon are seen to have varying degrees of weaknesses and there structural development are more prone to abnormalities of growth, productivity and reproduction beyond solar conversion.

II. DISCUSSION

Pure silicon is a poor conductor. However, slight amount of impurities make it much more better conductor. Trace of an element like boron, added with three electrons in the outermost shell causes deficiency. Silicon is a semiconductor, the electrons are bound but not tightly, so that little excitation will free them and let them move about. On exposure to the sun energy in photons is absorbed to set electrons free from silicon atoms. It has high absorption of visible and (infrared) light.

Black silicon is a needle-shaped surface structure. It is single crystalline silicon and has a height above 10 um and a diameter less than 1 um. Its main feature is an increased absorption of incident light – high reflectivity of the silicon. The unusual optical characteristics combined with the semi-conducting properties of silicon make this material interesting for solar sensor applications. In 1999, a group led by Eric Mazur and James [4]. Carey at the Harvard University developed a process in which black silicon was produced by irradiating silicon with femto second laser pulses. After irradiation in the presence of a gas containing sulfur hexafluoride and other dopants, the surface of silicon develops a self-organized microscopic structure of micrometer-sized cones. The resulting material has many remarkable properties, such as an enhanced absorption that extends to the infrared below the band gap of silicon, including the wavelengths for which unmodified silicon is transparent. This property is caused by sulfur atoms being forced to the silicon surface, creating a structure with lower band gap and therefore the ability to absorb longer wavelengths. In a similar manner, the sulfur atoms in the thio-sulfate molecule have a notable effect on black silicon which extended the visible range of the absorption range in the electromagnetic spectrum. This is what is called the synergistic effect in the composite. The sulfur atoms act as dopants to the silicon moiety, increasing the electron flow as well as creating a surface to accommodate lower band gap. This gives the plant the ability to absorb longer wavelengths. In live Mimosa, the leaves open during the day despite its dullness.

III. BACKGROUND OF STUDY

Black silicon is created by laser processing silicon wafers in a sulfur hexafluoride atmosphere. It has been said earlier that the surface of silicon develops a self-organized microscopic structure of micrometer-sized cones. The resulting material has many remarkable properties, such as an enhanced absorption that extends to the infrared below the band gap of silicon.

Black silicon is a semiconductor material, a surface modification of silicon. It is a needle-shaped surface structure. It is single crystalline silicon and has a height above 10 um and a diameter less than 1 um [5]. This modification was discovered in 1980s as an unwanted side effect of reactive ion etching (RIE). Reaction etching is a standard procedure for producing trenches and holes with a depth of up to several hundred micrometers and very high aspect ratios [5]. Another method for forming a structure was developed in Eric Mazur's laboratory at Harvard University (1998) as seen in Fig. 3. Its main feature is an increased absorption of incident light – high reflectivity of the silicon. The unusual optical characteristics combined with the semiconducting properties of silicon make this material interesting for solar sensor applications. In 1999, a group led by Eric Mazur and James Carey at the Harvard University developed a process in which black silicon was produced by irradiating silicon with femtosecond laser pulses [6]. After irradiation in the presence of a gas containing sulfur hexafluoride and other dopants, the surface of silicon develops a self-organized microscopic structure of micrometer-sized cones. The resulting material has many remarkable properties, such as an enhanced absorption that extends to the infrared below the band gap of silicon, including the wavelengths for which unmodified silicon is transparent. In Fig. 4, the enhanced absorption scan of the black silicon of the mimosa is as a result of leaching action on the silicon surface, creating a structure with lower band gap and therefore the ability to absorb longer wavelengths [7].

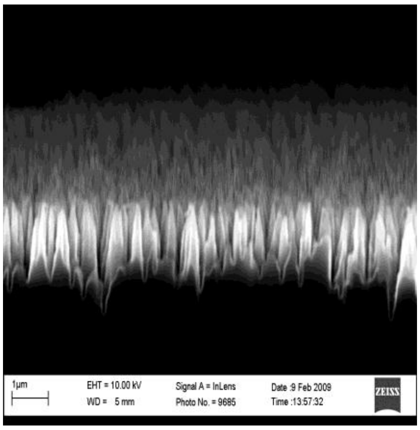

Fig. 3 Scanning Electron Micrograph of black silicon produced by cryogenic reaction ion etching [5]

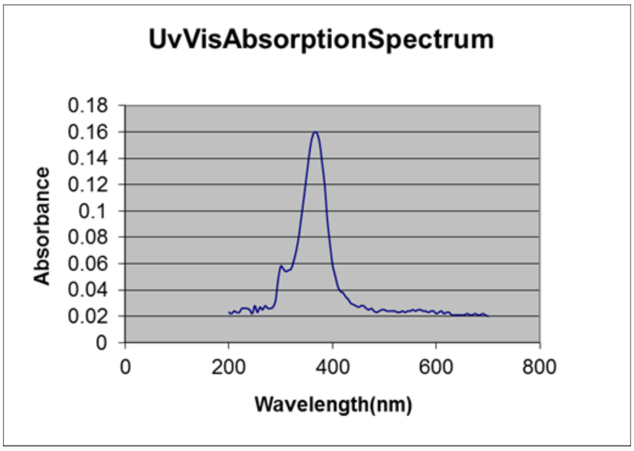

Fig. 4 The absorption spectra of silicon isolated from the mimosa extract (scanned at the pharmaceutical & medicinal chemistry department university of Nigeria, Nsukka)

Considering the absorption spectra of the silicon above, it will be noticed that the physical mechanism that causes the absorption across the visible spectrum extend well into the infrared for black silicon. According to W. Jody Mandeville 2001, in Fig. 5, the increased absorption (and resulting response gain in detectors) is appealing for military applications. Demonstrated techniques to enhance UV, Visible, and IR absorption of silicon dramatic indicate increase in absorption across the visible spectrum [8].

The potential applications include:

- Thermal imaging cameras;
- Photo detector with high-efficiency through increased absorption [9];
- Solar cells etc. [10];
- Image sensors with increased sensitivity [11].

The silicon isolated from the Mimosa pudica has been identified as back silicon having the similar chemical and physical properties. The deposition on the negative electrode plate of the electrolysis shows fine needle shaped crystalline and reflective silicon on removal from the electrolyte (Fig. 6).

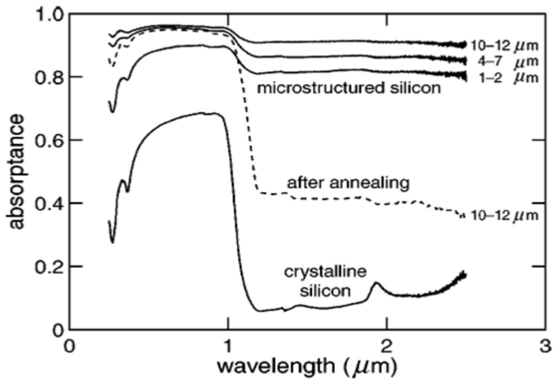

Fig. 5 Demonstrated technique to enhance Ultra Violet, Visible and Infra-red absorption of silicon shows dramatic increase in absorption across the visible spectrum [8]

Fig. 6 Electrolysis deposition of the white needle-shaped black silicon on a plate

The solar cell works in three steps:

- Photons in sunlight hit the solar panel and are absorbed by semiconductor material, such as silicon;
- Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference. Current starts flowing through the material to cancel the potential and this electricity is captured. Due to the special composition of solar cells, the electrons are only allowed to move in one direction;
- An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

IV. THE PURPOSE OF THE STUDY

The purpose of the study is to evaluate the boosting effects of black silicon (amorphous or micro-crystalline forms) of Mimosa pudica, on solar energy transformation and what it does to the efficiency, and transformation into electricity.

The chief material is the Mimosa pudica leaves. The collection is shown in the picture above in Fig. 7. Mimosa pudica is a wild herb growing luxuriantly in the rainforest – savanna mosaic ecological zone of Southeastern Nigeria. It is easily collected and transported to the laboratory. The method of using the extracts of this plant to develop electricity generating bio accumulators is found in Fig. 8.

Fig. 7 Collection of Mimosa pudica

Fig. 8 Mimosa pudica is a wild herb growing luxuriantly in the rainforest – savanna mosaic ecological zone of Southeastern Nigeria. It is easily collected and transported to the laboratory. The method of using the extracts of this plant to develop electricity generation

V. METHOD USED IN THE EXTRACTION OF SILICON FROM PLANT

The Mimosa pudica leaves were collected using cutters. After the exercise, the harvested leaves were placed in the hot air oven at 100 ^{o}C for an hour to dry. The initial weight recorded was 335g. The dried leaves were pulverized using mortar and pestle. Two units of 50g were weighed out. The pulverized leaves were placed in the soxhlet extraction unit to completely extract the chlorophyll constituents using distill water. Separation of chlorophyll from other constituents was effected using a mixture of petroleum ether and aqueous methanol. This yielded two components of chlorophyll a and b. The chlorophyll of interest is chlorophyll b present in aqueous methanol layer, after concentration the yield was 6g.

VI. REFERENCED PROCESS OF EXTRACTION OF SILICON FROM THE PLANT

Silicon in Mimosa pudica is extracted through many methods, but in this study, the rapid dilute acid extraction and spectrometric molybdenum yellow method of is used. Each batch consisting of 0.5g dry weight of the Mimosa leaf was treated directly with 10 ml of 0.6 M dilute hydrochloric acid and micro oven digested for 2 hours). The solution was decanted and the concentration of silicon was established spectrophotometrically [12].

Applying the spectrometric molybdenum yellow method, the silica in the plant extract was diluted by addition of 40 ml of distilled water and the silicon in the extract was measured. To do this silicon in 0.1 ml of the diluted extract was determined in 8 minutes. Changes of the plant weight were also made and silicon content measured.

VII. RESULTS

The evaluation commenced with the application of the Mimosa pudica extract on a PVC substrate. The ratio of the Chlorophyll, black silicon, thio-sulfate, in the following ratios; A (1:1:1), B (1:2:1), C (2:1:1), respectively. The milligram weight used was 100mg for each isolate. Further investigation was made by varying the concentration of black silicon in A, B, C; and its role as a semiconductor was observed. The boosting effects of silicon (amorphous or micro-crystalline forms), on solar energy transformation and what it does to the efficiency, and transformation into electricity was determined. The graph in Fig. 9 is explicit on the outcome of the silicon activities. Ratio, B which has the (1:2:1) chlorophyll; black silicon; thio-sulfate respectively, produced highest current value of 500mA. The transformation was enhanced by the semiconductor property of the black silicon which triggered (in other words, becomes a conductor) current flow on interaction with sulfur atoms. This property is caused by sulfur atoms being forced to the silicon surface, creating a structure with lower band gap and therefore the ability to absorb longer wavelengths that is appreciated in Fig. 10. The reference absorption scan in Fig. 11 stands as a standard for comparison with the practical results.

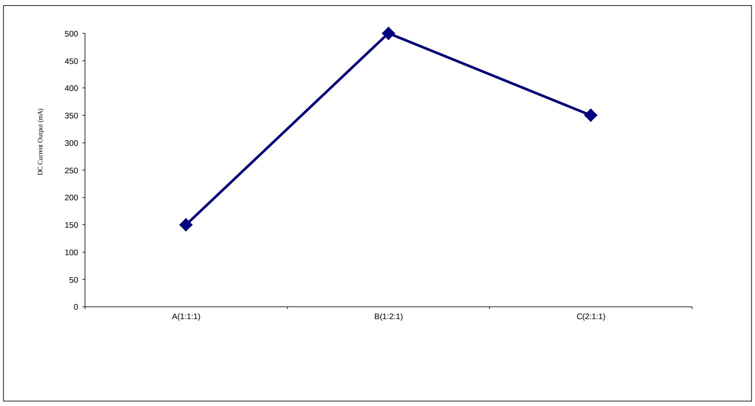

Fig. 9 Current output vs concentration ratio of chlorophyll A (1:1:1), black Silicon B (1:2:1), and thio-sulfate C (2:1:1) composite

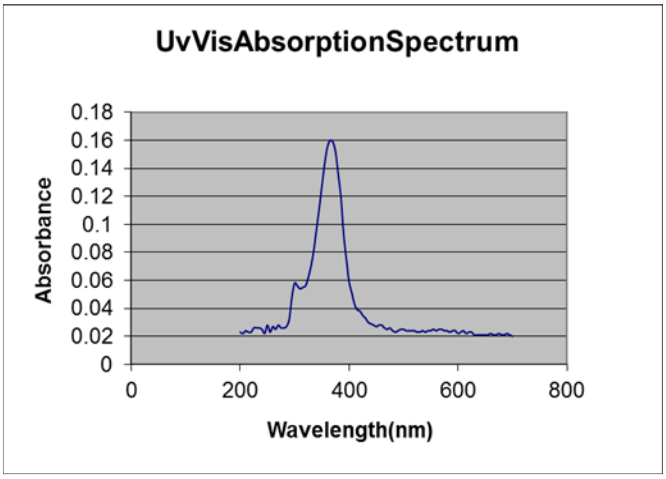

Fig. 10 The absorption spectra of black silicon isolated from the mimosa extract (scanned at the pharmaceutical & medicinal chemistry department university of Nigeria, Nsukka)

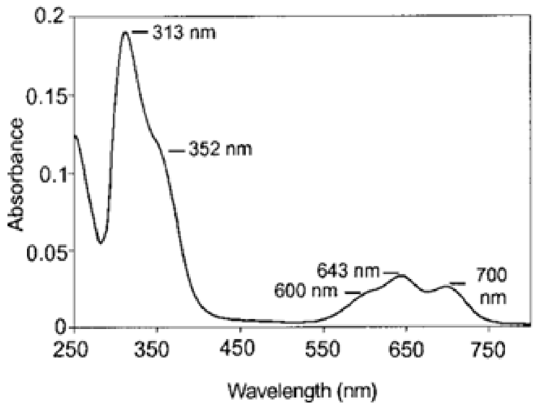

Fig. 11 Standard scan of the absorption spectra of black silicon [8]

The efficiency of a solar cell may be broken into the reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. As illustrated in Fig. 9, the overall efficiency is the product of each of these individual efficiencies. The present study is on the current transformation, that is, conductive efficiency of black silicon in the silicon, thiosulfate and chlorophyll composite.

A. *Reaction Tests for Silicon*

A qualitative test for silicon in organo silicon compounds, the compound is oxidized to silica with conc. sulfuric acid, plug glacial acetic acid or 70% nitric acid. The treatment 0.1g sodium fluoride in a test tube with 2 ml of concentrated sulfuric, silicon tetra fluoride vapor was observed followed by a white deposit of silica which indicated the presence of silicon [12].

Further test for silicon is the addition of 1 ml organo silicon sample to 2 ml of 0.1 N potassium permanganate. Observation - reduction of permanganate to black insoluble precipitate of Manganese oxide.

B. *Reaction Test for Thiosulfate*

For thiosulfate radical, a pinch from the ash sample was taken, placed in test tube. Distilled water was introduced to wash out the soluble part it was later decanted into another test tube. To the solution barium chloride was added. A heavy white precipitate soluble in dilute hydrochloric acid confirmed thio-sulfate [13].

C. *Innovation*

One of the accepted alternative energy sources revolves around solar energy which has since assumed the role of major contribution to the power portfolio. The interest in solar field has led to new and innovative technologies such as the mimosa solar panel. This is an original research both in conceptualization an implementation techniques. The innovation was conceived following the observed phenomena displayed by the Mimosa pudica leaves. Mimosa has physical features characterized by its ability to close the leaves when touched whilst the leaves open at sunrise and fold at sunset. The obvious control by the sun and photovoltaic response by the live mimosa plant stimulated the interest to embark on the research.

The discovery of the Mimosa pudica for solar development has explored and isolated the compounds responsible for the electrical potential and renewable property in the plant. The design was initially in form of solar accumulator, later improved as a thin film solar panel from a composite of the isolates (black silicon, chlorophyll and thiosulfate. What makes remarkable is that the energy is renewable on exposure to solar radiation. It is a reflection of the intrinsic property of Mimosa pudica as monitored in the live plant when the leaves open in daylight. Photovoltaic cells constructed with this weed extracts are exposed in sunlight and are found to accumulate solar energy which is transformed to electrical energy. Electrical energy stored is subsequently packaged to power various domestic appliances. The energy is renewable after exhaustion due to inherent solar properties of the isolates, especially the black silicon. Furthermore, the assemblage is at minimal cost when compared to other forms of photovoltaic cell constructions. The Mimosa solar panel in Fig. 12 is the improved version of the thin film modules and arrays of the solar cells.

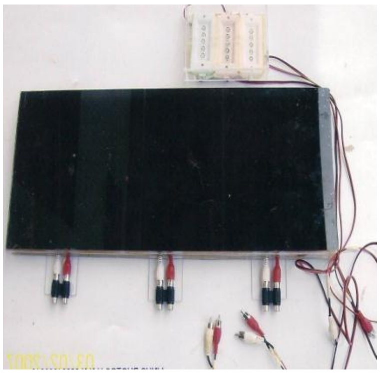

Fig. 12 Prototype of thin film Mimosa pudica solar panel

VIII. CONCLUSIONS

The results have shown that the crystalline black silicon content of the Mimosa pudica is the active constituent of the photovoltaic transformation activity in the live plant. As clearly demonstrated on the thin film substrate, the varied milligrams of the black silicon in the thiosulfate, chlorophyll ratios had synergistic action in solar electricity generation and transformation. This is an indication of renewability attribute of black silicon in Mimosa pudica. Photons in sunlight hit the solar panel and are absorbed by semiconductor material, such as silicon. The emergence of Mimosa pudica as solar energy material has introduced one way of reducing cost in developing cheaper solar panels. Method of obtaining silicon from bound state in silica is costly. It is a high energy process. Silicon from Mimosa pudica has an added advantage that it can be used in thin film wafers solar cells.

From the deductions on the graph in Fig. 13, one can appreciate the effect of black silicon in the composite of chloroplast black silicon and thio-sulfate making ratio variations of B (1:2:1) and C (2:1:1), A (1:1:1), respectively. The current output of 500 mA in Fig. 13 is an indication boosting effect. This means that the quantity of black silicon in the B composite had a boost in current transformation which is about 75% increase. The current output was replicated after exhausting the energy in the cells. All these activities of black silicon are energized by solar energy which accounts for the reduction in renewal time and energy transformation efficiency.

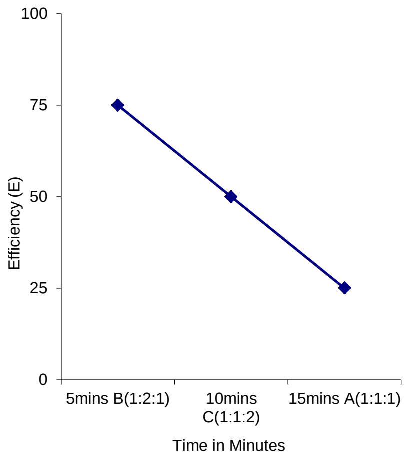

Fig. 13 The renewable time Vs composite of, black siliconthio-sulfate and chloroplast, B (1:2:1), C (1:1:2), A (1:1:1) respectively

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