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New Review of Dye Sensitive Solar Cells

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Abstract - *The aim of this study is to synthesize and study a new composition of silicon-containing phthalocyanine pigment, which is a phthalocyanine-based dye pigment, which is now used as a dye for dye-sensitive solar cells, which is one of the alternative energy sources. Is calculated. To achieve this goal, a silicon-containing phthalocyanine pigment-containing sodium hexafluorosilicate, urea, and phthalic anhydride were synthesized and studied. Based on the results of IR spectroscopic analysis, a pigment formation reaction was proposed, and scanning electron microscopic data were presented. Its differential thermal analysis, photodynamic analysis, and its relationship to inorganic and organic solvents were also analyzed. The optical absorption of the pigment was analyzed on a V-5000 spectrophotometer at wavelengths in the spectral with from 320 nm to 1000 nm. The study was performed in 5% and 20% dimethylformamide solutions. Absorption peaks have been reported to be well absorbed in wavelengths in the range from 400 nm to 500 nm. Derivatographic studies of the resulting pigment show that the main mass loss occurs in the range from 110-482°C, in which 18.25% of the basic mass, or 3.21 mg of mass, is lost, which means that the pigment is thermally stable. Using a DT 9205A multimeter for 10 days as a result of measurements in dye-sensitive solar cells based on silicon-containing phthalocyanine pigment, the first day was marked as 522 (mV), 64.45 (mA), and the lowest as the highest voltage and current. As an indicator, 295 (mV) and 10.15 (mA) values were recorded on the last day of measurement. Despite its low efficiency, the silicon-containing phthalocyanine pigment in this composition has shown its strength as an effective semiconductor pigment for a new generation of dye-sensitive solar cells.*

Keywords - *phthalocyanine, synthesis, dye-sensitive solar cell, organic semiconductor, a large number of heterostructures, photoanode.*

I. INTRODUCTION

Metal-containing phthalocyanines have been used traditionally on an industrial scale for many years. They have long been used as dyes and pigments, especially in colored printing inks, as pigments in paints, plastics, metal structures, and as one of the main materials for dyeing synthetic fibers. In addition, the expensive photophysical and semiconducting properties of phthalocyanines allow for many promising projects in the future [1]. Phthalocyanines, like plant chlorophylls, form organometallic compounds (metal coordination complexes) [2]. They were exhibited good thermal and chemical stability and also had extensive optical and electronic properties that can be improved as a result of synthetic modifications such as attaching functional groups around their molecules [3]. In addition, the use of metallic and non-metallic phthalocyanines in photovoltaics has been actively studied in both organic solar cells and in the synthesis of pigment substances [4].

We also consider phthalocyanines as light-absorbing materials in new third-generation dye-sensitive solar cells (DSSC) [5-6], which are one of the alternative energy sources, given their photophysical, photoconductive, i.e., light-sensitive semiconductor properties. We are conducting research on lash [7, 8]. In this regard, macrocyclic molecules based on metallic and non-metallic phthalocyanines are very thermally and chemically stable and can withstand metals such as Li, Cu, Zn, Co, Mn, Fe, Sn, Al and P, S, N, Cl, F, H phthalocyanines obtained with have been well studied [9,10].

Organic semiconductor devices based on a large number of heterostructures are being intensively studied today due to the simplicity of production technology, the availability of flexible substrates in their production, and their relative cheapness [11, 12]. These organic semiconductor phthalocyanines are sensitive to sunlight, resulting in microanalysis of photoanode titanium dioxide TiO_2 materials in dye-sensitive solar cells (DSSC) [13, 14] and other (OFET) [15], i.e., in the manufacture of electronic devices. It is used in conjunction with liquid electrolytes to form a layer. The literature describes the use of phthalocyanine, which contains nitrogen and phosphorus preservative groups, in the development of the gas-sensing analyzers, and as well as their use as corrosion inhibitors resistant to aggressive external environments [16,17].

Based on the practical work done in this direction, has been taken certain results have been achieved, as well as large-scale measures are being taken to develop a scientific basis for the production of multi-component coatings and supply the domestic market with import-substituting products [18].

Silicon-containing phthalocyanine is a stable and high-intensity pigment in solution in solution compared to other metal-containing phthalocyanine complexes and has been analyzed by a V-5000 Spectrophotometer. In the future, these silicon-containing phthalocyanine-based pigments can be widely used and commercialized in dye-sensitive solar cells [19, 20]. Because these types of dye pigments are sensitive to the visible light spectrum and have good absorption properties, the electrons in the dye pigment molecule are excited when sunlight enters the dye molecule through a transparent glass substrate [21]. In the literature today, dye-sensitive solar cells are referred to as third-generation solar cells, using complex substances and natural pigments based on routine as dyes [22]. Because rutin-based complex compounds are economically expensive and their preparation process is very complex, we are conducting synthesis and research on the use of silicon-containing phthalocyanine pigment as a dye as an alternative to rutin dyes. Silicon-preserved phthalocyanine pigment differs from routine pigment in that it has a high assimilation coefficient, is environmentally friendly, and is inexpensive [23].

In this paper, a large amount of heterostructure-based silicon-containing phthalocyanine pigment, one of the organic semiconductor substances, was synthesized and tested in dye-sensitive solar cells due to its organic semiconductor and photosensitizing properties, and their studies were analyzed [24].

A. Purpose of work: Synthesis of new silicon-containing phthalocyanine and analysis of the composition and structure of the synthesized silicon-containing phthalocyanine pigment (SiPc) using the results of infrared spectroscopy and scanning electron microscopic analysis. Also, measure its power output in national volts (mV) and national amperes (mA) using a DT 9205A multimeter based on the synthesized pigment to form a transparent glass contact on one side. In addition, the relationship of the synthesized pigment to various solvents includes thermal analysis and analysis of the areas of optical absorption.

B. Research methods.

In this study, the results of an IR spectroscopic IR spectroscopy on a SHIMADZU IR spectrophotometer and an electron microscope scanning at MIRA 2 LMU SEM were used to study the synthesis of a new silicon-containing phthalocyanine pigment. A multimeter DT 9205A was used to measure the power dissipated from the contact based on the silicon-containing phthalocyanine pigment in this synthesized composition. In addition, data for thermal analysis using a differential thermal analysis derivatogramm of this pigment and optical absorption analysis on a V-5000 Spectrophotometer were presented.

II. EXPERIMENTAL PART.

The synthesis of silicon-containing phthalocyanine pigment was carried out by the most common method of obtaining metallic phthalocyanine dyes. The silicon-containing phthalocyanine pigment (SiPc) in the composition we synthesized was carried out in the presence of ammonium molybdate as sodium hexafluorosilicate, urea, phthalic anhydride, and catalyst. At the end of the reaction, the formation of blue-green crystals after additional purification and neutralization was consistent with the data in the literature that the product was formed [25]. The new photoconductive pigment synthesized is distinguished by various properties. For example, its thermal stability, sensitivity to sunlight, and stability in solution expand its range of applications. We are currently conducting research on the synthesis of this silicon-containing phthalocyanine pigment (SiPc) and its application to dye-sensitive solar cells (DSSC), a third-generation solar cell that is one of the alternative energy sources [26]. The reaction for the formation of the silicon-containing phthalocyanine (SiPc) pigment is described below.

$$4C_6H_4(CO)_2O + 8CO(NH_2)_2 + Na_2[SiF_6] \xrightarrow{kat,t} C_{32}H_{16}N_8Si + 8NH_3 + 4H_2O + 8CO_2 + 2NaF + 2F_2$$

Reaction to form silicon-containing phthalocyanine (SiPc) pigment.

III. RESULTS AND THEIR DISCUSSION

The composition of the obtained new product was analyzed on SHIMADZU spectrophotometer Figure 1. In the IR spectrum of the phthalocyanine pigment-containing silicon, the absorption frequencies of 3192 cm^{-1} belonging to the N-H-group of valence oscillations were observed. It was observed that the absorption frequencies of 1450-1600 cm^{-1} belong to the vibrational frequencies characteristic of the Si- (Ar) -bond bound to the aromatic ring of phthalocyanine.

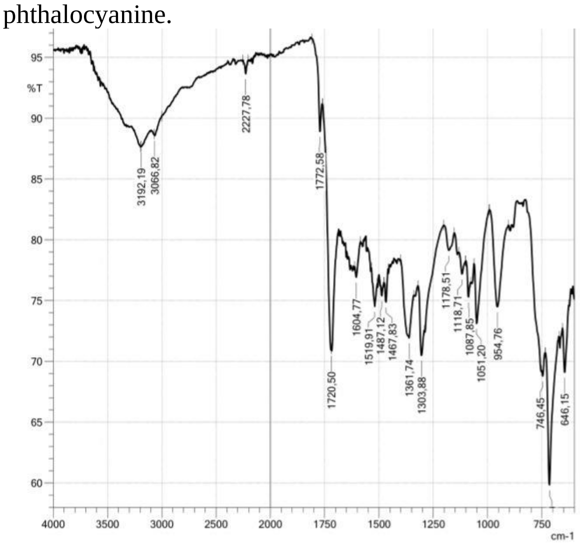


Fig 1. The infrared spectrum of silicon-preserving phthalocyanine (SiPc) pigment

It was observed that the absorption frequencies of valence vibrations in the aromatic ring belong to groups C=N in the areas 1467.83 cm^{-1} -1604.77 cm^{-1}. The presence of a pyrolysis ring in the area of 1519.91 cm^{-1}

was observed. The absorption area 2227.78 cm^{-1} $(C_2H_5)_2C = C(CN)COOC_2H_5$ was found to have a C≡N bond belonging to the $SOOS_2N_5$ group [27]. Absorption frequencies of 1303.88 cm^{-1} belonging to the C-O bond were observed. Secondary N-H bonds were observed at 3066.82 cm^{-1} absorption frequencies. 954,76-646,15cm^{-1} shows the presence of uneven deformation oscillations of the S – N bond in the fields. It was noted that the absorption frequencies in the range 2000–1600 cm^{-1} have a group of weak lines (composite frequencies), which are determined by the number and position of all aromatic compounds, depending on the type of benzene ring replacement.

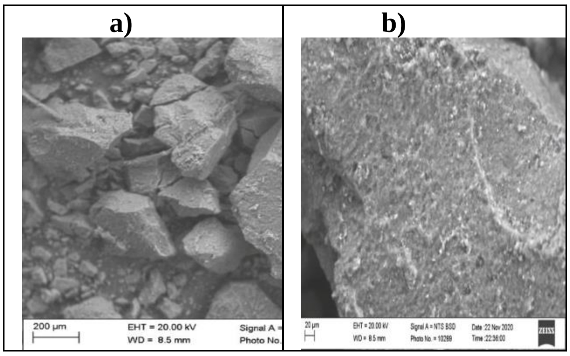


Fig 2. The appearance of silicon-containing phthalocyanine (SiPc) pigment in SEM

Fig-2 shows an image of the silicon-containing phthalocyanine (SiPc) pigment under a scanning electron microscope. The figure shows that the starting materials are completely dispersed from each other. The image, magnified a) -100, b) -500 times, gives information about the degree of reaction of the substance, the composition and structure of the layers close to the surface. However, from images a) -100 and b) -500 magnified, it can be seen that the high porosity of the pigment crystals and the absence of additives increase the intensity of the pigment. Also, given the pigment's good absorption of sunlight and its photodynamic properties, it can be used as a dye pigment in dye-sensitive solar.

The obtained analyzes showed a sample of the new silicon-containing phthalocyanine (SiPc) pigment in 1000-magnified images in SEM, leaving no residues of the reactants. This allows us to know that the reaction took place at the end, as well as the elemental composition of the substances formed in the reaction in parallel.

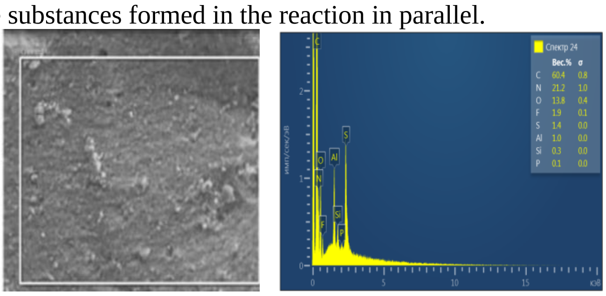


Fig 3. Elemental analysis image of silicon-containing phthalocyanine (SiPc) pigment in SEM.

Many phthalocyanine derivatives can be synthesized by replacing the two hydrogen atoms at the center of the phthalocyanine molecule with almost all the metallic and nonmetallic ions of the periodic table. However, the semiconducting properties of phthalocyanines are altered by electron donor or electron acceptor groups [28].

Table-1
Results of elemental analysis of silicon containing phthalocyanine pigment

Element	C	N	O	F	Al	Si	P	S
Quantity %	60.43	21.19	13.78	1.90	0.99	0.26	0.09	1.37

The elemental composition of a substance must be known in order to control the raw materials, production, and products used in any production. With this in mind, even in large clusters, elemental analysis on a separate surface was performed. Element analysis in large clusters showed that in addition to the silicon-containing phthalocyanine pigment at the study points, there were residual phosphorus residues from the substance used as the catalyst in the aluminum and incomplete reaction at the level.

A. Study of thermal analysis of silicon-containing phthalocyanine pigment

Thermal analysis of the new silicon-containing phthalocyanine (SiPc) pigment was performed in the temperature range of 20–500 °C. The resulting derivatogramm is shown in Figure 4, which consists of 4 curves. Analysis of the differential thermogravimetric analysis curve (DTGA) (curve 2) shows that the DTGA curve mainly occurs in 2 intensive decomposition temperature ranges. Decomposition range 1 corresponds to a temperature of 53-254 ^{0}C, and decomposition range 2 corresponds to a temperature of 258-479 ^{0}C

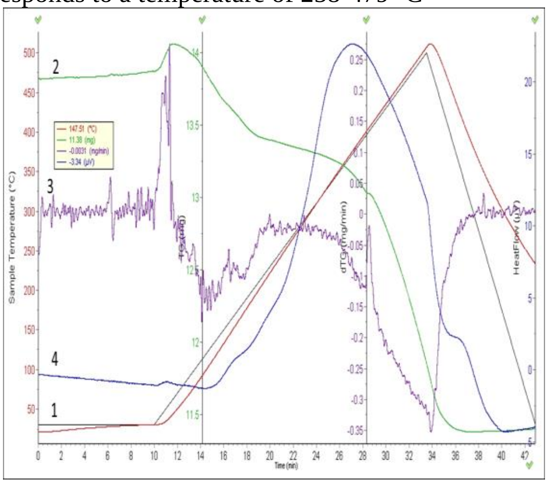


Fig 4. Derivatogramm of silicon-containing phthalocyanine pigment (SiPc).

1. Temperature curve; 2-differential thermogravimetric analysis curve (DTGA); 3-Derivative of the differential thermogravimetric analysis curve (DTGP); 4-DSK curve.

Analyzes have shown that intensive decomposition takes place in the 2nd decay interval. During this period, the amount of decomposition, i.e., 8.6% of decomposition, takes place. A detailed analysis of the differential thermogravimetric analysis curve and the DSK curve is given in the table below.

First of all, the mass is reduced by 3% due to the loss of moisture up to 100 ^{0}C. Subsequent mass loss occurs up to 150 °C, which results in the decomposition of excess urea by ammonia. Above 350 ^{0}C, the substance is liquefied, and the organic parts are decomposed into imine groups to ammonia and methane. Above 485 ^{0}C, a residue consisting of silicon fluoride and carbon coke is retained.

Table-2
Analysis of DTGA and DSK curves of silicon-containing phthalocyanine (SiPc) pigment [29]

№	Temperature,°C	Lost mass, %	The decomposition rate of the substance, mg/min	Amount of energy consumed (μV *s/mg))
1	50	0,946	0,147	0,25
2	100	3,082	0,122	3,55
3	200	4,621	0,489	1,01
4	300	8,606	0,197	2,02
5	400	14,21	0,235	3,02
6	500	18,32	0,235	2,14

These thermo-gravimetric studies show that the main mass loss is in the range of 110-482 ^{0}C. It loses 18.25% of the basic mass or 3.21 mg of the mass. After 485 ^{0}C, no change is observed, the mass remains unchanged.

The relationship of the obtained phthalocyanine pigment to various solvents was studied. This obtained silicon-containing phthalocyanine pigment was found to be well soluble in dimethylformamide and dimethylsulfoxide, insoluble in water, alkali, benzene, butanol-1, dioxane-1,4, and acetone. In addition, the peripheral substitution properties of phthalocyanines [30] effectively alter their spectral and electrochemical properties, as well as increase their solubility.

B. Analysis of photodynamic properties of silicon-containing phthalocyanine (SiPc) pigment

To study the photodynamic properties of the silicon-containing phthalocyanine pigment, it is necessary to analyze its spectral absorption characteristics. In the present study, the optical absorption of the silicon-containing phthalocyanine pigment was analyzed on a V-5000 spectrophotometer at wavelengths with a spectral width of 320 nm to 1000 nm. The studies were performed in 5% and 20% dimethylformamide solutions of the pigment. Figure 5 shows the measured optical absorption spectra of the silicon-containing phthalocyanine (SiPc) pigment relative to the solvent.

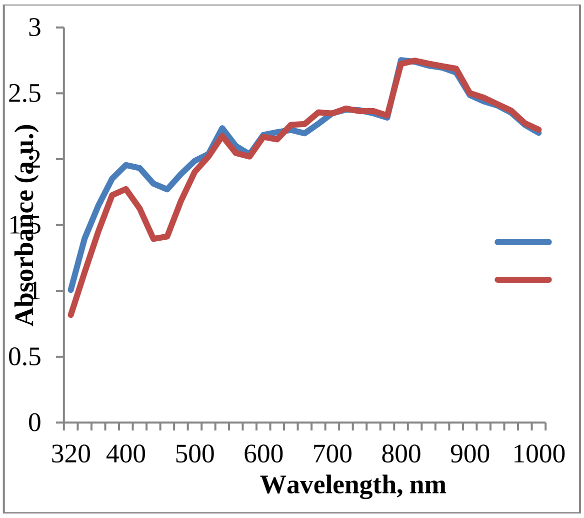


Fig 5. The optical absorption of silicon-containing phthalocyanine (SiPc) pigment.

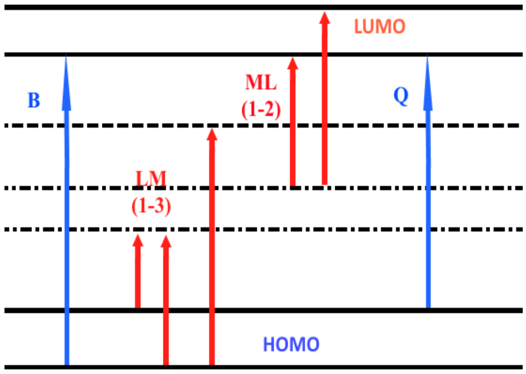
The optical absorption peaks of the obtained pigment showed characteristic peaks with high assimilation rates in the range of 380–560 nm and low levels of assimilation in the range of 800–920 nm. The remarkable chemical and photophysical properties of phthalocyanines are due to their multi-electron system. The band of strong optical absorption peaks results from the transition of p-p electrons from the ground state (HOMO) to the excited state (LUMO) energy levels [31].

C. Optical properties of phthalocyanine-based pigments

When the semiconductor phthalocyanine pigment molecules absorb light from the sun, the electrons transfer electrons from the highest energy-occupied molecular orbital (HOMO) to the lowest-energy molecular orbital (LUMO) should [32].

HOMO and LUMO are the highest molecular orbitals and the lowest molecular orbitals, respectively, and the zone of motion of the excited electrons. In the following diagram, the direction of motion of electrons in the highest and lowest absorption regions in regions (B) and (Q), i.e., the energy difference between HOMO and LUMO, or the HOMO-LUMO interval is sometimes called the boundary orbitals [33]. The electron energy difference between these two boundary orbitals can be used to predict the optical properties of metallic phthalocyanines in relation to incident light, as well as the intensity and stability of the pigments and their colors in solution.

The electron transition between the HOMO and LUMO orbitals, that is, the direction of movement of the excited electrons through the zones, is determined by the substitute radical molecules at the edges of the metal and phthalocyanine ring in the central atom. The electronic transition between these states creates two excited states. Molecular groups at the edges of the central atom and ligands affect the HOMO and LUMO transition energies. The above approaches are used in the physics and chemistry of phthalocyanines to describe their semiconducting and photosensitizing properties.



1-Scheme. The motion of excited electrons in phthalocyanines along with energy levels

Phthalocyanine molecules exhibit excellent optical absorption of visible and infrared light. It has been reported in the literature that most metallic phthalocyanines show very good absorption spectra in the range of 400 nm to 700 nm with a very good optical absorption range [34]. In addition, their absorption spectra may vary depending on the type of substituted radicals in the central atom and ligands. These absorption fields are materials of optical expansion.

D. Study of volt-ampere properties of silicon-containing phthalocyanine (SiPc) pigment

Pictures 6 and 7 below show the values obtained by measuring the power output (mV) and (mA) for 10 days using a DT 9205A multi-meter on contact based on the silicon-containing phthalocyanine pigment.

A 10% solution of phthalocyanine pigment-containing silicon was used to test the light-absorbing properties of phthalocyanine-based dye molecules. The voltage and current values of the semiconductor were measured by making a solution of the silicon-preserving pigment in dimethylformamide on one side using a transparent glass plate. It is very important to study the photoelectric and volt-ampere properties of the semiconductor pigment we recommend. This is because the literature uses a number of natural and synthetic pigments in dye-sensitive solar cells and provides efficiency values [35].

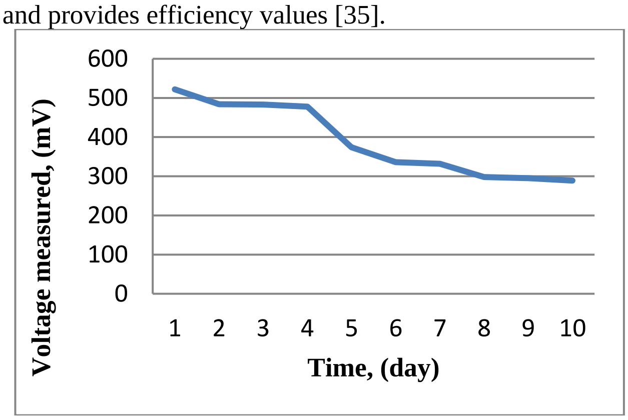


Fig 6. Power (mV) generated by a dye-sensitive solar cell

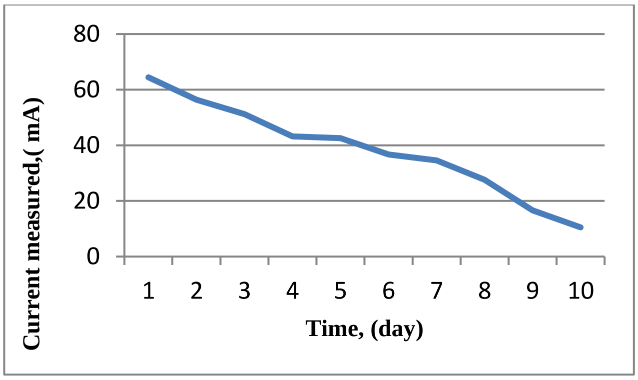


Fig 7. The power generated by the dye-sensitive solar cell is mA.

It was noted that the method of obtaining the pigment we used was simple and resistant to aggressive external environments; most importantly, the power output volt-ampere values were higher than the values given in the literature. During our measurements, the values of power output voltage and current varied slightly depending on the daily weather conditions and part of the day, so measurements were taken at different parts of the day, and their averages were given. From the above results, the highest value of voltage and current was 522 (mV) on the first day, 64.45 (mA), and the lowest value was 295 (mV), 10.15 (mA) on the last day of measurement. Values were recorded.

Despite its low efficiency, this silicon-containing phthalocyanine pigment has proven to be an effective semiconductor pigment for a new generation of solar cells. Therefore, silicon-containing phthalocyanine pigment may be an alternative semiconductor pigment in the preparation of a new generation of dye-sensitive solar cells. Further research on the technique of synthesizing pigments based on phthalocyanine and its derivatives is crucial to increase efficiency. Studies have shown that the synthesis temperature, the nature of the solvent, and the pH of the medium affect the efficiency of the energy output [36].

E. The difference between dye-sensitive solar cells and silicon-based solar cells

The differences between dye-sensitive solar cells and silicon-based solar cells are as follows: Effect of angle of incidence: Si silicon-based solar cells react sensitively to changes in the angle of incidence of light, so the decrease or increase in efficiency varies depending on the angle of incidence; however, no decrease in efficiency depending on the angle of incidence was observed in dye-sensitive solar cells (DSSCs). Due to this feature, the amount of power produced on a cloudy day or in the morning and evening is higher than other solar elements, so despite their relatively low efficiency, daily energy production is preferred. This means that solar elements of this type make it impossible to control the angle of incidence of the light, which is also suitable for application to the walls of buildings and to a building facing north.

Temperature effect: When the temperature rises from 25 °C to 45 °C, the efficiency of Si silicon-based solar cells decreases by more than 10%. However, in dye-sensitive solar cells, the efficiency increases with increasing temperature, but when the temperature rises above 45 ℃, the efficiency can decrease by 5% or more.

Shadow effect: The generation of electricity in Si silicon-based solar cells results in a decrease in the amount of light due to the shadow effect, resulting in decreased sensitivity and slower reaction rate, but due to the high electrochemical power of paint-sensitive solar cells, the reaction rate decreases as energy production decreases.

IV. CONCLUSION

The formation of the newly synthesized silicon-containing phthalocyanine (SiPc) pigment was analyzed by infrared analysis, SEM analysis, spectral analysis, and comparison with existing phthalocyanines. According to the results of the thermogravimetric analysis of the obtained pigment, it was determined that it is thermally stable. Its relation to solvents in various solvents and its optical absorption spectra, or photodynamic properties, have also been studied. Because this pigment has the ability to absorb photons well from sunlight, the dye has been recommended as a dye pigment for sensitive solar elements. Intensive research is aimed at expanding the use of silicon-containing phthalocyanine pigment (SiPc) in future solar cell, photodiode, and energy collection applications. From the voltammetric results obtained, 522 (mV), 64.45 (mA) on the first day as the highest value of voltage and current, and 295 (mV) on the last day of measurement as the lowest value, 10.15 (mA) values were recorded. Despite its low power output, the silicon-containing phthalocyanine pigment in this composition has proven to be an effective semiconductor pigment for a new generation of solar cells. Therefore, silicon-containing phthalocyanine pigment may be an alternative semiconductor pigment in the preparation of a new generation of dye-sensitive solar cells.

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