Synthesis, Characterization, and Electrochemical Activities of Ruthenium(II) Bipyridyl-Dithiocarbamate Complexes

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Five heteroleptic ruthenium(II) polypyridyl complexes [Ru(FL1)(dcbpy)(NCS)] (1), [Ru(FL2)(dcbpy)(NCS)] (2), [Ru(FL3)(dcbpy)(NCS)] (3), [Ru(FL4)(dcbpy)(NCS)] (4), and [Ru(FL5)(dcbpy)(NCS)] (5) (where FL1 = aniline dithiocarbamate, FL2 = p-anisidine dithiocarbamate, FL3 = p-toluidine dithiocarbamate, FL4 = dibenzyl dithiocarbamate, and FL5 = diphenyl dithiocarbamate, dcbpy = 2,2’-bipyridine-4,4’-dicarboxylic acid, NCS = ammonium thiocyanate) have been synthesized and characterized with melting point, FTIR, UV-Vis, photoluminescence, and NMR (1H and 13C NMR) techniques, while the electrochemical activities of the complexes were studied using cyclic voltammetry. The FTIR of the heteroleptic complexes showed successful coordination of the ligands to ruthenium(II) ion, while the UV-Vis confirmed six coordinate octahedral geometry of the complexes, and the photoluminescence gave the photophysical properties with high intensities indicating potentials for dye sensitization. The electrochemical activities of the ruthenium(II) complexes showed redox potentials which could enhance the dye-sensitizing abilities.

1. Introduction

In the 21st century, increased use of energy fossil fuels mainly from nonrenewable energy sources, such as carbon-based fossil fuels, has resulted in environmental pollution and global warming; therefore, affecting human livelihood is energy [1, 2]. The use of renewable energy sources is used to control these challenges for sustainable development [1]. Among these renewable energy sources (wind, water, and solar), the focus of this research is solar energy because of its application both as an unchallenged and renewable energy [1]. In 1991, dye-sensitized solar cells (DSSCs) were discovered as an alternative to solid-state silicon-based solar cells to control the high cost and exceptional stability [1, 3]. At present, the standard solar panels based on multicomponent silicon have power conversion efficiencies about 22% but it is expensive. In consideration of other metals in complex form, ruthenium(II) complexes have tremendous attention as photosensitizers in DSSCs because of their promising photoelectrochemical characteristics and extraordinary stability in the oxidized state [1]. In addition, sensitizers based on ruthenium complexes have been reported to reach power conversion efficiencies of over 11% [4–8]. Ruthenium(II) polypyridyl sensitizers have been extensively used as effective sensitizers because of their intense charge transfer absorption in the visible region of the electromagnetic spectrum [8]. In support of the previous statement, recently, researchers have reported incorporated dithiocarbamate ligands in dye sensitizers that are able to stabilize transition metals in various oxidation states and to enhance the efficiency of ruthenium(II) sensitizers’ systems [9, 10]. According to Tan et al., homoleptic dithiocarbamate complex is usually prepared in a single-pot synthesis from the reaction of a less commonly used primary amine or most commonly used secondary amine with carbon disulfide under basic conditions and in the presence of the appropriate metal ion synthon [11]. Similarly, Odularu and Ajibade stated that homoleptic complexes involved bidentate symmetrical bonding of two identical dithiocarbamate ligands to coordinate the dative ion [12].
On the alternative, Tan et al. recounted that preparation of heteroleptic dithiocarbamate complex entailed the reaction of a suitable dithiocarbamate salt, group 1 salt with a metal halide insertion of CS₂ into the metal-nitrogen bond of the corresponding amide complex. Additionally, Odularu and Ajibade reported that heteroleptic complexes are formed by monodentate unsymmetrical bonding, where another ligand is introduced with the dithiocarbamate. Based on Tan et al. and Odularu and Ajibade’s reports, this present study adopts the use of heteroleptic dithiocarbamate complexes for synergistic application in DSSCs.

Dithiocarbamate ligands such as diethyl, dibenzyl, and pyrrolidine have been used to prepare Ru(II) complexes that efficiently sensitize titanium dioxide band beyond the 700 nm region [13–16]. However, literature review reveals that there is limited research done in dye sensitization of application of mixed ruthenium(II) bipyridyl-dithiocarbamate complexes as sensitizers in DSSCs [17–20]. Wang reported electrochemical reactions could be studied at both macro- and microelectrodes with voltammetry and chronoamperometric techniques [21]. Additionally, the researcher listed several types of voltammetry (chronoamperometry, cyclic voltammetry (CV), differential pulse voltammetry (DPV), linear sweep voltammetry (LSV), nanoimpact experiments, semicircular sweep voltammetry (SCV), square wave voltammetry (SWV), and stripping voltammetry (SV)), but this study reported two (CV and LSV) of these several types of voltammetry, because they are the most often used electroanalytical methods [21]. Therefore, this paper reports the synthesis, characterization, and electrochemical activities of five heteroleptic ruthenium(II) complexes as prospective sensitizers for dye-sensitized solar cells.

2. Experimental

2.1. Materials. All chemicals and solvents were purchased from Associated Chemical Enterprises (ACE), Merck, and Sigma-Aldrich. They were used without any further purification: 2,2′-bipyridyl-4,4′-dicarboxylic acid, p-anisidine, aniline, dibenzylamine, diphenylamine, p-toluidine, carbon disulfide, sodium hydroxide, methanol, diethyl ether, acetonitrile, ruthenium(III) chloride, dimethylsulfoxide (DMSO), and ammonium thiocyanate. The metal precursor [RuCl₂(DMSO)₄] was synthesized using Bianchini and Lee’s method of synthesis [22]. The dithiocarbamate ligands were synthesized as described according to literature with slight modifications [22].

2.2. Physical Measurements. Melting points were recorded on STUART melting point apparatus and were uncorrected. Electronic absorption and emission spectra were recorded in DMSO solution in a PerkinElmer Lambda 25 UV-Vis spectrophotometer using a 1 cm quartz cell in the range of 800-200 nm. Infrared spectra of the compounds were recorded on a FTIR-ATR PerkinElmer 4000 Hz spectrophotometer, as KBr pellets in the range of 4000–400 cm⁻¹. The proton NMR (¹H NMR) and carbon NMR (¹³C NMR) spectra were recorded using a Bruker EMX 400 Hz and 100 MHz spectrophotometer, respectively, while tetramethylsilane (TMS) was used as an internal standard. An Autolab potentiostat that was equipped with a glassy carbon working electrode, Ag/AgCl reference electrode, an auxiliary platinum (Pt) counter electrode, and 0.1 M of tetra butyl ammonium hexafluorophosphate which acted as a supporting electrolyte was used for cyclic voltammetry measurements.

2.3. Synthesis of Dithiocarbamates (FL₁–FL₅)

2.3.1. Synthesis of Sodium Salt of Aniline Dithiocarbamate: FL₁. Aniline (0.05 mol, 4 mL) pipetted in a clean conical flask was cooled at a temperature less than 4°C to enhance precipitate formation. To this cold aniline, 10 mL of aqueous sodium hydroxide (0.05 mol, 2 g) and carbon disulfide (0.05 mol, 3 mL) were added dropwise with constant stirring. The contents in the conical flask were stirred mechanically for 5 h for complete synthesis and to precipitate out the sodium salt of aniline dithiocarbamate. The resulting precipitate was filtered and washed with diethyl ether to remove unreacted reactants and dried in a desiccator. The dried product was recrystallized from water. Colour: white, yield (%): 83.16, M.P. (°C): 88, selected FT-IR (cm⁻¹): ν(C-S) 1031, ν(C-S) 958. ¹H NMR (DMSO-d₆, 300 MHz, 25°C); (δ, ppm): 6.50–8.90 (m, 1H, C₆H₆); (δ, ppm): 6.51–8.15 (m, 1H, C₆H₆), 5.00 (s, 1H, N-H); Selected ¹³C NMR (DMSO-d₆, 100 MHz, 25°C); (δ, ppm): 218.00 (s, 1C, CS₂), 115.00–145.00 (m, 1C, C₆H₆).

2.3.2. Synthesis of Sodium Salt of p-Toluidine Dithiocarbamate: FL₂. To an aqueous solution of p-toluidine (0.05 mol, 10 mL) in a conical flask, sodium hydroxide (0.05 mol, 2 g) was added. This mixture was cooled and stirred. Later, cold carbon disulfide (0.05 mol, 3 mL) was added dropwise to the mixture. The reaction mixture was stirred for 5 h at a temperature 4°C. The resulting precipitate was filtered, washed with diethyl ether to remove unreacted reactants, and dried in a desiccator. The dried product was recrystallized from water. Colour: white, yield (%): 62.28, M.P. (°C): 72, selected FT-IR (cm⁻¹): ν(N-H) 3369, ν(C-N) 1635, ν(C-S) 1022, ν(C-S) 958. ¹H NMR (DMSO-d₆, 300 MHz, 25°C); (δ, ppm): 7.25–8.90 (m, 1H, C₆H₆); (δ, ppm): 6.50–7.47 (m, 1H, C₆H₆), 3.51 (s, 1H, N-H); Selected ¹³C NMR (DMSO-d₆, 100 MHz, 25°C); (δ, ppm): 218.00 (s, 1C, CS₂), 115.00–145.00 (m, 1C, C₆H₆).

2.3.3. Synthesis of Sodium Salt of p-Anisidine Dithiocarbamate: FL₃. A methanolic solution of p-anisidine (0.05 mol, 20 mL) pipetted in a clean conical flask was cooled at a temperature less than 4°C to enhance precipitate formation. A 10 mL of aqueous sodium hydroxide (0.05 mol, 2 g) was added, and later, carbon disulfide (0.05 mol, 3 mL) was added dropwise with constant stirring. The contents in the conical flask were stirred mechanically for 5 h for complete synthesis and to precipitate out the sodium salt of p-anisidine dithiocarbamate. The resulting precipitate was filtered and washed with diethyl ether to remove unreacted reactants and dried in a desiccator. The dried product was recrystallized from water. Colour: white, yield (%): 72.77, M.P. (°C): 82, selected FT-IR (cm⁻¹): ν(N-H) 3421, ν(C-N) 1622, ν(C-S) 1022, ν(C-S) 950. ¹H NMR (DMSO-d₆, 300 MHz, 25°C); (δ, ppm): 6.50–7.47 (m, 1H, C₆H₆), 4.57 (s, 1H, N-H); selected ¹³C NMR
2.4.2. Synthesis of $[\text{Ru}(\text{dcbpy})(\text{FL}_3)_2(\text{NCS})_2]: FC_3$.
Ruthenium metal salt (0.4 mmol, 0.2 g) was dissolved in 40 mL of methanol, and (0.4 mmol, 0.07 g) of FL$_3$ was added to the solution; this mixture was allowed to stir for 1 h before introducing dcbpy (0.4 mmol, 0.09 g) and (0.4 mmol, 0.03 g) of ammonium thiocyanate (NCS). The reaction mixture was then refluxed at 60°C for 3 h, and this was done in an inert environment. The solvent was then reduced in rotary evaporator and then reprecipitated the product in acetone. The resulting precipitate was filtered, washed with water to remove any traces of NaCl followed by diethyl ether, and dried in a desiccator. Colour: light brown, yield (%): 29.40, M.P. (°C): 240, selected FT-IR (cm$^{-1}$): ν(N-H) 3114, ν(C-N) 1653, ν(C-S$_\text{sym}$) 1013, ν(C-S$_\text{asy}$) 980. $^1$H NMR (DMSO-d$_6$, 300 MHz, 25°C): $\delta$ (ppm): 8.85-8.90 (m, 1H, CH=N), 7.33-7.92 (m, 1H, C$_6$H$_6$), 3.51 (s, 1H, N-H); selected $^{13}$C NMR (DMSO-d$_6$, 100 MHz, 25°C); (δ, ppm): 151.03, 156.00 (d, 1C, C=N), 120.06, 123.92 (d, 1C, C$_6$H$_5$), 31.17 (s, 1C, N-C).

2.4.3. Synthesis of $[\text{Ru}(\text{dcbpy})(\text{FL}_4)_2(\text{NCS})_2]: FC_4$.
Ruthenium metal salt (0.4 mmol, 0.2 g) was dissolved in 40 mL of methanol, and (0.4 mmol, 0.08 g) of FL$_4$ was added to the solution; this mixture was allowed to stir for 1 h before introducing dcbpy (0.4 mmol, 0.09 g) and (0.4 mmol, 0.03 g) of ammonium thiocyanate (NCS). The reaction mixture was then refluxed at 60°C for 3 h, and this was done in an inert environment. The solvent was then reduced in rotary evaporator and then reprecipitated the product in acetone. The resulting precipitate was filtered, washed with water to remove any traces of NaCl followed by diethyl ether, and dried in a desiccator. Colour: brown, yield (%): 19.02, M.P. (°C): 226, selected FT-IR (cm$^{-1}$): ν(N-H) 3114, ν(C-N) 1632, ν(C-S$_\text{sym}$) 1011, ν(C-S$_\text{asy}$) 959, $^1$H NMR (DMSO-d$_6$, 300 MHz, 25°C); (δ, ppm): 7.89-9.01 (m, 1H, CH=N), 6.53-7.38 (m, 1H, C$_6$H$_6$), 3.61 (s, 1H, N-H); selected $^{13}$C NMR (DMSO-d$_6$, 100 MHz, 25°C); (δ, ppm): 166.59 (s, 1C, C$_6$H$_5$), 150.99, 156.01 (d, 1C, C=N), 120.07, 123.91 (d, 1C, C$_6$H$_5$), 31.16, 40.91 (d, 1C, N-C).

2.4.4. Synthesis of $[\text{Ru}(\text{dcbpy})(\text{FL}_4)_2(\text{NCS})_2]: FC_5$.
Ruthenium metal salt (0.2 mmol, 0.1 g) was dissolved in 40 mL of methanol, and (0.2 mmol, 0.04 g) of FL$_4$ was added to the solution; this mixture was allowed to stir for an hour before introducing dcbpy (0.4 mmol, 0.04 g) and (0.4 mmol, 0.06 g) of ammonium thiocyanate (NCS). The reaction mixture was then refluxed at 60°C for 3 h, and this was done in an inert environment. The solvent was then reduced in rotary evaporator and then reprecipitated the product in acetone. The resulting precipitate was filtered, washed with water to remove any traces of NaCl followed by diethyl ether, and dried in a desiccator. Colour: light brown, yield (%): 57.56, M.P. (°C): 248, selected FT-IR (cm$^{-1}$): ν(N-H) 3114, ν(C-N) 1639, ν(C-S$_\text{sym}$) 1013, ν(C-S$_\text{asy}$) 961, $^1$H NMR (DMSO-d$_6$, 300 MHz, 25°C); (δ, ppm): 8.54 (s, 1H, CH=N) 8.33 (s, 1H, C$_6$H$_6$), 3.56 (s, 1H, N-H); selected $^{13}$C NMR (DMSO-d$_6$, 100 MHz, 25°C); (δ, ppm): 124.64 (d, 1C, C$_6$H$_5$), 68.01 (s, 1C, N-C).
2.4.5. Synthesis of [Ru(dcbpy)(FL)_2(NCS)]_2: FC-\textsubscript{5}. Ruthenium metal salt (3.3 mmol, 0.16 g) was dissolved in 40 mL of methanol, and (3.3 mmol, 0.08 g) of FL\textsubscript{5} was added to the solution; this mixture was allowed to stir for 1 h before introducing dcbpy (3.3 mmol, 0.08 g) and (3.3 mmol, 0.25 g) of ammonium thiocyanate (NCS). The reaction mixture was then refluxed at 60°C for 3 h, and this was done in an inert environment. The solvent was then reduced in a rotary evaporator and then precipitated the product in acetone. The resulting precipitate was filtered, washed with water to remove any traces of NaCl followed by diethyl ether, and dried in a desiccator. Colour: light brown, yield (%): 48.09, M.P. (°C): 163.00 (d, 1C, C=N), 120.04, 123.93 (d, 1C, C\textsubscript{6}H\textsubscript{6}).

3. Results and Discussion

3.1. Synthesis of Ruthenium(II) Complexes. The Ru(II) bipyridyl-dithiocarbamate complexes were synthesized by reacting the respective dithiocarbamate ligand with [RuCl\textsubscript{2}(DMSO)]\textsubscript{4}, 2,2'-bipyridine-4,4'-dicarboxylic acid, and ammonium thiocyanate in methanol as shown in Scheme 1. The complexes were stable at room temperature, and their colours range from light brown to dark brown. The molar conductivity measurements of the complexes indicated that the compounds are nonelectrolytes in solution with values less than 20 \(\mu\)S/cm [23].

3.2. Spectroscopic Studies

3.2.1. Infrared Studies. All complexes show absorption frequencies, \(\nu(N-H)\) peaks in the range 3114-3421 cm\(^{-1}\), and higher stretching frequencies than their free ligands, with the exception of FC-\textsubscript{5}, shown in Table 1. For both dcbpy (carboxylic (C=O) and azomethine (C=N)) and the thiocyanato bond (NCS), the free ligands have lower stretching vibrations in comparison with corresponding Ru(II) complexes, indicating the extent of coordination. For the dithiocarbamate ligands, the thioeureide bands, \(\nu(C-N)\), of free ligands 1487-1588 cm\(^{-1}\) were of higher stretching vibrations than the corresponding complexes, except FC-\textsubscript{1}. These shifts confirmed the presence of the \(\nu(C-N)\) bond and might be due to the delocalized electron density toward the metal center [23]. The vibrational frequencies in the complexes in the region of 1011-1031 cm\(^{-1}\) are due to \(\nu(C-S)_{asy}\) and the \(\nu(C-S)_{sym}\) was observed at 950-990 cm\(^{-1}\) as Manohar et al. similarly reported [24]. The ligand to metal coordination for (Ru-N) and (Ru-S) bands was observed at 487-508 cm\(^{-1}\) and 411-442 cm\(^{-1}\) for all metal complexes, respectively, shown in Table 1, which are in accordance with the literature [25].

3.2.2. UV-Vis Absorption Studies. The UV-Vis absorption spectra of FC-\textsubscript{1}-FC-\textsubscript{5} complexes are shown in Figure 1, and the UV-Vis spectra data of the Ru(II) complexes were recorded in DMSO (10\(^{-5}\) M). The distinctive 290 nm attributed to allow \(\pi - \pi^*\) transitions localized on the bipyridyldiyen entities, as it is in agreement with the literature [25]. The bands corresponding to the \(\pi - \pi^*\) transitions for all the Ru(II) complexes at 290-305 nm reflect the ligand involvement in the coordination with ruthenium(II) ion. The second type of transition appears at 305-430 nm which could be assigned to \(n - \pi^*\) transitions of nitrogen and sulfur atoms of FL-\textsubscript{1}-\textsubscript{5}, dcbpy, and NCS hetero atoms in accordance to the literature [26]. However, in line with Mishra and Yadaw, the broad peaks observed between 305 and 430 nm could be ascribed to metal-to-ligand charge transfer (MLCT) characteristic of Ru(II), where transitions from FL-\textsubscript{1}-\textsubscript{5}, dcbpy, and NCS are indistinguishable because of overlapping regions [27]. Additionally, in agreement with this first group of researchers, Islam et al., and this second group of researchers, Anthonymasy et al., the UV-Vis spectral data of Ru(II) complexes are distinctive of bands at a range of 280-305 nm as a result of ligand centered (LC) transitions, while the distinctive metal to ligand charge transfer (MLCT) transition of the Ru(II) complexes is in the range of 305-430 nm [28, 29]. The configuration of the electronic spectra of all the Ru(II) complexes showed the presence of an octahedral environment around the ruthenium(II) ion, as similarly reported in the literature [26].

3.2.3. Photophysical Studies. All the FC-\textsubscript{1}-FC-\textsubscript{5} complexes have very similar emission spectra due to the electron donors from contributing ligands as shown in Figure 2. All the complexes showed broad emission bands around 700 nm with high intensity which indicate good photoexcitation above the 400 nm region and extended excited lifetime which is a desirable property in dye sensitization, as they all agree with the literature [27, 30, 31].

3.2.4. Proton (\(^1H\)) NMR Studies. The \(^1H\) NMR spectra of all the ruthenium(II) complexes were recorded in DMSO-\textsubscript{d6} solution to confirm the binding mode of the ligands to ruthenium(II) ion. The resonances of aromatic protons for all the ligands and ruthenium(II) complexes appeared at a range of 6.50-7.90 ppm, because on complexation, the protons on the aromatics remain more or less unchanged in the ruthenium(II) complexes, as a result of delocalized electron density in the ring system and their extensive overlapping [26, 32-34]. The \(\delta(N-H)\) appears as a singlet at \(\delta\) 3.51-5.35 ppm in both the ligands and Ru(II) complexes while there is a downshifted shift of about in the complexes due to the incorporation of more nitrogen groups. In FL-\textsubscript{1} and FC-\textsubscript{1}, two singlets were observed at \(\delta\) 10.30 ppm and \(\delta\) 13.82 ppm and these can be attributed to the protons present in the hydroxyl group of 2,2'-bipyridine-4,4'-dicarboxylic acid [33-36]. However, it was further observed that the \(^1H\) NMR spectra of some ruthenium(II) complexes did not show some peaks probably due to the presence of the NCS (auxiliary ligand) as reported by Mishra and Yadaw or excessive overlapping as reported by Sathiyaraj and Jayabakrishnan [26, 27]. According to Mauri et al., one of the main complications of thiocyanate ancillary ligand is its ambidentate nature, due to its metal coordination property via the nitrogen or sulfur atom. Besides, it is to a certain extent labile and is easily replaced by other species in the
Scheme 1: Synthetic pathways of Ru(II) bipyridyl-dithiocarbamate complexes for (a) FC₁, (b) FC₂, (c) FC₃, (d) FC₄, and (e) FC₅.
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complex, such as 4-tert-butylpyridine (TBP) which is usually involved as additive in the redox mixture [8]. To overcome this thiocyanate problems, many research groups have investigated the field of NCS-free bipyridine ruthenium(II) complexes employed as dyes in DSSC to replace the NCS ligands [8]. All the ruthenium(II) complexes showed signal at 0.55-2.15 ppm due to the alkyl group, as similarly reported in the literature [26]. However, in dithiocarbamates, Tan et al. stated that 13C NMR data are naturally scarcer than 1H NMR data. As a result of this, the quaternary carbamoyl carbon atom, CNS2R2, is most characteristic, though it is not always observed because of its long relaxation times. In line with Tan et al.’s observation, some ligands and Ru(II) complexes (FL2, FL3, FL5, FC2, and FC4) were with long relaxation times [11].

3.3. Electrochemical Studies. The electrochemical studies involved cyclic voltammetry (CV) and linear sweep voltammetry electroanalytical techniques [21]. In CV, starting from an initial potential (E1) to a reversal potential (E2) and finally sweeping back to E1, the potential wave is triangular, where the positive or negative sign indicates either anodic or cathodic sweeps, and ν is the wave slope defined as the scan rate per second (V s⁻¹), but in the LSV, the forward potential sweep is only considered. In general, the scan rate is constant throughout the entire sweep for both CV and LSV [21].

3.3.1. Cyclic Voltammetry and Linear Sweep Voltammetry Studies for FC1-FC5 Complexes. The electrochemical properties of all ruthenium(II) complexes were explored with cyclic voltammetry and sweep voltammetry in a three-electrode system. Both cyclic and linear sweep voltammograms of Ru(II) complexes were recorded using Ag/Ag+ as reference electrode, platinum electrode as counter electrode, and glassy carbon as working electrode in dimethylsulfoxide medium (5×10⁻³ M) solution containing 0·1 M of tetrabutyl ammonium hexafluorophosphate as supporting electrolyte in the potential range from −1.5 V to +1.5 V with a scan rate of 25 mV s⁻¹. The cyclic voltammograms of FC1-FC5 complexes with displayed redox potentials are presented in Figures 3–7, while the linear sweep voltammograms of FC1-FC5 complexes with displayed redox potentials are presented in Figures 8–12. The complexes FC1-FC5 displayed negative potentials in the range −0.72 V to −0.75 V assigned to the reduction of the dcbpy moiety, while the oxidation potentials were observed in the range +1.15 V to +1.38 V due to the electron donating of the dithiocarbamate FL1, FL3 moieties and transfer to the anchoring ligand of ammonium thiocyanate to each ruthenium(II) complex as they agree with the literature [3, 26, 37, 38].
couple as confirmed with the similar redox potentials obtained in linear sweep voltammograms displayed good redox potentials in all complexes [21, 27, 39–41].

4. Conclusion and Recommendation

Five Ru(II) complexes were synthesized and characterized with physicochemical parameters and spectroscopic techniques which confirmed the successful synthesis of the complexes. Results obtained from the photophysical and electrochemical studies showed that these ruthenium(II) complexes have potentials as sensitizers for dye-sensitized solar cells (DSSCs).

Data Availability

The data and figures used to support the findings in the study in this research article are from master’s degree dissertation: http://vital.seals.ac.za:8080/vital/access/manager/Repository/vital:29498?site_name=GlobalView~~~~~~~^~^~^~^~~~~~~~amp;exact=sm_creator%3A%22Fudo%2C%20Zintle%22~~~~~~~amp;sort=sort_ss_title%2F.
Additional Points

Future Direction. Future direction entails the crystallographic studies of the synthesized Ru(II) complexes.

Conflicts of Interest

All authors declare no conflict of interest.

Authors’ Contributions

For this research, the following are the contributions of the authors: conceptualization and methodology, Peter Ajibade and Zintle Fudo; validation, Peter Ajibade and Ayodele Odularu; formal analysis, Peter Ajibade; investigation, Peter Ajibade, Zintle Fudo, and Ayodele Odularu; resources, Peter Ajibade; data curation, Peter Ajibade, Zintle Fudo, and Ayodele Odularu; writing—original draft preparation, Peter Ajibade, Zintle Fudo, and Ayodele Odularu; manuscript visualization, Zintle Fudo; manuscript writing, Zintle Fudo, Peter Ajibade, and Ayodele Odularu; review and editing, Ayodele Odularu; supervision, Peter Ajibade and Ayodele Odularu; project administration, Peter Ajibade and Ayodele Odularu; funding acquisition, Peter Ajibade.

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