Perylene diimide based electron transporting

materials for organic solar cells

M.Sc. Thesis

By

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DEPARTMENT OF CHEMISTRY INDIAN INSTITUTE OF TECHNOLOGY INDORE

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Perylene diimide based electron transporting

materials for organic solar cells

A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

Master of Science

бу

Sudhanshu Kumar



DEPARTMENT OF CHEMISTRY INDIAN INSTITUTE OF TECHNOLOGY INDORE

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INDIAN INSTITUTE OF TECHNOLOGY INDORE CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this thesis entitled report entitled "Perylene diimide based electron transporting materials for organic solar cells", in the partial fulfilment of the requirements for the award of the degree of MASTER OF SCIENCE and submitted to the DEPARTMENT OF CHEMISTRY, Indian Institute of Technology Indore, is an authentic record of my own work carried out during the time period from June 2022 of joining the M.Sc. program to May 2023 of M.Sc. thesis submission under the supervision of Prof. Rajneesh Misra, Professor, IIT Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

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This is to certify that the above statement made by the candidate is correct to the best

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DEDICATED TO MY PARENTS

AND FRIENDS.....

ABSTRACT

We have designed and synthesized the donor-acceptor functionalized perylene diimide (PDI) derivatives using Sonogashira cross-coupling reaction. The PDI molecules are the class of perylene dyes that shows a strong electron-accepting character with near-infrared (NIR) absorption and low-lying LUMO levels. Donor-acceptor functionalized PDI molecules optimize the performance of optical devices to achieve high Power conversion efficiency as well as advancement in the commercial viability of organic photovoltaics. Researchers have been developing PDI based non-fullerene acceptors (NFAs) in recent years to improve the efficiency and stability of organic solar cells. PDI derivatives has shown great potential for organic solar cells due to excellent NIR absorption and photothermal conversion efficiency. The photophysical and density functional theory (DFT) studies were investigated which show excellent donor-acceptor interaction and tuning of the HOMO-LUMO gap. PDI shows various applications in organic photovoltaics, OLEDs, and OFETs.

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ACRONYMS

OLEDs	Organic light-emitting diodes
OFETs	Organic field-effect transistors
OSCs	Organic solar cells
OPDs	Organic photovoltaic devices
НОМО	Highest occupied molecular orbital
LUMO	Lowest unoccupied molecular orbital

1. INTRODUCTION

Donor-acceptor (D-A) functionalized perylene diimide (PDI) molecules have played a significant role in the advancement of organic solar cell (OSC) technology.^{1,2} PDI derivatives are the key components in the development of efficient and cost-effective renewable energy sources.³ PDI molecules have shown great efficiency in optical devices leading to significant improvements in device performance. PDI-based non-fullerene acceptors (NFAs) have emerged as promising materials for use in OSCs due to their high molar extinction coefficient for enhancing device performance.⁴ Traditionally, fullerene derivatives, such as phenyl-C61-butyric acid methyl ester (PCBM), have been used as acceptor molecules in OSCs.⁵⁻⁷ However, non-fullerene based PDI acceptors have gained significant attention due to their inherent advantages.⁸⁻¹⁰

PDI-based donor-acceptor molecules possess a wide range of applications in OLEDs, OSCs, OPDs, and OFETs.¹¹⁻¹³ In organic solar cells, the donor organic molecule and acceptor molecule are sandwiched between the cathode and anode (Figure 1) to generate the electricity.^{14,15} The active layer of organic solar cells absorbs the solar light that emits free charge carriers. These charge carriers reach the electrodes to produce the photovoltage and photo electric current.



Figure 1. Mechanism of organic photovoltaics (D = donor, A = acceptor).

Perylene dyes play an important role in photo-functional materials due to their excellent thermal stability, chemical persistence, and light harvesting properties.^{16,17} In recent years PDI based molecules has garnered significant attention in the formation of active material for OSCs.¹⁸ PDI appears to be the most suitable perylene dye for light-based applications as a result of their excellent photophysical properties.¹⁹ The high molar extinction coefficient of PDI based molecules makes it an ideal material for NIR-absorbing dyes, activated solar cells, OLEDs, and OFETs.²⁰⁻²² PDI derivatives have the benefit of having red-shifted absorption and emission over unsubstituted PDI in terms of structural change, photostability, and chemical stability.²³



Figure 2. Chemical structure of PDI.

The PDI structure is quite symmetric. It consists of two active positions; *imide* and *bay* positions (Figure 2). Researchers have explored various strategies to modify the PDI structure by introducing different functional groups and side chains to enhance light absorption and extend the absorption range into NIR region. These structural modifications lead to improved light-harvesting properties and increased photocurrent generation. The imide position or the bay position of PDI can be further modified to form distinct derivatives by adding an alkyl chain or aryl substituent resulting in increased solubility.²⁴ The insertion of different substituent groups on *N*-positions will lead to a reduction in π - π stacking resulting an increment in solubility and aggregation of PDI in the solid state, but there is no significant effect on absorption and emission properties.^{25,26}

to synthesize the PDI functionalized derivatives for tuning optical and electrical properties (Figure 3).^{27,28}





The Efficiency of OSCs is highly altered by the development of efficient donor-acceptor PDI system. Coupling reactions on PDI have emerged as a powerful strategy to enhance its properties and performance as an electron-accepting material.²⁹ These coupling reactions involve the attachment of electron-donating moieties or conjugated systems into PDI, creating donor-acceptor architectures that facilitate efficient charge separation and transport. Moreover, coupling reactions on PDI can impact the charge mobility and morphology of the active layer in OSCs.³⁰

The introduction of conjugated side chains or bulky substituents on PDI can influence intermolecular packing and film morphology leading to improved charge transport and reduced charge recombination.³¹ In organic electronics, phenothiazine derivatives are often employed as electron-donating materials in organic semiconductors.³² It can be incorporated into the structure of conductive polymers or used as a dopant to improve the charge transport properties of OSCs.³³ Donor moiety can be attached to PDI with the help of precursor as a coupling partner that will help facilitates coupling reaction mechanisms such as Suzuki and Sonogashira cross-coupling, borylation as well as nitration at the bay positions.^{34,35} They have been extensively developed as PDI precursors to synthesize bay-functionalized PDI derivatives (Scheme 1).³⁶⁻³⁸



Scheme 1. Synthetic route of PDI precursors.

2. LITERATURE REVIEW

In recent years, the design and development of perylene diimide (PDI) functionalized donor-acceptor (D-A) systems has gained significant attention due to their potential applications in organic electronics such as organic photovoltaics and OFETs. Various molecular design strategies have been employed in PDI donor-acceptor systems to achieve efficient charge transfer and enhanced optoelectronic properties.^{39,40} The incorporation of electron-donating moieties, such as thiophene, carbazole, or fluorene units, as well as π -bridge linkers between the PDI core and the donor moiety (Figure 4).⁴¹ The attachment of linkers and donors into the PDI core influences the electronic interactions and the overall performance of the donor-acceptor system.⁴²



Figure 4. Chemical structures of PDI donor-acceptor system.

The self-assembly of PDI systems and their optoelectronic properties have been controlled by non-covalent interactions such as carbon-carbon stacking, hydrogen bonding and charge transfer interactions over the past few years.⁴³ Supramolecular architectures can be produced by incorporating complementary donor and acceptor moieties leading to improved charge transportation, exciton diffusion, and device functionality.^{44,45} Additionally, non-covalent interactions provide various opportunities for tuning the packing arrangement and

morphology of donor-acceptor systems leading to improved film formation and device stability.^{46,47}

Recent advancements in PDI functionalized donor-acceptor systems have provided valuable insights into the design principles and synthetic strategies for achieving high-performance organic materials. PDI systems demonstrate enhanced charge transfer properties in optical devices through molecular design, non-covalent interactions, side chain engineering, and device optimization. Further research and development are going on for the production of efficient and stable PDI based materials for a wide range of optoelectronic applications.

3. RESULTS AND DISCUSSION

3.1 Synthesis

The alkylation of phenothiazine **1** was carried out in the presence of propyl iodide and sodium hydroxide (NaOH). After the alkylation, bromination was done in the presence of Br_2 liquid to obtain compound **3**.⁴⁸ Sonogashira cross-coupling reaction was carried out between compound **3** and 2-methylbut-3-yn-ol in the presence of a palladiumbased catalyst to obtain compound **4**.⁴⁹ Then deprotection was done to obtain compound **5** (Scheme 2).⁵⁰



Scheme 2. Synthetic route of compound 5.

Perylenetetracarboxylic dianhydride (**PTCDA**) **6** undergoes ring opening amidation reaction followed by cyclization using 2ethylhexan-1-amine in *N*,*N*-dimethylformamide (DMF) to get compound **7**.⁵¹ Compound **7** was subjected to bromination to obtain compound **8**.⁵² Further, Compound **9** was obtained by the nitration of compound **8**.⁵³ Then Sonogashira cross-coupling reaction was carried out between compounds **9** and **5** in the presence of a palladium-based catalyst to obtain compound **10** (Scheme 3).



Scheme 3. Synthetic route of compounds 9 and 10.

4. EXPERIMENTAL SECTION:

4.1 General methods

Chemicals were used as received unless otherwise indicated. All the oxygen- or moisture-sensitive reactions were carried out under an argon atmosphere. ¹H NMR spectra were recorded using a 500 MHz spectrometer. Chemical shifts are reported in δ units, expressed in parts per million (ppm) downfield from tetramethylsilane (TMS) using residual protonated solvent as an internal standard (CDCl₃, 7.27 ppm). ¹³C NMR spectra were recorded using a 100 MHz spectrometer. Chemical shifts are reported in δ units, expressed in parts per million (ppm) downfield from tetramethylsilane (TMS) using the solvent as the internal standard (CDCl₃, 77.0 ppm). The ¹H NMR splitting patterns have been described as s, singlet; d, doublet; t, triplet; sxt, sextet; and m, multiplet. UV-visible absorption spectra of all compounds were recorded in dichloromethane (DCM) solution.

3.2 Experimental Procedure

Synthesis of compound 2:

In a 100 mL round bottomed flask, phenothiazine **1** (1 g, 5 mmol) and propyl iodide (0.623 mL, 5.5 mmol) were dissolved in dimethyl sulfoxide (30 mL) and stirred for 20 min at room temperature (RT). NaOH (0.26 g, 6.5 mmol) was added as a base at RT and stirred for 12 h. The organic layer was extracted using DCM and then passed through sodium sulfate (Na₂SO₄). The product alkylated phenothiazine **2** was purified through column chromatography with hexane in 97 % yield (1.9 g); White solid; ¹H NMR (500 MHz, CDCl₃) δ 7.08 - 7.19 (m, 4 H), 6.90 (d, *J*=7.78 Hz, 4 H), 3.80 (m, 2 H), 1.82 (sxt, *J*=7.29 Hz, 2 H), 0.99 (t, *J*=7.40 Hz, 3 H); ¹³C NMR (100 MHz, CDCl₃) δ 127.3, 127.1, 124.9, 122.4, 115.6, 49.3, 20.0, 11.2; HRMS (ESI, positive) *m/z* calculated for C₁₅H₁₅NS 241.0920 [M]⁺, measured 241.0920

Synthesis of compound 3:

In a 250 mL round bottomed flask, compound **2** (3 g, 12.43 mmol) and NaOH (1 g, 25 mmol) were dissolved in CHCl₃ (35 mL) and stirred for 15 min at 0 °C. Glacial Acetic Acid (70 mL, 1223.9 mmol) was added and then Br₂ (0.834 mL, 16.15 mmol) was added with the help of dropping funnel. The reaction mixture was stirred for 2 h at 0 °C. The organic layer was extracted using DCM and then passed through Na₂SO₄ to obtain pure compound **3** in 57% yield (2.24 g); Brownish liquid.

Synthesis of intermediate 4:

In a 100 mL round bottomed flask, a mixture of compound **3** (2.27 g, 7.08 mmol), copper iodide (8.07 mg, 0.04 mmol), 2-methylbut-3-yn-ol (0.83 mL, 8.4 mmol) and Pd(PPh₃)₂Cl₂ (198 mg, 0.28 mmol) was dissolved in 1 : 1 (v/v) THF (15 mL) and toluene (15 mL). The reaction mixture was degassed in an inert atmosphere for 15 min and refluxed for 12 h. The solvents were removed by rotary evaporator under reduced pressure. The organic layer was extracted using DCM and then passed through Na₂SO₄. Product **4** was purified through column chromatography with hexane/ethyl acetate (9:1) in 75% yield (1.69 g); Greenish oil;

Synthesis of intermediate 5:

In a 50 mL round bottomed flask, compound **4** (1 g, 3.01 mmol) and KOH (0.34 g, 6.1 mmol) were dissolved in isopropanol (20 mL) and stirred for 4 h at 80 °C. The organic layer was extracted using DCM and then passed through Na₂SO₄. Product **5** was purified through column chromatography with hexane in 80% yield (0.65 g); Greenish oil; ¹H NMR (500 MHz, CDCl₃) δ 7.22 - 7.27 (m, 2 H), 7.09 - 7.16 (m, 2 H), 3.02 (s, 1 H), 6.91 (td, J=7.51, 1.14 Hz, 1 H), 6.82 - 6.85 (m, 1 H), 6.75 (d, J=8.39 Hz, 1 H), 3.77 - 3.81 (m, 2 H), 1.81 (sext, J=7.26 Hz, 2 H) , 0.99 (t, J=7.40 Hz, 3 H); ¹³C NMR (100 MHz, CDCl₃) δ 145.8, 144.6, 131.3, 130.7, 127.6, 127.5, 127.4, 124.8, 124.2, 122.8, 115.8, 115.6, 115.0, 83.1, 49.3, 20.1, 11.3; HRMS (ESI, positive) *m/z* calculated for C₁₇H₁₅NS [M]⁺, measured 265.0878

Synthesis of compound 7:

In a 100 mL round bottomed flask, compound **6** (0.5 g, 1.27 mmol) and 2-ethylhexan-1-amine (0.22 g, 0.2 mL, 1.76 mmol,) were dissolved in DMF (40 mL) and stirred for 4 h at 100 °C. The reaction mixture was extracted by suction filtration using methanol solvent to obtain product **7** in 85% yield (0.65 g); Dark red solid; ¹H NMR (500 MHz, CDCl₃) δ 8.58 (d, J = 7.9 Hz, 4 H), 8.48 (d, J = 8.1 Hz, 4 H), 4.13 (dq, J = 7.5, 13.1 Hz, 4 H), 1.99 - 1.92 (m, 2 H), 1.43 - 1.38 (m, 7 H), 1.36 - 1.31 (m, 7 H), 0.96 (t, J = 7.3 Hz, 7 H), 0.90 (t, J = 6.9 Hz, 7 H). ¹³C NMR (100 MHz, CDCl₃) δ 163.8, 134.5, 131.4, 126.4, 123.3, 123.1, 44.4, 38.0, 30.8, 28.7, 24.1, 23.1, 14.1, 10.7

Synthesis of compound 8:

In a 500 mL round bottomed flask, compound **7** (2 g, 3.03 mmol) was dissolved in DCM (200 mL) and stirred at RT for 15 min. Then bromine (50 mL, 975.8 mmol) was added to the reaction mixture and kept stirring for 30 h. After the completion of reaction, an aqueous solution of sodium thiosulfate (Na₂S₂O₃) was used to quench the reaction mixture. The organic layer was extracted using DCM (5 times) and then passed through Na₂SO₄. Product **8** was purified through column chromatography with DCM in 10% yield (0.20 g); Dark red solid; ¹H NMR (500 MHz, CDCl₃) δ 8.74 (d, J = 8.1 Hz, 1 H), 8.71 - 8.61 (m, 4 H), 8.55 (d, J = 8.1 Hz, 1 H), 8.18 (d, J = 8.1 Hz, 1 H), 4.19 - 4.08 (m, 4 H), 1.94 (td, J = 6.0, 12.2 Hz, 2 H), 1.43 - 1.37 (m, 7 H), 1.35 - 1.29 (m, 7 H), 1.09 - 0.85 (m, 14 H). ¹³C NMR (100 MHz, CDCl₃)

δ 163.3, 163.0, 162.9, 162.1, 147.5, 135.3, 132.8, 131.3, 131.1, 129.2,
129.2, 128.8, 127.9, 127.3, 126.5, 126.3, 126.3, 124.7, 124.5, 124.0,
124.0, 123.8, 123.0, 44.6, 44.5, 38.0, 37.9, 30.7, 30.7, 28.7, 28.6, 24.0,
23.1, 23.1, 14.1, 10.6, 10.6

Synthesis of compound 9:

In a round bottom flask (100 mL), compound **8** (1 g, 1.4 mmol) was dissolved in DCM (30 mL), and HNO₃ (10 mL, 359.5 mmol) was added dropwise at RT. The reaction mixture was stirred at RT for 24 h. After completion of the reaction, the organic layer was extracted using DCM and then passed through Na₂SO₄. Product **9** was purified through column chromatography with hexane/DCM (1:3) in 90% yield (0.95 g); Dark red solid; ¹H NMR (500 MHz, CDCl₃) δ 9.71 - 9.65 (m, 1 H), 8.96 (s, 1 H), 8.84 - 8.74 (m, 2 H), 8.63 - 8.58 (m, 1 H), 8.25 - 8.16 (m, 1 H), 4.21 - 4.09 (m, 4 H), 1.98 - 1.92 (m, 2 H), 1.43 - 1.38 (m, 8 H), 1.32 (d, J = 4.7 Hz, 8 H), 0.95 (dt, J = 2.1, 7.4 Hz, 6 H), 0.90 (t, J = 7.0 Hz, 6 H). ¹³C NMR (100 MHz, CDCl₃) δ 163.3, 162.9, 162.8, 162.4, 162.3, 147.7, 140.3, 138.6, 134.3, 132.3, 132.2, 130.7, 129.3, 128.9, 128.6, 128.5, 128.4, 127.3, 126.7, 126.3, 124.5, 123.6, 123.3, 123.1, 122.3, 77.3, 77.2, 77.0, 76.7, 44.6, 44.6, 37.9, 30.7, 29.7, 28.7, 24.0, 23.1, 14.1, 10.6

Synthesis of compound 10:

In a round bottom flask (50 mL), A mixture of compound **9** (200 mg, 0.27 mmol), compound **5** (100 mg, 0.3 mmol), copper iodide (5 mg), diisopropyl amine (15 ml), and Pd(PPh₃)₂Cl₂ (30 mg, 0.04 mmol)

was dissolved in toluene (15 ml) and degassed in an inert atmosphere for 15 min and the reaction mixture was refluxed for 12 h. After completion of the reaction solvents were dried and the organic layer was extracted using DCM. The organic layer was passed through Na₂SO₄. Product 10 was purified through column chromatography with hexane/dichloromethane (3:1) in 75% yield (185 mg); Black solid; ¹H **NMR** (500 MHz, CDCl₃) δ 10.14 - 10.05 (m, 1 H), 8.90 - 8.66 (m, 3 H), 8.64 - 8.54 (m, 1 H), 8.27 - 8.19 (m, 1 H), 7.40 (dd, J = 1.8, 8.4 Hz, 1 H), 7.34 (d, J = 1.7 Hz, 1 H), 7.21 - 7.14 (m, 2 H), 7.00 - 6.95 (m, 1 H), 6.90 (dd, J = 5.0, 8.2 Hz, 2 H), 4.22 - 4.10 (m, 4 H), 3.88 (t, J = 7.2 Hz, 2 H), 1.95 (dt, J = 6.5, 12.6 Hz, 2 H), 1.91 - 1.84 (m, 2 H), 1.41 (td, J = 6.8, 13.8 Hz, 8 H), 1.37 - 1.31 (m, 8 H), 1.07 (t, J = 7.3 Hz, 3 H), 0.99 - 0.94 (m, 6 H), 0.93 - 0.89 (m, 6 H); ¹³C NMR (100 MHz, CDCl₃) δ 167.8, 162.9, 162.8, 162.2, 147.5, 147.0, 143.8, 137.7, 135.0, 132.5, 131.5, 130.9, 130.3, 130.0, 129.0, 128.8, 128.7, 128.6, 128.3, 127.9, 127.5, 127.4, 127.2, 127.1, 126.8, 126.2, 125.2, 124.3, 123.5, 123.3, 123.1, 122.6, 121.7, 115.7, 115.2, 114.9, 101.0, 91.0, 68.2, 49.6, 44.5, 44.4, 38.7, 38.0, 31.9, 30.7, 30.4, 29.7, 29.4, 28.9, 28.7, 24.0, 23.7, 23.1, 23.0, 20.1, 14.1, 11.3, 11.0, 10.6

5. PHOTOPHYSICAL PROPERTIES

The absorption spectra of compounds **9** and **10** were recorded in DCM (1×10^{-5} M) at RT shown in Figure 5 and Table 1.



Figure 5. The normalized electronic absorption spectra of compounds **9** and **10** in DCM $(1 \times 10^{-5} \text{M})$.

The UV-vis spectra of compounds **9** and **10** display absorption bands between 300-650 nm. Compounds **9** and **10** exhibit an intense absorption band at around 525 nm due to π - π * transitions while compound **10** shows additional absorption maxima with a low energy absorption band around 624 nm due to intramolecular charge transfer from phenothiazine to PDI core.⁵⁴ Due to phenothiazine donor moiety, compound **10** shows a red-shifted absorption band of 102 nm as compared to compound **9**.

Table 1. Photo	physical and	theoretical	properties of	of compounds 9	and
10.					

Compounds	$\lambda_{abs} (nm)^a$	3	${E_g}^b$
		(M⁻¹.cm⁻¹) ^a	(eV)
9	328 370 522	13,030 12,535 62,566	2.14
10	321 372 524 624	27,295 23,470 30,014 10,330	1.44

^aAbsorbance measured in DCM at a concentration of 1×10^{-5} M, ε ; molar extinction coefficient, ^bTheoretical values of the HOMO-LUMO gap calculated from the DFT calculation.

5.2 DENSITY FUNCTIONAL THEORY

The ground state electronic structures and frontier molecular orbital (FMO) geometries of compounds **9** and **10** were studied with DFT calculations by using Gaussian 09W program at the B3LYP/6-31G (d,p) level. Structure optimization was carried out in the gas phase to estimate the structure as well as electronic properties. Figure 6 shows the calculated frontier molecular orbitals.



Figure 6. The FMOs of compounds 9 and 10 at the B3LYP/6-31G (d, p) level.

The optimized structures of compounds **9** and **10** have distorted geometry. The frontier molecular orbitals (FMOs) as well as the energy levels of the theoretically calculated highest occupied molecular orbitals (HOMOs) and lowest unoccupied molecular orbitals (LUMOs) shown in Figure 7. In compound 9, electron density on HOMO and LUMO energy levels is localized throughout the whole molecule. In the case of compound 10, the electron density of HOMO energy level localized on the phenothiazine donor moiety, and the electron density of LUMO energy level localized on the PDI core due to the donor phenothiazine moiety.



Figure 7. Energy level diagram of FMOs of compounds 9 and 10.

The HOMO-LUMO band gap for compounds **9** and **10** is 2.52 eV and 1.74 eV respectively. In compound **10**, donor-acceptor interaction between the PDI core and donor phenothiazine unit results in the decrease of HOMO-LUMO band gap as compared to compound **9**.

6. CONCLUSION

We successfully designed and synthesized the PDI derivatives **9** and **10** by Sonogashira cross-coupling reaction. In contrast to photophysical properties, compound **10** shows redshift absorption as compared to compound **9** of 102 nm due to the phenothiazine donor moiety. As per the DFT study for compound **9**, due to the donor phenothiazine moiety, the electron density on HOMO energy level localized on phenothiazine donor moiety and electron density on LUMO energy level localized on PDI core. Compound **10** shows a broad absorption spectrum and low HOMO-LUMO band gap making them attractive D-A system for improving the power conversion efficiency and long-term stability of OSCs. Thus, the synthesized PDI derivative molecule can be used in various optoelectronic applications such as organic solar cells, and optoelectronic devices.

7. SUPPORTING INFORMATION



Figure. 8 ¹H NMR of compound **2**.



Figure. 9 ¹³C NMR of compound **2**.



Figure. 10 HRMS of compound 2.



Figure. 11 ¹H NMR of compound 5.



Figure. 12 ¹³C NMR of compound 5.



Figure. 13 HRMS of compound 5.



Figure. 14 ¹H NMR of compound 7.



Figure. 15 ¹³C NMR of compound 7.



Figure. 16 ¹H NMR of compound 8.



Figure. 17 ¹³C NMR of compound 8.



Figure. 18 ¹H NMR of compound 9.



Figure. 19¹³C NMR of compound 9.



Figure. 20 ¹H NMR of compound 10.



Figure. 21 ¹³C NMR of compound 10.

8. REFERENCES

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