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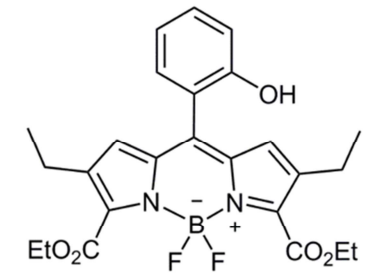
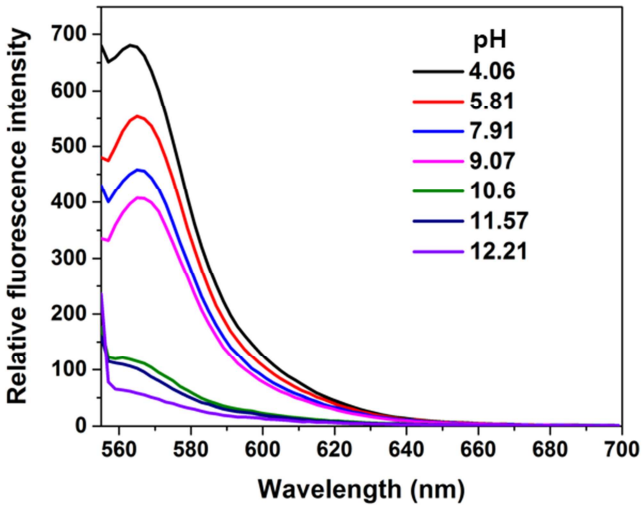
Graphical Abstract



Meso-hydroxyphenyl BODIPY



Substituents modification of *meso*-aryl BODIPYs for tuning photophysical properties

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Abstract

We successfully synthesized eight *meso*-aryl BODIPYs with 2,6-diethyl- or 1,2,6,7-tetraethyl substituents and characterized their photophysical properties. The steric hindrance resulting from the phenolic group in the *meso*-aryl moiety and the ethyl groups on the BODIPY core affected the synthesis of dipyrromethanes as an intermediate as well as the UV-Vis absorption and fluorescence emission due to the constrained rotation of the aryl ring. The potential use

of the *meso*-hydroxyphenyl BODIPY as a pH sensor was also shown by the pH-dependent fluorescence emissions.

Keywords: BODIPY, Fluorescent dye, UV/Vis spectroscopy, Fluorescence spectroscopy, pH sensor

1. Introduction

Fluorescence dyes, typically bearing π-conjugated bonds, have widely been studied in various areas because of fundamental interest in photo-chemical and -physical processes as well as technological applications such as analytical sensors, photovoltaic cells, light-emitting diodes, biomedical imaging, and biomarkers.[1–4] For example, cyanine dyes are used to label biomolecules such as proteins, antibodies, and peptides due to their fluorescence brightness, photostability, and low nonspecific binding.[5] To extend the use of fluorophores in technologically important fields, the first step will be to understand photophysical properties depending on the molecular structures and environmental conditions (e.g., solvent polarity and ions). However, it is difficult to systematically investigate the structure effect of most organic fluorophores because of limited structural modifications and poor solubility in common organic solvents.[6] 4,4-difluoro-4-bora-3a,4a-diaza-*s*-indacene (BODIPY) has recently received considerable attention due to its favorable photophysical properties, for example, narrow absorption and emission bands, high molar extinction coefficients, negligible triplet-state formation, and excellent photostability.[7] Furthermore, its facile structural modification[8] and high solubility in organic solvents make it easy to use in various areas such as molecular probes,[2,7,9] photosensitizers,[10–12] and chemical sensors.[13,14] To date, there are numerous BODIPY derivatives with different electronic and steric effects on the

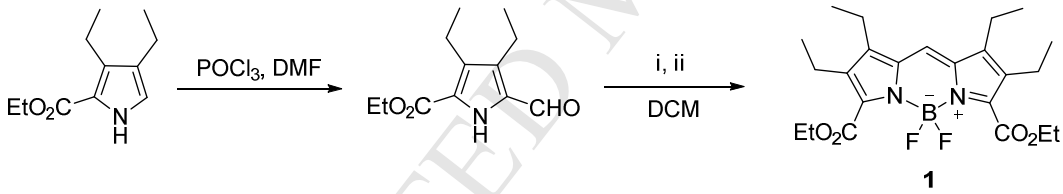
meso-position and periphery of boradiazaindacenes.[15–22] For example, electron-withdrawing substituents at the *meso*-position lowered the LUMO level leading to bathochromic shifts with respect to analogues with electron donating substituents. Additionally, the steric pressure at the 1,3,5,7-substituted BODIPY leads to the loss of its planarity resulting in increased non-radiative deactivation rates and lower quantum yields compared to the 3,5-substituted counterparts.[14] Though there has been many literature precedents for the BODIPYs with electron donating methyl groups in positions 3 and 5 on BODIPY core,[14,23–25] diethyl carboxylate substituents in positions 3 and 5[16] was employed in this work. The introduction of the diethyl carboxylate ester groups enables BODIPYs to increase water solubility after hydrolysis of the ester group, leading to facile biological applications. In addition, the carboxylate group can be converted to amide functional group for further applications, e.g. metal detection.

In particular, *meso*-hydroxyphenyl substituted BODIPYs have shown fluorescence on/off switching through deprotonation and protonation processes.[23–27] The emission intensity is attributed to the photoinduced electron transfer (PET) from the phenolate to the excited-state indacene acceptor moiety. Thus, it is important to systematically study how photophysical properties are affected by substituents at the periphery of *meso*-hydroxyphenyl substituted BODIPYs. Herein, we investigated the feasibility of synthesizing highly substituted *meso*-hydroxyphenyl/phenyl BODIPYs with di- or tetra-ethyl groups on the boradiazaindacenes as well as their photophysical properties. We successfully synthesized eight *meso*-aryl BODIPYs with 2,6-diethyl- or 1,2,6,7-tetraethyl substituents and characterized their quantum yield including the pH-dependent fluorescence emission.

2. Results and discussion

2.1. Design and synthesis of BODIPYs

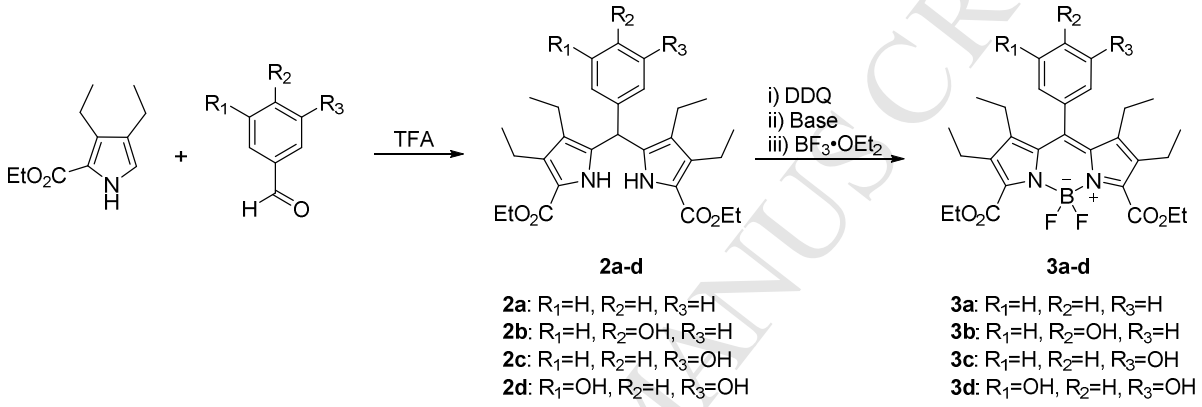
To compare its photophysical properties with BODIPYs having aryl units in the *meso* position, *meso*-unsubstituted BODIPY **1** was synthesized. The periphery of the dipyrromethene is substituted with different electron driving forces. The 1, 2, 6, and 7 positions are functionalized with ethyl groups, and the 3 and 5 positions are substituted with carboxylate units. First, ethyl 3,4-diethyl-5-formyl-1*H*-pyrrole-2-carboxylate was synthesized from ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate with $POCl_3$ in DMF with a known procedure (Scheme 1). Then, the aldehyde was condensed with ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate in the presence of Et_3N followed by treatment with BF_3•OEt_2 to yield BODIPY dye **1.**[18,28–30]



Scheme 1. Synthesis of *meso*-unsubstituted BODIPY **1**. Reagents and conditions: (i) Ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate, $POCl_3$, Et_3N; (ii) BF_3•OEt_2

After the successful synthesis of *meso*-unsubstituted BODIPY **1** from ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate, we then synthesized a series of *meso*-aryl-substituted BODIPYs **3a-d** with ethyl substituents at the 1, 2, 6, and 7 positions and carboxylate groups at the 3 and 5 positions on the boradiazaindacenes (Scheme 2). The dipyrromethanes **2a-d**, which are key intermediates, were prepared by condensation between the corresponding benzaldehyde and ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate in the presence of trifluoroacetic acid (TFA) as a catalyst. Whereas **2a** was synthesized in CH_2Cl_2 (DCM), **2b-2d** were prepared in THF, a

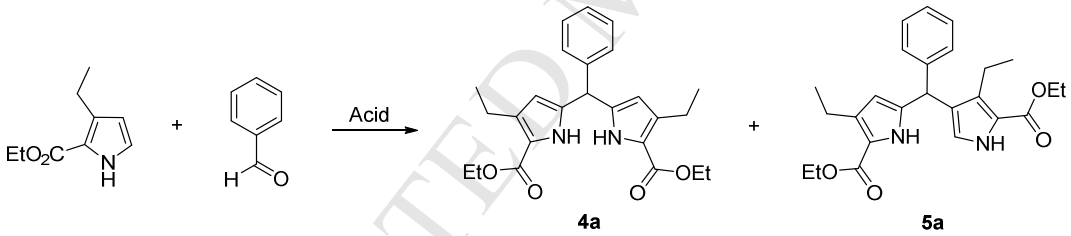
polar solvent, due to the limited solubility of the hydroxybenzaldehydes in CH_2Cl_2 (DCM). Products **2a-d** were further reacted with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ), a base, and BF_3•OEt_2 to yield BODIPYs **3a-d**. While Et_3N was used in the preparation of **3a** and **3c**, *N*,*N*-diisopropylethylamine (DIPEA) was used as a base for the **3b** and **3d** preparation.



Scheme 2. Synthesis of *meso*-aryl BODIPY **3a-3d**.

As shown in Scheme 2, 3-hydroxybenzaldehyde, 4-hydroxybenzaldehyde and 3,5-dihydroxybenzaldehyde were successfully condensed with ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate. However, 2-hydroxybenzaldehyde was unable to produce dipyrromethane. It was speculated that the steric interference between the 2-hydroxy group of benzaldehyde and the *β*-substituent of pyrrole prohibited the formation of dipyrromethane. Because the steric interference between the 2-hydroxy group of benzaldehyde and the *β*-substituent of pyrrole imposes a challenge on the formation of dipyrromethane, the elimination of the steric hindrance could facilitate the formation of dipyrromethane and BODIPY, sequentially, from 2-hydroxybenzaldehyde. In this sense, the synthesis of BODIPYs bearing ethyl substituents on the 2 and 6 positions was tried from ethyl 3-ethyl-1*H*-pyrrole-2-carboxylate (Scheme 3). Ethyl 3-ethyl-1*H*-pyrrole-2-carboxylate was prepared according to a previously reported

method.[24] Unfortunately, the condensation of ethyl 3-ethyl-1*H*-pyrrole-2-carboxylate and benzaldehyde in the presence of TFA not only suffered from a low yield of **4a** but also produced *α*,*β*-connected dipyrromethane **5a** resulting in a poor yield (Table 1, entry 1) of the corresponding BODIPY. Though it was already reported that the yield of dipyrromethane from the condensation between benzaldehyde and ethyl 3-ethyl-1*H*-pyrrole-2-carboxylate was negligible,[31] we optimized the reaction condition to improve the yield of **4a**. As shown in Table 1, the only desired product **4a** was obtained using 10 or 1 equiv. of TFA (entry 2 and 3), while the condensation with excess TFA produced **5a** as a side product (entry 1). 0.5 equiv. of methanesulfonic acid (MSA) in CH_2Cl_2 (DCM) could produce **4a** in an optimized yield of 25% without **5a** (entry 8). However, *p*-toluene sulfonic acid (*p*-TSA), trichloroacetic acid (TCA), and BF_3•OEt_2 were not effective for the formation of **4a** (entry 4, 5, and 6).



Scheme 3. Synthesis of dipyrromethane from ethyl 3-ethyl-1*H*-pyrrole-2-carboxylate and benzaldehyde.

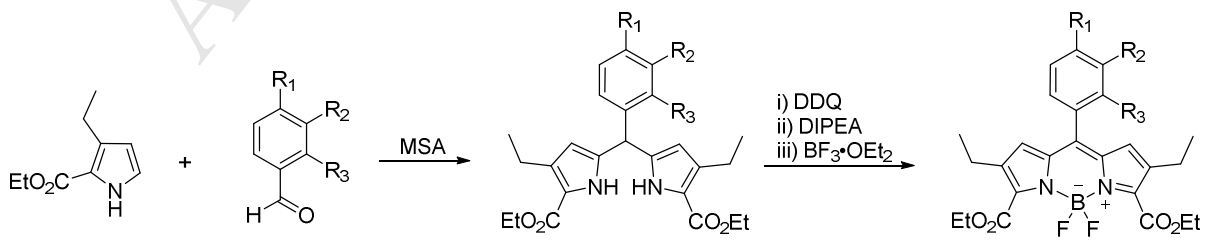
Table 1
Reaction condition optimization for **4a** from benzaldehyde (1 equiv.) and ethyl 3-ethylpyrrole-2-carboxylate (2 equiv.).[a]

Entry	Acid		solvent	Yield of **4a** (%)	Yield of **5a** (%)
	agent	equiv.			
1	TFA	40	DCM	9	10
2	TFA	10	DCM	8	-
3	TFA	1	DCM	12	-
4	*p*-TSA	1	DCM	Trace	-
5	TCA	20	DCM	[b] N.R.	[b] N.R.
6	$BF_3 \cdot OEt_2$	0.4	DCM	[c] N.A.	[c] N.A.
7	MSA	0.25	DCM	12	-
8	**MSA**	**0.5**	**DCM**	**25**	-
9	MSA	0.75	DCM	20	28
10	MSA	0.5	Toluene	5	21

[a] 1 equiv. of benzaldehyde and 2 equiv. of ethyl 3-ethylpyrrole-2-carboxylate were used. [b] N.R.: no reaction; [c] N.A.: no products, the reaction produced mostly polymers.

With these optimized conditions on hand, a series of dipyrromethane **4a-d** were prepared from 2-, 3- and 4-hydroxybenzalydehyde and subsequently converted to BODIPY **6a-d** using DIPEA as a base. It is worth mentioning that the 2-hydroxyphenyl group in the *meso* position of BODIPY **6d** is compatible with the 2,6-diethyl units on dipyrromethene due to the reduction of the steric interference.

The one-pot synthesis for BODIPYs[32] was also tried, but we observed numerous by-products spots on TLC, which led to extremely low yield after column separation (<5 %). Though we do not have the general hypothesis for the relatively low yields for BODIPY **1**, **3d**, and **6d** compared to other BODIPYs (*vide infra*), we suggest that the low yield is generally attributed to the formation of quite a few byproducts and several purification processes.



4a-d

4a: R_1=H, R_2=H, R_3=H
4b: R_1=OH, R_2=H, R_3=H
4c: R_1=H, R_2=OH, R_3=H
4d: R_1=H, R_2=H, R_3=OH

6a-d

6a: R_1=H, R_2=H, R_3=H
6b: R_1=OH, R_2=H, R_3=H
6c: R_1=H, R_2=OH, R_3=H
6d: R_1=H, R_2=H, R_3=OH

Scheme 4. Synthesis of *meso*-aryl BODIPY **6a-6d**.

2.2. Photophysical properties of BODIPYs

The photophysical properties of the synthesized BODIPYs were investigated in CH_2Cl_2 solution. As shown in Figure 1 and Table 2, BODIPY **1**, **3a-d**, and **6a-d** have narrow absorption bands with two absorption maxima. The main absorption at 534 - 554 nm resulted from the 0-0 band of a strong S_0-S_1 transition. The 0-1 vibrational band of the same transition generated the second maximum or shoulder at a short wavelength around 500 nm. In addition, a considerably weak broad absorption band is found at around 400 nm for the measured BODIPYs attributed to the S_0-S_2 transition. The emission spectra of the BODIPYs exhibit mirror symmetry with the absorption and Stokes-shifted band. Compared with the absorption spectra of **3a-d**, the absorption spectra of **6a-d** are red-shifted by 9 to 20 nm due to the increased π-conjugation of the chromophore **6a-d**. The blue-shifted absorption of **3a-d** can be attributed to almost perpendicular configurations between the BODIPY core and the aryl moiety, which hinders the delocalization of the LUMO into the aryl moiety and the contribution of the aryl ring to the electronic absorption band.[33] The dihedral angle between the 3-hydroxybenzene and BODIPY moiety is 89.5˚ in the **3c** crystal structure (Figure 2) obtained from X-ray diffraction analysis as observed in sterically hindered BODIPYs.[34] The internal steric interference resulting from the ethyl groups at the 1 and 7 positions also leads to relatively large Stokes shifts for **3a-d** ($\Delta\bar{\upsilon}$ = 866 - 933 cm^{-1}) compared to **6a-d** ($\Delta\bar{\upsilon}$ = 455 - 750 cm^{-1}) shown in the fluorescence emission spectra.

The high absorption coefficient (ε) in range of 56,300-107,100 M^{-1} cm^{-1} were observed for the synthesized BODIPYs as shown in Table 2. When compared in BODIPY **3a-3d** series,

the absorption coefficient value of **3c** and **3d** was lower than **3a** and **3b** due to steric hindrance between hydroxyl group in *meta*- positions and 1,2,6,7-tetraethyl substituents. In comparison to **3a** having 1,2,6,7-tetraethyl on BODIPY core, **6a** containing 2,6-diethyl substituents showed lower absorption coefficient. In the case of BODIPYs with phenolic group at *meso*-position, **6b** and **6c** have much higher absorption coefficients than their **3b** and **3c** counterparts. We also note the highest absorption coefficients of 107,100 M^{-1} cm^{-1} for **6c** among the synthesized BODIPYs.

The quantum yield value, Φ_f, empirically increases as the π-conjugation and the steric hindrance between the *meso*-substituted aryl ring and BODIPY core increase.[14,24,34,35] In a series of BODIPY **3a-d**, the larger quantum yield (Φ_f = 0.27) was observed in **3d** bearing the 3,5-dihydroxyaryl group at *meso*-position in BODIPY core compared to **3a-c** (Φ_f = 0.16-0.20). This attributed to reduced non-radiative energy loss due to the decreased free rotation of dihydroxyaryl group. When compare between **3a-c** and **6a-c** that has phenolic or aryl group at same position, slightly higher quantum yield was observed in **3a** (Φ_f = 0.17) and **3c** (Φ_f = 0.20) than counter partners **6a** (Φ_f = 0.16) and **6c** (Φ_f = 0.12), though **3b** (Φ_f = 0.16) and **6b** (Φ_f = 0.21) showed the contrast tendency. Exceptionally, **6d** containing *o*-phenolic moiety had the highest quantum yield of 0.54 among **3a-d** and **6a-d**. The interaction between the 2-hydroxy group and π-system in the boradiazaindacene core may hinder the free rotation of the aryl ring, which reduces the excited energy loss *via* a non-radiative decay process.[33,36] In addition to *meso*-(2-hydroxyphenyl) BODIPY **6d**, it is also worth noting that *meso*-unsubstituted BODIPY **1** had the highest quantum yield of 0.54 among all the synthesized BODIPYs.

Table 2
Photophysical Properties of BODIPY dyes **1**, **3a-d**, and **6a-d** in CH_2Cl_2.

BODIPY dyes	ε (M^{-1} cm^{-1})	λ_{abs} (nm)[a]	λ_{em} (nm)[b]	$\Delta\bar{\upsilon}$ (cm^{-1})	Φ_f[c]
1	56,300	544	566	715	0.54
3a	78,100	534	560	869	0.17
3b	71,400	534	562	933	0.16
3c	62,300	534	560	869	0.20
3d	64,400	535	561	866	0.27
6a	68,200	548	562	455	0.16
6b	95,300	544	558	461	0.21
6c	107,100	549	573	763	0.12
6d	65,600	554	578	750	0.54

[a] Absorption maximum. [b] Emission maximum. [c] Quantum yields (Φ_f) were determined with rhodamine 6G as a standard in ethanol (Φ_f = 0.95) [37]

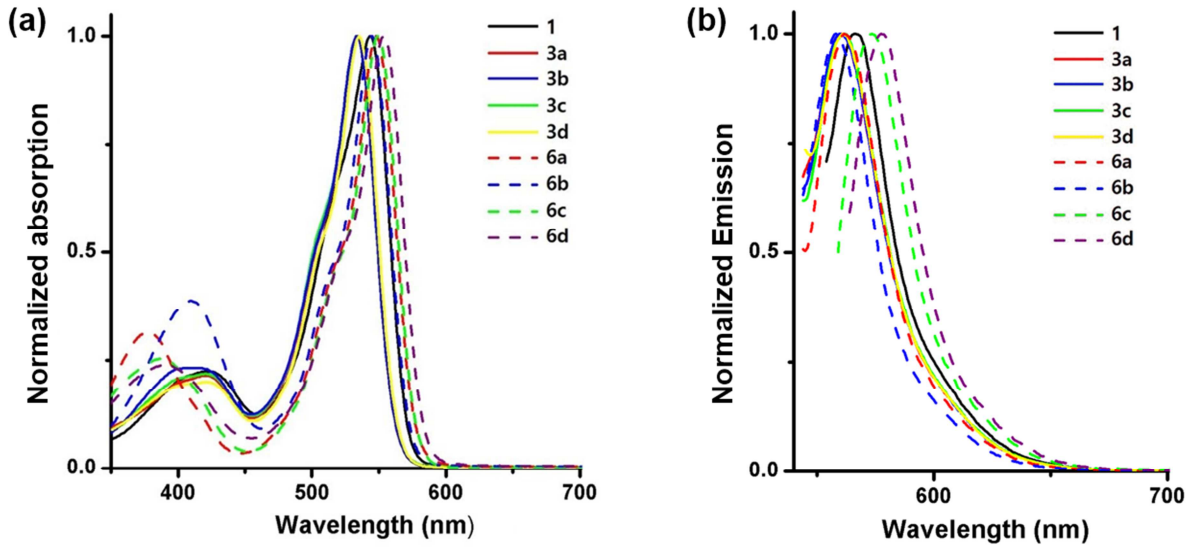


Fig. 1. (a) UV-Vis absorption spectra and (b) fluorescence emission spectra of BODIPYs **1**, **3a-d**, and **6a-d**.

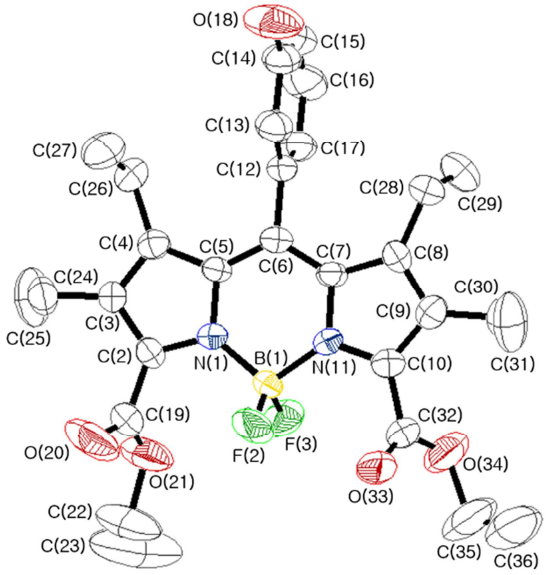


Fig. 2. Crystal structure of BODIPY **3c**. The dihedral angle between the BODIPY core and 3-hydroxybenzene (deg): 89.5. For full data of crystal **3c**, see the Supplementary data.

*2.3. pH dependent UV-Vis and Fluoresence studies of BODIPY **6d***

Further, we investigated the pH-dependent photophysical properties of **6d**, which had the highest quantum yield among the series of *meso*-aryl BODIPYs. The absorption spectra of **6d** in several pH conditions are shown in Figure 3a. A hypsochromic shift of the absorption maximum of **6d** from 548 nm at pH 4.06 to 536 nm at pH 12.21 was observed by increasing the pH. In comparison to the absorption spectra, fluorescence emission spectra of **6d** in aqueous solution show the absence of consistent pH-dependent shifts (Figure 3b). However, a sizeable increase in fluorescence emission intensity was observed by decreasing the pH down to 4.06, which can extend imaging applications to cancer markers. A phenolate formed by the deprotonation of a phenol moiety generates an intramolecular charge transfer (CT) state. The PET like quenching leads to a low fluorescence intensity in aqueous solution. On the other

hand, the protonation of a phenoxide ion at a lower pH suppresses the formation of the CT state and the non-radiative decay process resulting in enhanced fluorescence.[25]

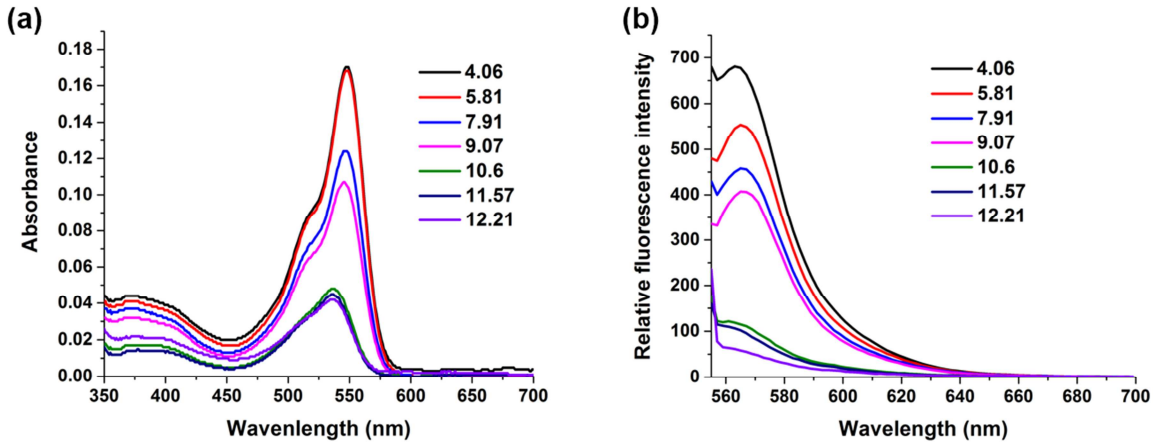


Fig. 3. (a) Absorption spectra and (b) fluorescence emission spectra (λ_{ex} = 548 nm of BODIPY **6d** in EtOH-H_2O (3:1) as a function of pH.

3. Conclusion

In summary, the highly sterically hindered *meso*-aryl BODIPY derivatives using ethyl 3,4-diethyl-1*H*-pyrrole-2-carboxylate or ethyl 3-ethyl-1*H*-pyrrole-2-carboxylate were synthesized and characterized. The steric hindrance resulting from the phenolic group in the *meso*-position and the ethyl groups at the 1,7 position affected the synthesis of dipyrromethanes as an intermediate as well as the UV absorption and fluorescence emission because of the constrained rotation of the aryl ring. The absorption spectra of **6a-d** are red-shifted 9 to 20 nm due to the increased π-conjugation with respect to the absorption spectra of **3a-d**. The internal steric interference resulting from 1,7 diethyl groups of **3a-d** BODIPY core also leads to relatively large Stokes shifts ($\Delta\bar{\upsilon}$ = 866 - 933 cm^{-1}) compared to **6a-d** ($\Delta\bar{\upsilon}$ = 455 - 750 cm^{-1})

as shown in the fluorescence emission spectra. Further, *meso*-hydroxyphenyl BODIPY **6d** showed pH-dependent fluorescence emission intensity, which can be applicable in clinical trial applications (i.e., cancer markers).

4. Experimental

4.1. Synthesis

4.1.1. Ethyl 3,4-diethyl-5-formyl-1H-pyrrole-2-carboxylate

$POCl_3$ (4.58 mL, 49.2 mmol) was dropped into dimethylformamide (DMF, 3.80 mL, 49.2 mmol) in a round bottom flask, and the mixture was maintained at 40 °C for 15 minutes. After adding 1,2-dichloroethane (80 mL) to the solution at 0 °C, Ethyl 3,4-diethylpyrrole-2-carboxylate (8.0 g, 41.0 mmol) in 1,2-dichloroethane (48 mL) was slowly added for 20 minutes. The reaction mixture was refluxed for 30 minutes and then cooled to room temperature. Sodium acetate (18.48 g, 225.3 mmol) in distilled H_2O (160 mL) was added, and the resulting mixture was refluxed at 100 °C. After 30 minutes, the organic layer was washed with distilled H_2O (100 mL), aq. sat. Na_2CO_3 solution (100 mL × 2), and brine (100 mL) sequentially. The solvent was dried over Na_2SO_4 and evaporated *in vacuo* to give the desired product ethyl 3,4-diethyl-5-formyl-1*H*-pyrrole-2-carboxylate as a pale brown solid (8.28 g, 90.6 %). ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.75 (1H, s), 9.54 (1H, br s) 4.35 (2H, q, *J* = 7.2 Hz), 2.75 (2H, q, *J* = 7.5 Hz), 2.74 (2H, q, *J* = 7.5 Hz), 1.38 (3H, t, *J* = 7.2 Hz), 1.24 (3H, t, *J* = 7.5 Hz), 1.16 (3H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 179.16, 160.68, 136.35, 133.10, 129.57, 124.21, 61.09, 17.83, 16.97, 15.88, 14.60; mp 48-50°C; MS (EI^+) *m/z* (%): 223 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{12}H_{17}NO_3$: 223.1208, Found: 223.1206.

*4.1.2. BODIPY **1***

Ethyl 3,4-diethylpyrrole-2-carboxylate (0.46 g, 2.38 mmol) and ethyl 3,4-diethyl-5-formyl-1*H*-pyrrole-2-carboxylate (0.58 g, 2.61 mmol) were dissolved in anhydrous dichloromethane (DCM, 40 mL), and this solution was cooled to 0 °C and stirred for 10 min under nitrogen atmosphere. $POCl_3$ (0.24 mL, 2.61 mmol) was added slowly to the solution and stirred for 1 h and then the mixture was warmed to room temperature where stirring continued further 4 h. Triethylamine (3.32 mL, 23.75 mmol) was added to the mixture and stirred for 15 min. BF_3•OEt_2 (2.93 mL, 23.75 mmol) was added dropwise by a syringe to the mixture and stirring continued another 2 h. After completion of the reaction, the resulting mixture was diluted with DCM (40 mL) and washed sequentially with aq. sat. $NaHCO_3$ solution, H_2O and brine. The organic layer was dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by column chromatography on a silica gel (EtOAC:hexane = 1:3, DCM only, and EtOAC:hexane = 1:6 in order) to yield the BODIPY **1** (0.075 g, 7.0 %) as a red solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.32 (1H, s), 4.43 (4H, q, *J* = 7.2 Hz), 2.65 (4H, q, *J* = 7.5 Hz), 2.56 (4H, q, *J* = 7.5 Hz), 1.43 (6H, t, *J* = 7.2 Hz), 1.21 (6H, t, *J* = 7.5 Hz), 1.13 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.53, 146.07, 145.61, 134.74, 134.07, 125.94, 61.87, 17.89, 17.79, 17.16, 15.38, 14.00; mp 130-132 °C; MS (EI^+) *m/z* (%): 448 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{23}H_{31}BF_2N_2O_4$: 448.2345, Found: 448.2347.

*4.1.3. Dipyrromethane **2a***

TFA (0.374 mL, 4.87 mmol) was added to a mixture of ethyl 3,4-diethylpyrrole-2-carboxylate (1.0 g, 5.12 mmol) and benzaldehyde (0.260 mL, 2.56 mmol) in anhydrous DCM (10 mL) under Ar and the resulting mixture was stirred overnight. After completion of the reaction, the reaction was neutralized with aq. sat. $NaHCO_3$ solution and extracted with DCM

(2 x 45 mL). The combined organic layer was washed with distilled H_2O (2 x 30 mL), brine (30 mL), dried over Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by column chromatography on a silica gel (EtOAC:hexane = 1:10) to yield the desired product **2a** (1.11 g, 91.0 %) as a pale orange liquid which then turned to solid upon kept in the refrigerator. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.40 (2H, br s), 7.32-7.24 (3H, m), 7.07 (2H, d, *J* = 8.1 Hz), 5.55 (1H, s), 4.21 (4H, q, *J* = 7.2 Hz), 2.70 (4H, q, *J* = 7.5 Hz), 2.30 (4H, q, *J* = 7.5 Hz), 1.31 (6H, t, *J* = 7.2 Hz), 1.14 (6H, t, *J* = 7.5 Hz), 0.90 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.52, 139.71, 134.06, 131.71, 129.13, 128.38, 127.60, 123.86, 117.64, 60.01, 40.76, 18.71, 17.44, 16.14, 15.87, 14.72; MS (EI^+) *m/z* (%): 478 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{38}N_2O_4$: 478.2832, Found: 478.2836.

*4.1.4. BODIPY **3a***

To a stirred solution of dipyrromethane **2a** (0.55 g, 1.15 mmol) in anhydrous DCM (18 mL) was added a solution of DDQ (0.31 g, 1.38 mmol, 1.2 equiv.) in anhydrous DCM (22 mL) at room temperature under nitrogen atmosphere and stirred for 1 h. Then, Et_3N (2.3 mL) and BF_3•Et_2O (3.07 mL) were added sequentially and stirring was continued for overnight. After completion of the reaction, the reaction mixture was sequentially washed with aq. sat. $NaHCO_3$ solution, distilled H_2O and brine. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:5)to afford the desired BODIPY **3a** (0.34 g, 56 %) as red solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.50-7.36 (5H, m), 4.45 (4H, q, *J* = 7.2 Hz), 2.41 (4H, q, *J* = 7.2 Hz), 1.62 (4H, q, *J* = 7.3 Hz), 1.43 (6H, t, *J* = 7.2 Hz), 1.06 (6H, t, *J* = 7.2 Hz), 0.67 (6H, t, *J* = 7.3Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.46, 148.23, 148.06, 145.64, 135.07, 134.02, 132.44, 129.84, 128.46, 128.41, 62.16, 19.01, 17.57, 16.48, 15.50, 14.25; mp 150-152 °C; MS (EI^+) *m/z* (%): 524 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{35}BF_2N_2O_4$: 524.2658,

Found: 524.2664.

*4.1.5. Dipyrromethane **2b***

TFA (2.17 mL, 28.34 mmol) was added to a solution of ethyl 3,4-diethylpyrrole-2-carboxylate (1.0 g, 5.12 mmol) and 4-hydroxybenzaldehyde (0.156 g, 1.28 mmol) in THF (10 mL) under Ar. After the resulting mixture was stirred overnight, the reaction was quenched with 0.2N NaOH solution. The organic layer was extracted with DCM (40 mL), washed with distilled H_2O (40 mL) and dried over Na_2SO_4. After evaporation of the solvent *in vacuo*, the crude product was purified by column chromatography on a silica gel (DCM:EtOAc = 97:3) to yield the desired product **2b** (0.22 g, 34.9 %) as a red liquid which then turned to solid upon kept in the refrigerator. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.54 (2H, br s), 7.18 (1H, br s), 6.89 (2H, d, *J* = 8.3 Hz), 6.72 (2H, d, *J* = 8.3 Hz), 4.25 (4H, q, *J* = 7.1 Hz), 2.70 (4H, q, *J* = 7.3 Hz), 2.31 (4H, q, *J* = 7.3 Hz), 1.30 (6H, t, *J* = 7.1 Hz), 1.14 (6H, t, *J* = 7.3 Hz), 0.91 (6H, t, *J* = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.82, 155.24, 134.11, 132.41, 130.82, 129.22, 123.57, 117.16, 115.84, 60.03, 39.64, 18.52, 17.18, 15.91, 15.70, 14.47; MS (EI^+) *m/z* (%): 494 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{38}N_2O_5$: 494.2781, Found: 494.2785.

*4.1.6. BODIPY **3b***

DDQ (0.05 g, 0.22 mmol) was added to the solution of **2b** (0.11 g, 0.22 mmol) in DCM (6 mL) under Ar. The solution was stirred for 2 hours, and then, *N*,*N*-diisopropylethylamine (0.3 mL, 2.2 mmol) was added. The resulting mixture was refluxed for 30 minutes before BF_3•Et_2O (0.4 mL, 3.3 mmol) was added. After 12 hours of refluxing, the red solution was cooled to room temperature. The reaction was quenched with 1N NaOH solution, and then, the pH was adjusted to 5~6 with 1N HCl. The organic layer was extracted with DCM (15 mL), washed with distilled H_2O (15 mL) and dried over Na_2SO_4. After evaporation of the

solvent *in vacuo*, purification by column chromatography (DCM:EtOAc = 97:3) on a silica gel yielded BODIPY **3b** (0.03 g, 25.0 %) as a red solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.19 (2H, d, *J* = 8.1 Hz), 6.94 (2H, d, *J* = 8.1 Hz), 6.27 (1H, br s), 4.45 (4H, q, *J* = 7.2 Hz), 2.43 (4H, q, *J* = 7.2 Hz), 1.72 (4H, q, *J* = 7.3 Hz), 1.42 (6H, t, *J* = 7.1 Hz), 1.07 (6H, t, *J* = 7.3 Hz), 0.70 (6H, t, *J* = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.49, 157.30, 148.46, 148.14, 145.43, 134.90, 132.79, 129.77, 125.84, 115.42, 62.00, 18.93, 17.41, 16.25, 15.22, 14.04; mp 154-156 °C; MS (EI^+) *m/z* (%): 540 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{35}BF_2N_2O_5$: 540.2607, Found: 540.2609.

*4.1.7. Dipyrromethane **2c***

TFA (8 mL, 104 mmol) was added to a solution of ethyl 3,4-diethylpyrrole-2-carboxylate (1.0 g, 5.12 mmol) and 3-hydroxybenzaldehyde (0.130 g, 1.06 mmol) in THF (10 mL) under Ar. After the resulting mixture was stirred overnight, 0.2N NaOH was added. The product layer was extracted with DCM (40 mL) and dried over Na_2SO_4. After evaporation of the solvent *in vacuo*, the crude product was purified by column chromatography on a silica gel (DCM:EtOAc = 97:3) to yield the desired product **2c** (0.44 g, 83.7 %) as a bright red solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.81 (2H, br s), 7.07 (1H, t, *J* = 7.8 Hz), 6.90 (1H, br s), 6.67 (1H, d, *J* = 7.8 Hz), 6.57 (1H, d, *J* = 7.8 Hz), 6.54 (1H, br s), 5.49 (1H, s), 4.17 (4H, q, *J* = 7.1 Hz), 2.69 (4H, q, *J* = 7.3 Hz), 2.32 (4H, q, *J* = 7.3 Hz), 1.25 (6H, t, *J* = 7.1 Hz), 1.13 (6H, t, *J* = 7.3 Hz), 0.92 (6H, t, *J* = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.72, 156.36, 141.17, 133.96, 131.89, 129.75, 123.76, 119.91, 117.18, 115.06, 114.31, 59.99, 39.94, 18.50, 17.17, 15.87, 15.84, 14.37; MS (EI^+) *m/z* (%): 494 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{38}N_2O_5$: 494.2781, Found: 494.2781.

*4.1.8. BODIPY **3c***

DDQ (0.087 g, 0.38 mmol) was added to the solution of **2c** (0.19 g, 0.38 mmol) in DCM (10 mL) under Ar. The solution was stirred for 2 hours, and then, triethylamine (0.535 mL, 3.83 mmol) was added. The reaction mixture was refluxed for 30 minutes before BF_3•Et_2O (0.711 mL, 5.76 mmol) was added. After 12 hours of refluxing, the red solution was cooled to room temperature. The reaction was quenched with 1N NaOH solution, and then, the pH was adjusted to 5~6 with 1N HCl. The organic layer was extracted with DCM (20 mL), washed with distilled H_2O (20 mL) and dried over Na_2SO_4. After evaporation of the solvent *in vacuo*, purification by column chromatography (DCM:EtOAc = 99:1 → 9:1) on a silica gel yielded BODIPY **3c** (0.034 g, 16.2 %) as a red solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30 (1H, t, *J* = 7.8 Hz), 7.02 (1H, d, *J* = 6.8 Hz), 6.88 (1H, d, *J* = 7.8 Hz), 6.83 (1H, s), 6.32 (1H, br s), 4.44 (4H, q, *J* = 7.0 Hz), 2.41 (4H, q, *J* = 7.3 Hz), 1.70 (4H, m), 1.42 (6H, t, *J* = 7.4 Hz), 1.05 (6H, t, *J* = 7.4 Hz), 0.71 (6H, t, *J* = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.60, 156.05, 148.39, 147.74, 145.08, 135.30, 135.15, 132.36, 129.89, 120.78, 116.97, 115.80, 62.19, 19.06, 17.60, 16.36, 15.39, 14.24; mp 171-173 °C; MS (EI^+) *m/z* (%): 540 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{35}BF_2N_2O_5$: 540.2607, Found: 540.2609.

*4.1.9. Dipyrromethane **2d***

TFA (9.8 mL, 128 mmol) was added to a solution of ethyl 3,4-diethylpyrrole-2-carboxylate (0.50 g, 2.56 mmol) and 3,5-dihydroxybenzaldehyde (0.18 g, 1.28 mmol) in THF (5 mL) at room temperature under nitrogen atmosphere and the resulting mixture was stirred for overnight. After completion of the reaction, the reaction mixture was neutralized with aq. sat. $NaHCO_3$ solution and extracted with DCM (2 x 40 mL). The combined organic layer was washed with distilled H_2O (2 x 25 mL), brine (25 mL), dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:3 – 1:2) to afford the desired dipyrromethane **2d** (0.50 g, 77%) as a pale brown liquid

which turned to solid upon kept in the refrigerator. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.76 (2H, br s), 7.02 (2H, br s), 6.17 (1H, s), 6.08 (2H, s), 5.34 (1H, s), 4.21 (4H, q, *J* = 7.0 Hz), 2.67 (4H, q, *J* = 7.2 Hz), 2.30 (4H, q, *J* = 7.2 Hz), 1.28 (6H, t, *J* = 7.0 Hz), 1.12 (6H, t, *J* = 7.2 Hz), 0.92 (6H, t, *J* = 7.2 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.50, 157.58, 141.99, 134.43, 132.44, 124.10, 117.37, 107.92, 102.50, 60.48, 40.36, 18.79, 17.39, 16.13, 16.00, 14.62; MS (EI^+) *m/z* (%): 510 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{38}N_2O_6$: 510.2730, Found: 510.2730.

*4.1.10. BODIPY **3d***

To a stirred solution of dipyrromethane **2d** (0.54 g, 1.05 mmol) in anhydrous DCM (18 mL) was added a solution of DDQ (0.29 g, 1.26 mmol, 1.2 equiv.) in anhydrous DCM (22 mL) at room temperature under nitrogen atmosphere and stirred for 1 h. Then, Et_3N (2.11 mL) and BF_3•Et_2O (3.31 mL) were added sequentially and stirring was continued for overnight. After completion of the reaction, the reaction mixture was sequentially washed with aq. sat. $NaHCO_3$ solution, distilled H_2O and brine. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:1 and EtOAc:DCM = 3:20 in order) to afford the desired BODIPY **3d** (0.04 g, 6.3 %) as a red solid. ^{1}H NMR (300 MHz, Methanol-d_4): δ 6.42 (1H, t, *J* = 2.1 Hz), 6.34 (2H, d, *J* = 2.1 Hz), 4.39 (4H, q, *J* = 7.2 Hz), 2.47 (4H, q, *J* = 7.5 Hz), 1.96 (4H, q, *J* = 7.5 Hz), 1.39 (6H, t, *J* = 7.2 Hz), 1.08 (6H, t, *J* = 7.5 Hz), 0.88 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, Methanol-d_4): δ 163.99, 160.26, 150.63, 149.99, 146.65, 136.15, 133.16, 108.05, 104.78, 63.29, 19.95, 18.34, 16.98, 15.94, 14.61; mp 210-212 °C; MS (EI^+) *m/z* (%): 556 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{35}BF_2N_2O_6$: 556.2556, Found: 556.2558.

*4.1.11. Dipyrromethane **4a***

MSA (0.04 mL, 0.60 mmol) was added to a solution of ethyl 3-ethylpyrrole-2-carboxylate (0.40 g, 2.40 mmol) and benzaldehyde (0.12 mL, 1.20 mmol) in DCM (20 mL) at room temperature under nitrogen atmosphere and the resulting mixture was stirred for overnight. After completion of the reaction, aq. sat. $NaHCO_3$ solution was added to the mixture to quench MSA and then extracted with DCM (2 x 30 mL). The combined organic layer was washed with distilled H_2O (2 x 30 mL), brine (30 mL), dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by column chromatography (EtOAc:hexane = 1:7 – 1:6) to yield the desired product **4a** (0.13 g, 25 %) as a pale yellow liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.40 (2H, br s), 7.33-7.20 (5H, m), 5.77 (2H, d, *J* = 3.0 Hz), 5.35 (1H, s), 4.18 (4H, q, *J* = 7.2 Hz), 2.71 (4H, qd, *J* = 7.5 and 1.5 Hz), 1.30 (6H, t, *J* = 7.2 Hz), 1.14 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 161.94, 140.56, 136.18, 135.16, 128.90, 128.57, 127.49, 118.30, 110.54, 60.19, 44.64, 20.69, 15.06, 14.73; MS (EI^+) *m/z* (%): 422 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{25}H_{30}N_2O_4$: 422.2206, Found: 422.2206.

*4.1.12. BODIPY **6a***

To a stirred solution of dipyrromethane **4a** (0.12 g, 0.291 mmol) in anhydrous DCM (4 mL) was added a solution of DDQ (0.08 g, 0.35 mmol, 1.2 equiv.) in anhydrous DCM (6 mL) at room temperature under nitrogen atmosphere and stirred for 1 h. Then, Et_3N (0.58 mL) and BF_3•Et_2O (0.78 mL) were added sequentially and stirring was continued for overnight. After completion of the reaction, the reaction mixture was diluted with DCM (15 mL) and sequentially washed with aq. sat. $NaHCO_3$ solution, H_2O and brine. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:5) to afford the desired BODIPY **6a** (0.06 g, 47 %) as a sticky merlot color solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.53 (5H, m), 6.65 (2H, s), 4.46 (4H,

q, *J* = 7.1 Hz), 2.61 (4H, q, *J* = 7.5 Hz), 1.45 (6H, t, *J* = 7.1 Hz), 1.14 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.33, 148.42, 145.28, 138.77, 135.23, 133.72, 130.76, 130.38, 129.43, 128.34, 61.94, 19.84, 14.26, 14.06; MS (EI^+) *m/z* (%): 468 ($[M]^+$, 100 %), HRMS *m/z* (M^+) calcd. for $C_{25}H_{27}BF_2N_2O_4$: 468.2032, Found: 468.2035.

*4.1.13. Dipyrromethane **4b***

MSA (0.09 mL, 1.18 mmol) was added to a solution of ethyl 3-ethylpyrrole-2-carboxylate (0.2 g, 1.20 mmol) and 4-hydroxybenzaldehyde (0.07 mL, 0.60 mmol) in DCM (2 mL) under Ar. After the resulting mixture was stirred overnight, the reaction was quenched with 0.2N NaOH solution. The organic layer was extracted with DCM (20 mL), washed with distilled H_2O (20 mL) and dried over Na_2SO_4. After evaporation of the solvent *in vacuo*, the crude product was purified by column chromatography on a silica gel (EtOAc:hexane = 1:6) to yield the desired product **4b** (0.136 g, 52.2 %) as a reddish liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.14 (2H, br s), 7.01 (2H, d, *J* = 8.4 Hz), 6.72 (2H, d, *J* = 8.4 Hz), 6.39, (1H, br s), 5.81 (2H, d, *J* = 2.4 Hz), 5.27 (1H, s), 4.22 (4H, q, *J* = 7.0 Hz), 2.72 (4H, q, *J* = 7.5 Hz), 1.30 (6H, t, *J* = 7.0 Hz), 1.15 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.24, 155.27, 136.74, 135.54, 132.06, 129.62, 118.09, 115.86, 110.42, 60.38, 43.73, 20.72, 15.06, 14.72; MS (EI^+) *m/z* (%): 438 ($[M]^+$, 100 %), HRMS *m/z* (M^+) calcd. for $C_{25}H_{30}N_2O_4$: 438.2155, Found: 438.2152.

*4.1.14. BODIPY **6b***

To a stirred solution of dipyrromethane **4b** (0.19 g, 0.43 mmol) in anhydrous DCM (7 mL) was added a solution of DDQ (0.12 g, 0.51 mmol, 1.2 equiv.) in anhydrous DCM (13 mL) at room temperature under nitrogen atmosphere and stirred for 1 h. Then, Et_3N (0.85 mL) was added and after 5 min stirring, BF_3•Et_2O (1.14 mL) was added dropwise. The resulting

mixture was stirred for overnight. After completion of the reaction, the reaction mixture was diluted with DCM (35 mL) and washed sequentially with aq. sat. $NaHCO_3$ solution, H_2O and brine. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:2 and DCM:MeOH = 98:2 in order) to afford the desired BODIPY **6b** (0.11 g, 54 %) as a sticky merlot color solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34 (2H, d, *J* = 8.7 Hz), 7.09 (1H, br s), 7.01 (2H, d, *J* = 8.7 Hz), 6.69 (2H, s), 4.46 (4H, q, *J* = 7.2 Hz), 2.61 (4H, q, *J* = 7.5 Hz), 1.44 (6H, t, *J* = 7.2 Hz), 1.14 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.02, 159.71, 149.34, 144.45, 138.81, 135.38, 132.87, 129.73, 125.91, 116.02, 62.31, 20.10, 14.50, 14.30; MS (EI^+) *m/z* (%): 484 ($[M]^+$, 100 %), HRMS *m/z* (M^+) calcd. for $C_{25}H_{27}BF_2N_2O_5$: 484.1981, Found: 484.1981.

*4.1.15. Dipyrromethane **4c***

MSA (0.19 mL, 2.92 mmol) was added to a solution of ethyl 3-ethylpyrrole-2-carboxylate (0.40 g, 2.40 mmol) and 3-hydroxybenzaldehyde (0.15 g, 1.20 mmol) in DCM (5 mL) at room temperature under nitrogen atmosphere and the resulting mixture was stirred for overnight. After completion of the reaction, aq. sat. $NaHCO_3$ solution was added to the mixture to quench MSA and extracted with DCM (2 x 35 mL). The combined organic layer was washed with distilled H_2O (2 x 30 mL), brine (30 mL), dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by column chromatography (EtOAc:hexane = 1:4) to afford the desired product **4c** (0.31 g, 60 %) as a pale brown oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.45 (2H, br s), 7.13 (1H, t, *J* = 7.8 Hz), 6.77-6.68 (3H, m), 6.14 (1H, br s), 5.78 (2H, d, *J* = 2.4 Hz), 5.26 (1H, s), 4.18 (4H, q, *J* = 7.0 Hz), 2.70 (4H, q, *J* = 7.5 Hz), 1.29 (6H, t, *J* = 7.0 Hz), 1.13 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.22, 156.25, 142.09, 136.20, 135.38, 130.01, 120.70, 118.19, 115.48, 114.60, 110.58, 60.36, 44.40, 20.71, 15.01, 14.69; MS (EI^+) *m/z* (%): 438 ($[M]^+$, 100 %), HRMS *m/z* (M^+) calcd. for

$C_{25}H_{30}N_2O_5$: 438.2155, Found: 438.2153.

*4.1.16. BODIPY **6c***

To a stirred solution of dipyrromethane **4c** (0.4 g, 0.91 mmol) in anhydrous DCM (10 mL) was added a solution of DDQ (0.25 g, 1.09 mmol, 1.2 equiv.) in anhydrous DCM (25 mL) at room temperature under nitrogen atmosphere and stirred for 1 h. Then, Et_3N (1.83 mL) was added and after 5 min stirring, BF_3•Et_2O (2.43 mL) was added dropwise. The resulting mixture was stirred for overnight. After completion of the reaction, the reaction mixture was diluted with DCM (50 mL) and washed sequentially with aq. sat. $NaHCO_3$ solution, H_2O and brine. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:2 and DCM:MeOH = 98:2 in order) to afford the desired BODIPY **6c** (0.17 g, 38 %) as sticky merlot color solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34 (1H, t, *J* = 8.1 Hz), 7.09 (1H, dt, *J* = 8.1, 1.2 Hz), 6.99-6.97 (2H, m), 6.70 (2H, s), 6.35 (1H, br s), 4.43 (4H, q, *J* = 7.0 Hz), 2.57 (4H, q, *J* = 7.5 Hz), 1.42 (6H, t, *J* = 7.0 Hz), 1.11 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.72, 156.11, 148.53, 145.36, 139.00, 135.43, 135.02, 129.90, 129.78, 122.90, 118.34, 117.60, 62.29, 20.09, 14.46, 14.27; MS (EI^+) *m/z* (%): 484 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{25}H_{27}BF_2N_2O_5$: 484.1981, Found: 484.1983.

*4.1.17. Dipyrromethane **4d***

MSA (0.04 mL, 0.60 mmol) was added to a solution of ethyl 3-ethylpyrrole-2-carboxylate (0.40 g, 2.40 mmol) and 2-hydroxybenzaldehyde (0.13 mL, 1.20 mmol) in DCM (5 mL) at room temperature under nitrogen atmosphere and the resulting mixture was stirred for overnight. After completion of the reaction, aq. sat. $NaHCO_3$ solution was added to the mixture to quench MSA and extracted with DCM (2 x 30 mL). The combined organic layer

was washed with distilled H_2O (2 x 30 mL), brine (30 mL), dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude product was purified by column chromatography (EtOAc:hexane = 1:3) to afford the desired product **4d** (0.26 g, 49 %) as a pale brown liquid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 9.26 (2H, br s), 7.13-7.04 (2H, m), 6.87-6.78 (2H, m), 6.64 (1H, br s), 5.86 (2H, d, *J* = 2.7 Hz), 5.56 (1H, s), 4.22 (4H, q, *J* = 7.2 Hz), 2.72 (4H, q, *J* = 7.5 Hz), 1.29 (6H, t, *J* = 7.2 Hz), 1.15 (6H, t, *J* = 7.5 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 162.09, 153.36, 135.84, 135.48, 130.11, 128.96, 126.88, 121.29, 118.06, 116.60, 110.25, 60.32, 39.72, 20.70, 15.07, 14.72; MS (EI^+) *m/z* (%): 438 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{25}H_{30}N_2O_5$: 438.2155, Found: 438.2151.

*4.1.18. BODIPY **6d***

To a stirred solution of dipyrromethane **4d** (0.38 g, 0.88 mmol) in anhydrous DCM (13 mL) was added a solution of DDQ (0.24 g, 1.05 mmol, 1.2 equiv.) in anhydrous DCM (17 mL) at room temperature under nitrogen atmosphere and stirred for 1 h. Then, Et_3N (1.76 mL) and BF_3•Et_2O (2.34 mL) were added sequentially and stirring was continued for overnight. After completion of the reaction, the reaction mixture was diluted with DCM (30 mL) and sequentially washed with aq. sat. $NaHCO_3$ solution, H_2O and brine. The organic layer was dried over anhydrous Na_2SO_4 and concentrated *in vacuo*. The crude was purified by column chromatography (EtOAc:hexane = 1:3 and EtOAc:DCM = 1:20 in order) to afford the desired BODIPY **6d** (0.05 g, 12 %) as a sticky merlot color solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.40 (1H, t, *J* = 7.5 Hz), 7.18 (1H, d, *J* = 7.8 Hz), 7.05-7.00 (2H, m), 6.62 (2H, s), 5.78 (1H, br s), 4.46 (4H, q, *J* = 7.0 Hz), 2.59 (4H, q, *J* = 7.3 Hz), 1.43 (6H, t, *J* = 7.0 Hz), 1.11 (6H, t, *J* = 7.3 Hz); ^{13}C NMR (75 MHz, $CDCl_3$): δ 161.53, 153.54, 145.88, 144.52, 139.22, 135.75, 132.18, 131.60, 129.33, 120.42, 120.32, 117.06, 62.27, 20.06, 14.36, 14.28; MS (EI^+) *m/z* (%): 484 ($[M]^+$, 100 %); HRMS *m/z* (M^+) calcd. for $C_{29}H_{35}BF_2N_2O_4$: 484.1981, Found: 484.1984.

4.2. Measurements and Characterization

NMR spectra were recorded on the Varian Gemini 300 FT-NMR 300 MHz for ^{1}H and 75 MHz for ^{13}C with the chemical shifts (δ) reported in parts per million (ppm) relative to TMS and the coupling constants (*J*) quoted in Hz. $CDCl_3$, DMSO-d_6, and CD_3OD were used as solvents with TMS as an internal standard. UV absorptions were measured on the Shimadzu UV-1800 spectrometer, and fluorescence emissions and quantum yield were recorded on the Perkin Elmer LS-55B fluorescence spectrometer and Agilent Cary Eclipse Fluorescence Spectrophotometer, respectively. Rhodamine 6G was used as the reference for the quantum yield. The Origin 8 program was used to analyze the spectra. Single crystal X-ray diffraction data were collected on a Bruker D8 Venture diffractometer, with Mo Kα radiation (λ = 0.71073 Å). Mass spectra were acquired on the Jeol JMS-700 in the central laboratory at Kangwon National University.

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Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/(will be filled). CCDC-1539238 (**3c**) contains the supplementary crystallographic data for this paper. These data can be obtained free of charge via http://ccdc.cam.ac.uk/conts/retrieving.html (or from the CCDC, 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 1223 336033; e-mail: deposit@ccdc.cam.ac.uk).

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