Note

Base-Mediated Cyclization Reaction of 2-(5-Hydroxy-1-pentynyl)benzonitriles to 4-Amino-2,3-dihydronaphtho[2,3-b]furanes and Synthesis of Furanonaphthoquinones

Chih-Jyun Tsai, Chin-Chau Chen, Chih-Wei Tsai, and Ming-Jung Wu

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Base-Mediated Cyclization Reaction of 2-(5-Hydroxy-1-pentynyl)benzonitriles to 4-Amino-2,3-dihydronaphtho[2,3-*b*]furanes and Synthesis of Furanonaphthoquinones

Chih-Jyun Tsai,[a] Chin-Chau Chen,[a] Chih-Wei Tsai[b] and Ming-Jung Wu[a,b,*]

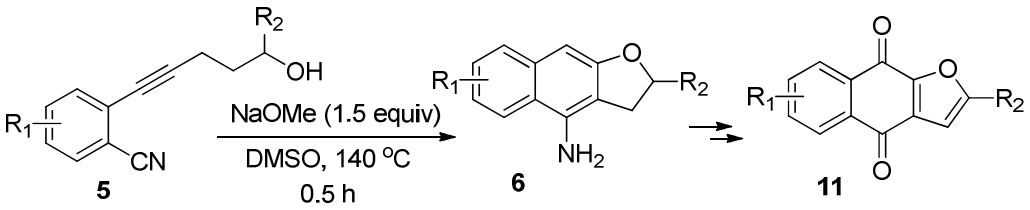
[a]Department of Chemistry, National Sun Yat-sen University, Kaohsiung, Taiwan

[b]Department of Medicinal and Applied Chemistry, Kaohsiung Medical University, Taiwan

E-mail: mijuwu@faculty.nsysu.edu.tw

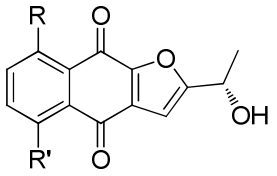
Abstract

An efficient transformation of 2-(5-Hydroxy-1-pentynyl)benzonitriles **5** to furanonaphthoquinones **11** is presented. Treatment of **5** with one and half equivalents of NaOMe in DMSO at 140 ^{o}C for 0.5 h gave **6** in good yields. Conversion of **6** to **11** was carried out by oxidation of **6** with Fremy's salt and KH_2PO_4 in acetone and water and followed by dehydrogenation using palladium on charcoal in diphenyl ether at reflux temperature.

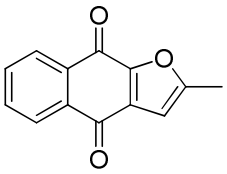


Many nature occurring or synthetic furanonaphthoquinones have been found to exhibit broad spectrum of biological activities, especially the antitumor activity.[1] For instance, kigelinone (**1**) was isolated from the wood of *Kigelia pinnata* by Inoue and showed good antitumor activity.[1a] Compounds **2** and **3** were isolated from *Crescentia cujete* by Kingston and exhibited high cytotoxicity against Vero cells.[1c] The synthetic compound FNQ3 (**4**) reported by Takegami was found good antiviral activity against Japanese encephalitis virus (JEV).[1d] (Scheme 1) Because of the importance of furanonaphthoquinones to the drug development, several synthetic methods have been developed to construct this ring system.[2] But most of them suffer from either long synthetic sequence or limitation of using 2-hydroxy-1,4-naphthoquinone as the starting material. We herein wish to report an efficient synthesis of furanonaphthoquinones by the cyclization of 2-(5-hydroxy-1-pentynyl)benzonitriles **5** to 4-amino-2,3-dihydronaphtho[2,3-*b*]furanes **6** followed by oxidation and dehydrogenation reactions.

Scheme 1. Structures of some furanonaphthoquinones

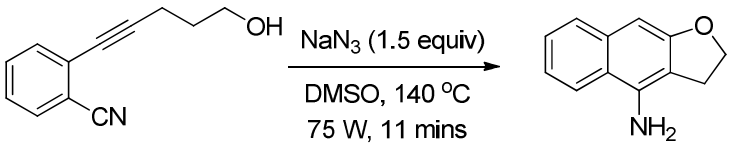


1. R = OH; R' = H
2. R = H; R' = H
3. R =H; R' = OH



FNQ3 (**4**)

Scheme 2. Preliminary result of cyclization reaction



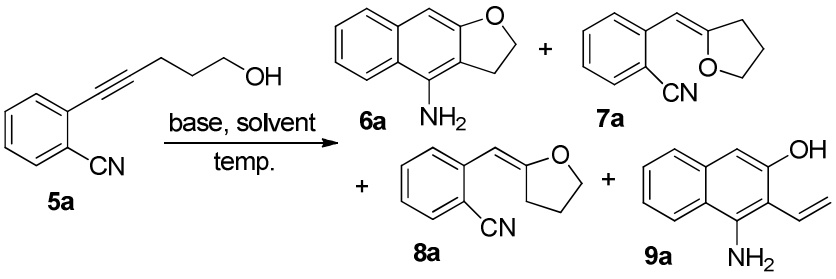
5a **6a**

The starting 2-(5-hydroxy-1-pentynyl)benzonitrile (**5a**) was prepared by the Sonogashira coupling reaction of 2-bromobenzonitrile and 4-petyn-1-ol using palladium as the catalyst.[3] During our investigation of the reaction of internal alkynes with sodium azide to triazoles,[4] we found that reaction of **5a** with one and half equivalents of NaN_3 gave compound **6a** albeit in low yield. (Scheme 2) Apparently sodium azide reacts as a base in this reaction followed by nucleophilic addition and subsequent cyclization reactions to give compound **6a**. We then anticipated that if a more suitable base was employed into this reaction, compound **6a** should be obtained in higher yield. Compound **6a** could further be oxidized to furanonaphthoquinones.

Six different bases were screened for this study and the results were summarized in Table 1. It was found that reaction of **5a** with one and half equivalents of NaOMe in

DMSO at 140 °C for 0.5 h gave compound **6a** in 66% yield. Bases, such as NaOH, K_2CO_3 and Na_2CO_3, were found to be not as efficient as NaOMe for the formation of **6a**. Using the stronger bases, such as KO*t*Bu and NaH, compound **9a** was obtained as the major products. Apparently compound **9a** came from the further elimination reaction of product **6a**. Various solvents have also been tested. The polar aprotic solvents, such as DMF and NMP, also provided compound **6a** but in lower yields and the major products is **7a**. When the reaction was carried out in CH_3CN, 1,4-dioxane or toluene, only **7a** and **8a** were obtained, no **6a** was formed. To summarize the screening study, the optimized reaction conditions for compound **6a** is the treatment of **5a** with one and half equivalents of NaOMe in DMSO at 140 °C for 0.5 h.

Table 1. Screening the base, temperature and solvent effects on the cyclization reactions of **5a**.



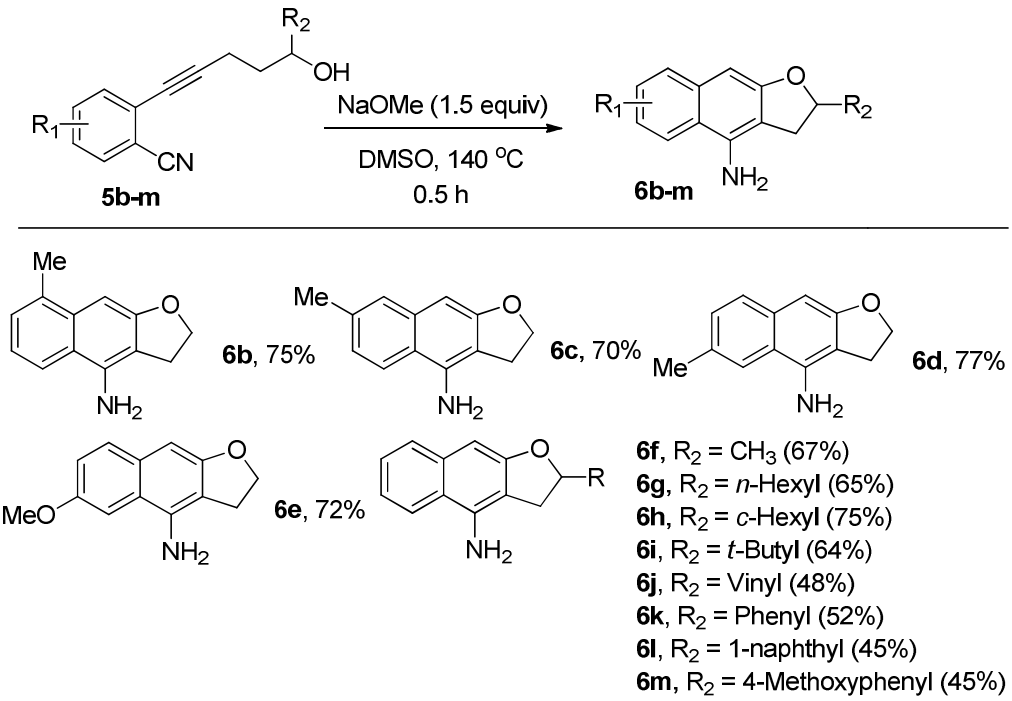
Entry	Base	Solvent	Temp. (°C)	Products/Yields
1	NaOH	DMSO	140	**6a**/49;**7a**/40; **8a**/8

2	K_2CO_3	DMSO	140	**7a**/63; **8a**/10
3	Na_2CO_3	DMSO	140	**7a**/44; **8a**/9
4	NaH	DMSO	140	**6a**/16; **9a**/43
5	KO*t*Bu	DMSO	140	**6a**/8; **9a**/38
6	NaOMe	DMSO	140	**6a**/66
7	NaOMe	DMF	140	**6a**/18; **7a**/63; **8a**/12
8	NaOMe	NMP	140	**6a**/24; **7a**/61; **8a**/11
9	NaOMe	CH_3CN	140	**7a**/64; **8a**/11
10	NaOMe	1,4-dioxane	140	**7a**/36; **8a**/51
11	NaOMe	toluene	140	**7a**/55; **8a**/24
12	NaOMe	DMSO	120	**6a**/43;**7a**/22; **8a**/5
13	NaOMe	DMSO	100	**6a**/26;**7a**/53; **8a**/8

With the optimized reaction conditions in hand, other substrates[5] **5b-l** were carried out for the cyclization reaction to give various 4-amino-2,3-dihydronaphtho[2,3-*b*]furanes **6b-l** in modest to good chemical yields. The results are summarized in scheme 3. Compounds **5b-e** bearing primary hydroxyl group gave the cyclization products **6b-e** in 70-77% yields. Compounds **5f-h** bearing

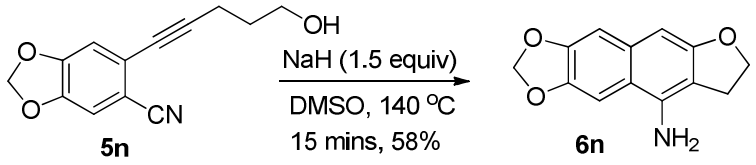
secondary hydroxyl group and R_2 is an alkyl group also produced the cyclization products **6f-i** in good chemical yields. However, when R_2 is a vinyl or an aryl group, such as **5j-m**, the cyclization products **6j-m** was obtained in lower yields.

Scheme 3. Synthesis of 4-amino-2,3-dihydronaphtho[2,3-b]furanes



On the other hand, treatment of **5n** under the optimized reaction conditions gave a complex product mixture. Although we did not isolate any identified product, the acetal cleavage must take place under this reaction conditions. Therefore we carried out the cyclization reaction of **5n** in DMSO at 140 ^{o}C using the less nucleophilic base, NaH, and the reaction time was reduced to 15 min, product **6n** was obtained in 58% yield. (Scheme 4)

Scheme 4. Synthesis of **6n**



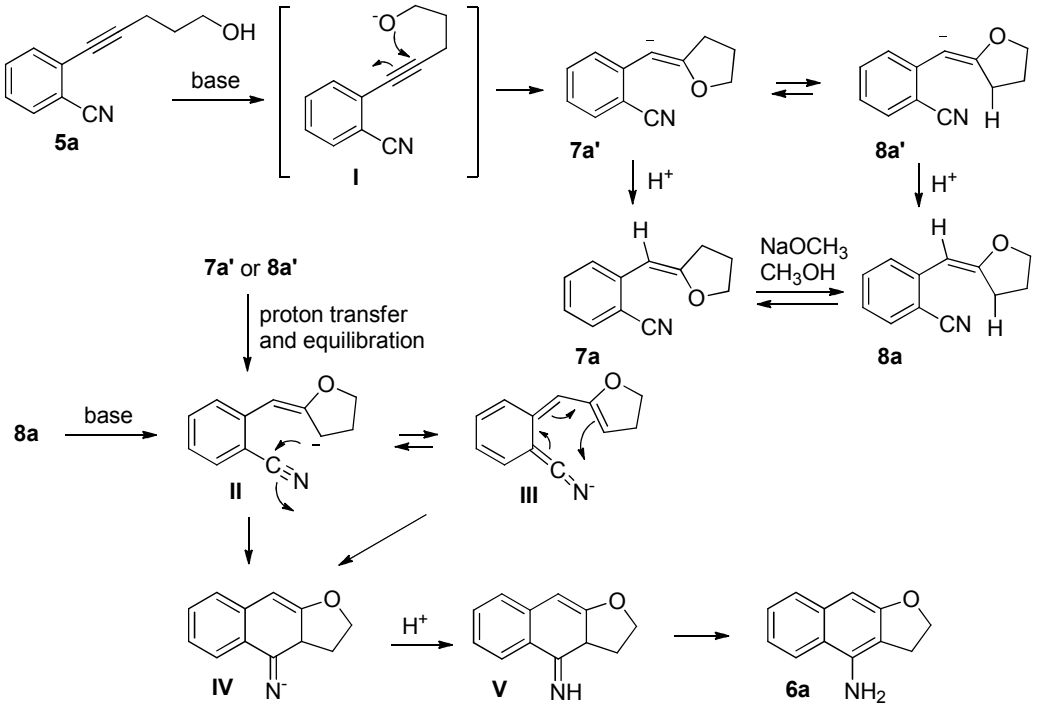
5n **6n**

The proposed mechanism for the cyclization of **5a** to **6a** is shown in scheme 5. The first step is the deprotonation of **5a** with base to form alkoxide **I** that would undergo intramolecular 5-exo-dig cyclization to form the vinyl anions **7a'** and **8a'**. The vinyl anions **7a'** or **8a'** could undergo direct proton transformation and equilibration to give anion **II** or protonation to give the intermediates **7a** and **8a**. Under the described reaction conditions, compounds **7a** and **8a** undergo equilibrium to each other. Further deprotonation of **8a** would also give anion **II** that could directly attack the cyano group to give the iminium ion **IV**[6] or undergoes tautomerization to form ketenimine anion **III**, then the electrocyclic ring closure reaction to give **IV**.[7] Finally protonation of **IV** to give imine **V** and following the imine-enamine tautomerization, to convert the imine **V** to the final product **6a**.

To understand more insight of the reaction mechanism, we carried out the experiments by recharging either compound **7a** or **8a** into the optimized reaction conditions, both of them were converted to **6a** slowly. After stirring for 24 hours, only 52% of **6a** was obtained and isolated both the staring material and its isomer. Comparing to the one-pot reaction, conversion of **5a** to **6a** under the optimized

reaction conditions requires only 0.5 hour. We therefore conclude that the intramolecular proton transfer from **7a'** or **8a'** to anion **II** must be faster than the formation of **7a** and **8a** and these two isomers can undergo equilibrium to each other under this reaction conditions.

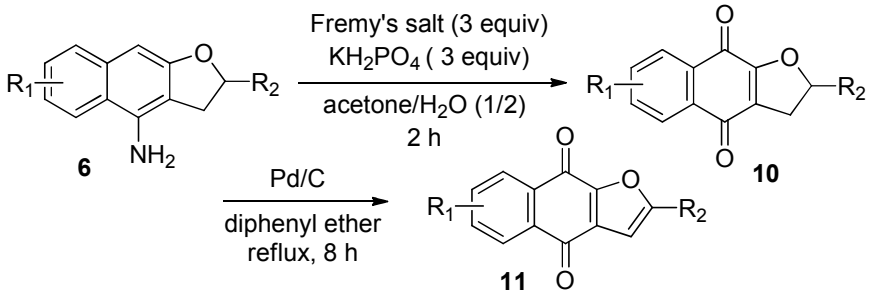
Scheme 5. Proposed mechanism for the formation of **6a**



For the conversion of 4-amino-2,3-dihydronaphtho[2,3-*b*]furanes **6** to furanonaphthoquinones **11** are summarized in Table 2. Oxidation of compounds **6a-k, 6n** were carried out by using Fremy's salt[8] and KH_2PO_4 in acetone and water to give dihydrofuranonaphthoquinones **10a-k** and **10n** in good yields except compound **6b**. The low yield for the conversion of **6b** to **10b** could be due to the steric hindrance of the methyl group at 8-position to prevent the oxidation take place at the 9-position.

Finally, all of the dihydrofuranonaphthoquinones **10a-k** and **10n** were dehydrogenated using palladium on charcoal in diphenyl ether at reflux temperature[9] to give furanonaphthoquinones **11a-e, 4, 11g-i, 11k** and **11n** in 48-86% yields. Only compound **10j** gave a complex mixture of products under this reaction conditions.

Table 2. Oxidation and dehydrogenation of **6** to Furanonaphthoquinones **11**.



Compounds	Products/Yields (%)	
6a	**10a**/88	**11a**/75
6b	**10b**/46	**11b**/62
6c	**10c**/92	**11c**/77
6d	**10d**/92	**11d**/72
6e	**10e**/88	**11e**/68
6f	**10f**/92	**4**/65(80)[a]
6g	**10g**/81	**11g**/48
6h	**10h**/77	**11h**/38[b]
6i	**10i**/88	**11i**/86
6j	**10j**/93	**11j**/decomposed
6k	**10k**/84	**11k**/63
6n	**10n**/75	**11n**/52

[a]the value in parentheses is carried out in 1.85 mmole scale.
[b]26% of **11k** was also obtained.

In conclusion, we have developed an efficient synthesis of

4-amino-2,3-dihydronaphtho[2,3-*b*]furanes through the base-mediated cyclization of 2-(5-hydroxy-1-pentynyl)benzonitriles. The base, such as NaOMe, used in this transformation is ready available, easy to handle and not expensive. The 4-amino-2,3-dihydronaphtho[2,3-*b*]furanes have been demonstrated to be easily converted to furanonaphthoquinones by oxidation and dehydrogenation, respectively.

Experimental Section

The general procedure for the preparation of compound 5a (5a-e, 5n): To the solution of 2-bromobenzonitrile (10.0 g, 55.0 mmol) in THF (50 mL) was added $Pd(PPh_3)_4$ (0.50 g, 0.43 mmol), alkyne (66.0 mmol), CuI (0.521 g, 2.74 mmol) and Et_3N (6.65g, 65.93 mmol), respectively. The reaction mixture was well stirred at room temperature for 8 hours. The reaction mixture was quenched with saturated aqueous solutions of NH_4Cl and extracted with EtOAc. The combined organic extracts were dried over anhydrous $MgSO_{4(S)}$. After filtration and removal of solvent, the residue was purified by column chromatography to give compound **5a-e, 5n**.

2-(5-Hydroxypent-1-ynyl)benzonitrile (5a)

Yield 9.04 g, 89%. A yellow oil: R_f = 0.48 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.89 (quin, *J* = 6.5 Hz, 2H), 1.94 (brs, 1H), 2.62 (t, *J* = 6.5 Hz, 2H), 3.86 (t, *J* = 6.0 Hz, 2H), 7.34 (td, *J* = 8.0, 2.0 Hz, 1H), 7.41-7.52 (m, 2H), 7.60 (dd, *J* = 8.0, 0.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.0, 30.8, 61.1, 77.6, 97.0, 115.2, 117.9, 127.7, 127.9, 132.1, 132.3, 132.4; MS (70 eV) m/z (%): 185 (6) [M^+], 85 (85), 71 (100); HRMS (EI-magnetic sector) Calcd for $C_{12}H_{11}ON$, 185.0841; Found, 185.0839.

2-(5-Hydroxypent-1-ynyl)-3-methylbenzonitrile (5b)

Yield 2.38 g, 47%. A yellow oil: R_f = 0.43 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.93-1.91 (m, 3H), 2.44 (s, 3H), 2.67 (t, *J* = 7.0 Hz, 2H), 3.88 (t, *J* = 6.0 Hz, 2H), 7.23 (t, *J* = 7.5 Hz, 1H), 7.40 (d, *J* = 7.5 Hz, 1H), 7.45 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.1, 20.8, 31.0, 61.2, 76.7, 100.9, 115.4, 118.3, 127.4, 127.4, 129.8, 138.4, 141.2; MS (70 eV) m/z (%): 199 (82) [M^+], 181 (88), 180 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0999.

2-(5-Hydroxypent-1-ynyl)-4-methylbenzonitrile (5c)

Yield 4.51 g, 89%. A yellow oil: R_f = 0.44 (4:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.91-1.87 (m, 3H), 2.37 (s, 3H), 2.62 (t, *J* = 7.0 Hz, 2H), 3.87 (brs, 2H), 7.15 (d, *J* = 5.0 Hz, 1H), 7.30 (s, 1H), 7.48 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.0, 21.6, 30.9, 61.2, 77.8, 96.3, 112.3, 118.2, 127.7, 128.7, 132.3, 132.7, 143.3; MS (70 eV) m/z (%): 199 (70) [M^+], 181 (93.63), 180 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0998.

2-(5-Hydroxypent-1-ynyl)-5-methylbenzonitrile (5d)

Yield 4.56 g, 90%. A yellow oil: R_f = 0.47 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.91-1.82 (m, 3H), 2.35 (s, 3H), 2.60 (t, *J* = 7.0 Hz, 2H), 3.87 (t, *J* = 6.0 Hz, 2H), 7.29 (dd, *J* = 8.0, 1.0 Hz, 1H), 7.37 (d, *J* = 8.0 Hz, 1H), 7.40 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.0, 21.0, 30.9, 61.2, 77.6, 95.9, 115.1, 118.0, 125.0, 132.0, 132.7, 133.3, 138.2; MS (70 eV) m/z (%): 199 (58) [M^+], 181 (94), 180 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0997.

2-(5-Hydroxypent-1-ynyl)-5-methoxybenzonitrile (5e)

Yield 4.61g, 91%. A yellow oil: R_f = 0.40 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.87 (quin, *J* = 6.5 Hz, 2H), 2.00 (brs, 1H), 2.58 (t, *J* = 7.0 Hz, 2H), 3.81 (s, 3H), 3.85 (t, *J* = 4.8 Hz, 2H),7.02 (dd, *J* = 9.0, 3.0Hz, 1H), 7.07 (d, *J* = 2.5 Hz, 1H), 7.37 (d, *J* = 8.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.0, 31.0, 55.6, 61.2, 94.8, 116.1, 116.9, 117.7, 119.1, 120.1, 133.4, 158.6; MS (70 eV) m/z (%): 215 (90) [M^+], 197 (100), 182 (66); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}O_2N$, 215.0946; Found, 215.0949.

The general procedure for the preparation of compound 5f (5f-m): The solution of compound **12** (183 mg, 1.0 mmol) in THF (10 mL) under nitrogen was cooled to 0^{o}C. The Grignard reagent (1.2 mL, 1M) was then added dropwise to the

solution for 0.5 hour. The reaction mixture was warmed to room temperature subsequently quenched with saturated $NH_4Cl_{(aq)}$ and extracted with CH_2Cl_2. The combined organic extracts were dried over anhydrous $MgSO_{4(S)}$. After filtration and removal of solvent, the residue was purified by column chromatography to give compound **5f-m**.

2-(5-Oxohex-1-ynyl)benzonitrile (5f)

Yield 179.13 mg, 90%. A yellow oil: R_f= 0.52 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.22 (d, *J* = 6.5 Hz, 3H), 1.74 (q, *J* =7.0 Hz, 2H), 2.41 (brs, 1H), 2.52-2.64 (m, 2H), 4.01-4.07 (m, 1H), 7.31 (td, *J* = 8.0, 1.0 Hz, 1H), 7.43-7.48 (m,2H) 7.56 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.0, 23.3, 37.1, 66.4, 77.3, 97.3, 115.0, 117.7, 127.6, 127.8, 132.0, 132.2, 132.3; MS (70 eV) m/z (%): 199 (45) [M^+], 180 (100), 154 (55); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0997.

2-(5-Oxoundec-1-ynyl)benzonitrile (5g)

Yield 231.34 mg, 86%. A yellow oil: R_f= 0.60 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.86 (t, *J* = 7.0 Hz, 3H), 1.24-1.51 (m, 10H), 1.67-1.84 (m, 2H), 1.95 (brs, 1H), 2.57-2.68 (m, 2H), 3.83-3.88 (m, 1H), 7.33 (td, *J* = 7.5, 1.5 Hz, 1H), 7.45-7.50 (m, 2H), 7.58 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.0, 16.0, 22.5, 25.5, 29.3, 31.7, 35.5, 37.4, 70.4, 77.4, 97.5, 115.3, 117.8, 127.6, 127.9, 132.1, 132.2, 132.3; MS (70 eV) m/z (%): 269 (29) [M^+], 184 (100), 153 (73); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{23}ON$, 269.1780; Found, 269.1781.

2-(5-Cyclohexyl-5-oxopent-1-ynyl)benzonitrile (5h)

Yield 240.3 mg, 90%. A yellow solid: R_f= 0.60 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.99-1.27 (m, 5H), 1.31-1.38 (m, 1H), 1.63-1.86 (m, 7H), 1.93 (brs, 1H), 2.63 (t, *J* = 7.0 Hz, 2H), 3.59-3.63 (m, 1H), 7.33 (td, *J* = 7.5, 1.5 Hz, 1H), 7.45-7.50 (m, 2H), 7.59 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.3, 26.1, 26.2, 26.4, 27.8, 29.0, 32.4, 43.7, 77.3, 77.4, 97.6, 115.2, 117.8, 127.6, 127.9, 132.1, 132.2, 132.3; MS (70 eV) m/z (%): 267 (21) [M^+], 184 (100), 140 (58); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{21}ON$, 267.1623; Found, 267.1626.

2-(6,6-Dimethyl-5-oxohept-1-ynyl)benzonitrile (5i)

Yield 183.27 mg, 76%. A colorless oil: R_f = 0.63 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.94 (s, 9H), 1.56-1.64 (m, 1H), 1.79 (brs, 1H), 1.83-1.90 (m, 1H), 2.67 (t, *J* = 6.5 Hz, 2H), 3.52 (d, *J* = 10.5 Hz, 1H), 7.34 (td, *J* = 7.0, 2.0 Hz, 1H), 7.47-7.52 (m, 2H), 7.61 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 17.0, 25.6, 29.9, 34.9, 77.6, 78.2, 97.7, 115.3, 117.9, 127.6, 128.0, 132.1, 132.3, 132.4; MS (70 eV) m/z (%): 241 (10) [M^+], 184 (100), 142 (43); HRMS (EI-magnetic sector) Calcd for $C_{16}H_{19}ON$, 241.1467; Found, 241.1466.

2-(5-Oxohept-6-en-1-ynyl)benzonitrile (5j)

Yield 122.38 mg, 58%. A brown oil: R_f = 0.62 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.85 (q, *J* = 7.0 Hz, 2H), 2.35 (brs, 1H), 2.52-2.67 (m, 2H), 4.40 (q, *J* = 6.5 Hz, 1H), 5.14 (d, *J* = 10.5 Hz, 1H), 5.32 (d, *J* = 17.0 Hz, 1H), 5.85-5.92 (m, 1H), 7.33 (td, *J* = 7.5, 1.5 Hz, 1H), 7.45-7.50 (m, 2H), 7.58 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 15.7, 35.1, 71.4, 77.5, 97.0, 115.1, 115.1, 117.7, 127.6, 127.8, 132.1, 132.3, 132.3, 140.3; MS (70 eV) m/z (%): 211 (8) [M^+], 154 (100), 140 (73); HRMS (EI-magnetic sector) Calcd for $C_{14}H_{13}ON$, 211.0997; Found, 211.0994.

2-(5-Oxo-5-phenylpent-1-ynyl)benzonitrile (5k)

Yield 229.68 mg, 88%. A yellow oil: R_f = 0.58 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.97-2.13 (m, 2H), 2.48-2.72 (m, 3H), 5.01 (t, *J* = 5.0 Hz, 1H), 7.27 (t, *J* = 7.5 Hz, 1H), 7.33-7.37 (m, 3H), 7.43-7.41 (m, 2H), 7.48-7.52 (m, 2H), 7.60 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 16.2, 37.2, 72.6, 77.7, 97.0, 115.2, 117.8, 125.8, 125.8, 127.5, 127.6, 127.8, 128.4, 128.4, 132.1, 132.3, 132.4, 144.1; MS (70 eV) m/z (%): 261 (33) [M^+], 107 (100), 79 (90); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{15}ON$, 261.1154; Found, 261.1152.

2-(5-Hydroxy-5-(naphthalen-1-yl)pent-1-yn-1-yl)benzonitrile (5l)

Yield 202.0 mg, 65%. A yellow oil: R_f = 0.25 (4:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.22 (d, *J* = 8.0 Hz, 1H), 7.87 (d, *J* = 8.0 Hz, 1H), 7.78 (d, *J* = 8.0 Hz, 1H), 7.72 (d, *J* = 8.0 Hz, 1H), 7.63 (d, *J* = 8.0 Hz, 1H), 7.53-7.47 (m, 3H), 7.49 (d, *J* = 8.0 Hz, 1H), 7.48 (d, *J* = 8.0 Hz, 1H), 7.39-7.35 (m, 1H), 5.80 (dd, *J* = 9.0, 4.0 Hz, 1H), 2.90-2.80 (m, 1H), 2.68-2.62 (m, 1H), 2.46 (brs, 1H), 2.32-2.26 (m, 1H), 2.21-2.14 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 139.8, 133.8, 132.4, 132.3, 132.2, 130.2, 128.8, 128.0, 127.8, 127.7, 126.1, 125.5, 125.4, 123.2, 122.9, 117.9, 115.2, 97.1, 77.9, 69.7, 36.4, 16.5; MS (ESI) m/z (%): 334 (100) [M+Na]$^+$; HRMS (ESI-TOF) Calcd for $C_{22}H_{17}NONa$ [M+Na]$^+$, 334.1208; Found, 334.1206.

2-(5-Hydroxy-5-(4-methoxyphenyl)pent-1-yn-1-yl)benzonitrile (5m)

Yield 221.0 mg, 76%. Ayellowoil: R_f= 0.15 (4:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.62 (d, *J* = 8.0 Hz, 1H), 7.51 (d, *J* = 8.0 Hz, 1H), 7.50 (t, *J* = 8.0 Hz, 1H), 7.36 (t, *J* = 8.0 Hz, 1H), 7.35 (d, *J* = 8.0, 2H), 6.89 (d, *J* = 8.0 Hz, 2H), 4.97 (dd, *J* = 8.0, 5.5 Hz, 1H), 3.80 (s, 3H), 2.70-2.64 (m, 1H), 2.54-2.47 (m, 1H), 2.20 (brs, 1H), 2.14-2.07 (m, 1H), 2.04-1.95 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.1, 136.2, 132.4, 132.3, 132.2, 127.9, 127.7, 117.9, 115.3, 113.9, 97.0, 77.8, 72.4, 55.2, 37.2, 16.3; MS (ESI) m/z (%): 314 $[M+Na]^+$; HRMS (ESI-TOF) Calcd for $C_{19}H_{17}NO_2Na$ $[M+Na]^+$, 314.1157; Found, 314.1156.

6-(5-Hydroxypent-1-yn-1-yl)benzo[*d*][1,3]dioxole-5-carbonitrile (5n)

Yield 4.30 g, 85%. A yellow solid: R_f= 0.41 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.77 (brs, 1H), 1.87 (quin, *J* = 6.5 Hz, 2H), 2.59 (t, *J* = 7.0 Hz, 2H), 3.84 (t, *J* = 6.0 Hz, 2H), 6.06 (s, 2H), 6.87 (s, 1H), 6.96 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 15.9, 30.8, 61.1, 77.5, 95.4, 102.5, 108.5, 111.2, 111.8, 118.0, 123.7, 147.3, 151.1; MS (70 eV) m/z (%): 229 (8) $[M^+]$, 88 (100), 73 (63), 70 (96), 61 (98); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{11}O_3N$, 229.0739; Found, 229.0739.

General Procedure for the preparation of

4-Amino-2,3-dihydronaphtho[2,3-*b*]furanes 6a-m. The solution of compound **5a-m** (0.5 mmol) in DMSO (2.0 mL) containing NaOMe (0.75 mmol) was heated to 140 ^{o}C. The reaction mixture was stirred at that temperature for 0.5 hour. The reaction mixture was cooled to room temperature, subsequently quenched with saturated $NH_4Cl_{(aq)}$ and extracted with EtOAc. The combined organic extracts were dried over anhydrous $MgSO_{4(S)}$. After filtration and removal of solvent, the residue was purified by silica gel column chromatography to give compound **6a-m**. The physical and spectral data of **6a-m** are illustrated as follows.

2,3-Dihydronaphtho[2,3-*b*]furan-4-amine (6a)

Yield 61.05 mg, 66%. A white solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500

MHz, $CDCl_3$) δ 3.16 (t, *J* =8.0Hz, 2H), 4.06 (brs, 2H), 4.66 (t, *J* = 8.5 Hz, 2H), 6.56 (s, 1H), 7.25 (t, *J* = 8.0 Hz, 1H), 7.35 (t, *J* = 7.0 Hz, 1H), 7.67-7.62 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 27.1, 71.3, 95.3, 110.1, 119.7, 120.2, 122.1, 125.8, 127.5, 135.6, 137.9, 159.1; mp: 140-142 °C; MS (70 eV) m/z (%):185 (19) [M^+], 85 (86), 71 (100); HRMS (EI-magnetic sector) Calcd for $C_{12}H_{11}ON$, 185.0841; Found, 185.0843.

8-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6b)

Yield 74.6 mg, 75%. A white solid: R_f= 0.54 (1:2:3 EA/DCM/Hex); ^1H NMR (500 MHz, $CDCl_3$) δ 2.57 (s, 3H), 3.19 (t, *J* = 8.5 Hz, 2H), 4.09 (brs, 2H), 4.68 (t, *J* = 8.5 Hz, 2H), 6.79 (s, 1H), 7.17 (t, *J* = 8.5 Hz, 1H), 7.23 (d, *J* = 7.0 Hz, 1H), 7.56 (d, *J* = 8.0 Hz, 1H);^{13}C NMR (125 MHz, $CDCl_3$) δ 20.2, 27.1, 71.3, 92.1, 109.7, 118.4, 119.5, 121.6, 126.7, 133.6, 134.7, 138.4, 159.2 ; mp: 202-204 °C; MS (70 eV) m/z (%): 199 (100) [M^+], 170 (20), 57 (16); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0998.

7-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6c)

Yield 69.6 mg, 70%. A white solid: R_f= 0.55 (1:2:3 EA/DCM/Hex); ^{1}HNMR (500 MHz, $CDCl_3$) δ 2.44 (s, 3H), 3.14 (t, *J* = 8.0 Hz, 2H), 4.03 (brs, 2H), 4.64 (t, *J* = 8.5 Hz, 2H), 6.57 (s, 1H), 7.08 (dd, *J* = 8.5, 1.5Hz, 1H), 7.40 (s, 1H), 7.55 (d, *J* = 8.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.4, 27.0, 71.2, 94.8, 109.2, 117.9, 120.0, 124.2, 126.7, 135.4, 135.9, 137.8, 159.2; mp: 154-156 °C; MS (70 eV) m/z (%): 199 (100) [M^+], 170 (23), 156 (123); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0994.

6-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6d)

Yield 76.6 mg, 77%. A white solid: R_f= 0.56 (1:2:3 EA/DCM/Hex); ^1H NMR (500 MHz, $CDCl_3$) δ 2.48 (s, 3H), 3.16 (t, *J* = 8.5 Hz, 2H), 4.04 (brs, 2H), 4.66 (t, *J* = 8.0 Hz, 2H), 6.63 (s, 1H), 7.20 (dd, *J* = 8.5, 1.5 Hz, 1H), 7.44 (s, 1H), 7.54 (d, *J* = 8.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.7, 27.1, 71.2, 95.1, 110.2, 119.5, 119.8, 127.4, 127.9, 131.5, 133.6, 137.3, 158.4; mp: 112-114 °C; MS (70 eV) m/z (%): 199 (100) [M^+], 200 (39), 170 (52); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0999.

6-Methoxy-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6e)

Yield 77.4 mg, 72%. A white solid: R_f= 0.48 (1:2:3 EA/DCM/Hex); ^1H NMR (500 MHz, $CDCl_3$) δ 3.16 (t, *J* = 8.0 Hz, 2H), 3.91(s, 3H), 3.94 (brs, 2H), 4.65 (t, *J* = 8.5 Hz, 2H), 6.63 (s, 1H), 6.98 (d, *J* =2.5 Hz, 1H), 7.07 (dd, *J* =9.0, 2.5 Hz, 1H), 7.56 (d, *J* =9.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 27.3, 55.4, 71.1, 95.4, 100.4, 111.1,

117.5, 120.3, 128.9, 130.6, 136.7, 155.4, 157.5; mp: 156-158 °C; MS (70 eV) m/z (%): 215 (24) [M^+],70 (66), 61 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}O_2N$, 215.0946; Found, 215.0948.

2-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine(6f)

Yield 66.65 mg, 67%. A white solid: R_f= 0.54 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.52 (d,*J* = 6.5 Hz, 3H), 2.76 (dd, *J* = 8.0, 7.0 Hz, 1H), 3.27 (dd, *J* = 15.0, 8.5 Hz, 1H), 5.03 (brs, 2H), 5.04-5.02 (m, 1H), 6.64 (s, 1H), 7.27-7.26 (m, 1H), 7.36-7.34 (m, 1H), 7.67-7.63 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.0, 34.4, 79.7, 95.3, 110.4, 119.7, 120.2, 122.0, 125.7, 127.5, 135.6, 137.8, 158.7; MS (70 eV) m/z (%): 199 (100) [M^+], 184 (48), 156 (48); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{13}ON$, 199.0997; Found, 199.0996.

2-Hexyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6g)

Yield 87.4 mg, 65%. A white solid: R_f= 0.56 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.91 (t, *J* =7.0 Hz, 3H), 0.92-1.56 (m, 9H), 1.69-1.76 (m,1H), 1.85-1.92 (m, 1H), 2.80 (dd, *J* =15.0, 7.0 Hz, 1H), 3.23 (dd, *J* = 15.0, 8.5 Hz, 1H), 4.87 (quin, *J* = 7.5 Hz, 1H), 6.63 (s, 1H), 7.25 (t, *J* = 8.5 Hz, 1H), 7.35 (t, *J* = 8.0 Hz, 1H), 7.65 (dd, *J* = 13.0, 8.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.1, 22.6, 25.4, 29.2, 31.8, 32.8, 36.3, 83.7, 95.2, 110.4, 119.6, 120.1, 121.9, 125.7, 127.5, 135.6, 137.7, 158.8; mp: 56-58 °C; MS (70 eV) m/z (%): 269 (100) [M^+], 172 (55), 57 (59); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{23}ON$, 269.1780; Found, 269.1781.

2-Cyclohexyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6h)

Yield 100.1 mg, 75%. A white solid: R_f= 0.58 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.08-1.34 (m,5H), 1.65-1.81 (m, 5H), 2.01 (d, *J* = 13.0 Hz, 1H), 2.89 (dd, *J* = 15.0, 7.5 Hz, 1H), 3.12 (dd, *J* = 15.0, 9.0 Hz, 1H), 4.02 (brs, 2H), 4.60 (q, *J* = 7.5 Hz, 1H), 6.63 (s, 1H), 7.24 (td, *J* = 7.0, 1.0 Hz, 1 H), 7.35 (td, *J* = 7.5, 0.5 Hz, 1H), 7.65 (t, *J* = 8.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 25.7, 25.9, 26.4, 28.3, 28.6, 30.3, 43.3, 87.7, 94.9, 110.5, 119.5, 120.1, 121.8, 125.6, 127.4, 135.6, 137.6, 159.0; mp: 56-58 °C; MS (70 eV) m/z (%): 267 (49) [M^+], 172 (100), 57 (54); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{21}ON$, 267.1623; Found, 267.1622.

2-*Tert*-butyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6i)

Yield 77.1 mg, 64%. A white solid: R_f= 0.58 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.02 (s, 9H), 2.95 (dd, *J* =15.0, 8.0 Hz, 1H), 3.05 (dd, *J* = 15.0, 9.0 Hz, 1H), 4.04 (brs, 2H), 4.58 (t, *J* = 8.0 Hz, 1H), 6.65 (s, 1H), 7.24 (td, *J* =8.0, 1.0 Hz, 1 H), 7.35 (t, *J* =7.5 Hz, 1H), 7.65 (t, *J* = 10.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$)

δ25.1, 28.2, 34.6, 91.1, 94.7, 110.7, 119.5, 120.1, 121.8, 125.7, 127.5, 135.6, 137.5, 159.4; mp: 114-116 °C; MS (70 eV) m/z (%): 241 (100) [M^+], 172 (92), 143 (39); HRMS (EI-magnetic sector) Calcd for $C_{16}H_{19}ON$, 241.1467; Found, 241.1469.

2-Vinyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6j)

Yield 50.6 mg, 48%. A white solid: R_f= 0.56 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.93(dd, *J* = 15.0, 7.0 Hz, 1H), 3.33 (dd, *J* = 15.0, 9.0 Hz, 1H), 4.04 (brs, 2H), 5.25-5.31(m, 2H), 5.43 (dt, *J* = 17.5, 1.0 Hz, 1H), 6.03-6.10 (m, 1H), 6.68 (s, 2H), 7.26 (td, *J* = 6.5, 1.0 Hz, 1H), 7.36 (td, *J* = 8.0, 1.0 Hz, 1H), 7.65 (t, *J* = 7.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 33.2, 83.6, 95.3, 109.7, 116.9, 119.7, 120.2, 122.1, 125.8, 127.6, 135.6, 137.3, 137.9, 158.5; mp:102-104 °C; MS (70 eV) m/z (%): 211 (100) [M^+], 196 (100), 165 (23); HRMS (EI-magnetic sector) Calcd for $C_{14}H_{13}ON$, 211.0997; Found, 211.1000.

2-Phenyl-2,3-dihydronaphtho[2,3-*b*]furan-4-amine(6k)

Yield 67.8 mg, 52%. A white solid: R_f= 0.50 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.13 (dd, *J* = 15.0, 7.0 Hz, 1H), 3.60 (dd, *J* = 15.0, 9.0 Hz, 1H), 4.05 (brs, 2H), 5.86 (t, *J* = 7.0 Hz, 1H), 6.77 (s, 1H), 7.27-7.44 (m, 7H), 7.69 (dd, *J* = 8.0, 5.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 35.8, 84.2, 95.3, 109.6, 119.8, 120.2, 122.1, 125.7, 125.9, 127.6, 128.1, 128.7, 135.7, 137.9, 142.1, 158.8; mp: 116-118 °C; MS (70 eV) m/z (%): 261 (68) [M^+], 61 (90), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{15}ON$, 261.1154; Found, 261.1154.

2-(Naphthalen-1-yl)-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6l)

Yield 70.0 mg, 45%. A brown solid: R_f= 0.60 (3:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (d, *J* = 8.0 Hz, 1H), 7.90 (d, *J* = 8.0 Hz, 1H), 7.80 (d, *J* = 8.0 Hz, 1H), 7.71 (d, *J* = 8.0 Hz, 1H), 7.67 (d, *J* = 8.0 Hz. 1H), 7.65 (d, *J* = 8.0 Hz, 1H), 7.55-7.50 (m, 2H), 7.43 (d, *J* = 8.0 Hz, 1H), 7.39 (d, *J* = 8.0 Hz, 1H), 7.27 (d, *J* = 8.0 Hz, 1H), 6.86 (s, 1H), 6.53 (dd, *J* = 9.5, 7.0 Hz, 1H), 4.03 (brs, 2H), 3.80 (dd, *J* = 15.0, 9.5 Hz, 1H), 3.18 (dd, *J* = 15.0, 7.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 158.9, 138.1, 137.5, 135.8, 133.9, 129.7, 129.1, 128.3, 127.6, 126.3, 125.9, 125.7, 125.5, 123.1, 122.7, 122.2, 120.2, 119.9, 109.5, 95.5, 82.1, 35.6;mp: 161-162 °C; MS (ESI) m/z (%): 312 $[M+H]^+$; HRMS (ESI-TOF) Calcd for $C_{22}H_{18}NO$ $[M+H]^+$, 312.1388; Found, 312.1386.

2-(4-Methoxyphenyl)-2,3-dihydronaphtho[2,3-*b*]furan-4-amine (6m)

Yield 66.0 mg, 45%. A yellow oil: R_f= 0.50 (2:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.69 (d, *J* = 7.5 Hz, 1H), 7.67 (d, *J* = 7.5 Hz, 1H), 7.38 (t, *J* = 7.5 Hz, 1H),

7.36 (d, *J* = 9.0 Hz, 2H), 7.28 (t, *J* = 7.5 Hz, 1H), 6.91 (d, *J* = 9.0 Hz, 2H), 6.73 (s, 1H), 5.81 (dd, *J* = 9.0, 7.5 Hz, 1H), 4.10 (brs, 2H), 3.81 (s, 3H), 3.56 (dd, *J* = 15.0, 9.0 Hz, 1H), 3.14 (dd, *J* = 15.0, 7.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 159.5, 158.8, 137.8, 135.7, 134.0, 127.6, 127.2, 125.9, 122.1, 120.2, 119.8, 114.0, 109.9, 95.3, 84.1, 55.3, 35.7; MS (ESI) m/z (%): 292 $[M+H]^+$; HRMS (ESI-TOF) Calcd for $C_{19}H_{18}NO_2$ $[M+H]^+$, 292.1337; Found, 292.1338.

Furo[2',3':6,7]naphtho[2,3-*d*][1,3]dioxol-9-amine (6n)

Yield 66.4 mg, 58%. A colorless solid: R_f= 0.48 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.15 (t, *J* = 8.0 Hz, 2H), 3.86 (brs, 2H), 4.64 (t, *J* = 8.0 Hz, 2H), 5.99 (s, 2H), 6.55 (s, 1H), 6.96 (s, 1H), 7.1 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 27.2, 71.3, 95.8, 97.6, 100.9, 104.1, 109.3, 115.1, 132.4, 137.3, 145.2, 147.5, 158.3; mp: 214-216 ^{o}C; MS (70 eV) m/z (%): 229 (34) $[M^+]$, 61 (100), 57 (53); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{11}O_3N$, 229.0739; Found, 229.0741.

(*Z*)-2-Benzylidenetetrahydrofuran (7a)

Yield 70.0 mg, 64%. A colorless oil: R_f= 0.80 (2:1 Hex/EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.17 (d, *J* = 8.0 Hz, 1H), 7.54 (d, *J* = 8.0 Hz, 1H), 7.47 (t, *J* = 8.0 Hz, 1H), 7.10 (t, *J* = 8.0 Hz, 1H), 5.68 (s, 1H), 4.39 (t, *J* = 7.2 Hz, 2H), 2.82 (t, *J* = 7.2 Hz, 2H), 2.08 (quin, *J* = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 161.9, 140.4, 132.5, 132.4, 127.6, 124.3, 118.9, 108.6, 93.1, 73.0, 31.6, 24.0; MS (ESI) m/z (%): 208 $[M+Na]^+$, 186 $[M+H]^+$; HRMS (ESI-TOF) Calcd for $C_{12}H_{11}NONa$ $[M+Na]^+$, 208.0738; Found, 208.0736.

(*E*)-2-Benzylidenetetrahydrofuran (8a)

Yield 13.0 mg, 51%. A colorless oil: R_f= 0.78 (2:1 Hex/EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.57 (d, *J* = 8.0 Hz, 1H), 7.47 (t, *J* = 8.0 Hz, 1H), 7.33 (d, *J* = 8.0 Hz, 1H), 7.14 (t, *J* = 8.0 Hz, 1H), 6.23 (s, 1H), 4.31 (t, *J* = 7.2 Hz, 2H), 2.82 (t, *J* = 7.2 Hz, 2H), 2.14 (quin, *J* = 7.2 Hz, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.2, 141.6, 133.0, 132.2, 126.5, 124.6, 118.5, 110.6, 95.9, 70.2, 28.9, 25.0; MS (ESI) m/z (%): 208 $[M+Na]^+$, 186 $[M+H]^+$; HRMS (ESI-TOF) Calcd for $C_{12}H_{11}NONa$ $[M+Na]^+$, 208.0738; Found, 208.0737.

4-Amino-3-vinylnaphthalen-2-ol (9a)

Yield 41.0 mg, 43%. A yellow oil: R_f= 0.60 (2:1 Hex/EtOAc); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (s, 1H), 7.95 (d, *J* = 8.0 Hz, 1H), 7.49 (d, *J* = 8.0 Hz, 1H), 7.29 (t, *J* = 8.0 Hz, 1H), 7.17 (t, *J* = 8.0 Hz, 1H), 6.96 (dd, *J* = 18.4, 12.0 Hz, 1H), 6.63 (s, 1H), 5.76 (dd, *J* = 18.4, 2.0 Hz, 1H), 5.55 (dd, *J* = 12.0, 2.0 Hz, 1H), 5.30 (brs, 2H); ^{13}C

NMR (100 MHz, $CDCl_3$) δ 155.7, 143.9, 136.3, 132.5, 127.7, 127.6, 123.6, 123.0, 120.6, 118.8, 110.3, 100.5; MS (ESI) m/z (%): 186 $[M+H]^+$; HRMS (ESI-TOF) Calcd for $C_{12}H_{12}NO$ $[M+H]^+$, 186.0919; Found, 186.0917.

General Procedure for the preparation of dihydrofuranonaphthoquinones 10a-k and 10n: To the stirred solution of Fermy's salt (402 mg, 1.5 mmol) in H_2O (2 mL) containing KH_2PO_4 (204 mg, 1.5 mmol) was added a solution of compound **6a-k** or **6n** (0.5 mmol) in acetone (1 mL) at room temperature. The reaction mixture was stirred at room temperature for 2 hours. Subsequently the saturated $NaCl_{(aq)}$ was added and the mixture was extracted with CH_2Cl_2. The combined organic extracts were dried over anhydrous $MgSO_{4(S)}$. After filtration and removal of solvent, the residue was purified by silica gel column chromatography to give compound **10a-k** and **10n**. The physical and spectral data of **10a-k** and **10n** are illustrated as follows.

2,3-Dihydronaphtho[2,3-*b*]furan-4,9-dione (10a)

Yield 88.0 mg, 88%. A yellow solid: R_f= 0.62 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.22 (t, *J* = 10.0 Hz, 2H), 4.80 (t, *J* = 10 Hz, 2H), 7.66-7.14 (m, 2H), 8.07 (dd, *J* = 7.5, 1.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 27.3, 73.2, 124.4, 126.0, 126.2, 131.4, 133.0, 133.0, 134.1, 160.7, 177.7, 182.1; mp: 200-202 °C; MS (70 eV) m/z (%): 200 (100) $[M^+]$, 172 (39), 104 (47); HRMS (EI-magnetic sector) Calcd for $C_{12}H_8O_3$, 200.0473; Found, 200.0475.

8-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10b)

Yield 49.22 mg, 46%. A yellow solid: R_f= 0.62 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.74 (s, 3H), 3.21 (t, *J* = 9.5Hz, 2H), 4.78 (t, *J* = 9.5 Hz, 2H), 7.45 (dd, *J* = 7.5, 0.5 Hz, 1H), 7.56 (t, *J* = 7.5 Hz, 1H), 8.01 (dd, *J* = 8.0, 1.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.8, 27.2, 73.2, 122.6, 125.0, 128.9, 133.2, 134.7, 137.17, 141.8, 161.5, 179.6, 182.2; mp: 168-170 °C; MS (70 eV) m/z (%): 214 (52) $[M^+]$, 61 (83), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{10}O_3$, 214.0630; Found, 214.0633.

7-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10c)

Yield 98.4 mg, 92%. A yellow solid: R_f= 0.64 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.47 (s, 3H), 3.20 (t, *J* = 10.0 Hz, 2H), 4.79 (t, *J* = 9.5 Hz, 2H), 7.45 (d, *J* = 8.0 Hz,1H), 7.85 (s, 1H), 7.94 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.6, 27.3, 73.2, 124.3, 126.2, 126.8, 130.7, 131.4, 134.7, 144.0, 160.6, 178.0, 182.2; mp: 196-198 ^{o}C; MS (70 eV) m/z (%): 214 (100) [M^+], 186 (64), 118 (46); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{10}O_3$, 214.0630; Found, 214.0633.

6-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10d)

Yield 98.4 mg, 92%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.48 (s, 3H), 3.20 (t, *J* = 10.0 Hz, 2H), 4.79 (t, *J* =10.0 Hz, 2H), 7.46 (d, *J* = 8.0 Hz, 1H), 7.86 (s, 1H), 7.95 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.9, 27.3, 73.3, 124.1, 126.5, 126.6, 129.2, 133.0, 133.5, 145.5, 160.9, 177.7, 182.5; mp: 182-184 ^{o}C; MS (70 eV) m/z (%):214 (100) [M^+], 186 (65), 57 (70); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{10}O_3$, 214.0630; Found, 214.0633.

6-Methoxy-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10e)

Yield 101.2 mg, 88%. A yellow solid: R_f= 0.55 (1:2:3 EA/DCM/Hex);^{1}HNMR (500 MHz, $CDCl_3$) δ 3.20 (t, *J* = 10.0 Hz, 2H), 3.94 (s, 3H), 4.79 (t, *J* = 10.0 Hz, 2H), 7.10 (dd, *J* = 8.5, 3.5 Hz, 1H), 7.53 (d, *J* = 2.0 Hz, 1H), 8.01 (d, *J* = 8.5 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 27.3, 55.9, 73.4, 110.6, 118.4, 123.8, 124.8, 128.8, 135.6, 161.3, 164.6, 176.9, 182.0; mp: 182-184 ^{o}C; MS (70 eV) m/z (%): 230 (15) [M^+], 71 (71), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{10}O_4$, 230.0579; Found, 230.0578.

2-Methyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10f)

Yield 98.42 mg, 92%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.56 (d, *J* = 6.0 Hz, 3H), 2.80 (dd, *J* = 17.0, 9.0 Hz, 1H), 3.33 (dd, *J* = 17.0, 10.0 Hz, 1H), 5.15-5.22 (m, 1H), 7.65-7.72 (m, 2H), 8.06 (dd, *J* = 6.0, 4.5 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.9, 34.3, 83.1, 123.8, 126.0, 126.3, 131.5, 132.9, 133.1, 134.1, 159.8, 178.0, 182.4; MS(70 eV) m/z (%): 214 (100) [M^+], 186 (56), 158 (42); HRMS (EI-magnetic sector) Calcd for $C_{13}H_{10}O_3$, 214.0630; Found, 214.0632.

2-Hexyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10g)

Yield 115.0 mg, 81%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.87 (t, *J* = 6.5 Hz, 3H), 1.23-1.53 (m, 8H), 1.69-1.76 (m, 1H), 1.86-1.93 (m, 1H), 2.83 (dd, *J* = 17.0, 8.5 Hz, 1H), 3.26 (dd, *J* = 17.0, 10.0 Hz, 1H),

4.99-5.06 (m, 1H), 7.62-7.70 (m, 2H), 8.03 (td, *J* = 7.0, 1.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.0, 22.5, 24.7, 28.9, 31.6, 32.5, 35.9, 86.8, 123.9, 125.9, 126.2, 131.5, 132.8, 133.0, 134.0, 160.0, 177.9, 182.3; mp: 84-86 °C; MS (70 eV) m/z (%):284 (36) [M^+], 71 (89), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{20}O_3$, 284.1412; Found, 284.1410.

2-Cyclohexyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10h)

Yield 108.5 mg, 77%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.07-1.31 (m, 5H), 1.70-1.81 (m , 5H), 1.96 (d, *J* = 13.0 Hz, 1H), 2.96 (dd, *J* = 17.0, 8.5 Hz, 1H), 3.17 (dd, *J* = 17.5, 10.5 Hz, 1H), 4.78-4.83 (m, 1H), 7.65-7.72 (m, 2H), 8.07 (td, *J* = 7.5, 1.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 25.5, 25.7, 26.2, 27.6, 28.0, 29.7, 30.0, 42.7, 90.7, 124.1, 125.9, 126.3, 131.6, 132.9, 133.1, 134.1, 160.3, 177.9, 182.3; mp: 54-56 °C; MS (70 eV) m/z (%):282 (32) [M^+], 71 (86), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{18}O_3$, 282.1256; Found, 282.1256.

2-(*Tert*-butyl)-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10i)

Yield 112.6 mg, 88%. A yellow solid: R_f= 0.62 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.01 (s, 3H), 2.99 (dd, *J* = 17.5, 9.0 Hz,1H), 3.10 (dd, *J* = 17.5, 11.0 Hz, 1H), 4.74 (t, *J* = 9.5 Hz, 1H), 7.65-7.72 (m, 2H), 8.07 (td, *J* =7.5, 1.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 24.7, 28.3, 34.7, 94.2, 124.4, 125.9, 126.3, 131.6, 132.9, 133.0, 134.1, 160.4, 177.8, 182.4; mp: 116-118 °C; MS (70 eV) m/z (%): 256 (40) [M^+], 70 (100), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{16}H_{16}O_3$, 256.1099; Found, 256.1098.

2-Vinyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10j)

Yield 105.1 mg, 93%. A yellow solid: R_f= 0.61 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.00 (dd, *J* = 17.0, 8.0 Hz, 1H), 3.39 (dd, *J* = 17.5, 11.0 Hz, 1H), 5.33 (d, *J* = 10.5 Hz, 1H), 5.42-5.48 (m, 2H), 5.99-6.06 (m, 1H), 7.65-7.73 (m, 2H), 8.06 (td, *J* = 7.5, 1.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 33.0, 86.1, 118.4, 123.8, 126.0, 126.3, 131.5, 133.0, 134.1, 135.1, 159.7, 177.7, 182.2; mp: 102-104 °C; MS (70 eV) m/z (%): 226 (58) [M^+], 198 (100), 104 (99); HRMS (EI-magnetic sector) Calcd for $C_{14}H_{10}O_3$, 226.0630; Found, 226.0632.

2-Phenyl-2,3-dihydronaphtho[2,3-*b*]furan-4,9-dione (10k)

Yield 115.9 mg, 84%. A yellow solid: R_f= 0.58 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.27 (dd, *J* = 17.5, 8.5 Hz, 1H), 3.67 (dd, *J* = 17.0, 11.0 Hz, 1H), 5.02 (dd, *J* = 11.0, 7.5 Hz, 1H), 7.35-7.41 (m, 5H), 7.68-7.75 (m, 2H), 8.10 (td, *J* =

8.5, 1.0 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 35.3, 86.8, 123.8, 126.0, 126.1, 126.4, 128. 9, 131.6, 133.0, 134.2, 139.5, 159.8, 177.7, 182.2; mp: 102-104 °C; MS (70 eV) m/z (%): 276 (6) [M^+], 70 (100), 61 (100); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{12}O_3$, 276.0786; Found, 276.0789.

7,8-Dihydrofuro[2',3':6,7]naphtho[2,3-*d*][1,3]dioxole-5,9-dione (10n)

Yield 91.5 mg, 75%. A yellow solid: R_f= 0.52 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.18 (t, *J* = 10.0 Hz, 2H), 4.77 (t, *J* = 10.0 Hz, 2H), 6.13 (s , 2H), 7.46 (d, *J* = 6.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 27.3, 73.4, 102.7, 106.0, 106.1, 123.4, 127.9, 130.4, 151.5, 152.5, 160.7, 176.7, 181.2; mp: 220-222 °C; MS (70 eV) m/z (%): 244 (13) [M^+], 71 (86), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_8O_5$, 244.0372; Found, 244.0373.

General Procedure for the preparation of furanonaphthoquinones 11a-e, 4, 11g-i, 11k and 11n: The solution of **10a-i, 10k** and **10n** (0.1 mmol) in diphenyl ether (2 mL) containing Pd/C (20.0 mg) was placed in the high pressure reactor and the reaction mixture was heated to 260 °C and stirred for 8 hours. After cooling to room temperature, the reaction mixture was directly purified by silica gel column chromatography to give compound **11a-e, 4, 11g-i, 11k and 11n**. The physical and spectral data of **11a-e, 4, 11g-i, 11k and 11n** are illustrated as follows.

Naphtho[2,3-*b*]furan-4,9-dione (11a)

Yield 14.8 mg, 75%. A yellow solid: R_f= 0.64 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.01 (d, *J* = 2.0 Hz, 1H), 7.75-7.78 (m, 3H), 8.19-8.24 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 108.6, 126.9, 127.1, 130.5, 132.5, 133.2, 133.9, 134.0, 148.6, 152.7, 173.6, 180.5; mp: 198-200 °C; MS (70 eV) m/z (%): 198 (100) [M^+], 170 (42), 114 (40); HRMS (EI-magnetic sector) Calcd for $C_{12}H_6O_3$, 198.0317; Found, 198.0317.

8-Methylnaphtho[2,3-*b*]furan-4,9-dione (11b)

Yield 13.1 mg, 62%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.84 (s, 3H), 6.95 (d, *J* = 1.5 Hz, 1H), 7.53 (d, *J* = 7.5 Hz, 1H), 7.59 (t, *J* = 7.5 Hz, 1H), 7.72 (d, *J* = 1.5 Hz, 1H), 8.14 (d, *J* = 7.5 Hz, 1H); ^{13}C NMR (125

MHz, $CDCl_3$) δ 23.0, 108.1, 126.1, 128.7, 129.6, 133.0, 134.9, 138.3, 142.5, 148.1, 153.5, 176.0, 180.6; mp: 230-232 °C; MS (70 eV) m/z (%): 212 (100) [M^+], 61 (72), 57 (94); HRMS (EI-magnetic sector) Calcd for $C_{13}H_8O_3$, 212.0473; Found, 212.0473.

7-Methylnaphtho[2,3-b]furan-4,9-dione (11c)

Yield 16.3 mg, 77%. A yellow solid: R_f= 0.61 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.51 (s, 3H), 6.99 (d, *J* = 1.5 Hz, 1H), 7.53 (dd, *J* = 8.0, 1.0 Hz, 1H), 7.76 (d, *J* = 1.5 Hz, 1H), 8.02 (d, *J* = 0.5 Hz, 1H), 8.08 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.8, 108.6, 127.3, 127.5, 130.5, 131.0, 132.4, 134.4, 145.2, 148.5, 152.7, 173.9, 180.5; mp: 184-186 °C; MS (70 eV) m/z (%): 212 (43) [M^+], 85 (79), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_8O_3$, 212.0473; Found, 212.0473.

6-Methylnaphtho[2,3-*b*]furan-4,9-dione (11d)

Yield 15.2 mg, 72%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.51 (s, 3H), 6.98 (d, *J* = 1.5 Hz, 1H), 7.55 (d, *J* = 8.0 Hz, 1H), 7.75 (d, *J* = 1.5 Hz, 1H), 7.98 (s, 1H), 8.10 (d, *J* = 8.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.8, 108.6, 127.1, 127.6, 130.2, 130.3, 133.2, 134.5, 145.1, 148.4, 152.9, 173.6, 180.9; mp: 174-176 °C; MS (70 eV) m/z (%): 212 (100) [M^+], 184 (26), 128 (35); HRMS (EI-magnetic sector) Calcd for $C_{13}H_8O_3$, 212.0473; Found, 212.0470.

6-Methoxynaphtho[2,3-*b*]furan-4,9-dione (11e)

Yield 16.4 mg, 68%. A yellow solid: R_f= 0.60 (1:2:3 EA/DCM/Hex);^{1}H NMR (500 MHz, $CDCl_3$) δ 6.16 (s, 2H), 6.95 (d, *J* = 2.0 Hz, 1H), 7.85 (s, 1H), 7.60 (s,1H), 7.72 (d, *J* = 2.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 29.7, 102.8, 106.6, 106.8, 108.6, 129.3, 123.0, 130.3, 148.2, 152.3, 152.6, 172.7, 179.5; mp: 184-186 °C; MS (70 eV) m/z (%): 242 (25) [M^+], 70 (65), 61 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_6O_5$, 242.0215; Found, 242.0212.

FNQ3 (4)

Yield 13.64 mg, 65%. A yellow solid: R_f= 0.65 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.52 (s, 3H), 6.61 (d, *J* = 0.5Hz, 1H), 7.72-7.74 (m, 2H), 8.15-8.21 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.1, 29.7, 105.0, 126.8, 126.9, 131.9, 132.5, 133.1, 133.6, 133.8, 151.7, 160.5, 173.1, 180.9; MS (70 eV) m/z (%): 212 (100) [M^+], 184 (37), 183 (81); HRMS (EI-magnetic sector) Calcd for $C_{13}H_8O_3$, 212.0473; Found, 212.0470.

2-Hexylnaphtho[2,3-*b*]furan-4,9-dione (11g)

Yield 13.5 mg, 48%. A yellow solid: R_f= 0.65 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.88-0.91 (m, 3H), 1.25-1.33 (m, 8H), 1.58-1.77 (m, 2H), 2.80 (t, *J* = 7.5 Hz, 2H), 7.70-7.75 (m, 2H), 8.15-8.21 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.0, 22.5, 27.4, 28.3, 28.7, 29.7, 31.4, 104.2, 126.8, 126.8, 131.8, 132.6, 133.1, 133.5, 133.8, 151.5, 164.9, 173.1, 181.0; mp: 86-88 °C; MS (70 eV) m/z (%): 282 (27) [M^+], 61 (100), 57 (85); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{18}O_3$, 282.1256; Found, 282.1258.

2-Cyclohexylnaphtho[2,3-*b*]furan-4,9-dione (11h)

Yield 10.6 mg, 38%. A yellow solid: R_f= 0.66 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.24-1.54 (m, 6H), 1.72-1.86 (m, 2H), 2.80 (dd, *J* = 13.0, 3.0 Hz, 2H), 2.78-2.84 (m, 1H), 7.69-7.75 (m, 2H), 8.14-8.21 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 25.6, 25.7., 31.0, 37.5, 102.4, 126.8, 126.8, 131.7, 132.6, 133.1, 133.5, 133.8, 151.3, 168.9, 173.2, 181.1; mp: 106-108 °C; MS (70 eV) m/z (%): 280 (80) [M^+], 71(87), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{16}O_3$, 280.1099; Found, 280.1099.

2-(*Tert*-butyl)naphtho[2,3-*b*]furan-4,9-dione (11i)

Yield 21.8 mg, 86%. A yellow solid: R_f= 0.66 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ1.40 (s, 9H), 7.69-7.75 (m, 2H), 8.14-8.21 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 28.7, 29.7, 33.5, 101.6, 126.8, 131.6, 132.7, 133.1, 133.5, 133.8, 151.5, 172.2, 173.2, 181.1; mp: 54-56 °C; MS (70 eV) m/z (%): 254 (18) [M^+], 240 (18), 239 (100); HRMS (EI-magnetic sector) Calcd for $C_{16}H_{14}O_3$, 254.0943; Found, 254.0943.

2-Phenylnaphtho[2,3-*b*]furan-4,9-dione (11k)

Yield 17.2 mg, 63%. A yellow solid: R_f= 0.62 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.20 (s, 1H), 7.43-7.51 (m, 3H), 7.73-7.79 (m, 2H), 7.90 (d, *J* = 7.5 Hz, 2H), 8.19-8.26 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 102.9, 125.5, 126.9, 126.9, 128.3, 129.1, 130.3, 132.4, 132.8, 133.7, 133.6, 134.0, 151.6, 160.3, 173.0, 180.8; mp: 224-226 °C; MS (70 eV) m/z (%): 274 (7) [M^+], 71 (93), 57 (100); HRMS (EI-magnetic sector) Calcd for $C_{18}H_{10}O_3$, 274.0630; Found, 274.0627.

Furo[2',3':6,7]naphtho[2,3-*d*][1,3]dioxole-5,9-dione (11n)

Yield 12.5 mg, 52%. A yellow solid: R_f= 0.61 (1:2:3 EA/DCM/Hex); ^{1}H NMR (500 MHz, $CDCl_3$) δ 6.16 (s, 2H), 6.95 (d, *J* = 2.0 Hz, 1H), 7.85 (s, 1H), 7.60 (s, 1H), 7.72 (d, *J* = 2.0 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 29.7, 102.8, 106.6, 106.8, 108.6, 129.3, 123.0, 130.3, 148.2, 152.3, 152.6, 172.7, 179.5; mp: 184-186 °C; MS (70 eV)

m/z (%): 242 (25) [M^+], 70 (65), 61 (100); HRMS (EI-magnetic sector) Calcd for $C_{13}H_6O_5$, 242.0215; Found, 242.0212.

2-(5-Oxopent-1-yn-1-yl)benzonitrile (12)

To the solution of oxalyl dichloride (5.14 g, 40.53 mmol) inCH_2Cl_2 (50 mL) at -78 ^oC was added DMSO (3.16 g, 40.53 mmol) dropwise for 0.5 hour. Subsequently compound **5a** (5.0 g, 27.02 mmol) was added into the reaction mixture and stirred for another 1.5 hours. Et_3N (20.46 g, 202.65 mmol) was then injected slowly to the reaction mixture. After warming to room temperature, the reaction mixture was poured into saturated $NH_4Cl_{(aq)}$ and extracted with EtOAc. The combined organic extracts were dried over anhydrous $MgSO_{4(S)}$. After filtration and removal of solvent, the residue was purified by column chromatography to give compound **12**. Yield 3.95 g, 80%. A yellow oil: R_f= 0.41 (3:1 Hex/EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.71-2.86 (m, 4H), 7.34-7.37 (m, 1H), 7.46-7.52 (m, 2H), 7.60 (d, *J* = 7.5 Hz, 1H), 9.85 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.7, 15.2, 32.8, 77.9, 95.2, 115.3, 117.6, 127.3, 127.9, 132.1, 132.3, 132.3, 132.4, 132.4, 176.1, 199.9; MS (70 eV) m/z (%): 183 (11) [M^+], 154 (100), 127 (85), 57 (72); HRMS (EI-magnetic sector) Calcd for $C_{12}H_9ON$, 183.0684; Found, 183.0684.

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Supporting Information Available: The supporting information is available free of charge on the ACS Publication website at http://pubs.acs.org. The scheme for preparation of compounds **5a-5n**; ^{1}H NMR and ^{13}C NMR Spectra (PDF) of all compounds.

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5. The detailed scheme for preparation of compounds **5a-5n** is available in the supporting information.

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