Synthesis of DNA Oligomers Containing Modified Uracil Possessing Electron-Accepting Benzophenone Chromophore

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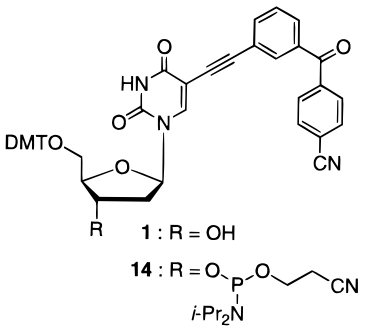
Current interest in DNA-mediated electron transfer (ET) is focused on the question of how DNA is a good medium for ET.[1,2] Designed oligomers possessing strong electron acceptors have been synthesized and used for such studies.[3−7] More recently, DNA containing modified nucleoside has proven to be very useful because the distance between a donor and an acceptor in duplex DNA could be accurately determined.[8,9] We herein report the design and synthesis of a novel nucleoside $d^{CNBP}U$ possessing *p*-cyano-substituted benzophenone (CNBP)[10] chromophore at C5 of dU through an acetylenic unit and its incorporation into DNA oligomers via its phosphoramidite derivative. The melting temperature and the CD spectra of the 12-mer duplex containing $d^{CNBP}U$ in the middle of the sequence indicated that the incorporation of $d^{CNBP}U$ has a relatively small effect on the duplex stability. The synthetic method described here can provide novel and useful DNA oligomers for studying DNA-mediated charge transport that possess a strong electron-accepting chromophore at the predetermined sites without perturbing the π-stack.

We have recently demonstrated that CNBP is an excellent chromophore for one-electron oxidation of DNA.[10] Molecular modeling studies of the oligonucleotide containing $d^{CNBP}U$ have shown that the benzophenone chromophore is extruded into a major groove of B-form DNA without perturbing the local structure. Synthesis of 5′-*O*-DMTr-$d^{CNBP}U$ (**1**) and its phosphoramidite **14** was



started from *m*-bromobenzoic acid (**2**) (Scheme 1). Friedel−Crafts reaction of the acid chloride derived from **2** with toluene produced 3′-bromo-4-methylbenzophenone (**3**). The methyl group of **3** was converted to a cyano group in three steps. Heating **3** with *N*-bromosuccinimide (2.5 equiv) in acetonitrile in the presence of AIBN produced geminal dibromide **4**, which was then treated with sodium acetate in dimethylformamide to give aldehyde **5**. *p*-Cyanobenzophenone derivative **6** was obtained from the oxime of **5** by dehydration. Cross-coupling of **6** with ethynyltrimethylsilane in the presence of Pd catalyst produced ethynylbenzophenone **7**.

An alternative synthetic route for **7** that is more suitable for larger scale preparation was also developed. Friedel−Crafts reaction of 3-bromobenzoyl chloride with anisole produced benzophenone derivative **8**, which was then treated with aluminum trichloride to give 3′-bromo-4-hydroxybenzophenone (**9**) in 57% for two steps after recrystallization. Cross coupling of **9** with ethynyltrimethylsilane followed by conversion of its phenolic hydroxyl group to the triflate produced **11**. Substitution of the triflate with a cyanide ion was accomplished under the influence of Pd catalyst in the presence of 18-crown-6.[11] The reaction cleanly proceeded to produce **7**, but prolonged reaction and elevated reaction temperature decreased the yield of **7** as a result of the competitive desilylation of both **7** and starting **11**. Purification of the crude reaction mixture gave **7** (40%, conversion yield 47%) with a recovery of **11** (recovery 15%). Protodesilylation of **7** with tetrabutylammonium fluoride in the presence of acetic acid furnished the synthesis of 3′-ethynyl-4-cyanobenzophenone (**12**).

Cross-coupling of **12** with 5′-*O*-DMTr-5-iodo-dU (**13**) was carried out in the presence of Pd catalyst to give **1** in a high yield (Scheme 2). Phosphoramidite **14** was obtained by a standard procedure. Synthesis of 12-mer

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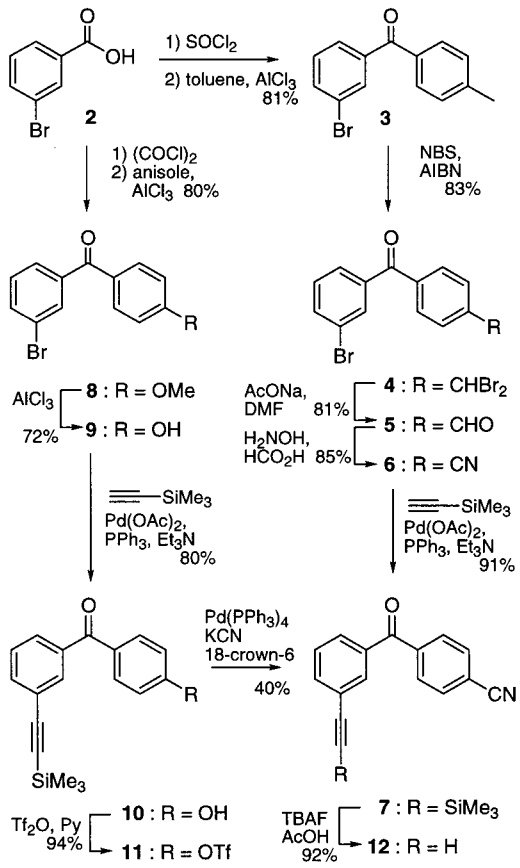
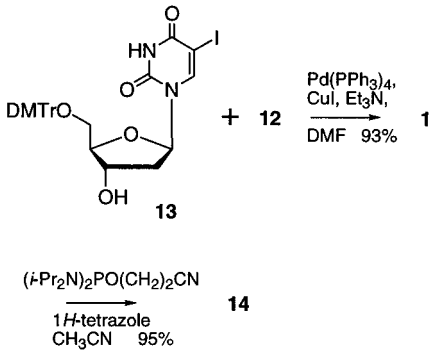
Scheme 1



Scheme 2



5′-d(ACT GGT ^{CNBP}UAC AGT)-3′ was carried out by an automated DNA synthesis. Because d^{CNBP}U was not so stable under standard deprotection conditions (concentrated ammonia, 55 °C, 8 h), phenoxyacetyl-dA and 4-isopropylphenoxyacetyl-dG phosporamidites were used for the synthesis of the 12-mer. The coupling of phosphoramidite **14** was conducted for 15 min to compensate for the decreased coupling reactivity due to the steric bulkiness of the benzophenone. Removal of the 12-mer from solid support using concentrated ammonia was followed by incubation at 37 °C for 3 h to afford the completely deprotected oligomer (Figure 1). Incorporation of d^{CNBP}U in the oligomer was confirmed by nucleoside analysis of the mixture obtained by enzymatic digestion using snake venom phosphodiesterase, P1 nuclease, and alkaline phosphatase. The produced d^{CNBP}U comigrated on reverse-phase HPLC with an authentic sample obtained by deprotection of **1**. The molecular weight of the 12-mer was confirmed by MALDI-TOFMS (calcd 3872.68, found 3873.61).

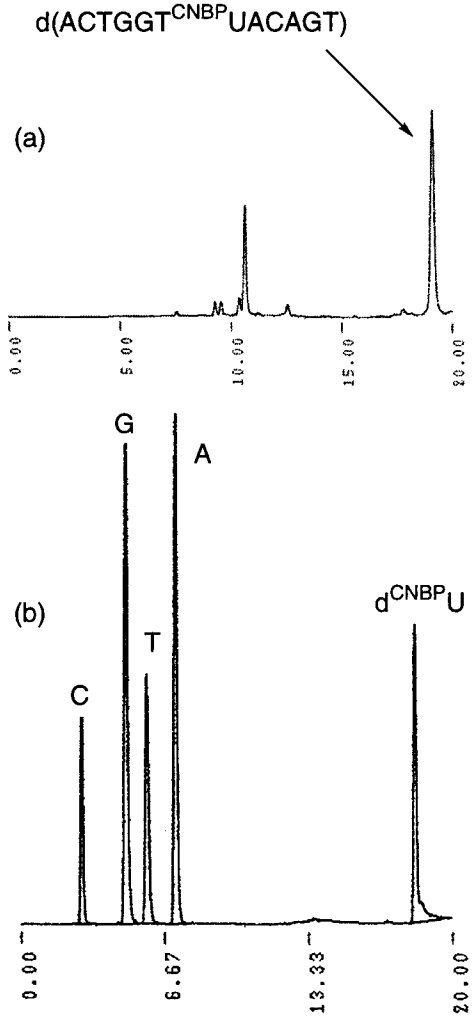


Figure 1. HPLC analysis of d^{CNBP}U-containing 12-mer d(ACTGGT^{CNBP}UACAGT). (a) Crude products obtained by DNA sythesizer. The ODN was prepared by the β-(cyanoethyl)phosphoramidite method. After automated synthesis, deprotection was conducted for 3 h at 37 °C with concentrated ammonia. The desired d(ACTGGT^{CNBP}UACAGT) eluted about at 19 min. (b) The nucleosides and d^{CNBP}U resulting from enzymatic digestion of d(ACTGGT^{CNBP}UACAGT). The HPLC purified 12-mer was incubated at 37 °C for 2 h with calf intestine AP (100 unit/mL), s.v.PDE (0.3 unit/mL), and nuclease P1 (100 unit/mL). HPLC conditions: (a) CHEMCOBOND 5-ODS-H column (10 × 150 mm) 5−25% (20 min) acetonitrile in 100 mM TEAA buffer (linear gradient), 1 mL/min, monitored at 254 nm. (b) CHEMCOBOND 5-ODS-H column (4.6 mm × 150 mm) 5−13−75% (0−8−20 min) acetonitrile in 100 mM TEAA buffer (linear gradient), 1 mL/min, monitored at 254 nm.

The melting temperature of the duplex consisting of the 12-mer and its complement 5′-d(ACT GTA ACC AGT) (T_m = 35.8 °C) was slightly lower than the duplex containing dT in place of d^{CNBP}U (T_m = 39.2 °C).[12] The small decrease in the melting temperature (ΔT_m = 3.4 °C) suggested that the incorporation of d^{CNBP}U has a relatively small effect on the duplex stability. CD spectra of the duplex indicated a typical B-form structure (Figure 2). Very weak but apparent negative induced CD ob-

(12) A similar decrease in melting temperature has been reported for oligomers containing bulky phenanthroline-substituted deoxyuridine. See: Hurley, D. J.; Tor, Y. *J. Am. Chem. Soc.* **1998**, *120*, 2194−2195.

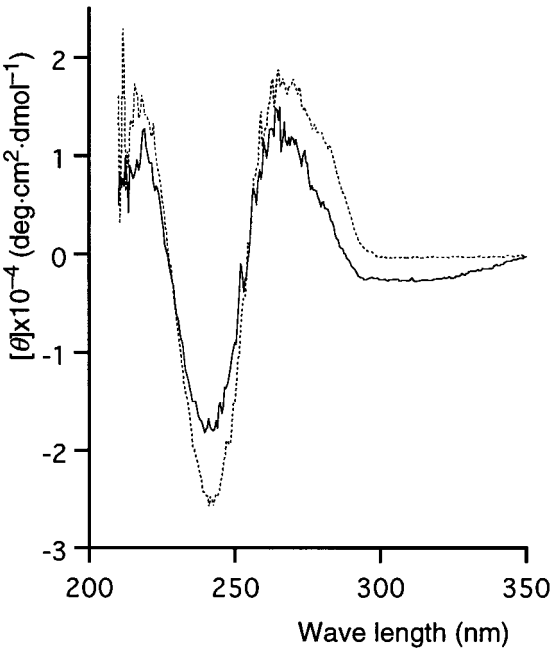


Figure 2. CD spectra of d^{CNBP}U-containing oligomer. CD spectra of 12-mer duplex d(ACTGGT**X**ACAGT)/d(ACTGTAACCTCA) (150 μM base concentration for each strand) was measured in 10 mM sodium cacodylate buffer (pH 7.0) and 100 mM NaCl: **X** = ^{CNBP}U (solid line) and **X** = T (dotted line).

served in the 290−330 nm range implies that the benzophenone chromophore is in a chiral environment. On the basis of these results, we concluded that the CNBP chromophore in the duplex oligomer actually located in the major groove of the B-form duplex without perturbing the π-stack. Experiments on photoinduced charge transport using d^{CNBP}U-containing DNA oligomers will be reported in due course.

Experimental Section

General Procedure for Workup and Purification. The reaction mixture was diluted with water and extracted with ethyl acetate or chloroform. The extracts were washed with saturated $NaHCO_3$ and brine, dried over anhydrous $MgSO_4$, filtered, and concentrated in vacuo. The crude products were purified by column chromatography on silica gel (ccsg) with the indicated elution solvent.

3′-Bromo-4-methylbenzophenone (3). A mixture of 3-bromobenzoic acid (**2**) (5.16 g, 25.7 mmol) and thionyl chloride (30 mL) was refluxed for 1 h. Excess reagent was removed in vacuo, and the residue was dissolved in toluene (40 mL). To the solution was added anhydrous aluminum trichloride (7.28 g, 54.6 mmol) in several portions, and the mixture was stirred for 3 h at ambient temperature. The reaction mixture was poured onto crushed ice (45 g) and concentrated hydrochloric acid (10 mL). The produced suspension was stirred for 30 min and extracted with ethyl acetate. The crude product was recrystalized from hexane and ethyl acetate to give **3** (5.75 g, 81%): ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.43 (s, 3 H), 7.28 (d, 2 H, J = 8.4 Hz), 7.33 (t, 1 H, J = 8.0 Hz), 7.66−7.69 (2 H), 7.68 (d, 2 H, J = 8.4 Hz), 7.89 (t, 1 H, J = 1.4 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.8, 122.4, 128.2, 129.0, 129.7, 130.1, 132.5, 134.6, 134.9, 139.7, 143.6, 194.5; MS m/z (%) 276 (M^+) (48), 274 (M^+) (48), 119 (100); HRMS calcd for $C_{14}H_{11}O^{79}Br$ 273.9993, found 273.9989.

3′-Bromo-4-(dibromomethyl)benzophenone (4). To a solution of **3** (1.03 g, 3.75 mmol) in acetonitrile (20 mL) was added *N*-bromosuccinimide (1.65 g, 9.29 mmol) and 2,2′-azobisisobutyronitrile (63.7 mg, 0.39 mmol), and the mixture was stirred at reflux for 5 h. The reaction mixture was concentrated in vacuo, and the residue was dissolved in ethyl acetate and filtered. The crude product was obtained by concentrating the filtrate. **2** (1.35 g, 83%) (ccsg, toluene/hexane = 2:1) as a colorless oil that solidify on standing: ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.67 (s, 1 H), 7.36 (t, 3 H, J = 7.8 Hz), 7.68 (d, 2 H, J = 8.4 Hz), 7.69 (2 H), 7.72 (2 H), 7.78 (d, 2 H, J = 8.4 Hz),7.92 (t, 1 H, J = 1.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 39.7, 122.6, 126.6, 128.4, 129.9, 130.2, 132.6, 135.5, 137.8, 138.8, 145.7, 193.6; MS m/z (%) 434 (M^+) (2), 432 (M^+) (2), 355 (56), 353 (100), 351 (58); HRMS calcd for $C_{14}H_9O^{79}Br_2$ [(M − Br) $^+$] 350.9020, found 350.9036.

4-(3-Bromobenzoyl)benzaldehyde (5). To a solution of **4** (4.05 g, 9.36 mmol) in DMF (20 mL) was added sodium acetate (3.84 g, 46.8 mmol), and the mixture was stirred at reflux for 8 h. The reaction mixture was evaporated to dryness in vacuo and diluted with ethyl acetate. **5** (2.18 g, 81%) (ccsg, toluene/hexane = 2:1): ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.38 (t, 1 H, J = 8.0 Hz), 7.70 (d, 2 H, J = 8.0 Hz), 7.74 (d, 2 H, J = 8.0 Hz), 7.90 (d, 2 H, J = 8.4 Hz), 7.93 (t, 1 H, J = 1.6 Hz), 8.00 (d, 2 H, J = 8.4 Hz), 10.13 (s, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 122.7, 128.5, 129.5, 130.0, 130.2, 132.7, 135.8, 138.4, 138.6, 141.6, 191.6, 194.0; MS m/z (%) 290 (M^+) (73), 133 (100); HRMS calcd for $C_{14}H_9O_2{}^{79}Br$ 287.9786, found 287.9784.

4-(3-Bromobenzoyl)benzonitrile (6). To a mixture of **5** (2.53 g, 8.75 mmol) and sodium formate (915 mg, 13.5 mmol) in formic acid (20 mL) was added hydroxylamine hydrochloride (622 mg, 9.0 mmol), and the mixture was stirred at reflux for 3 h. **4** (2.12 g, 85%) (ccsg, hexane/ethyl acetate = 8:1): ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.38 (t, 1 H, J = 8.0 Hz), 7.67 (m, 1 H), 7.75 (m, 1 H), 7.79 (d, 2 H, J = 8.4 Hz), 7.85 (d, 2 H, J = 8.4 Hz), 7.90 (t, 1 H, J = 1.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 116.0, 117.7, 122.8, 128.4, 130.0, 132.2, 132.6, 136. 0, 138.0, 140.3, 193.2; MS m/z (%) 287 (M^+) (92), 285 (M^+) (93), 130 (100); HRMS calcd for $C_{14}H_8ON^{79}Br$ 284.9789, found 284.9781.

4-(3-Trimethylsilylethynylbenzoyl)benzonitrile (7). To a mixture of **6** (887 mg, 3.10 mmol), palladium(II) acetate (7.1 mg, 0.03 mmol), and triphenylphosphine (40.5 mg, 0.15 mmol) in deaerated triethylamine (15 mL) was added ethynyltrimethylsilane (0.66 mL, 4.7 mmol), and the mixture was stirred at reflux for 5 h under nitrogen. **7** (856 mg, 91%) (ccsg, hexane/ethyl acetate = 30:1): ^{1}H NMR ($CDCl_3$, 100 MHz) δ 0.23 (s, 9 H), 7.44 (t, 1 H, J = 7.6), 7.70 (2 H), 7.85 (d, 2 H, J = 8.4 Hz), 7.80 (s, 1 H), 7.90 (d, 2 H, J = 8.4 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 0.0, 96.2, 103.3, 115.8, 117.8, 123.8, 128.5, 129.5, 130.1, 132.1, 133.1, 136.2, 136.3, 140.6, 193.9; MS m/z (%) 303 (M^+) (55), 288 (100); HRMS calcd for $C_{19}H_{17}ONSi$ 303.1080, found 303.1078.

4-(3-Ethynylbenzoyl)benzonitrile (12). To a solution of **7** (730 mg, 2.40 mmol) in THF (10 mL) were added acetic acid (0.2 mL, 3.5 mmol) and tetrabutylammonium fluoride (3.60 mL of a 1.0 M solution in THF, 3.6 mmol), and the mixture was stirred at ambient temperature for 2 h. **6** (513 mg, 92%) (ccsg, hexane/ethyl acetate = 15:1): ^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.13 (s, 1 H), 7.47 (t, 1 H, J = 7.8), 7.74 (2 H), 7.79 (d, 2 H, J = 8.2 Hz), 7.85 (s, 1 H), 7.85 (d, 2 H, J = 8.2 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 78.8, 82.2, 115.9, 117.8, 122.8, 128.7, 129.9, 130.0, 132.1, 133.3, 136.3, 136.4, 140.5, 193.8; MS m/z (%) 231 (M^+) (100), 129 (77), 101 (20); HRMS calcd for $C_{16}H_9ON$ (M^+) 231.0685, found 231.0692.

5-{3-(4-Cyanobenzoyl)phenylethynyl}-2′-deoxy-5′-*O*-(4,4′-dimethoxytrityl) Uridine (1). To a solution of **12** (275 mg, 1.19 mmol), 2′-deoxy-5′-*O*-(4,4′-dimethoxytrityl)-5-iodouridine (**13**) (651 mg, 0.99 mmol), and triethylamine (0.28 mL, 2.0 mmol) in 10 mL of deaerated DMF were added tetrakis(triphenylphosphine)palladium(0) (121 mg, 0.11 mmol) and copper(I) iodide (189 mg, 1.0 mmol) under nitrogen. The mixture was stirred at ambient temperature for 5 h. **1** (720 mg, 93%) (ccsg, chloroform/methanol = 100:1) as pale yellow foamy solids: ^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.33 (m, 1 H), 2.53 (m, 1 H), 3.31 (m, 1 H), 3.42 (m, 1 H), 3.66 (s, 3 H), 3.67 (s, 3 H), 4.09 (m, 1 H), 4.57 (m, 1 H), 6.34 (m, 1 H), 6.72−6.76 (4 H), 7.07−7.42 (12 H), 7.65−7.77 (5 H), 8.26 (s, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 40.4, 54.9, 63.4, 70.4, 79.1, 83.1, 85.2, 85.9, 86.1, 90.7, 98.0, 113.1, 113.2, 114.7, 118.0, 122.6, 126.6, 127.5, 127.8, 129.1, 129.3, 129.4, 129.5, 129.7, 129.9, 131.7, 135.2, 135.5, 136.3, 140.4, 143.1, 144.5, 149.2, 158.0, 158.0, 161.3, 194.0; FABMS m/z 760 [(M + H)$^+$]; HRMS calcd for $C_{46}H_{38}O_8N_3$ [(M + H)$^+$] 760.2660, found 760.2660.

5-{3-(4-Cyanobenzoyl)phenylethynyl}-2′-deoxy-5′-*O*-(4,4′-dimethoxytrityl) Uridine 3′-*O*-(2-Cyanoethyl *N*,*N*-diisopropylphosphoramidite) (14). To a solution of **1** (241 mg, 0.34

mmol) in anhydrous acetonitrile (2 mL) was added 2-cyanoethyl tetraisopropylphosphordiamidite (0.13 mL, 0.45 mmol) and tetrazole (0.93 mL of a 0.5 M solution in CH_3CN, 0.47 mmol) under nitrogen. The mixture was stirred at ambient temperature for 1.5 h. The resulting mixture was diluted with ethyl acetate, washed with water and brine, and dried over anhydrous $MgSO_4$. Removal of the solvent afforded **14** (292 mg, 96%) as a mixture of two diastereoisomers. This compound was used for automated DNA synthesis without purification. Formation of phosphoramidite was confirmed by ^{31}P NMR: ^{31}P NMR (C_6D_6, 162 MHz) δ 149.5, 149.1.

3′-Bromo-4-methoxybenzophenone (8). To a suspension of **2** (10.4 g, 51.8 mmol) in benzene (35 mL) were added oxalyl chloride (7.0 mL, 80.2 mmol) and catalytic amount of DMF, and the mixture was stirred at ambient temperature for 3 h. The reaction mixture was evaporated to dryness in vacuo, and the residue was dissolved in CS_2 (40 mL). To the solution were added anisole (11.3 mL, 104 mmol) and anhydrous aluminum trichloride (10.9 g, 82.1 mmol) in several portions. The mixture was stirred for 3 h at ambient temperature. The reaction mixture was poured onto crushed ice (45 g) and concentrated hydrochloric acid (10 mL) and stirred for 30 min. The crude product was recrystalized from hexane and ethyl acetate to give **8** (12.0 g, 80%): ^1H NMR ($CDCl_3$, 400 MHz) δ 3.13 (s, 1 H), 6.96 (d, 2 H, J = 9.2 Hz), 7.34 (t, 1 H, J = 8.0 Hz), 7.64−7.69 (2 H), 7.80 (d, 2 H, J = 9.2 Hz), 7.87 (s, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 55.7, 113.6, 122.3, 128.0, 129.3, 129.6, 132.3, 132.4, 134.5, 140.0, 163.3, 193.5; MS *m*/*z* (%) 292 (M^+) (73), 290 (M^+) (73), 135 (100); HRMS calcd for $C_{14}H_{11}O_2{}^{79}Br$ (M^+) 289.9942, found 289.9939.

3′-Bromo-4-hydroxybenzophenone (9). To a solution of **8** (10.1 g, 34.7 mmol) in benzene (45 mL) was added aluminum trichloride (11.6 g, 86.7 mmol), and the mixture was stirred at reflux for 2 h. The reaction mixture was poured onto crushed ice (40 g) and concentrated hydrochloric acid (5 mL) and stirred for 30 min. The crude product was recrystalized from hexane and ethyl acetate to give **9** (6.81 g, 72%): ^1H NMR ($CDCl_3$, 100 MHz) δ 5.62 (s, 1 H), 6.90 (d, 2 H, J = 8.4 Hz), 7.34 (t, 1 H, J = 8.0 Hz), 7.65 (m, 1 H), 7.68 (m, 1 H), 7.75 (d, 2 H, J = 8.4 Hz), 7.86 (s, 1 H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 115.2, 122.4, 128.1, 129.6, 129.7, 132.4, 132.7, 134.7, 139.9, 159.8, 193.7; MS *m*/*z* (%) 278 (M^+) (41), 276 (M^+) (41), 121 (100); HRMS calcd for $C_{13}H_9O_2{}^{79}Br$ (M^+) 275.9786, found 275.9779.

3′-Trimethylsilylethynyl-4-hydroxybenzophenone (10). To a mixture of **9** (1.51 g, 5.41 mmol), palladium(II) acetate (31.7 mg, 0.14 mmol), and triphenylphosphine (103 mg, 0.39 mmol) in triethylamine (20 mL) was added ethynyltrimethylsilane (1.50 mL, 10.6 mmol), and the mixture was stirred at reflux for 5 h under nitrogen. **10** (1.28 g, 80%) (ccsg, hexane/ethyl acetate = 8:1): ^1H NMR ($CDCl_3$, 400 MHz) δ 0.23 (s, 9 H), 6.92 (d, 2 H, J = 8.8 Hz), 7.40 (t, 1 H, J = 7.4 Hz), 7.63 (m, 1 H), 7.67 (m, 1 H), 7.74 (d, 2 H, J = 8.8 Hz), 7.80 (t, 1 H, J = 1.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 0.1, 95.5, 103.9, 115.3, 123.3, 128.2, 129.4, 132.8, 132.9, 135.1, 135.1, 138.1, 160.3, 195.2; MS *m*/*z* (%) 294 (M^+) (74), 279 (100), 121 (21); HRMS calcd for $C_{18}H_{18}O_2Si$ (M^+) 294.1076, found 294.1086.

4-(3′-Trimethylsilylethynylbenzoyl)phenyl Trifluoromethanesulfonate (11). To a solution of **10** (1.04 g, 3.52 mmol) in pyridine (15 mL) was slowly added trifluoromethanesulfonic anhydride (0.68 mL, 4.04 mmol). The mixture was stirred at 0 °C for 5 min and then allowed to warm to ambient temperature, and the stirring was continued for 2 h. **11** (1.42 g, 94%) (ccsg, hexane/ethyl acetate = 20:1): ^1H NMR ($CDCl_3$, 400 MHz) δ 0.24 (s, 9 H), 7.40 (d, 2 H, J = 8.6 Hz), 7.44 (t, 1 H, J = 7.8 Hz), 7.67−7.72 (2 H), 7.82 (t, 1 H, J = 1.8 Hz), 7.88 (d, 2 H, J = 8.6 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 0.0, 96.0, 103.4, 118.6 (q, J_{CF} = 318 Hz), 121.4, 123.7, 128.5, 129.5, 132.0, 132.9, 136.0, 136.7, 137.0, 151.9, 193.6; MS *m*/*z* (%) 426 (M^+) (100), 411 (70); HRMS calcd for $C_{19}H_{17}O_4F_3SSi$ (M^+) 426.0569, found 426.0573.

4-(3-Trimethylsilylethynylbenzoyl)benzonitrile (7). To a mixture of **11** (537 mg, 1.26 mmol), potassium cyanide (98.6 mg, 1.51 mmol), and 18-crown-6 (132 mg, 0.50 mmol) in benzene (12 mL) was added tetrakis(triphenylphosphine)palladium(0) (290 mg, 0.25 mmol). The mixture was stirred at reflux for 2 h under nitrogen. **5** (152 mg, 40%) (ccsg, hexane/ethyl acetate = 20:1) accompanied by starting material **11** (78 mg, 15% recovery).

General Procedure for Oligomer Synthesis and Purification. Automated DNA synthesis was carried out by using a standard β-(cyanoethyl)phosphoramidite method with Applied Biosystems 392 DNA synthesizer. The coupling of phosphoramidite **14** was conducted as usual except for the coupling time of 15 min. Synthesized oligomers were deprotected and removed from the solid support by treating with concentrated ammonia at 37 °C for 3 h. Purification of the oligomers was performed on a CHEMCOBOND 5-ODS-H HPLC column with a linear gradient of 5−25% acetonitrile in 100 mM triethylammonium acetate for 20 min.

Measurement of Melting Temperature and CD Spectra. Melting temperature of the oligomer (50 μM base concentration) was measured with Jasco V-550 UV−vis spectrometer in a buffer containing 10 mM sodium cacodylate (pH 7.0) and 100 mM NaCl. CD spectrum of the oligomer (300 μM base concentration) was recorded on a Jasco J-720 instrument at 25 °C in the same buffer solution.

Supporting Information Available: ^1H NMR spectral data of **1** and **4**−**12**. This material is available free of charge via the Internet at http://pubs.acs.org.

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