New Synthesis of Quinoxaline Derivatives Based on Palladium Catalyzed Oligomerization of 1,2-Diisocyanoarenes†

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Abstract – Various 2,3-disubstituted quinoxaline derivatives were synthesized from monomeric and oligomeric (3-substituted quinoxaline-2-yl)palladium(II)s, which were prepared by the reaction of *o*-diisocyanoarenes with *trans*-bromo(methyl)bis(phosphine)palladium(II).

Insertion reaction of carbon monoxide as well as isonitrile with organometallic compounds is fundamental, but important in organometallic chemistry.[1] Especially, most synthetic reactions with carbon monoxide catalyzed by transition metal complexes involve the insertion reaction as a key step in the catalytic cycles. However, unlike carbon monoxide, isonitriles are able to undergo multiple, successive insertion into carbon-metal linkage of organometallic compounds.[2] It has been well known that polymerization of isonitriles is catalyzed by some transition metal complexes to give poly(*N*-substituted iminomethylene)s.[3] The successive insertion of isonitriles with *trans*-bromo(methyl)bis(phosphine)palladium(II) provides a product of triple isonitriles insertion, which are stabilized by intramolecular chelation.[4]

Recently, we found that the successive insertion of the two isocyano groups on *o*-diisocyanobenzenes was completely controlled with *trans*-bromobis(dimethylphenylphosphine)-methylpalladium(II) to afford *trans*-bromobis(dimethylphenylphosphine)(3-methylquinoxaline-2-yl)palladium(II), which underwent further insertion of *o*-diisocyanobenzene, ultimately leading

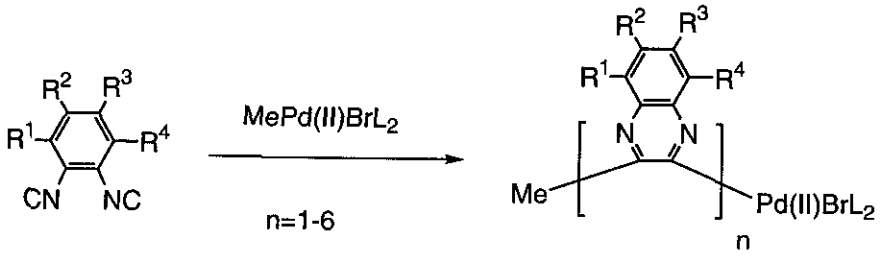
†*Dedicated to the memory of the late Professor Yoshio Ban.*

to polymerization of *o*-diisocyanobenzene.[5] (Scheme 1) The oligomerization of 1,2-diisocyano-3,6-di-*p*-tolylbenzene (1a) catalyzed by methylpalladium(II) complexed with optically active phosphine afforded a mixture of oligo(5,8-di-*p*-tolylquinoxaline-2,3-diyl)palladium(II) complexes (2a) (L").[5] Of interest is that HPLC permitted separation of the two pentameric diastereomers (2a) (n=5, L") and of the two hexameric diastereomers (2a) (n=6, L"), which have helicity as well as chirality of the phosphine ligand.[5]

Some quinoxaline derivatives exhibit various biological activities such as antibacterial activity, fungicidal activity, insecticidal activity, anthelmintic activity and so on.[6] Of particular note is the recent finding that quinoxaline derivatives inhibit selectively the platelet-derived growth factor (PDGF) receptor kinase and the PDGF-dependent DNA synthesis.[7]

In general, quinoxaline derivatives have been conventionally prepared by condensation of α-diketone with 1,2-diaminoarenes.[6] Herein, we wish to report new preparation of 2,3-disubstituted quinoxalines, including oligomeric quinoxaline-2,3-diyl derivatives by synthetic elaboration of monomeric to oligomeric *trans*-bromobis(phosphine)(quinoxaline-2-yl)palladium(II) complexes, which are formed and isolated in the reaction of *o*-diisocyanoarenes with *trans*-bromo(methyl)-bis(phosphine)palladium(II).

Scheme 1



1 2

L: L'=PMe_2Ph, L" = PhP

2a: R^1=R^4=*p*-tolyl, R^2=R^3=H
2b: R^1=R^4=*p*-Pr-C6H4, R^2=R^3=H
2c: R^1=R^4=*p*-Me3SiC6H4, R^2=R^3=H
2d: R^1=R^4=*p*-Me2NC6H4, R^2=R^3=H
2e: R^1=R^2=R^3=R^4=CH_3

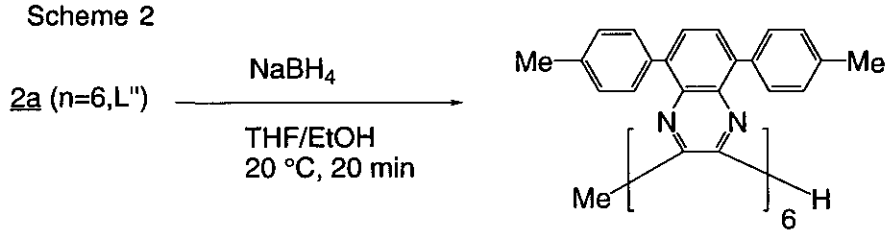
Results and Discussion

(1) Reduction and Alkylations of (3-Substituted quinoxaline-2-yl)palladium(II) Complexes.

Oligo(quinoxaline-2,3-diyl)palladium(II) complexes (2), which were produced in the reaction of *o*-diisocyanobenzenes with *trans*-bromo(methyl)bis(phosphine)palladium(II), were stable in H_2O and air. However, the palladium(II) complexes were readily reduced with $NaBH_4$ and alkylated by coupling with Grignard reagents.

The reduction was demonstrated by the reaction of a diastereomerically pure hexameric helical *trans*-bromobis[bis((*S*)-2-methylbutyl)phenylphosphine](5,8-di-*p*-tolylquinoxaline-2,3-diyl)palladium(II) (2a) (n=6, L")[5] with sodium borohydride in THF containing EtOH to give optically active hexameric 5,8-di-*p*-tolylquinoxaline (3a) (n=6) ($[\alpha]_D^{26}$ = -462°) in 50% yield. (Scheme 2)

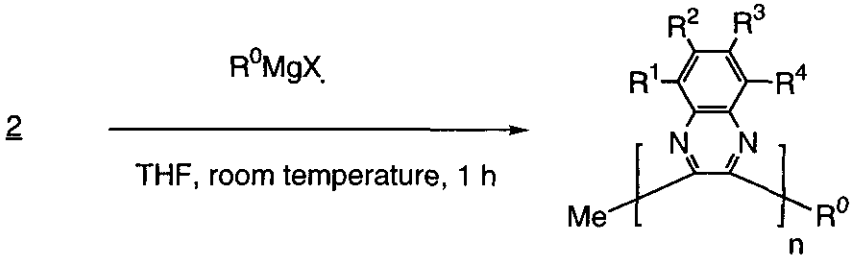
Scheme 2



3a (n=6)

Carbon-carbon bond formation with oligomeric helical bromobis(phosphine)(quinoxaline-2,3-diyl)palladium(II) complexes (2) was achieved in moderate to fairly good yields by coupling reaction with some Grignard reagents. (Table 1) The coupling with vinylmagnesium bromide took place similarly to afford the corresponding vinylation product but in low isolated yields, probably because of its polymerization ability.

Table 1



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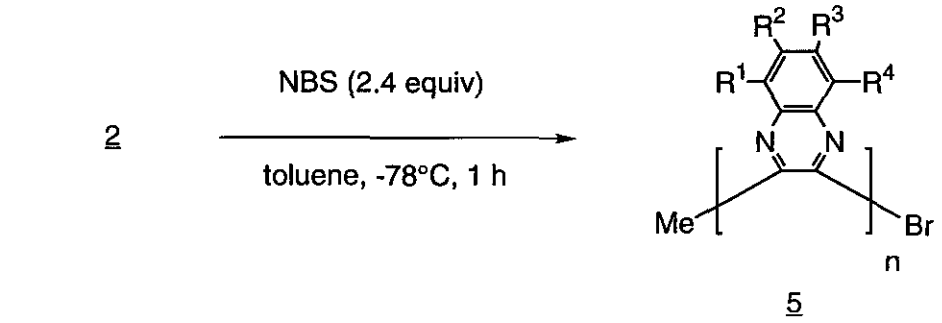
Quinoxaline-2-yl Palladium(II) Complex	R^0MgBr	Product (%; $[\alpha]_D^{20}$)
(+) 2a (n=6, L'')	Me	(+) 4a (n=6) (79%; +421°)
(−) 2a (n=6, L'')	Me	(−) 4a (n=6) (98%; −430°)
(+) 2b (n=5, L'')	Me	(+) 4b (n=5) (91%; +430°)
(−) 2b (n=5, L'')	Me	(−) 4b (n=5) (78%; −440°)
(−) 2b (n=6, L'')	Me	(−) 4b (n=6) (89%; −448°)
(±) 2c (n=5, L'')	Me	(±) 4c (n=5) (81%)
(±) 2d (n=6, L'')	Me	(±) 4d (n=6) (94%)
(±) 2e (n=3, L')	Ph	(±) 4e (n=3) (75%)
(±) 2a (n=6, L'')	Ph	(±) 4a (n=6) (40%)
(±) 2b (n=5, L'')	CH2=CH	(±) 4b (n=5) (15%)
(±) 2b (n=5, L'')	CH≡C	(±) 4b (n=5) (55%)

Although the enantiomeric excesses of (4a) and (4b) (Table 1) due to the helical structure have not been determined, it may be presumed that the racemization of the helical structure would not be significantly involved.

(2) Halogenation of (3-Substituted quinoxaline-2-yl)palladium(II) Complexes

2-Haloquinoxalines are a useful synthetic intermediate for preparation of 2-substituted quinoxaline derivatives. Bromination of *trans*-bromobis(dimethylphenylphosphine)(3,5,6,7,8-pentamethylquinoxaline-2-yl)palladium(II) complex (2e) (n=1, L') was readily feasible with NBS in toluene at -78 °C to afford the corresponding 2-bromoquinoxaline (5e) (n=1) in moderate yields. Some oligomeric *trans*-bromobis(phosphine)(quinoxaline-2,3-diyl)palladium(II) complexes (2) (n≥2) were brominated in the same manner to give the corresponding bromides (5) in moderate to good yields. (Table 2)

Table 2



2 → 5

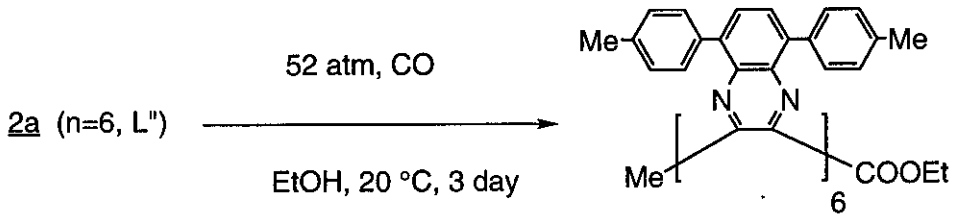
Quinoxaline-2-yl Palladium(II) Complex	Product (%; $[\alpha]_D^{25}$)
2e (n=1,L')	5e (n=1) (82%)
2e (n=2,L')	5e (n=2) (90%)
2e (n=3,L')	5e (n=3) (73%)
(+) 2a (n=6,L'')	(+) 5a (n=6) (73%; +300°)
(–) 2a (n=6,L'')	(–) 5a (n=6) (82%; –287°)

Iodination of *trans*-bromobis(dimethylphenylphosphine)(5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline-3-yl)palladium(II) (2e) (n=2 L') was readily carried out by treatment with I_2 in CH_2Cl_2 at 20 °C for 2 h to provide 3-iodo-5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline in 92% yield.

(3) Carboalkoxylation of Oligomeric (Quinoxaline-2,3-diyl)palladium(II) Complexes

As aforementioned, carbon-metal bond of organometallic compounds undergoes insertion of carbon monoxide, which is followed by alcoholysis to form carboalkoxy group. The introduction of carboester group *via* organopalladium complexes is convenient for functionalization of poly(2,3-quinoxaline)s, which is prepared by the present palladium catalyzed polymerization of *o*-diisocyanoarenes. The carboester functionalization was demonstrated by the reaction of hexameric (quinoxaline-2,3-diyl)palladium(II) complexes with carbon monoxide in EtOH, giving the corresponding (quinoxaline-2-yl)carboxylic acid ethyl ester in moderate yields. (Scheme 3)

Scheme 3

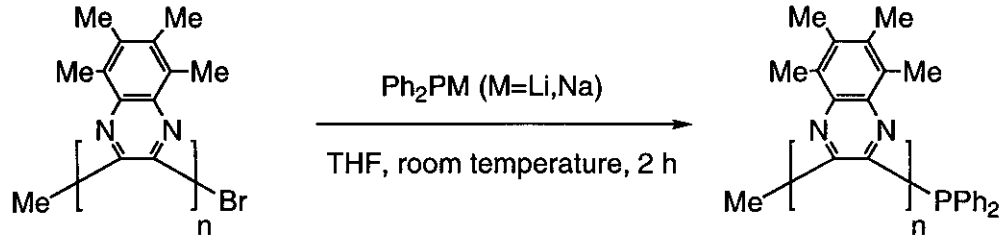


6a
Yield, 74%

(4) Synthesis of Diphenyl(quinoxaline-2,3-diyl)phosphines

2-Bromo-3,5,6,7,8-pentamethylquinoxaline (5e) (n=1) already described reacted with lithium diphenylphosphide and sodium diphenylphosphide in THF to the desired tertiary phosphine in moderate yields. The reactions with higher oligomeric quinoxaline-2,3-diyl bromides (n≥3) resulted in remarkable low yields. (Table 3)

Table 3



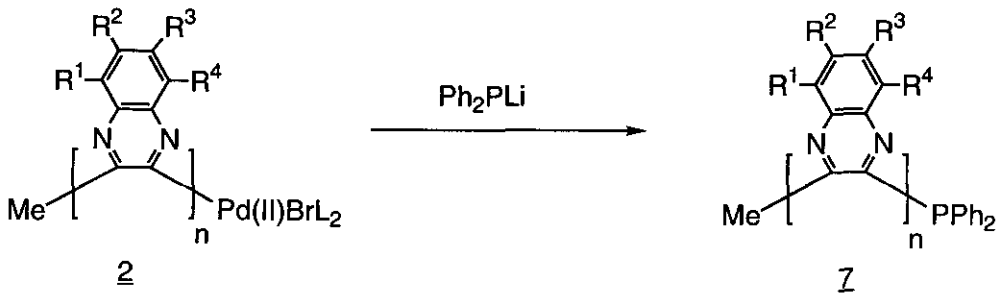
5e 7e

Quinoxaline-2-yl Bromide	Ph2PM	Product (%)
5e (n=1)	M=Na	7e (n=1) (77%)
5e (n=2)	M=Li	7e (n=2) (41%)
5e (n=3)	M=Li	7e (n=3) (4%)

General synthesis of diphenyl(oligomeric quinoxaline-2,3-diyl)phosphines was offered by alternative route. Upon direct treatment with lithium diphenylphosphide at -78 °C, *trans*-

bromobis(phosphine)(oligomeric quinoxaline-2,3-diyl)palladium(II) complexes (2) were converted to the corresponding diphenyl(oligomeric quinoxaline-2,3-diyl)phosphines in moderate to good yields. (Table 4)

Table 4



2 7

Quinoxaline-2-yl Palladium(II) Complex	Ph2PLi (mol. equiv) (Reaction Conditions)	Product (%; $[\alpha]_D^{20}$)
2e (n=1, L')	(2.5) (toluene; -78 °C, 75 min)	7e (n=1) (98%)
2e (n=2, L')	(5.0) (toluene; -78 °C, 30 min)	7e (n=2) (98%)
2e (n=3, L')	(5.1) (toluene; -78 °C, 35 min)	7e (n=3) (50%)
(+) 2a (n=6, L'')	(50) (toluene; -78 °C, 50 min)	(+) 7a (n=6) (93%; +417°)
(–) 2a (n=6, L'')	(41) (toluene; -78 °C, 210 min)	(–) 7a (n=6) (83%; –418°)

The two diastereomerically pure hexameric *trans*-bromobis[bis((*S*)-2-methylbutyl)phenylphosphine](quinoxaline-2,3-diyl)palladium(II) complexes (+) (2a) (n=6, L") and (–) (2a) (n=6, L") afforded the corresponding optically active tertially phosphines (+) (7a) (n=6) and (–) (7a) (n=6) respectively. The two enantiomeric helical tertiary phosphines (+)-(7a) and (–)-(7a) thus prepared exhibited the respective Cd spectra, which are of complete mirror images to each other. (Figure 1)

The direct coupling of (quinoxaline-2,3-diyl)palladium(II) bromide and lithium diphenylphosphide,

which is mechanistically interesting, may involve transmetallation and subsequent reductive elimination on the palladium complex intermediate.

EXPERIMENTAL SECTION

^{1}H-Nmr spectra were measured with a Varian VXR-200, Gemini-200, and JEOL JNM-EX270 spectrometer in $CDCl_3$. Chemical shifts are reported in δ ppm. Infrared spectra were measured with a Shimadzu ir-435 spectrometer. Data are given in cm^{-1}. Cd spectra were measured with JASCO J-600. Recycling gpc purification was performed with JAI LC-908 equipped with JAIGEL-1H and 2H columns ($CHCl_3$). Preparative hplc separation was done on a Shimadzu LC-8A (YMC R-055-10 column, 50x500 mm). Mass spectra were recorded on a JEOL JMS-SX102A mass spectrometer. Optical rotation was measured with Perkin-Elmer polarimeter 243.

Materials. All solvents were dried over appropriate desiccant and distilled under nitrogen. *Trans*-bromobis(dimethylphenylphosphine)(3,5,6,7,8,-pentamethylquinoxaline-2-yl)palladium(II) (2e) (n=1, L'),[5] *trans*-bromobis(dimethylphenylphosphine)(5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline-3-yl)palladium(II) (2e) (n=2, L'),[5] *trans*-bromobis(dimethylphenylphosphine)-(5,6,7,8,5',6',7',8',3'',5'',6'',7'',8''-tridecamethyl-2,2':3',2''-terquinoxalinyl)palladium(II) (2e) (n=3, L'),[5] *trans*-bromobis[bis((*S*)-2-methylbutyl)phenylphosphine]methylpalladium(II),[5] were prepared according to the procedures reported.

Preparation of (+)- and (−)-*trans*-Bromobis[bis((*S*)-2-methylbutyl)phenylphosphine]-sexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl)palladium(II) ((+)- and (−)-(2a) (n=6, L'')).
To a THF solution (20 ml) of *trans*-bromobis[bis((*S*)-2-methylbutyl)phenylphosphine]methyl-palladium(II) (206.0 mg, $2.93x10^{-4}$ mol) was added 1,2-diisocyano-3,6-di-*p*-tolylbenzene (452.0 mg, 1.47 mmol), and the mixture was stirred at room temperature for 20 h. The solvent was removed under reduced pressure, and the residue, which was a mixture of quinoxaline oligomers, was subjected to preparative gpc on polystyrene gel (eluent: $CHCl_3$) to afford quinoxaline hexamer (±)-(2a) (n=6, L'') (249.1 mg, 37%). Then the diastereomeric mixture of helical 2,3-quinoxaline hexamers (+)-(2a) and (−)-(2a) (n=6, L'') was separated to each diastereomer by preparative hplc on silica gel (eluent : *n*-hexane/EtOH/$CHCl_3$ = 1000/3/8).

(+)- 2a (n=6, L") $[\alpha]_D^{20}$ = +219° (c 0.39, $CHCl_3$). Anal. Calcd for $C_{165}H_{153}N_{12}BrP_2Pd$: C, 77.65; H, 6.04; N, 6.59. Found: C, 77.34; H, 6.35; N, 6.56. Ir (KBr) 2916, 1745, 1571, 1513, 1453, 1259, 1182, 1096, 1027, 980, 808 cm^{-1}.

(–)- 2a (n=6, L") $[\alpha]_D^{20}$ = -468° (c 0.31, $CHCl_3$). Anal. Calcd for $C_{165}H_{153}N_{12}BrP_2Pd$: C, 77.65; H, 6.04; N, 6.59. Found: C, 77.82; H, 5.54; N, 6.98. Ir (KBr) 2926, 1894, 1610, 1572, 1510, 1450, 1259, 1183, 1098, 1037, 979, 909, 804 cm^{-1}.

Reduction of (–)-*trans*-Bromobis[bis((*S*)-2-methylbutyl)phenylphosphine]sexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl)palladium(II) (–)-(2a) (n=6, L").

To a solution of (–)- 2a (n=6, L") (11.7 mg, 4.58×10^{-6} mol) in THF (2 ml)-EtOH (1 ml) was added sodium borohydride (24.5 mg, 6.47×10^{-4} mol). The mixture was stirred at 20 °C for 20 min. The reaction mixture was quenched with water and the mixture was extracted several times with CH_2Cl_2. The combined extract was washed with water, dried over magnesium sulfate and the solvent was evaporated. The residue was subjected to column chromatography on silica gel, gpc on polystyrene gel and column chromatography on florisil gel to give 4.3 mg (50%) of (–)- 3a (n=6, L"). $[\alpha]_D^{26}$ = -462° (c 0.299, $CHCl_3$). High resolution mass calcd for $C_{133}H_{101}N_{12}$ (MH^+) 1865.8272, found 1865.8315. ^{1}H-Nmr ($CDCl_3$) 0.86-2.79 (m, 39H), 5.78-8.89 (m, 61H).

General Procedure for the Reaction of 2 with Grignard Reagents.

To a THF solution (3 ml) of 2 (2.23×10^{-6} mol) was added a large excess of Grignard reagent, and the mixture was stirred at room temperature for 1 h. After excess of Grignard reagent was quenched with water, the mixture was extracted several times with $CHCl_3$. The combined extract was washed with water, dried over magnesium sulfate and the solvent was evaporated under reduced pressure. The residue was subjected to preparative tlc on silica gel to afford 4.

(+)-2,2'''''-Dimethylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((+)-(4a) (n=6))

Yield, 79%. $[\alpha]_D^{20}$ = +421° (c 0.373, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 1.25 (s, 3H), 1.27 (s, 3H), 1.36 (s, 3H), 1.69 (s, 3H), 1.71 (s, 3H), 1.82 (s, 3H), 1.94 (s, 3H), 2.32 (s, 3H), 2.33 (s, 3H), 2.44 (s, 3H), 2.50 (s, 6H), 2.54 (s, 3H), 2.72 (s, 3H), 6.00-8.16 (m, 60H). High resolution mass calcd for $C_{134}H_{103}N_{12}$ (MH^+) 1879.8428, found 1879.8503.

(–)-2,2''''''-Dimethylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((–)-(4a) (n=6))

Yield, 98%. $[\alpha]_D^{20}$ = -430° (c 0.543, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 1.25 (s, 3H), 1.26 (s, 3H), 1.36 (s, 3H), 1.69 (s, 3H), 1.70 (s, 3H), 1.81 (s, 3H), 1.94 (s, 3H), 2.31 (s, 3H), 2.33(s, 3H), 2.43 (s, 3H), 2.50 (s, 6H), 2.54 (s, 3H), 2.72 (s, 3H), 6.00-8.16 (m, 60H).

Preparation of (+)- and (–)-*trans*-Bromobis[bis((*S*)-2-methylbutyl)phenylphosphine]-*quinque*[5,8-bis(4-*n*-propylphenyl)quinoxaline-2,3-diyl]palladium(II) ((+)- and (–)-(2b) (n=5, L'')).

(+)- and (–)- 2b (n=5, L'') were prepared in the same manner as that of (+)- and (–)-(2a) (n=6, L'').

(+)- 2b (n=5, L'') $[\alpha]_D^{20}$ = +133° (c 1.16, $CHCl_3$). Anal. Calcd for $C_{163}H_{177}N_{10}BrP_2Pd$: C, 77.55; H, 7.07; N, 5.55. Found: C, 77.18; H, 6.92; N, 5.71. Ir (KBr) 2956, 2916, 2863, 1573, 1513, 1454, 1183, 1123, 981, 828, 799 cm^{-1}.

(–)- 2b (n=5, L'') $[\alpha]_D^{20}$ = -312° (c 0.270, $CHCl_3$). Anal. Calcd for $C_{163}H_{177}N_{10}BrP_2Pd$: C, 77.55; H, 7.07; N, 5.55. Found: C, 77.39; H, 6.92; N, 5.60. Ir (KBr) 2904, 1897, 1610, 1571, 1511, 1452, 1405, 1375, 1113, 979, 796 cm^{-1}.

(+)-2,2''''-Dimethylquinque[5,8-bis(4-*n*-propylphenyl)quinoxaline-2,3-diyl] ((+)-(4b) (n=5))

Yield, 91%. $[\alpha]_D^{20}$ = +430° (c 0.076, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 0.25-2.80 (m, 76H), 6.01 (d, 4H, J=7.8 Hz), 6.15 (d, 4H, J=7.8 Hz), 6.24 (d, 4H, J=8.0 Hz), 6.44 (d, 4H, J=8.3 Hz), 6.63 (d, 4H, J=8.1 Hz), 7.06 (d, 4H, J=7.9 Hz), 7.32 (d, 4H, J=8.1 Hz), 7.38-7.73 (m, 18H), 7.81 (d, 4H, J=8.0 Hz). High resolution mass calcd for $C_{132}H_{127}N_{10}$ (MH^+) 1852.0245, found 1852.0122.

(–)-2,2''''-Dimethylquinque[5,8-bis(4-*n*-propylphenyl)quinoxaline-2,3-diyl] ((–)-(4b) (n=5))

Yield, 78%. $[\alpha]_D^{20}$ = -440° (c 0.334, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 0.26-2.80 (m, 76H), 6.02 (d, 4H, J=8.1 Hz), 6.15 (d, 4H, J=8.1 Hz), 6.24 (d, 4H, J=8.0 Hz), 6.44 (d, 4H, J=8.1 Hz), 6.63 (d, 4H, J=8.1 Hz), 7.06 (d, 4H, J=7.9 Hz), 7.32 (d, 4H, J=8.0 Hz), 7.38-7.73 (m, 18H), 7.81 (d, 4H, J=8.1 Hz).

(–)-2,2''''''-Dimethylsexi[5,8-bis(4-*n*-propylphenyl)quinoxaline-2,3-diyl] ((–)-(4b) (n=6))

To a THF solution (20 ml) of (–)- 2b (n=5, L'') (56.2 mg, 2.23×10^{-5} mol) was added 3,6-bis(4-*n*-propylphenyl)-1,2-diisocyanobenzene (24.0 mg, 6.58×10^{-5} mol), and the mixture was stirred at room temperature for 37 h. To the mixture was added a large excess of MeMgBr (ether solution). The mixture was stirred at room temperature for 1 h. After excess of Grignard reagent was quenched with water, the mixture was extracted several times with ether. The combined extract was washed with water, dried over magnesium sulfate and the solvent was evaporated under reduced pressure. The residue was subjected to preparative gpc on polystyrene gel (eluent: $CHCl_3$) and preparative tlc on silica gel (eluent: *n*-hexane/CH_2Cl_2 = 1/1) to afford 44.0 mg (89%) of (–)- 4b (n=6). $[\alpha]_D^{20}$ = -448° (c 0.108, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 0.08-2.84 (m, 90H), 5.87-8.16 (m, 60H). High resolution mass calcd for $C_{158}H_{151}N_{12}$ (MH^+) 2216.2184, found 2216.2029.

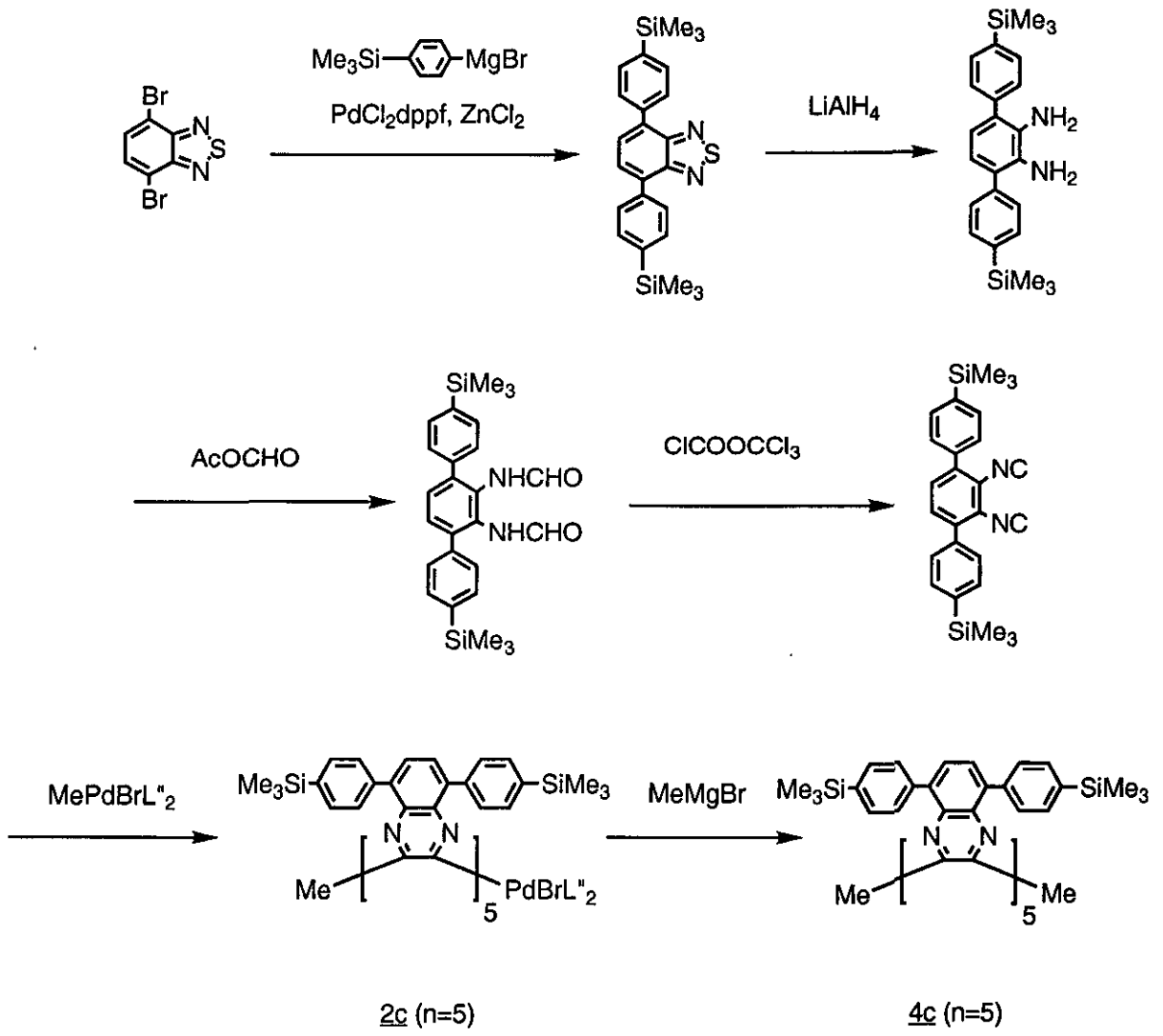
(±)-2,2''''-Dimethylquinque[5,8-bis(4-trimethylsilylphenyl)quinoxaline-2,3-diyl] ((±)-(4c) (n=5))

(±)- 4c (n=5) was prepared following the Scheme 4.

Preparation of 4,7-bis(4-Trimethylsilylphenyl)-2,1,3-benzothiadiazole.

To a suspension of zinc chloride (4.32 g, 31.7 mmol) in THF (80 ml) was added an ether solution of *p*-trimethylsilylphenylmagnesium bromide (30.8 mmol) dropwise, and the mixture was stirred at room temperature for 3 h. Then, a mixture of 4,7-dibromo-2,1,3-benzothiadiazole (3.87 g, 13.2 mmol) and $PdCl_2$dppf (242 mg, 0.331 mmol) in THF (50 ml) was added. The mixture was stirred at room temperature for 21 h. The reaction mixture was quenched with water and the mixture was extracted several times with ether. The combined extract was washed with water, dried over magnesium sulfate and the solvent was evaporated. The residue was subjected to column chromatography on silica gel (eluent: CH_2Cl_2/*n*-hexane = 1/2) to afford 3.1667 g (55%) of 4,7-bis(4-trimethylsilylphenyl)-2,1,3-benzothiadiazole. Anal. Calcd for $C_{24}H_{28}N_2SSi_2$: C, 66.63; H, 6.52; N, 6.48. Found: C, 66.91; H, 6.58; N, 6.49. ^{1}H-Nmr ($CDCl_3$) 0.34 (s, 18H), 7.72 (d, 4H, J = 8.2 Hz), 7.80 (s, 2H), 7.95 (d, 4H, J = 8.2 Hz).

Scheme 4



2c (n=5) 4c (n=5)

Preparation of 1,2-Diamino-3,6-bis(4-trimethylsilylphenyl)benzene.

To a THF solution (60 ml) of 4,7-bis(4-trimethylsilylphenyl)-2,1,3-benzothiadiazole (3.1667 g, 7.32 mmol) was added LiAlH4 (556 mg ,14.7 mmol) at 0 °C. The mixture was stirred at 0 °C for 1 h and heated under reflux for 1 h. After excess of LiAlH4 was quenched with water, the mixture was extracted several times with ether. The combined extract was washed with water, dried over magnesium sulfate and the solvent was evaporated. The residue was subjected to column chromatography on silica gel (eluent: CH_2Cl_2) to give 1.9678 g (66%) of 1,2-diamino-3,6-bis(4-

trimethylsilylphenyl)benzene. ^{1}H-Nmr ($CDCl_3$) 0.32 (s, 18H), 6.80 (s, 2H), 7.49 (d, 4H, J = 8 Hz), 7.64 (d, 4H, J = 8 Hz).

Preparation of 3,6-bis(4-Trimethylsilylphenyl)-1,2-diformamidobenzene.

To a solution of 1,2-diamino-3,6-bis(4-trimethylsilylphenyl)benzene (620.2 mg, 1.53 mmol) in CH_2Cl_2 (10 ml) was added acetic formic anhydride (0.38 g, 4.32 mmol) at 0 °C. The reaction mixture was stirred over night gradually warming up to room temperature. Then, the solution was washed with water and the solvent was removed under reduced pressure. The residue was washed with *n*-hexane to give 503.8 mg (71%) of 3,6-bis(4-trimethylsilylphenyl)-1,2-diformamidobenzene. Anal. Calcd for $C_{26}H_{32}N_2O_2Si_2$: C, 67.80; H, 7.00; N, 6.08. Found: C, 67.85; H, 7.03; N, 5.90. ^{1}H-Nmr ($CDCl_3$) 0.31 (s, 18H), 7.13-8.27 (m, 14H). Ir (KBr) 3220, 2964, 1692, 1664, 842, 816 cm^{-1}.

Preparation of 3,6-bis(4-Trimethylsilylphenyl)-1,2-diisocyanobenzene.

A CH_2Cl_2 suspension (10 ml) of 3,6-bis(4-trimethylsilylphenyl)-1,2-diformamidobenzene (600.0 mg, 1.30 mmol) and triethylamine (2.7 ml, 19.5 mmol) was cooled to -78 °C. To the mixture was added dropwise a CH_2Cl_2 solution (10 ml) of trichloromethylchloroformate (0.78 ml,19.5 mmol) at -78 °C. The mixture was stirred at that temperature for 8 h, then gradually warmed up to -20 °C. At -20 °C, 10% aq. K_2CO_3 (20 ml) was added dropwise. The mixture was extracted several times with CH_2Cl_2. The combined extract was washed with water, dried over magnesium sulfate and the solvent was evaporated. The residue was subjected to column chromatography on silica gel (eluent: *n*-hexane/CH_2Cl_2 = 1/1) to give 253.9 mg (46%) of 3,6-bis(4-trimethylsilylphenyl)-1,2-diisocyanobenzene. Anal. Calcd for $C_{26}H_{28}N_2Si_2$: C, 73.55; H, 6.65; N, 6.60. Found: C, 73.47; H, 6.69; N, 6.41. ^{1}H-Nmr ($CDCl_3$) 0.34 (s, 18H), 7.54 (s, 2H), 7.54 (d, 4H, J = 8 Hz), 7.69 (d, 4H, J = 8 Hz).

***Preparation of* (±)-2,2''''-Dimethylquinque[5,8-bis(4-trimethylsilylphenyl)quinoxaline-2,3-diyl] ((±)-(4c) (n=5)).**

(±)-2c (n=5, L") was prepared in 39% yield in the same manner as that of (±)-2a (n=6, L"). Then, (±)-2c (n=5, L") was reacted with MeMgBr to give (±)-4c (n=5) in 81% yield. ^{1}H-Nmr ($CDCl_3$) -0.75

(s, 18H), -0.46 (s, 18H), 0.27 (s, 18H), 0.37 (s, 18H), 0.42 (s, 18H), 2.75 (s, 6H), 5.80 (d, 4H, J=7.9 Hz), 6.40 (d, 4H, J = 8.0 Hz), 6.45 (d, 4H, J = 8.0 Hz), 6.64 (d, 4H, J = 7.9 Hz), 6.92 (d, 4H, J = 7.9 Hz), 7.29-7.86 (m, 30H). Ms m/z 2152 (MH^+).

(±)-2,2''''''-Dimethylsexi[5,8-bis(4-*N*,*N*-dimethylanilino)quinoxaline-2,3-diyl] ((±)-(4d) (n=6))

(±)-4d (n=6) was prepared in the same manner as that of (±)-4c (n=5).

Yield, 81%. ^{1}H-Nmr ($CDCl_3$) 1.96 (s, 6H), 2.03 (s, 6H), 2.08 (s, 6H), 2.24 (s, 6H), 2.27 (s, 6H), 2.67 (s, 3H), 2.71 (s, 6H), 2.76 (s, 3H), 2.90 (s, 12H), 3.01 (s, 6H), 3.04 (s, 6H), 3.06 (s, 6H), 3.09 (s, 6H), 5.87-8.26 (m, 60H). Ms m/z 2228 (MH^+).

(±)-5,6,7,8,5',6',7',8',3'',5'',6'',7'',8''-Tridecamethyl-3-phenyl-2,2':3',2''-terquinoxaline ((±)-(4e) (n=3))

Yield, 75%. ^{1}H-Nmr ($CDCl_3$) 1.95 (s, 3H), 2.20 (s, 3H), 2.34 (s, 3H), 2.36 (s, 3H), 2.37 (s, 3H), 2.41 (s, 6H), 2.44 (s, 3H), 2.48 (s, 3H), 2.73 (s, 3H), 2.77 (s, 3H), 2.80 (s, 3H), 2.95 (s, 3H), 7.23-7.27 (m, 3H), 7.67-7.72 (m, 2H). Ir (KBr) 2916, 1560, 1451, 1377, 1289, 1191, 1125, 1046, 821, 697 cm^{-1}. High resolution mass calcd for $C_{43}H_{44}N_6$ (M^+) 644.3627, found 644.3655.

(±)-2-Methyl-2''''''-phenylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((±)-(4a) (n=6))

Yield, 40%. ^{1}H-Nmr ($CDCl_3$) 1.09 (s, 3H), 1.44 (s, 3H), 1.63 (s, 3H), 1.68 (s, 3H), 1.73 (s, 3H), 1.74 (s, 3H), 1.77 (s, 3H), 1.90 (s, 3H), 2.31 (s, 3H), 2.42 (s, 3H), 2.47 (s, 3H), 2.49 (s, 3H), 2.58 (s, 3H), 5.97-8.16 (m, 65H). High resolution mass calcd for $C_{139}H_{105}N_{12}$ (MH^+) 1941.8585, found 1941.8757.

(±)-2-Methyl-2''''-vinylquinque[5,8-bis(4-*n*-propylphenyl)quinoxaline-2,3-diyl] ((±)-(4b) (n=5))

Yield, 15%. ^{1}H-Nmr ($CDCl_3$) 0.38-2.89 (m, 73H), 5.15 (d, 2H, J = 8.20 Hz), 6.03-8.57 (m, 51H). High resolution mass calcd for $C_{133}H_{127}N_{10}$ (MH^+) 1864.0245, found 1864.0331.

2-Ethynyl-2''''-methylquinque[5,8-bis(4-*n*-propylphenyl)quinoxaline-2,3-diyl] ((±)-

(4b) (n=5))

Yield, 55%. ^{1}H-Nmr ($CDCl_3$) 0.08-3.23 (m, 74H), 5.77-8.15 (m, 50H). High resolution mass calcd for $C_{133}H_{125}N_{10}$ (MH^+) 1862.0089, found 1862.0173.

General Procedure for the Reaction of 2 with NBS.

To a toluene solution (2 ml) of 2 (7.13×10^{-6} mol) was added *N*-bromosuccinimide (1.71×10^{-5} mol) at -78 °C. The reaction mixture was stirred at -78 °C for 1 h. The solvent was concentrated in vacuo, and the residue was subjected to preparative tlc on silica gel to give 5.

2-Bromo-3,5,6,7,8-pentamethylquinoxaline ((5e) (n=1))

Yield, 82%. ^{1}H-Nmr ($CDCl_3$) 2.43 (s, 6H), 2.69 (s, 3H), 2.72 (s, 3H), 2.83 (s, 3H). High resolution mass calcd for $C_{13}H_{15}N_2Br$ (M^+) 278.0419, found 278.0422.

3-Bromo-5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline ((5e) (n=2))

Yield, 90%. ^{1}H-Nmr ($CDCl_3$) 2.47 (s, 6H), 2.50 (s, 3H), 2.51 (s, 3H), 2.70 (s, 3H), 2.72 (s, 3H), 2.76 (s, 3H), 2.78 (s, 3H), 2.83 (s, 3H). High resolution mass calcd for $C_{25}H_{27}N_4Br$ (M^+) 462.1419, found 462.1431.

3-Bromo-5,6,7,8,5',6',7',8',3'',5'',6'',7'',8''-tridecamethyl-2,2':3',2''-terquinoxaline ((5e) (n=3))

Yield, 73%. ^{1}H-Nmr ($CDCl_3$) 2.02 (s, 3H), 2.21 (s, 3H), 2.33 (s, 3H), 2.35 (s, 3H), 2.40 (s, 3H), 2.41 (s, 3H), 2.54 (s, 6H), 2.66 (s, 3H), 2.74 (s, 3H), 2.86 (s, 6H), 3.17 (s, 3H). High resolution mass calcd for $C_{37}H_{39}N_6Br$ (M^+) 646.2420, found 646.2468.

(+)-2-Bromo-2'''''-methylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((+)-(5a) (n=6))

Yield, 73%. $[\alpha]_D^{25}$ = +300° (c 0.141, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 1.20 (s, 3H), 1.25 (s, 3H), 1.35 (s, 3H), 1.66 (s, 3H), 1.91 (s, 3H), 1.97 (s, 3H), 2.30 (s, 3H), 2.32 (s, 3H), 2.44 (s, 3H), 2.50 (s, 6H), 2.54 (s, 3H), 2.67 (s, 3H), 5.93-8.12 (m, 60H). High resolution mass calcd for $C_{133}H_{100}N_{12}Br$ (MH^+) 1943.7377, found 1943.7496.

(–)-2-Bromo-2'''''-methylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((–)-(5 a) (n=6))

Yield, 82%. $[\alpha]_D^{25}$ = -287° (c 0.169, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 1.21 (s, 3H), 1.25 (s, 3H), 1.35 (s, 3H), 1.66 (s, 3H), 1.91 (s, 3H), 1.97 (s, 3H), 2.30 (s, 3H), 2.32 (s, 3H), 2.44 (s, 3H), 2.50 (s, 6H), 2.54 (s, 3H), 2.67 (s, 3H), 5.93-8.12 (m, 60H).

Preparation of 3-Iodo-5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline.

To a CH_2Cl_2 solution (3 ml) of *trans*-bromobis(dimethylphenylphosphine)(5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline-3-yl)palladium(II) (2e) (n=2, L') (12.4 mg, 1.47×10^{-5} mol) was added iodine (7.8 mg, 3.07×10^{-5} mol). The mixture was stirred at 20 °C for 2 h. The solvent was evaporated under reduced pressure and the residue was subjected to preparative tlc (eluent: CH_2Cl_2) to give 6.9 mg (92%) of 3-iodo-5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline. ^{1}H-Nmr ($CDCl_3$) 2.46 (s, 3H), 2.47 (s, 3H), 2.50 (s, 6H), 2.70 (s, 3H), 2.71 (s, 3H), 2.78 (s, 3H), 2.79 (s, 3H), 2.83 (s, 3H). High resolution mass calcd for $C_{25}H_{27}N_4I$ (M^+) 510.1279, found 510.1270.

Preparation of (±)-2-Ethoxycarbonyl-2'''''-methylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((±)-(6 a) (n=6)).

A solution of (±)-2a (n=6, L") (8.7 mg, 3.41×10^{-6}mol) in EtOH (5 ml) was heated with 52 kg/cm^2 of CO in 50 ml of autoclave at 20 °C for 3 d. The solution was concentrated and the residue was subjected to preparative tlc on silica gel (eluent: CH_2Cl_2/*n*-hexane = 1/1) to give 4.9 mg (74%) of (±)-6a (n=6). ^{1}H-Nmr ($CDCl_3$) 1.24 (t, 3H, J = 7.0 Hz), 1.26 (s, 3H), 1.30 (s, 3H), 1.62 (s, 3H), 1.63 (s, 3H), 1.70 (s, 3H), 1.81 (s, 3H), 1.95 (s, 3H), 1.97 (s, 3H), 2.31 (s, 3H), 2.42 (s, 3H), 2.50 (s, 3H), 2.52 (s, 3H), 2.54 (s, 3H), 3.56 (dq, 1H, J = 7.0 Hz, J = 10.7 Hz), 4.16 (dq, 1H, J = 7.0 Hz, J = 10.7 Hz), 5.98-8.17 (m, 60H). Ir (KBr) 3696, 1736, 1518, 1460, 1142, 1130, 1052, 982, 810 cm^{-1}. High resolution mass calcd for $C_{136}H_{105}N_{12}O_2$ (MH^+) 1937.8483, found 1937.8517.

General Procedure for the Reaction of (5 e) with Ph_2PM (M=Li, Na).

To a solution of diphenylchlorophosphine (0.43 ml, 2.40 mmol) in dioxane (10 ml) was added sodium (230 mg, 10.0 mg atom), and the mixture was refluxed with stirring for 7 h. Then, (quinoxaline-2-yl) bromide (5e) (1.45×10^{-5} mol) was added to the mixture, and the reaction mixture was stirred at room temperature for 2 h. The mixture was filtered and the filtrate was concentrated.

The residue was dissolved in ether and the extract was washed with sat. aq. NaCl. Then, evaporation of the ether solvent and chromatography on silica gel (eluent: CH_2Cl_2/*n*-hexane = 2/1) afforded (7e).

2-Diphenylphosphino-3,5,6,7,8,-pentamethylquinoxaline (7e) (n=1)

Yield, 77%. ^{1}H-Nmr ($CDCl_3$) 2.30 (s, 3H), 2.36 (s, 3H), 2.42 (s, 3H), 2.67 (d, 3H, J = 1.2 Hz), 2.73 (s, 3H), 7.35-7.45 (m, 10H). High resolution mass calcd for $C_{25}H_{25}N_2P$ (M^+) 384.1755, found 384.1740.

3-Diphenylphosphino-5,6,7,8,3',5',6',7',8'-nonamethyl-2,2'-biquinoxaline (7e)(n=2)

Yield, 41%. ^{1}H-Nmr ($CDCl_3$) 2.41 (s, 3H), 2.43 (s, 3H), 2.45 (s, 6H), 2.48 (s, 3H), 2.49 (s, 3H), 2.66 (s, 3H), 2.73 (s, 3H), 2.74 (s, 3H), 7.16-7.37 (m, 10H). ^{31}P-Nmr ($CDCl_3$) -3.03 (s). High resolution mass calcd for $C_{37}H_{37}N_4P$ (M^+) 568.2755, found 568.2764.

3-Diphenylphosphino-5,6,7,8,5',6',7',8',3'',5'',6'',7'',8''-tridecamethyl-2,2':3',2''-terquinoxaline (7e) (n=3)

Yield, 4%. ^{1}H-Nmr ($CDCl_3$) 2.09 (s, 3H), 2.13 (s, 3H), 2.21 (s, 3H), 2.22 (s, 3H), 2.28 (s, 3H), 2.30 (s, 3H), 2.35 (s, 6H), 2.41 (s, 3H), 2.47 (s, 3H), 2.74 (s, 3H), 2.78 (s, 3H), 3.03 (s, 3H), 7.22-7.53 (m, 10H). ^{31}P-Nmr ($CDCl_3$) -4.94 (s).

General Procedure for the Reaction of 2 with Lithium Diphenylphosphide.

Lithium diphenylphosphide (0.146 mmol) generated in THF (0.2 ml) was concentrated and the residue was dissolved in toluene (2 ml), and the mixture was cooled to -78 °C. To the mixture was added 2, and the mixture was stirred at -78 °C for 30 ~ 210 min. Then, excess of lithium diphenylphosphide was quenched with deoxygenated water. The solvent was removed in vacuo, and the residue was subjected to preparative tlc on silica gel (eluent: CH_2Cl_2/*n*-hexane = 1/1) to give 7.

(+)-2-Diphenylphosphino-2''''''-methylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((+)-(7a) (n=6))

Yield, 93%. $[\alpha]_D^{20}$ = +417° (c 0.060, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 1.24 (s, 3H), 1.38 (s, 3H), 1.53 (s, 3H), 1.56 (s, 3H), 1.62 (s, 3H), 1.64 (s, 3H), 1.82 (s, 3H), 1.90 (s, 3H), 2.27 (s, 3H), 2.29 (s, 3H), 2.43 (s, 3H), 2.48 (s, 3H), 2.49 (s, 3H), 5.94-8.18 (m, 70H). ^{31}P-Nmr ($CDCl_3$) -5.16 (s). High resolution mass calcd for $C_{145}H_{110}N_{12}OP$ (MH^+) 2065.8663, found 2065.8535. Cd spectra is shown in Figure 1.

(–)-2-Diphenylphosphino-2''''''-methylsexi(5,8-di-*p*-tolylquinoxaline-2,3-diyl) ((–)-(7a) (n=6))

Yield, 83%. $[\alpha]_D^{20}$ = -418° (c 0.182, $CHCl_3$). ^{1}H-Nmr ($CDCl_3$) 1.24 (s, 3H), 1.38 (s, 3H), 1.53 (s, 3H), 1.56 (s, 3H), 1.62 (s, 3H), 1.64 (s, 3H), 1.81 (s, 3H), 1.90 (s, 3H), 2.27 (s, 3H), 2.29 (s, 3H), 2.43 (s, 3H), 2.48 (s, 3H), 2.49 (s, 3H), 5.94-8.18 (m, 70H). ^{31}P-Nmr ($CDCl_3$) -5.15 (s). Cd spectra is shown in Figure 1.

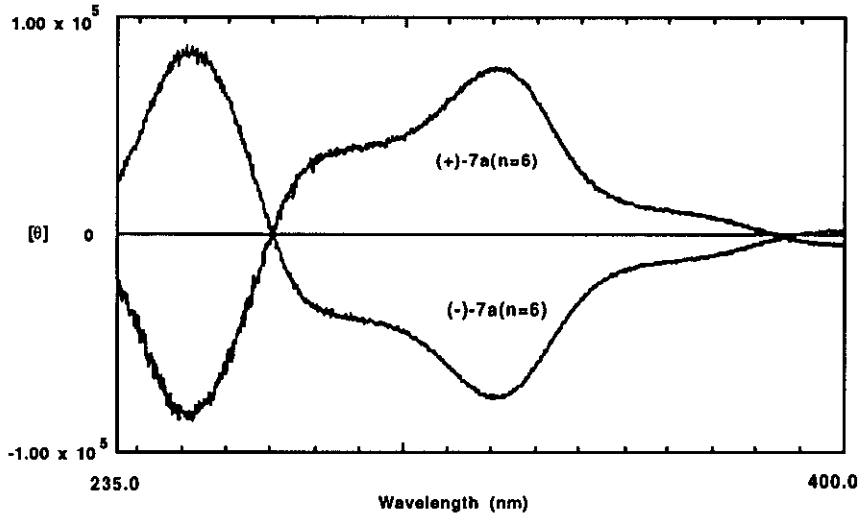


Figure 1. Cd spectra of (+)-7a and (-)-7a (n=6).

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