Catalytic Asymmetric Allylic Alkylation with A Novel P-S Bidentate Ligand

Jahyo Kang*, Sung Hoon Yu, Joo In Kim, and Hyung Geun Cho

Department of Chemistry, Sogang University, Seoul 121-742, Korea

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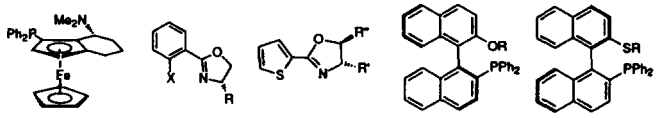
Both enantiomers of (*S*)-(-)-2-(diphenylphosphino)-2′-mercapto-1,1′-binaphthyl and their derivatives were obtained by synthesis from racemic 2,2′-dihydroxy-1,1′-binaphthyl and subsequent resolution. The utilities of these ligands were investigated briefly. And among these, *S*-methyl derivative **15** has proved to be an effective ligand for Pd-catalyzed allylic alkylation.

Introduction

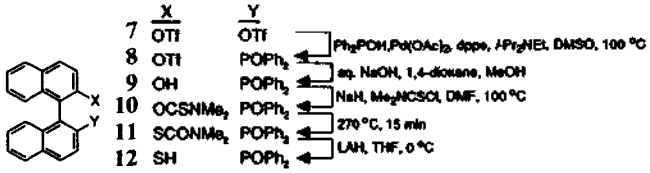
Chiral monophosphine bidentate ligands in which one donor is phosphine and the other is different, such as nitrogen, oxygen, sulfur, have been relatively less studied except the case of P-N chelate ligands such as ferrocenylaminophosphine **1**,[1] phosphinoaryloxazolines **2**.[2] These ligands provide good chiral environments for the Pd-catalyzed Grignard cross coupling and allylic alkylation.[1,2] Interest in heterobidentate ligands has been increased recently and many new ligands have been developed, among which N-S ligands (**3** and **4**) as well as P-N ligands have been shown to give successful results in asymmetric palladium-catalyzed allylic alkylation.[3]



1 **2** X=PPh$_2$ **4** **5** **6**
3 *X*=SMe

Recently, optically active 2-(diphenylphosphino)-2′-alkoxy-1,1′-binaphthyls (MOPs) **5** were reported to give high enantioselectivity for several types of catalytic asymmetric reactions such as palladium-catalyzed asymmetric hydrosilylation[4a-b] and rhodium-catalyzed asymmetric hydroformylation of olefins.[4c] In the past decade, a number of atropisomeric C_2 symmetry binaphthyl derivatives were prepared and used as chiral modifiers in metal-mediated asymmetric reactions.[5] So, it may be valuable to make new chiral ligands for asymmetric catalysis based on the atropisomeric binaphthyl backbone such as MOPs. And sulfur was selected as donor rather than oxygen because of its better ligating property to metals. Although sulfur has such an advantage, chiral chelating P-S ligands have not been used in asymmetric catalysis and only a few chelate P-S complexes of late transition metal have been prepared and characterized.[6]

Additionally, it was observed that a simple monosubstitution of oxygen of β-amino alcohols by sulfur induces higher degrees of enantioselectivity and asymmetric amplification than β-amino alcohol in the asymmetric catalytic addition of dialkylzinc reagents to aldehydes, which was ascribed to the following features: 1) enhanced polarizability of sulfur as compared to oxygen, 2) high affinity of thiol and thiolate toward metals, and 3) less tendency of metal thiolates to diminish the Lewis acidity of the metal as compared to metal alcoholate.[7] Thus, it was of great interest to us to evaluate the effects of disubstitution of both oxygen and nitrogen of β-amino alcohols by heavier atoms such as sulfur and phosphorus in the catalytic addition of dialkylzinc reagents to aldehydes.



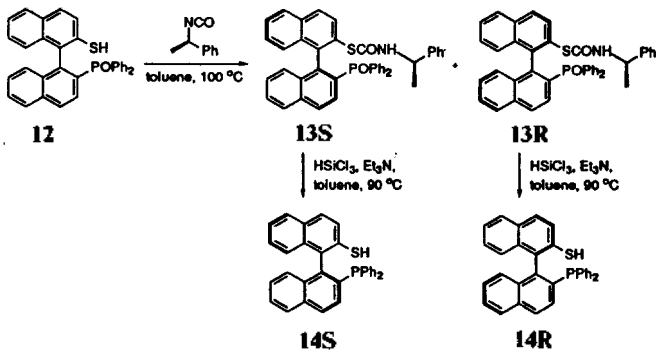
Scheme 1.

During the course of our study, Gladiali reported a synthesis and reactions of *S*-alkyl (*R*)-2-diphenylphosphino-2′-mercapto-1,1′-binaphthyl **6** from optically pure (*R*)-(+)-1,1′-binaphthol.[8] Herein is reported a synthesis of both enantiomers of (*S*)-(−) and (*R*)-(+)-2-(diphenylphosphino)-2′-mercapto-1,1′-binaphthyl starting from racemic 1,1′-binaphthol and resolution in *ca.* 20% overall yield.

Results and Discussion

The racemic thiol phosphine oxide **12** was synthesized from racemic 1,1′-binaphthyl 2,2′-ditriflate **7**[9] (Scheme 1). Monophosphinylation of the ditriflate **7** was accomplished with 30 mol% each of palladium diacetate and 1,2-bis(diphenylphosphino)ethane (dppe) in dimethyl sulfoxide at 100 ℃ for 24 h by modification of Morgans' conditions,[10] which gave 68% yield of diphenylphosphine oxide **9** after hydrolysis of the resulting monotriflate **8** with aqueous sodium hydroxide in 1,4-dioxane and methanol (2 : 1). Subsequently, the *O*-binaphthyl thiocarbamate **10** was prepared from **9** (1.2 equiv of NaH in DMF, 0 ℃, 20 min; then Me_2NCSCl, 100 ℃, 24 h) in 66% yield. Immersion of neat **10** into a paraffin bath at 270 ℃ for 15 min provided successful Newman-Kwart thermal rearrangement into the *S*-binaphthyl carbamate **11** in 71% yield.[11] Subsequent treatment of **11** with $LiAlH_4$ (THF, 0 ℃) afforded 97% yield of the thiol **12** which was to be resolved.

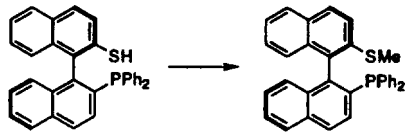
After numerous attempts, a suitable resolving agent was found ((*R*)-(+)-α-methylbenzyl isocyanate, toluene, 100 ℃) to give diastereomeric *S*-aryl carbamates, **13S** (64% yield)



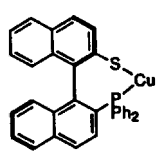
Scheme 2.

and **13R** (50% yield), which could be easily separated pure by column chromatography. These diastereomers were individually subjected to simultaneous deoxygenation and hydrolysis with trichlorosilane (6.0 equiv) and triethylamine (8 equiv) in toluene (100 ℃, 1 h) to give the enantiopure phosphine thiols, (*S*)-(−)-**14S** (90% yield; 100% ee by HPLC: mp 178 ℃; $[\alpha]_D^{25}$-29.6° (*c* 0.28, $CHCl_3$)) and (*R*)-(+)-**14R** (90 % yield; 100% ee by HPLC; $[\alpha]_D^{25}$+30.0° (*c* 0.30, $CHCl_3$)), respectively (Scheme 2).

Absolute configurations of these enantiomers were determined by comparison with reported specific rotations of those of phosphine sulfide **15R**,[8] which was easily obtained from methylation of the optically pure thiol **14R** in DMF (NaH, MeI, 0 ℃, 78%, 100% ee, $[\alpha]_D^{25}$+51.4° (*c* 1.57, $CHCl_3$) (lit.8 $[\alpha]_D^{25}$+52.6 (*c* 0.5, $CHCl_3$)), and its enantiomer **15S** was also derived from the enantiomeric thiol **14S** in the same manner.



The utilities of the optically pure ligand were sought. Unfortunately, the thiol phosphine **14** did not function as an effective chiral ligand for asymmetric catalytic addition of diethylzinc to aldehydes: Reaction with cinnamaldehyde with diethylzinc at 0 ℃ in the presence of 5 mol% of the ligand **14S** under otherwise identical condition[7] gave disappointingly low ee of (*S*)-1-phenyl-1-penten-3-ol (14% ee in 52% yield). Additionally, conjugate addition of *n*-butylmagnesium bromide to 2-cyclohexen-1-one in ether at −78 ℃ in the presence of 10 mol% of the copper thiolate **16R** gave only 16% ee of (*S*)-3-*n*-butylcyclohexanone in 53% yield (20% ee in 70% yield in THF in the presence of HMPA additive).



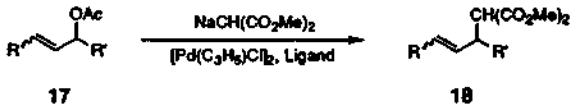
16R

Also, it was attempted to use the methylthio phosphine **15** in palladium-catalyzed allylic alkylation. The development of efficient enantioselective catalysts for this reaction is an important goal of current research in this area. It was found that the methylthio phosphine **15** provided an effective chiral environment in Pd-catalyzed allylic alkylation as shown in Table 1.

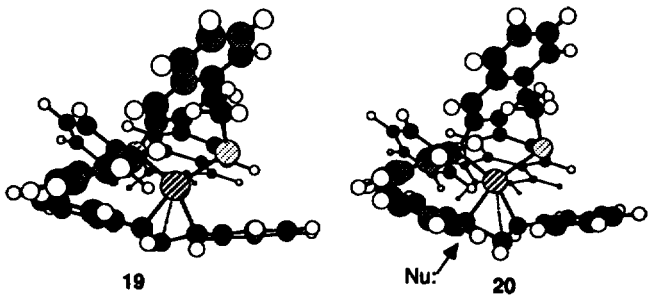
Table 1. Enantioselective Allylic Alkylation of racemic Allylic Acetates with Dimethyl Malonate using Pd Catalyst[a]

Entry	Acetate[b]	Ligand	Solvent	Temp.	Time (min)	Yield (%)[c]	Ee (%)[d]
1	A	**15R**	THF	rt	20	94	82(*S*)[e]
2	A	**15R**	THF	rt	20	92	80(*S*)
3	A	**15S**	DMF	rt	10	96	85(*R*)
4	A	**15S**	DMF	−30 ℃	240	65	91(*R*)
5	A	**15S**	toluene	rt	15	90	79(*R*)
6	B	**15R**	THF	rt	60	92	25(*S*)

[a] Acetate:$[Pd(C_3H_5)Cl]_2$: L=1: 0.025: 0.06 except for the entry 1 (Acetate:$[Pd(C_3H_5)Cl]_2$: L=1: 0.05: 0.1). [b] A: (*rac*)-1,3-diphenyl-2-propen-1-yl acetate, B: (*rac*)-2-cyclohexen-1-yl acetate. [c] Isolated yield. [d] Absolute configuration was determined by comparison with the specific rotation reported in ref 13. [e] $[\alpha]_D^{22}=-10.06°$ (*c* 0.43, EtOH).



There are several points to be considered in order to find out which carbon would be attacked by nucleophile in the transition state for asymmetric Pd-catalyzed allylic alkylation.[2,12-3] With the ligand (*R*)-(+)-**15R**, on the basis of steric interactions in the two possible incipient π-allylpalladium species, **19** and **20**, it can be deduced that the allylpalladium species **20** with two outward phenyl groups of the allylic ligand may be more stable than the corresponding diastereomeric species **19**, which has a severe interaction between the phenyl group of allylic ligand with the phenyl group of the diphenylphosphino group. If the assumption is correct, the nucleophile should attack at the allyl terminus trans to the sulfur atom in **20**, considering the facts that the (*S*)-configuration of the product was obtained (Table 1) and also that the steric compression usually weakens the relevant Pd-carbon bond, at which the nucleophilic attack usually occurrs.[13]



In summary, optically pure 2-(diphenylphosphino)-2′-mercapto-1,1′-binaphthyl enantiomers were obtained from racemic 1,1′-binaphthol (8 steps, *ca.* 20% overall yield) and their

S-methyl derivatives were shown to be effective ligands for palladium-catalyzed allylic alkylation.

Experimental

General. All reactions involving air- or moisture sensitive materials were carried out under an inert atmosphere of N_2. THF and toluene were freshly distilled from sodium/benzophenone, DMF and CH_2Cl_2 from powdered CaH_2, and MeOH from NaOMe. Melting points were determined on a Thomas-Hoover capillary melting point apparatus and uncorrected. ^1H NMR spectra were obtained on Varian Gemini 200 (200 MHz) and 300 (300 MHz) spectrometers. Elemental analyses were performed by a Carlo Erba EA 1108 elemental analyzer. Optical rotations were obtained on a Rudolph Autopol III digital polarimeter. Enantiomeric excesses (%) of products were determined either by chiral HPLC or GC; methyl 2-carbomethoxy-3,5-diphenylpent-4-enoate, **18** (R=R'=Ph) by HPLC on a Daicel Chiralcel OP(+) column and dimethyl 2-cyclohexen-1-ylmalonate, **18** (R=R'=$(CH_2)_3$) by GC on a Chiraldex B-PH capillary column (30 m×0.25 mm).

2,2'-Bis(trifluoromethanesulfonyloxy)-1,1'-binaphthyl, 7. To a solution of racemic binaphthol (24.90 g, 86.90 mmol) and pyridine (21.10 mL, 260.60 mmol) in CH_2Cl_2 was added trifluoromethanesulfonic anhydride (35.10 mL, 208.50 mmol) at 0 ℃, and the mixture was stirred for 20 min. After removal of the solvent, the residue was diluted with 300 mL ethyl acetate and then washed twice with water, 5% HCl, saturated $NaHCO_3$, and brine. The organic phase was dried over Na_2SO_4 and concentrated. The residue was chromatographed with 30% ethyl acetate in *n*-hexane to give the ditriflate 7 as a white solid (47.66 g, 100%): mp 114 ℃; NMR ($CDCl_3$) δ 7.24-8.17 (m, 12H); IR (Nujol) 3039, 1422, 1219 cm^{-1}; MS 550 (M^+), 417, 284, 269, 268; Anal. Calcd for $C_{22}H_{12}F_6O_6S_2$: C, 48.00; H, 2.20; S, 11.65. Found: C, 47.98; H, 2.16; S, 11.48.

2-(Diphenylphosphinyl)-2'-(trifluoromethanesulfonyloxy)-1,1'-binaphthyl, 8. To a mixture of the ditriflate 7 (10.00 g, 18.20 mmol), diphenylphosphine oxide (8.45 g, 41.80 mmol), palladium diacetate (1.22 g, 5.43 mmol), and 1,2-bis(diphenylphosphino)ethane (dppe, 2.17 g, 5.45 mmol) were added 80 mL dimethyl sulfoxide and diisopropylethylamine (12.50 mL, 71.80 mmol) and the mixture was heated with stirring at 100 ℃ for 24 h. After cooling to room temperature, the reaction mixture was concentrated under reduced pressure (0.1-0.2 mmHg) to give a dark brown residue. The residue was diluted with ethyl acetate, and the organic layer was washed twice with water, dried over $MgSO_4$, and concentrated under reduced pressure. Chromatography on silica gel with 30% ethyl acetate in *n*-hexane gave the trifluoromethanesulfonyloxy phosphine oxide **8** (7.84 g, 72%) and hydroxy phosphine oxide **9** (0.64 g, 8%) as white solids.: NMR ($CDCl_3$) δ 8.03-6.97 (m, 22H); IR (KBr) 3057, 1418, 1211, 1141, 941 cm^{-1}; MS 602 (M^+), 454, 453, 201.

2-(Diphenylphosphinyl)-2'-hydroxy-1,1'-binaphthyl, 9. To a solution of the triflate-phosphine oxide **8** (35.15 g, 58.33 mmol) in a 2 : 1 mixture of 1,4-dioxane and MeOH (260 mL) was added 3 N NaOH solution (260 mL) at room temperature. The reaction mixture was stirred for 30 min, acidified (pH 1) by addition of concd. HCl, and then extracted many times with CH_2Cl_2. The organic phase was dried over $MgSO_4$ and concentrated under reduced pressure to give pale yellow solid, which was washed with CH_2Cl_2 to give the hydroxy phosphine oxide **9** as a white solid (25.73 g, 94%): NMR ($CDCl_3$) δ 9.00 (s, 1H), 7.97-6.38 (m, 22H); IR (KBr) 3421, 3054, 1437 cm^{-1}; MS 470 (M^+), 268, 239; Anal. Calcd for $C_{32}H_{23}O_2P$: C, 81.69; H, 4.93. Found: C, 81.29; H, 4.82.

2-(*N,N*-Dimethylthiocarbamoyloxy)-2'-(diphenylphosphinyl)-1,1'-binaphthyl, 10. To a solution of the hydroxy phosphine oxide **9** (10.79 g, 22.20 mmol) in dry DMF (80 mL) was added NaH (0.66 g, 27.50 mmol) at 0 ℃ and the mixture was stirred for 20 min. Subsequently, *N,N*-dimethylthiocarbamoyl chloride (3.40 g, 27.50 mmol) was added at 0 ℃ to the resulting yellow mixture, which was heated at 100 ℃ for 24 h and then cooled. To the mixture was added 1% KOH aqueous solution until no more solid was appeared. The solid was filtered, air-dried, and washed with CH_2Cl_2 many times to give unreacted hydroxy phosphine oxide **9** (1.47 g, 14%) as a white solid. The filtrate was evaporated and the residue was washed with ethyl acetate many times to give the thiocarbamate **10** (8.35 g, 66%) as a white solid.: mp 215 ℃; NMR ($CDCl_3$) δ 7.98-6.79 (m, 22H), 3.02 (d, J=14.3 Hz, 6H); IR (KBr) 3056, 2936, 1541, 1219, 1167, 1117 cm^{-1}; MS 557 (M^+), 541, 453, 284, 268, 201, 88, 72.

2-(*N,N*-Dimethylcarbamoylthio)-2'-(diphenylphosphinyl)-1,1'-binaphthyl, 11. A Pyrex flask containing the thiocarbamate **10** (0.55 g, 0.99 mmol) was immersed for 15 min into a hot paraffin bath at 270 ℃. After being cooled to room temperature, the brown solid was dissolved in CH_2Cl_2 and chromatographed on silica gel with 70% ethyl acetate in *n*-hexane to give the *S*-aryl carbamate **11** (0.39 g, 71%) and the starting unrearranged thiocarbamate **10** (0.05 g, 9%) as white solid.: mp 247 ℃; NMR ($CDCl_3$) δ 8.03-6.77 (m, 22H), 2.74 (s, 6H); IR (KBr) 3056, 2928, 1659, 1097 cm^{-1}; MS 557 (M^+), 485, 453, 284, 72.

2-(Diphenylphosphinyl)-2'-mercapto-1,1'-binaphthyl, 12. A solution of the *S*-aryl carbamate **11** (7.57 g, 13.57 mmol) in 150 mL of dry THF was cooled at 0 ℃, and lithium aluminium hydride (2.85 g, 81.45 mmol) was added in portion. The reaction mixture was stirred for 30 min at 0 ℃, and dilute with ether, after which 10% HCl solution was added. The solution was extracted with ethyl acetate and the extracts were washed with brine, dried over Na_2SO_4, and evaporated to give pale brown solid, which was washed with ethyl acetate several times to give racemic thiol phosphine oxide **12** (6.40 g, 97%): NMR ($CDCl_3$) δ 8.05-6.82 (m, 22H), 3.49 (s,1H); IR (KBr) 3056, 2437, 1185, 1113 cm^{-1}; MS 486, 453, 297, 284, 201.

(*R*)- and (*S*)-2-(Diphenylphosphinyl)-2'-(*N*-(*R*)-α-methylbenzylcarbamoylthio)-1,1'-binaphthyl, 13S and 13R. To a solution of the thiol **12** (0.50 g, 1.03 mmol) in toluene (3 mL) was added (*R*)-(+)-α-methylbenzyl isocyanate (ee >99.9%, 0.60 mL, 4.10 mmol) at rt. The mixture was heated for 1 h at 100 ℃ and then cooled. After addition of a small amount of water, the mixture was extracted with ethyl acetate, and the combined extracts were washed with brine, dried over Na_2SO_4 and evaporated to give a pale yellow solid, which was chromatographed on silica gel with 40% ethyl acetate in *n*-hexane to give (*S*)-2-(diphenylphosphinyl)-2'-(*N*-(*R*)-α-methylbenzylcarbamoylthio)-1,1'-binaphthyl **13S**

(0.21 g, 32%) and (*R*)-2-(diphenylphosphinyl)-2′-(*N*-(*R*)-α-methylbenzylcarbamoylthio)-1,1′-binaphthyl **13R** (0.17 g, 25%) as white solids.

(*S*, *R*) carbamate **13S**: NMR ($CDCl_3$) δ 8.89 (d, J=7.2 Hz, 1H), 7.96-6.51 (m, 27H), 4.82 (m, 1H), 0.91 (d, J=7.1 Hz, 3H); IR (KBr) 3188, 3056, 2975, 1670, 1218, 1186 cm^{-1}; MS 453, 284, 201, 147, 132, 105.

(*R*,*R*) carbamate **13R**: NMR ($CDCl_3$) δ 8.97 (d, J=7.6 Hz, 1H), 7.95-6.35 (m, 27H), 4.94 (m, 1H), 1.38 (d, J=7.1 Hz, 3H); IR (KBr) 3196, 3055, 2972, 1671, 1218, 1185 cm^{-1}; MS 453, 284, 201, 147, 132, 105.

(*S*)-(−)-2-(Diphenylphosphino)-2′-mercapto-1,1′-binaphthyl, 14S. To a mixture of the optically pure *S*-aryl carbamate **13S** (0.48 g, 0.76 mmol) and Et_3N (0.89 mL, 6.40 mmol) in toluene (2 mL) was added Cl_3SiH (0.48 mL, 4.80 mmol) at 0 ℃. The reaction mixture was stirred at 90 ℃ for 1 h. After cooling to rt and dilution with ether, the mixture was quenched with a small amount of 3 N HCl solution. The resulting suspension was filtered through Celite and washed with ethyl acetate. The filtrate was extracted with ethyl acetate, and the extracts were washed with brine, dried over Na_2SO_4, and then evaporated to give pale yellow solid. The crude thiol was purified by silica gel column chromatography with 10% ethyl acetate in *n*-hexane as eluent, giving (*S*)-(−) thiol **14S** (0.32 g, 90%, 100% ee): mp 178 ℃; $[\alpha]_D^{25}$-29.6° (*c* 0.28, $CHCl_3$); NMR ($CDCl_3$) δ 7.95-6.64 (m, 22H), 3.16 (s, 1H); IR (KBr) 3050, 2567, 1431, 808, 742, 696 cm^{-1}; MS 470 (M^+), 469, 437, 282; Anal. Calcd for $C_{32}H_{23}PS$: C, 81.68; H, 4.93; S 6.81. Found: C, 81.94; H, 5.11; S 6.42.; HPLC resolution; Chiralcel OT; eluent 70% IPA in *n*-hexane; flow rate 0.3 mL/min; retention times, 29.8 (*R*) and 50.8 (*S*) min; S 100%.

(*R*)-(+)-Thiol **14R** was obtained from the optically pure *S*-aryl carbamate **13R** in an analogous manner and its spectral data were identical except for specific rotation ($[\alpha]_D^{25}$+30.0° (*c* 0.30, $CHCl_3$)) and HPLC resolution ratio (*R* 100%).

(*R*)-(+)-2-(Diphenylphosphino)-2′-(methylthio)-1,1′-binaphthyl, 15R. To a solution of the thiol **14R** (43 mg, 0.09 mmol, 100% ee) in dry DMF 2 mL at 0 ℃, was added NaH (10 mg, 0.42 mmol). After being stirred for 5 min, MeI (0.01 mL, 0.16 mmol) was added and then the yellow solution turned to white. It was diluted with Et_2O, quenched with 3 N HCl solution. The solution was extracted with ethyl acetate, and the combined extracts were washed with brine, dried over Na_2SO_4 and stripped solvent off. The residue was chromatographed to give 34 mg (78%, 100% ee) of the methylthio phosphine **15R**.: mp 158 ℃; $[\alpha]_D^{25}$+51.4° (*c* 1.57, $CHCl_3$) (lit.[8] $[\alpha]_D^{25}$ 52.6° (*c* 0.5, $CHCl_3$); NMR ($CDCl_3$) δ 7.98-6.67 (m, 22H), 2.30 (s, 3H); IR (KBr) 3049, 2918, 1583, 1433, 810, 744, 694 cm^{-1}; MS 469, 437, 281, 218; HPLC resolution; Chiralcel OD; eluent 10% IPA in *n*-hexane; flow rate 0.2 mL/min; retention time, 74.9 (*R*) and 88.1 (*S*) min; *R* 100%.

(*S*)-(−) phosphine sulfide **15S** was obtained in an analogous manner and its spectral data were identical except for specific rotation ($[\alpha]_D^{25}$-51.0° (*c* 1.50, $CHCl_3$)) and HPLC resolution ratio.

General Procedure for Allylic Alkylation using Pd-Catalyst: Methyl (*R*)-2-carbomethoxy-3,5-diphenylpent-4-enoate. A solution of 0.81 mmol $NaCH(CO_2Me)_2$, generated from 0.09 mL (0.81 mmol) of dimethyl malonate and 19 mg (0.81 mmol) of NaH in 5 mL of solvent, were added dropwise to a solution of 3.7 mg (0.01 mmol) of [Pd(π-Allyl)Cl]$_2$, 11.7 mg (0.024 mmol) of **15S** (or **15R**), 102 mg (0.404 mmol) of 1,3-diphenyl-2-propen-1-yl acetate in 2 mL solvent via a cannula at rt (or −30 ℃). The reaction mixture was stirred at rt (or −30 ℃). After reaction was complete, the reaction mixture was poured into water (20 mL) and extracted with ethyl acetate. The resulting extracts were washed with brine, dried over Na_2SO_4, and filtered. The solution was evaporated under reduced pressure. The residue was purified by column chromatography with 20% ethyl acetate in *n*-hexane) to afford the product: ^{1}H NMR ($CDCl_3$, 300 MHz): δ 3.52 (s, 3H), 3.71 (s, 3H), 3.96 (d, J=11.1 Hz, 1H), 4.27 (dd, J=8.4 and 11.1 Hz, 1H), 6.33 (dd, J=8.4 and 15.9 Hz, 1H), 6.49 (d, J=15.9 Hz, 1H), 7.20-7.35 (m, 10H).; HPLC resolution; Chiralcel OP(+); eluent 10% IPA in *n*-hexane; flow rate 0.4 mL/min; retention times, 57.8(*S*) and 77,6(*R*) min.

Dimethyl (*S*)-2-cyclohexen-1-yl malonate. ^{1}H NMR ($CDCl_3$, 300 MHz): δ 1.32-1.43 (m, 1H), 1.51-1.63 (m, 1H), 1.70-1.83 (m, 2H), 1.96-2.03 (m, 2H), 2.87-2.95 (m, 1H), 3.30 (d, J=9.6 Hz, 1H), 3.75 (s, 6H), 5.51-5.55 (m, 1H), 5.75-5.82 (m, 1H).; GC resolution; Chiraldex B-PH; temperatures of 120 ℃ (oven), 250 ℃ (injection port) and 250 ℃ (detector); flow rate, 0.85 mL/min; retention times, 52.8(*R*) and 53.7(*S*) min.

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Synthesis of Polymers Having *N*-Hydroxymaleimide Units by Thermolysis of *N*-(Isopropyloxycarbonyloxy)maleimide Polymers

Kwang-Duk Ahn* and C. Grant Willson†

Functional Polymer Lab., Korea Institute of Science and Technology, P.O. Box 131, Cheongryang, Seoul 130-650, Korea
†Department of Chemical Engineering, The University of Texas, Austin, TX 78712, U. S. A
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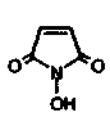
N-(Isopropyloxycarbonyloxy)maleimide (iPOCMI) has been synthesized and polymerized to give both the homopolymer and copolymers with substituted styrenes. These polymers were readily deprotected by thermolysis of the isopropyloxycarbonyl (iPOC) groups to provide the corresponding *N*-hydroxymaleimide (HOMI) polymers. The homopolymer and styrenic copolymers of iPOCMI were radically obtained in higher conversion and higher molecular weight than those obtained by direct polymerizations of *N*-hydroxymaleimide. The homopolymer of iPOCMI was transformed into poly(*N*-hydroxymaleimide)(PHOMI) by thermolysis of iPOC groups at 205 ℃ with concurrent release of propene and carbon dioxide. The copolymer of iPOCMI and styrene was thermally deprotected to the copolymer of HOMI and styrene at 235 ℃. The mass loss was 28% and the T_g of the resulting copolymer was 250 ℃. The thermal deprotection readily provided the desired, polar HOMI polymers which have T_gs above 240 ℃. The deprotection was accompanied by large changes in aqueous base solubility.

Introduction

A novel technology based on the "chemical amplification" concept has been established that affords a desired modification of polymer properties by thermal and photochemical acidolytic deprotection of side-chains.[1] Among the protecting groups that have been studied for this purpose, the *tert*-butyloxycarbonyl (*t*-BOC) group has been particulary useful in conjuction with phenolic polymers for application to the design of highly sensitive photoimaging systems.[2,3] Our continuing search for novel polymeric photoresist materials which can provide high resolution images possessing high thermal stability and aqueous base developing capabilities, led us to study maleimide (MI) polymers by virtue of their unique thermal stability and polar functionality.[4] Polymers with succinimide structures in the main-chain can be obtained by radical copolymerization of maleimide monomers. In particular, the polymers and copolymers of *N*-hydroxymaleimide **1** (HOMI) are potential candidates for this application because they bear highly acidic *N*-hydroxy functional groups. For example,[5] *N*-hydroxysuccinimide **2** and *N*-hydroxy-3,4-dimethylsuccinimide **3** are known to have pK_a values of 6.0 and 7.2, respectively, whereas those of succinimide (N-H) and phenol (O-H) derivatives are about 10.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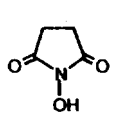
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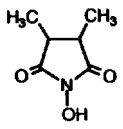
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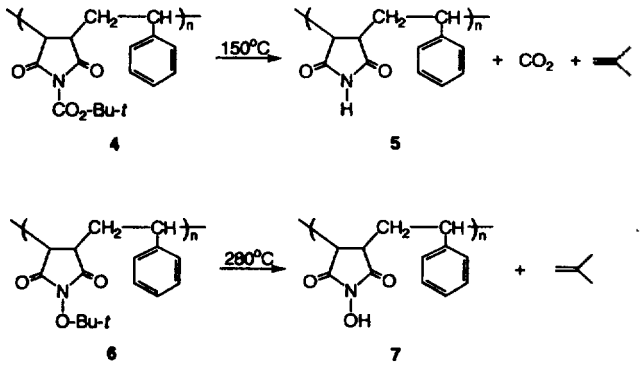

4 **5** **6** **7**

Scheme 1.

The HOMI monomer **1** is a 1,2-disubstituted ethylene and has an active hydrogen. Hence, it is not surprising that we were not able to obtain high molecular weight polymers by direct free radical polymerization of **1**. Otsu and coworkers[6,7] reported the synthesis of high molecular weight polymers from 1,2-disubstituted ethylenic monomers *via* a protection-thermal deprotection scheme. They obtained poly(fumaric acid) by heating poly(di-*t*-butyl fumarate) at 180 ℃[6] and polymaleimide by thermolysis of poly(*N*-*t*-butylmaleimide) at 330 ℃.[7] In previous articles we have reported functional polymaleimides which have excellent photoimaging properties and high glass transition temperatures (T_g).[8~11] Two parent functionalized polymaleimides were converted to the aqueous alkali soluble polymers by thermal deprotection (Scheme 1).