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Asymmetric Cyclopropanation of Olefins with Diazoacetate Using Chiral Copper Catalysts

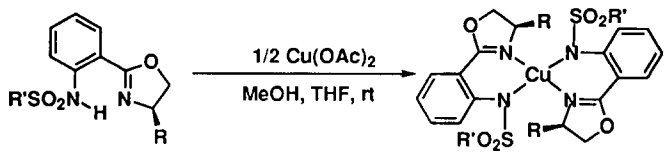
Tsuyoshi Ichiyanagi, Makoto Shimizu, Tamotsu Fujisawa*

Department of Chemistry for Materials, Mie University, Tsu, Mie 514, Japan

Abstract: Chiral 2-(2-aryl- or 2-alkyl-sufonylamino)phenyl-4-phenyl-1,3-oxazolines were found to be effective ligands for copper-catalyzed enantioselective cyclopropanation reaction of olefins. The reaction of styrene with *d*-menthyl diazoacetate in the presence of optically active copper catalysts gave cyclopropanation products in a ratio of *trans* : *cis* = 83 : 17 with 63% ee (*trans*) and 84% ee (*cis*).

Asymmetric cyclopropanation of simple olefins using transition metal catalysts has been an important tool for useful natural products synthesis.[1] The first example of an enantioselective cyclopropane formation was reported more than 30 years ago,[2] although the optical yields were low. Subsequently, a number of research groups have tried to improve the selectivity of this synthetically useful cyclopropanation reaction.[3-6] Recently, some nitrogen-containing ligands such as semicorrine[7] and bis(oxazolines)[8]-copper complexes have been shown to be effective catalysts for asymmetric cyclopropanation. We have recently reported an enantioselective Diels-Alder reaction catalyzed by magnesium - chiral diamine, 2-(2-aryl- or 2-alkyl-sufonyl-amino)phenyl-4-phenyl-1,3-oxazoline, complexes to prepare norbornene derivatives from 2-alkenoyl-1,3-oxazolidin-2-one and cyclopentadiene.[9] Chiral ligands were easily prepared from *D*-phenylglycine as the starting material in a three-step procedure. To extend the utility of these chiral ligands, we now wish to report on the chiral copper-catalyzed asymmetric cyclopropanation reaction of diazoacetate with alkenes.

Chiral ligands were conveniently prepared by the following procedure:[10] In the presence of zinc chloride the reaction of *D*-phenylglycinol was treated with 2-aminobenzonitrile in chlorobenzene and then the amino group was sulfonylated with arylsulfonyl chloride, or trifluoromethanesulfonic anhydride, in the presence of triethylamine and DMAP in dichloromethane. Chiral copper catalysts **2a-g** were prepared by the reaction of 1 equivalent of cupric acetate and 2 equivalents of chiral ligands **1a-g** in a methanol and tetrahydrofuran (1:1) solution at room temperature. They were stable in air and moisture and could be isolated by silica gel chromatography, and elemental analysis of Cu-complex **2g** indicated a 2:1 ratio of chiral ligand **1g** and copper.[11] These complexes were stored more than one month under air without noticeable decrease of reactivity as a catalyst.



1 2

a: R=Ph R'=Tol
b: R=Ph R'=1-Naph
c: R=Ph R'=2-Naph
d: R=Ph R'=2,4,6-$Me_3C_6H_2$
e: R=Ph R'=CF_3
f: R=Ph R'=4-$^tBuC_6H_4$
g: R=^{t}Bu R'=Tol

The cyclopropanation reaction of styrene with *d*-menthyl diazoacetate using the chiral copper complex **2a** was examined as a model reaction. In all cases, 1 mol% amount of the catalyst was used for the reaction, which was carried out at room temperature. First, the solvent effect was examined. The cyclopropanation reaction in halomethane solvents gave good results. Among the solvents, dichloroethane was found to be the most effective. The use of benzene and hexane instead of dichloroethane showed moderate stereoselectivity and low yield. On the other hand, center metals other than copper were not effective for the cyclopropanaion reactions. The use of palladium acetate and cobalt acetate instead of cupric acetate gave the corresponding cyclopropane carboxylate in less than 30% enantiomeric excess and moderate yield.

Next, the effects of substituents at the phenyl group of the sulfonamide group in the chiral oxazoline ligands were investigated. As shown in Table 1, most of the ligands having a phenyl group at the oxazoline ring produced the cyclopropane product with good *trans* vs *cis* selectivity of ca. 83 / 17, in which the enantioselectivity of the *cis*-isomer was usually higher than that of the *trans*-isomer. The use of a bulkier substituent at the phenyl group of the sulfonamide group, for example, toluene, 1-naphthalene, 2-naphthalene and 4-*tert*-butylbenzensulfonyl group **1a-c**, **1f** gave good stereoselectivity of both *trans*- and *cis*-isomers. The highest enantioselectivity of the *cis*-isomer was obtained using catalyst **2a** in 84% ee (entry 1), and the use of the bulkyier catalyst **2d** having methyl groups at *ortho*-positions of the benzenesulfonamide group gave moderate selectivity (entry 4). The use of catalyst **2e** which had a trifuluoromethyl group **1e** gave the cyclopropanation product in moderate yield and enantioselectivity (entry 5). In the Diels-Alder reaction reported previously, the use of such a chiral ligand **1e** showed an interesting character due to the electron-negative nature of the trifluoromethyl group which behaved as a ligand to coordinate or interact with metals.[12] However, in this cyclopropanation reaction, **1e** did not show such behavior, but acted as a bulky substituent as in the cases with other alkyl or aryl groups.

The substituent at the asymmetric carbon was important to determine the enantioselectivity; switching the phenyl group to a *tert*-butyl group decreases the enantioselectivity dramatically, but the ratio of *trans* vs *cis* selectivity was not changed (entry 1 and entry 7). This is a different result as compared with that obtained with Evans and Masamune's copper catalyst.[3g,8]

The reaction of styrene with several diazoesters catalyzed by the Cu-complex **2a** was examined, and results are summarized in Table 2. The use of ethyl ester gave the product in 92% yield with good asymmetric induction (entry 8). In general, the use of a bulky alkoxy group of the ester gave high *trans*-selectivity and enantioselectivity. The selectivity of *trans*-isomer was dramatically increased when 2,6-di-*tert*-butylphenyl ester was used as a reactant but the enantioselectivity was not good (entry 10).

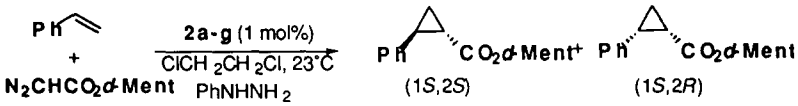
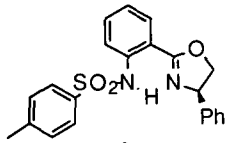
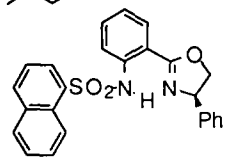
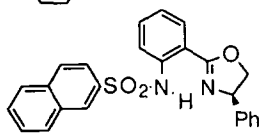
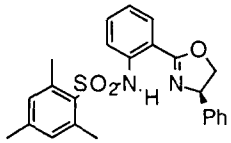
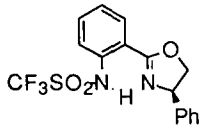
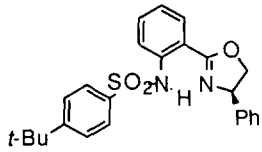
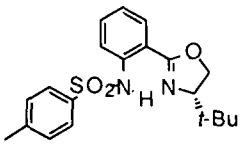


Table 1. The effect of a substituent of chiral ligand

Entry	Ligand	Yield(%)	*trans*:*cis*[a]	%ee(*trans*)	%ee(*cis*)
1		66	83:17	63	84
2		62	82:18	56	82
3		66	82:18	62	82
4		28	83:17	53	74
5		45	83:17	39	56
6		60	82:18	65	83
7		48	86:14	57[b]	55[c]

a) Determined using capillary gas chromatography (SE-30 50 m, 200 °C constant).
b) Absolute configuration was (1*R*,2*R*). c) Absolute configuration was (1*R*,2*S*).

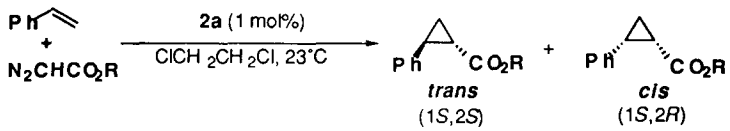
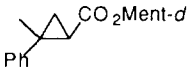
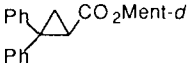
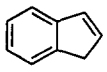
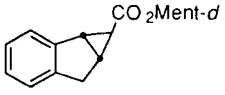
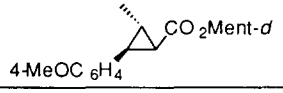


Table 2. Asymmetric cyclopropanation of styrene and diazoester using chiral copper 2a catalysts.

Entry	R of ester	Yield(%)	*trans*:*cis*[a)]	% ee(*trans*)	% ee(*cis*)
8	Ethyl	92	67:33	48[b)]	84[b)]
9	*tert*-Butyl	56	86:14	47[b)]	87[b)]
10	2,6-Di-*tert*-butylphenyl	73	93: 7	9[b)]	- d)
11	*l*- Menthyl	34	82:18	66 [a)]	86 [a)]
12	*d*-Menthyl	66	83:17	63[a)]	84 [a)]

a) Ratio of *trans*- and *cis*-isomers was determined using capillary gas chromatography. (SE-30, 50 m, 180 °C or 200 °C constant) b) Determined by HPLC using optically active column after $LiAlH_4$ reduction. (Chiralcel OJ, Hexane : 2-propanol = 9 : 1) c) Determined using capillary gas chromatography. (SE-30, 50 m, 200 °C constant) d) Not determined.

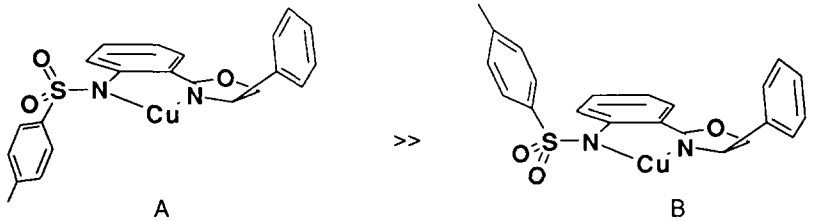
Table 3. Asymmetric cyclopropanation of alkens and *d*-menthyl diazoacetate using copper catalyst 2a.

Entry	Alkene	Product	Yield/%	*trans*/*cis*[a)]	% ee[a)] *trans*	*cis*
13			30	63/37	72	82
14			27	--	59	
15			51	81/19	52	81
16			29	81/19	64	74

a) Determined by the gas chromatography analysis. i) SE-30, 50 m, 200 °C const. ii) FFAP, 50 m, 160 °C const. iii) SE-30 50 m, 220 °C const. and absolute configuration was not determined. b) Determined by HPLC analysis (Hibar column, Hexane : 2-propanol = 100 : 1) and absolute configuration was not determined.

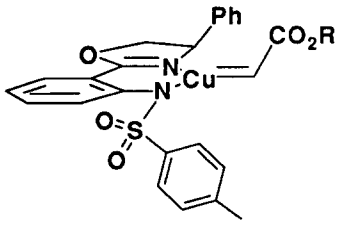
The use of *tert*-butyl diazoacetate increased the enantioselectivity of the *cis*-isomer up to 87%ee in moderate yield (entry 9) and menthyl diazoacetate improved the enantioselectivity of the *trans*-isomer. Among diazoacetates, the *d*-menthyl ester gave the cycloadduct with good yield and enantoselectivity (entry 11). Although the use of *l*-menthyl diazoacetate showed good enantioselectivity, yield was poor due to the formation of *l*-menthyl fumarate and maleate as by-products. Next, the cyclopropanation reaction of several alkenes was carried out using 1 mmol amount of *d*-menthyl diazoacetate in the presence of 1 mol% amount of the chiral copper catalyst **2a** and 1 mol% of phenyl hydrazine under an argon atmosphere in dichloroethane at 23 °C. The results are summarized in Table 3. In the reactions of α-methyl styrene, indene, and *p*-methoxy-β-methylstyrene comparable results were obtained (entry 13, 15, 16), whereas 1,1-diphenylethene showed low enantioselectivity (entry 14).

The mechanism of the reaction may be explained as follows: Although without an activator, such as phenyl hydrazine or diazoacetate, the reaction could not proceed, the use of an activation catalyst smoothly effected the cycloprapane-forming reaction. This implies that copper complexes **2a-e**, which were used as a pre-catalyst upon activation with diazoacetate or phenylhydrazine, were reduced with simultaneous loss of one of the chiral ligands to form copper(I) : chiral ligand = 1 : 1 complexes. These are considered to be the true catalysts in the cyclopropanation reaction. Despite the marked structural differences in the present ligands of the complex **2a-g**, the *trans* vs *cis* selectivities of the catalysts are always identical. Moreover, in the cyclopropanation of styrene with menthyl diazoacetate, Aratani's, Pfaltz's, Masamune's, and our catalysts produce a *trans* vs *cis* ratio of ca. 82 : 18. Therefore, the *trans* vs *cis* selectivity appears to be determined exclusively by the structure of the olefinic substrate and diazo compound conformation, and the conformation **A** is more stable than that of **B** by the MM2 calculation. Then chiral copper(I) reacts with diazoacetate to generate a chiral carbenoid intermediate **C** or **D** from conformer **A**. Styrene can approach to the reaction center either from the bottom (**C'**) or top (**D'**) due to the repulsion between the phenyl group of styrene and the selectivity is dependent on the bulkiness of the ester part. Subsequent reaction gave the transition state **T1-T4**, producing cis-(1*S*,2*S*) or trans-(1*S*,2*R*)-cyclopropane carboxylate. In the case of the formation of trans-cyclopropanation, an approach depicted as in **E** would be involved The transition state **T6** generated from **E** can change more stable **T7**, producing trans-(1*R*,2*S*)-cyclopropane.[7,13,14] Therefore decrease of the enantioselectivity was observed with trans-cyclopropane. In contrast, it was difficult to produce *cis*-(1*R*,2*R*)-isomer due to the steric repulsion between phenyl group and ester part of carbenoid *via* **T5**. Consequently, the enantioselectivity of *trans*-isomer decreased compared with that of *cis*-isomer.

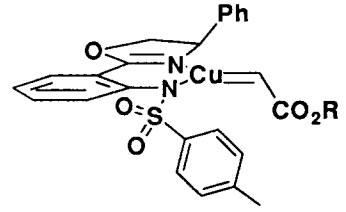


A B

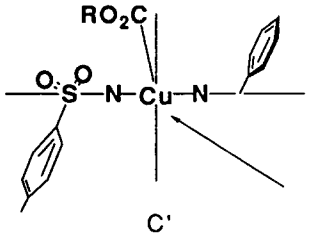
More stable



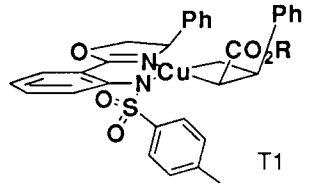
C



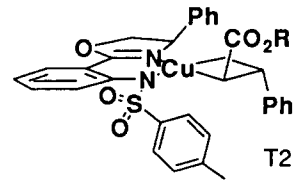
D



C'



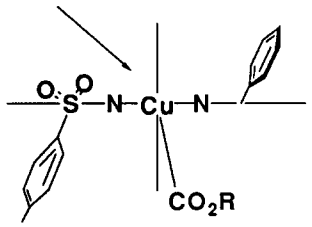
T1



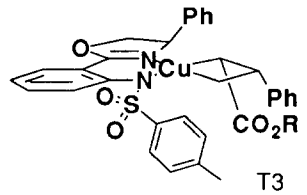
T2

(1*S*,2*S*)

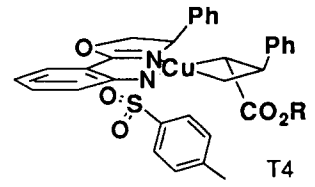
(1*S*,2*R*)



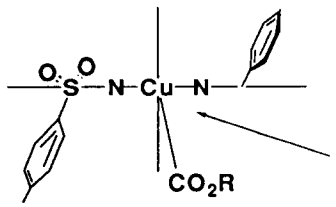
D'



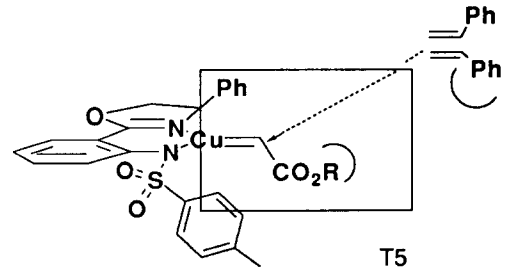
T3



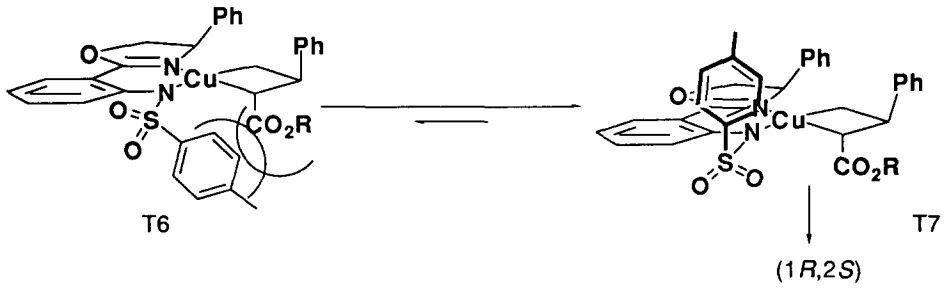
T4



E



T5



Copper-catalyzed asymmetric cyclopropanation of styrene derivatives was achieved utilizing the chiral 2-(2-aryl or 2-alkyl-sulfonylamino)phenyl-4-phenyl or *tert*-butyl-1,3-oxazoline ligand. The catalyst was easily prepared and was stable in air and moisture. The use of the present catalyst effected the cyclopropane-forming reaction with moderate to good enantioselectivity irrespective of the substituent of the ester part of diazoacetate.

Acknowledgment: We would like to thank Mr. Takatoshi Ito for his careful exact mass spectra analyses.

Experimental section

Infrared spectra were determined on a JASCO IR-810 spectrometer. ^{1}H- and ^{13}C-NMR spectra were recorded with JEOL α-500, JNM EX-270, and JNM-PMX 60si spectrometers using tetramethylsilane as an internal standard. High performance liquid chromatography (HPLC) was carried out on a Hitachi L-4000 detector and a Hitachi L-6000 pump using a Daicel Chiralcel OJ column. Optical rotations were measured with a Union PM-101 polarimeter. Exact mass spectra were taken on a JEOL JMS-DX303-HF spectrometer. All the melting points are uncorrected. Tetrahydrofuran (THF) was distilled from sodium benzophenone ketyl before use. Dichloromethane, dichloroethane, and chlorobenzene were pretreated with diphosphorus pentaoxide, distilled from CaH_2, and stored over molecular sieves 4A. Triethylamine was distilled from CaH_2. Methanol was distilled from magnesium methoxide and stored over molecular sieves 3A. Purification of products was performed by column chromatography on silica gel of Wakogel C-300 or Merck Silica Gel-60, and/or preparative TLC on silica gel of Merck Kisel Gel PF254 or Wakogel B-5F. The starting materials ethyl,[15] *tert*-butyl,[16] 2,6-di-*tert*-butylphenyl,[17] and menthyl diazoacetate[7] and *tert*-leucinol[18] were synthesized according to the literature. Cupric acetate were used as received from Wako Pure Chemical Industrial Ltd. Reaction flask was sealed with a red rubber septum and was magnetically stirred, unless otherwise mentioned. Anhydrous solvents and reaction mixtures were transferred by an oven-dried syringe or cannula.

(4*S*)-2-(2-Aminophenyl)-4-*tert*-butyl-1,3-oxazoline: To a mixture of (*L*)-(-)-*tert*-leucinol (856 mg, 7.3 mmol) and 2-aminobenzonitrile (924 mg, 7.6 mmol) in dichloromethane (20 ml) was added zinc chloride (300 mg, 2.2 mmol) at room temperature, and the reaction mixture was heated at 140 °C for 24 h. The reaction mixture was cooled to room temperature and was quenched with 20 ml of saturated aqueous ammonium chloride. The resultant mixture was extracted 3 times with 20 ml of dichloromethane. The combined organic layers were dried over anhydrous sodium sulfate, filtered, and concentrated. The crude product was purified by flash column chromatography on silica gel using ethyl acetate-hexane (9 : 1) as an eluent to afford 1.35 g

(85%) of the title compound as a colorless solid. $[\alpha]_D^{23}$ = +1.8 (c 0.56, $CHCl_3$); mp 70-71 °C; R*f* 0.44 (ethyl acetate : hexane = 1 : 3). ^{1}H-NMR (270 MHz, $CDCl_3$): δ 0.96 (s, 9H), 4.10-4.15 (m, 2H), 4.25-4.29 (m, 1H), 6.18 (br, 2H), 6.65-6.73 (m, 2H), 7.20-7.24 (m, 1H), 7.70 (dd, *J* = 7.93, 1.53 Hz, 1H). IR ($CHCl_3$): 2160, 1730, 1395, 1345, 1300, 1170, 910 cm^{-1}. MS (EI) *m/z* (relative intensity), 218(16), 173(2), 161(100), 133(74), 118(29), 106(28), 92(28), 77(7), 65(29), 57(8). Calcd for $C_{13}H_{18}N_2O$: 218.1395. Found: 218.1419.

(4*S*)-2-(2-*p*-Toluenesulfonylaminophenyl)-4-*tert*-butyl-1,3-oxazoline: To a solution of (4*S*)-2-(2-aminophenyl)-4-*tert*-butyloxazoline (218 mg, 1.0 mmol) in dry dichloromethane (3 ml) at 0°C were added triethylamine (0.7 ml, 5.0 mmol) and *N,N*-4-dimethylaminopyridine (1.2 mg, 0.01 mmol), and after 5 min *p*-toluenesulfonylchloride (209 mg, 1.1 mmol) was added. The mixture was stirred for 24 h at room temperature. The reaction was quenched with excess saturated aqueous ammonium chloride and extracted with ethyl acetate. The organic layer was dried over anhydrous sodium sulfate, filtered, and concentrated in vacuo. The product was purified by flash chromatography on silica gel and recrystallized from ethyl acetate - hexane to afford the title compound (314.8 mg, yield 85%). $[\alpha]_D^{23}$ = -20.3 (c 0.42, $CHCl_3$); R*f* 0.36 (ethyl acetate : hexane = 1 : 3). ^{1}H-NMR (270 MHz, $CDCl_3$): δ 0.96 (s, 9H), 2.32 (s, 3H), 4.12-4.36 (m, 2H), 4.51-4.55 (m, 1H), 6.93-6.99 (m, 1H), 7.15-7.20 (m, 2H), 7.33-7.45 (m, 1H), 7.67-7.70 (m, 4H), 12.62 (br, 1H). IR ($CHCl_3$): 3465, 3250, 2950, 1635, 1605, 1595, 1490, 1360, 970 cm^{-1}. MS(EI) *m/z* (relative intensity), 372(14), 315(15), 302(2), 266(4), 209(9), 180(5), 160(100), 131(45), 118(12), 104(12), 91(80), 77(9), 65(34), 57(18). Calcd for $C_{20}H_{24}N_2O_3S$: 372.1497. Found: 372.1508.

(4*R*)-2-{2-(4-*tert*-Butylbenzenesulfonyl)amino}phenyl-4-phenyl-1,3-oxazoline: To a solution of (4*R*)-2-(2-aminophenyl)-4-phenyloxazoline (500 mg, 2.1 mmol) in dry dichloromethane (15 ml) at 0°C were added triethylamine (1.5 ml, 10 mmol) and 0.01 equiv of *N,N*-4-dimethylaminopyridine, and after 5 min 4-*tert*-butylbenzenesulfonylchloride (586 mg, 2.4 mmol) was added. The mixture was stirred for 24 h at room temperature. The reaction was quenched with excess saturated aqueous ammonium chloride and extracted with ethyl acetate. The organic layer was dried over anhydrous sodium sulfate, filtered, and concentrated in vacuo. The product was purified by flash chromatography on silica gel and recrystallized from ethyl acetate - hexane to afford the title compound (693 mg, 73%). $[\alpha]_D^{23}$ =-45.2 (c 0.43, CHCl3); mp 147-148 °C; R*f* = 0.38 (ethyl acetate : hexane = 1 : 3). ^{1}H-NMR (500 MHz, CDCl3): δ 1.29 (s, 9H), 4.22 (dd, *J* = 8.24, 8.24Hz, 1H), 4.73 (dd, *J* = 8.24, 10.07Hz, 1H), 5.50 (dd, *J* = 8.24, 10.07Hz, 1H), 7.03-7.06 (m, 1H), 7.24-7.42 (m, 8H), 7.71-7.83 (m, 4H). IR (CHCl3): 2950, 1630, 1500, 1340, 1270, 1160, 1065, 950 cm^{-1}. MS(EI) *m/z* (relative intensity), 434(100), 370(43), 339(6), 314(3), 263(16), 250(4), 235(37), 223(6), 207(16), 197(22), 180(9), 166(22), 151(4), 133(48), 118(32), 103(33), 91(71), 77(44), 65(12), 57(21), 51(8). Calcd for $C_{25}H_{26}N_2O_3S$: 434.1664. Found: 434.1650. Anal. Calcd for $C_{25}H_{26}N_2O_3S$: C, 69.10; H, 6.03; N, 6.45%. Found: C, 69.22; H, 6.08; N, 6.61%.

General procedure of chiral copper catalysts:[11] A typical experimental procedure was exemplified by the reaction of **2g** with cupric acetate. To a solution of cupric acetate (84 mg, 0.4 mmol) in methanol (3 ml) was added a solution of chiral ligand **2g** (0.8 mmol) in tetrahydrofuran (3 ml) at room temperature. The color of the solvent changed to deep red brown from blue and the reaction was monitored by TLC. after 1h, the

mixture was heated to 40°C and stirred for 30 min. The reaction was quenched by saturated aqueous sodium hydrogen carbonate and extracted with dichloromethane. The organic layer was dried over anhydrous sodium sulfate, filtered, and concentrated in vacuo. The product was purified by flash chromatography on silica gel (hexane : ethyl acetate = 2 : 1) and obtained in quantitative yield.

Bis[(4*R*)-2-(2-toluenesulfonylamino)phenyl-4-phenyl-1,3-oxazolinate]copper(II) (2a): Mp 322 °C(dec); R*f* 0.30 (ethyl acetate : hexane = 1 : 3). IR(CHCl3) 1620, 1310, 955, 945 cm^{-1}. MS(CI) m/z (relative intensity) 845(100), 392(25), 273(2), 138(3), 43(4).

Bis[(4*R*)-2-{2-(1-naphtharenesulfonyl)amino}phenyl-4-phenyl-1,3-oxazolinate]copper(II) (2b): Mp 166-168 °C; R*f* 0.15 (ethyl acetate : hexane = 1 : 3). IR (CHCl3) 1620, 1490, 1310, 1120 cm^{-1}. MS(CI) *m/z* (relative intensity) 917(57), 882(5), 767(4), 623(24), 427(100), 191(7), 138(13), 98(5), 56(8).

Bis[(4*R*)-2-{2-(2-naphtharenesulfonyl)amino}phenyl-4-phenyl-1,3-oxazolinate]copper(II) (2c): Mp 309 °C(dec), R*f* 0.20 (ethyl acetate : hexane = 1 : 3). IR (CHCl3) 1620, 1125, 1075 cm^{-1}. MS(CI) *m/z* (relative intensity) 917(57), 882(5), 767(4), 623(24), 427(100), 191(7), 138(13), 98(5), 56(8).

Bis[(4*R*)-2-{2-(2,4,6-trimethylbenzenesulfonyl)amino}phenyl-4-phenyl-1,3-oxazolinate]-copper(II) (2d): Mp 89-91 °C; R*f* 0.50 (ethyl acetate : hexane = 1 : 3). IR (CHCl3) 1610, 1485, 1120, 940 cm^{-1}. MS(CI) *m/z* (relative intensity) 901(100), 420(52), 309(3), 74(4).

Bis[(4*R*)-2-(2-trifluoromethanesulfonylamino)phenyl-4-phenyl-1,3-oxazolinate]copper(II) (2e): Mp 270 °C(dec), R*f* 0.30 (ethyl acetate : hexane = 1 : 3). IR (CHCl3) 1620, 1490, 1330. 1125, 970 cm^{-1}. MS(CI) *m/z* (relative intensity) 801(100), 434(3), 370(20), 283(2), 148(5), 73(1).

Bis[(4*R*)-2-{2-(4-*tert*-butylbenzenesulfonyl)amino}phenyl-4-phenyl-1,3-oxazolinate]-copper(II) (2f): Mp 352 °C(dec); R*f* 0.33 (ethyl acetate : hexane = 1 : 3). IR (CHCl3) 1620, 1490, 1080, 950 cm^{-1}. MS(CI) *m/z* (relative intensity)929(100), 466(10), 434(10).

Bis[(4*S*)-2-(2-*p*-toluenesulfonylaminophenyl)-4-*tert*-butyl-1,3-oxazolinate]-copper(II) (2g): Mp 320 °C(dec); R*f* 0.33 (ethyl acetate : hexane = 1 : 3). IR (CHCl3) 1615, 1490, 1140, 1085, 945 cm^{-1}. MS(CI) m/z (relative intensity) 805(9), 744(27), 631(8), 491(5), 372(100), 279(3), 200(4), 73(4). Anal. Calcd for C40H46N4O6S2Cu: C, 59.57; H, 5.75; N, 6.95%. Found: C, 59.41; H, 6.00; N, 6.93%.

General procedure of cyclopropanation: A typical experimental procedure was exemplified by cyclopropanation of styrene and *d*-menthyl diazoacetate using the copper complex **2a** as a catalyst: To a solution of chiral copper catalyst **2a** (25.4 mg, 0.03 mmol) in dichloroethane (1.5 ml) was added a solution of phenylhydradine (0.15 M in dichloroethane 0.2 ml, 0.03 mmol) at room temperature under an argon atmosphere or 2 drops of a solution of *d*-menthyl diazoacetate (see below) were added with stirring and heated in an oil bath in 85°C (ca. 3 min) under argon. After 5 min or cooled to room temperature, styrene (0.69 ml, 6.0 mmol) was added to the mixture in one portion, then a solution of *d*-menthyl diazoacetate (673 mg, 3.0 mmol) in dichloroethane (1.0 ml) was continuously added within 20 h by means of a syringe pump. The reaction mixture was stirred for additional 2h and passed through a silica gel column chromatography (hexane : ethyl acetate = 20 : 1 as a eluent) to afford a mixture of *d*-menthyl 2-phenylcyclopropane-1-carboxrate as a colorless oil. The ratio of *trans*- and *cis*-isomers and the enantioselectivity of them were determined by using capillary gas chromatography analysis (SE-30, 50 m, 230 °C constant).

Ethyl 2-phenylcyclopropane-1-carboxylate[18]: Yield 92%, *trans* : *cis* = 67 : 33, R*f* 0.24, 0.32 (hexane : ethyl acetate = 15 : 1) : R*t* *trans*-isomer: 7.95, 9.76 min, *cis*-isomer: 7.93, 10.08 min (HPLC Dicel OJ, hexane : 2-propanaol = 9 : 1). ^{1}H-NMR (60 MHz, CCl4) *trans* -isomer δ 1.25-2.00 (m, 6H), 2.4-2.6 (m, 1H), 4.13 (q, *J* = 7.1 Hz, 2H), 7.15-7.20 (m, 5H), *cis*-isomer δ 0.97-2.60 (m, 6H), 3.86 (q, *J* = 7.1 Hz, 2H), 7.25-7.30 (m, 5H). IR (CHCl3) 2950, 1720, 1450, 1150 cm^{-1}.

***tert*-Butyl 2-phenylcyclopropane-1-carboxylate:** Yield 56%, *trans* : *cis* = 86 : 14, R*f* 0.37, 0.49 (hexane : ethyl acetate = 15 : 1). ^{1}H-NMR (270 MHz, $CDCl_3$): δ 1.05-2.65 (m, 13H including at 1.13ppm, s, *cis* and at 1.46 ppm, s, *trans*), 7.03-7.50 (m, 5H). IR (CHCl3) 2950, 1725, 1395, 1250 cm^{-1}. Enantiomeric purity was determined by HPLC analysis converted to the correspnding alcohol after $LiAlH_4$ reduction.

2,6-Di-*tert*-butylphenyl 2-phenylcyclopropane-1-carboxylate: Yield 73%, *trans* : *cis* = 96 : 4, R*f* 0.4 (hexane : ethyl acetate = 20 : 1). R*t* *trans*-isomers 20.24, 23.19 min, *cis*-isomers 14.02, 16.63 min (HPLC Chiralcel OJ, hexane : 2-propanaol = 9 : 1). ^{1}H-NMR (270 MHz, $CDCl_3$): δ 1.36 (s, 9H), 1.37, (s, 9H), 1.49-1.59 (m, 1H), 1.72-1.87 (m, 1H), 2.16-2.20 (m, 1H), 2.68-2.74 (m, 1H), 7.70-7.37 (m, 8H). IR (CHCl3) 2950, 1720, 1400, 1140 cm^{-1}. MS(EI) *m/z* (relative intensity), 350(2), 174(31), 157(9), 145(36), 129(100), 115(29), 102(11), 91(22), 83(79), 69(35), 55(67). Calcd for $C_{24}H_{30}O_2$: 350.2264. Found: 350.2224.

***d*-Menthyl 2-phenylcyclopropane-1-carboxylate:** Yield 66%, *trans* : *cis* = 83 : 17, R*f* 0.5 (hexane : ethyl acetate = 15 : 1), R*t* *trans*-isomers 60.230, 62.270 min, *cis*-isomers 50.743, 52.490 min (SE-30 50m, 200°C constant). ^{1}H-NMR (270 MHz, $CDCl_3$): *trans*-isomers δ 0.67-2.00 (m, 23H), 2.50 (m, 1H), 4.75 (m, 1H), 7.0-7.40 (m, 5H), *cis*-isomesrs δ 0.45-1.75 (m, 23H), 2.0 (m, 1H), 4.40 (m, 1H), 7.10-7.30 (m, 5H).

***d*-Menthyl 2,2-diphenylcyclopropane-1-carboxylayte (Cyclopropane from 1,1-diphenylethene):** Yield 27%, Rf 0.3 (hexane : ethyl acetate = 15 : 1). R*t* 21.31, 22.15 min (HPLC Hibar column, hexane : ethyl acetate = 100 : 1). ^{1}H-NMR (270 MHz, $CDCl_3$): δ 0.63-2.15 (m, 20H), 2.43-2.48 (m, 1H), 4.37 (dt, 1H, *J* = 3.96, 10.89 Hz), 7.04-7.47(m, 10H).

***d*-Menthyl 2-metyl-2-phenylcyclopropane-1-carboxylate (Cyclopropane from 1-methyl-1-phenylethene):** Yield 30%, *trans* : *cis* = 63 : 37, R*f* 0.36, 0.28 (hexane : ethyl acetate = 20 : 1). R*t* *trans*-isomers 88.176, 89.270 min (SE-30 50 m, 220 °C constant), *cis*-isomers 39.196, 39.863 min (SE-30 50 m, 230 °C, constant). ^{1}H-NMR (270 MHz, $CDCl_3$): *trans*-isomers δ 0.77-2.04 (m, 24H incruding at 1.49 ppm, s and 1.51 ppm, s), 4.73-4.82 (m, 1H), 7.18-7.34 (m, 5H), *cis*-isomers δ 0.60-1.94 (m, 24H, incruding at 0.62 ppm, d, *J* = 6.93 Hz, at 0.63 ppm, d, 6.93 Hz, at 1.46 ppm, s, and at 1.47 ppm, s), 4.32-4.49 (m, 1H, incruding at 4.37 ppm, dt, *J* = 4.28, 10.88 Hz and at 4.43 ppm, dt, *J* = 6.60, 10.89 Hz), 6.18-7.36 (m, 5H).

Cyclopropane from indene: Yield 51%, *trans* : *cis* = 81 : 19, R*f* 0.40, 0.32 (hexane : ethyl acetate = 15 : 1). R*t* *trans*-isomers 111.443, 113.750 min, *cis*-isomers: 80.203, 86.030 min (SE-30 50 m, 200 °C, constant). ^{1}H-NMR (500 MHz, $CDCl_3$): *trans*-isomers δ 0.77 (d, *J* = 7.02 Hz, 2.28H), 0.78 (d, *J* = 7.02 Hz, 0.72H), 0.85-1.07 (m, 9H), 1.19-1.20 (m, 1H), 1.34-1.36 (m, 1H), 1.50-1.5 2 (m, 1H), 1.63-1.69 (m, 1H), 1.89-1.90 (m, 1H), 2.01-2.14 (m, 1H), 2.92 (d, *J* = 6.62 Hz), 2.95 (d, *J* = 6.62 Hz), 3.05 (d, *J* = 17.40 Hz, 1H), 3.26 (dd, *J* = 6.41, 17.40 Hz, 1H), 4.68 (dt, *J* = 10.99, 4.27 Hz, 1H), 7.12-7.17 (m, 3H), 7.36-7.37 (m, 1H), *cis*-isomers δ 0.43 (d, *J* = 7.02 Hz, 3H), 0.61-0.92 (m, 9H), 1.09-1.70 (m, 5H), 1.97-2.03 (m, 1H),

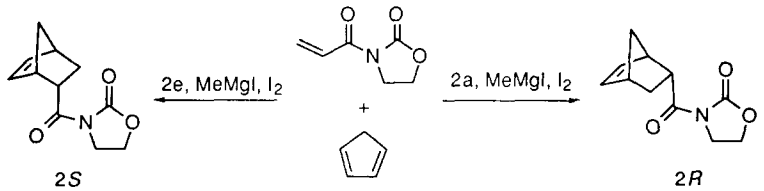
2.22-2.27 (m, 1H), 2.90-2.96 (m, 1H), 3.16-3.22 (m, 1H), 3.43 (d, J = 17.09 Hz, 1H), 4.30-4.50 (m, 1H, including at 4.38 ppm, dt, J = 10.68, 4.27 Hz, and at 4.41 ppm, dt, J = 10.99, 3.97 Hz), 7.08-7.20 (m, 3H), 7.25-7.32 (m, 1H). IR ($CHCl_3$) 2950, 2925, 1710 cm^{-1}. MS(EI) *m/z* (relative intensity) 312(23), 196(10), 175(95), 157(97), 130(100), 115(46), 95(87), 81(90), 69(72), 57(100). Calcd for $C_{21}H_{28}O_2$: 312.2090. Found: 312.2075.

***d*-Menthyl 2-(4-methoxyphenyl)cyclopropropane-1-carboxylate (Cyclopropane from anethol)** : Yield 29%, *trans : cis* = 81 : 19, R*f* 0.38, 0.33 (hexane : ethyl acetate = 15 : 1). R*t* *trans*-isomer 72.990, 91.016 min (SE-30 50 m, 200 °C constant), *cis*-isomer 183.320, 187.773 min (FFAP 50 m, 160 °C, constant). ^{1}H-NMR (500 MHz, $CDCl_3$): δ *trans*-isomers 0.70 (d, J = 7.32 Hz, 0.54 H), 0.76 (d, J = 7.32 Hz, 2.46H), 0.88-1.10 (m, 1H), 1.30 (d, J = 6.11 Hz, 0.54H), 1.32 (d, J = 6.10 Hz, 2.46H), 1.36-1.99 (m, 16H), 2.35-2.38 (m, 1H), 3.78 (s, 3H), 4.70-4.82 (m, 1H including at 4.72 ppm, dt, J = 4.27, 10.98 Hz and at 4.78 ppm, dt, J = 4.27, 10.98 Hz), 6.80-6.83 (m, 2H), 7.00-7.02 (m, 2H), *cis*-isomers δ 0.46-2.07 (m, 23H incruding at 0.47 ppm, d, J = 6.93 Hz, at 0.65 ppm, d, J = 6.93 Hz, and at 1.25 ppm, dd, J = 1.65, 5.94 Hz), 2.25-2.32 (m, 1H), 3.76 (s, 3H), 4.35-4.50 (m, 1H incruding at 4.40 ppm, dt J = 4.29, 10.88 Hz and at 4.47 ppm, dt J = 4.62, 10.89 Hz), 6.78 (dd, 2H, J = 2.31, 8.90 Hz), 7.13 (dd, 2H, J = 2.97, 8.90 Hz). IR ($CHCl_3$) 2950, 2925, 1710, 1520, 1170 cm^{-1}. MS(EI) *m/z* (relative intensity), 344(12), 206(100), 189(15), 161(84), 149(19), 121(16), 83(41), 69(28), 55(45). Calcd for $C_{22}H_{32}O_3$:344.2351. Found: 344.2324.

Reference and Notes:

1. a) Salaün, J. *Chem. Rev.* **1989**, *89*, 1247-1270. b) Doyle, M. P. *Chem. Rev.* **1986**, *86*, 919-939. c) Doyle, M. P. *Recl. Trav. Chim. Pay-Bas* **1991**, *110*, 305-316.
2. a) Nozaki, H.; Moriuchi, S.; Takaya, H.; Noyori, R. *Tetrahedron Lett.* **1966**, 5239-5242. b) Nozaki, H.; Moriuchi, S.; Takaya, H.; Noyori, R. *Tetrahedron* **1968**, *24*, 3655-3669.
3. Copper catalyzed asymmetric cyclopropanation; a) Aratani, T.; Yoneyoshi, Y.; Nagase, T. *Tetrahedron Lett.* **1975**, 1707-1710. b) Aratani, T.; Yoneyoshi, Y.; Nagase, T. *Tetrahedron Lett.* **1977**, 2599-2602. c) Aratani, T. *Pure Appl. Chem.* **1985**, *57*, 1839-1844. d) Aratani, T.; Yoneyoshi, Y.; Nagase, T. *Tetrahedron Lett.* **1982**, *23*, 685-688. e) Müller, D.; Umbricht, G.; Weber, B.; Pfaltz, A. *Helv. Chim. Acta* **1991**, *74*, 232-240. f) Leutengger, U.; Umbricht, G. Fahrni, C.; von Matt, P.; Pfaltz, A. *Tetrahedron* **1992**, *48*, 2143-2156. g) Lowenthal, R. E.; Abiko, A.; Masamune, S. *Tetrahedron Lett.* **1990**, *31*, 6005-6008. h) Ito, K.; Katuki, T. *Tetrahedron Lett.* **1993**, *34*, 2661-2664. i) Ito, K.; Katuki, T. *Synlett* **1993**, 638-640. j) Ito, K.; Katuki, T. *Chem. Lett.* **1994**, 1857-1859. k) Kanemasa, S.; Hamura, S.; Harada, E.; Yamamoto, H. *Tetrahedron Lett.* **1994**, *35*, 7985-7988. l) Gant, T. G.; Noe, M. C.; Corey, E. J. *Tetrahedron Lett.* **1995**, *36*, 8745-8748. m) Austin, R. E.; Dalmann, C. J.; Muller, P. *J. Am. Chem. Soc.* **1991**, *113*, 1423-1424. n) Abram, D. M. H.; Zhou, Z. *J. Chem. Soc. Chem. Commun.* **1984**, 1038-1040. o) Dammast, F.; Reißig, H. -U. *Chem. Ber.* **1993**, *126*, 2449-2456. and the references sited therein.
4. a) Doyle, M. P.; Protopopova, M. N.; Pouller, C. D; Rogers, D. H. *J. Am. Chem. Soc.* **1995**, *117*, 7281-7282. b) Doyle, M. P.; Kalinin, A. V. *Tetrahedron Lett.* **1996**, *37*, 1371-1374.
5. Fukuda, T; Katsuki, T. *Synlett* **1995**, 825-826.

6. Nishiyama, H.; Itoh, Y.; Matsumoto, H.; Park, S. -B.; Itoh, K. *J. Am. Chem. Soc.* **1994**, *116*, 2223-2224.
7. Fritschi, H.; Leutenegger, U.; Pfaltz, A. ; Keller, W.; Kratky, C. *Helv. Chim. Acta* **1988**, *71*, 1553-1565.
8. Evans, D. A.; Woerpel, K. A.; Hinmann, M. M.; Faul, M. M. *J. Am. Chem. Soc.* **1991**, *113*, 726-728.
9. Fujisawa, T.; Ichiyanagi, T.; Shimizu, M. *Tetrahedron Lett.* **1995**, *36*, 5031-5034.
10. a)Dawson, G. J.; Frost, C. G.; Williams, J. M. J. *Tetrahedron Lett.* **1993**, *34*, 3149-3152. b) Allen, J. V.; Dawson, G. J.; Frost, C. G.; Williams, J. M. J.; Coote, S. J. *Tetrahedron* **1994**, *50*, 799-808.
11. Fritschi, H.; Leutenegger, U.; Siegmann, K.; Pfaltz, A. *Helv. Chim. Acta* **1988**, *71*, 1541-1552.
12. In the reaction of 3-acryloyl-1,3-oxazolidin-2-one and cyclopentadiene, the use of chiral ligand **1a** gave the 2*R*-cycloadduct but the use of Tf derivative **1e** gave the 2*S*-adduct predominantly.



Ichiyanagi, T.; Shimizu, M.; Fujisawa, T. *J. Org. Chem.* submitted for publication.
13. Nakamura, A.; Konishi, A.; Tsujitani, R.; Kudo, M.; Otsuka, S. *J. Am. Chem. Soc.* **1978**, *100*, 3449-3461.
14. Salomon, R. G.; Kochi, J. K. *J. Am. Chem. Soc.* **1973**, *95*, 3300-3310.
15. Regitz, M; Maas, G. *Diazo Compounds*; Academic press: New York, 1986.
16. Regitz, M.; Hocker, J.; Liedhegener, A. *Org. Synth.* **1973**, *Col. vol. 5*, 179-183.
17. Doyle, M. P.; Bagheri, V.; Wandless, T. J.; Harn, N. K.; Brinker, D. A.; Eagle, C. T.; Loh, K.-L. *J. Am. Chem. Soc.* **1990**, *112*, 1906-1912.
18. McKennon, M. J.; Meyers, A. I.; Dranz, K. Schwarm, M. *J. Org. Chem.* **1993**, *58*, 3568-3571.
19. Nakamura, A.; Konishi, A.; Tatsuno, Y.; Otsuka, S. *J. Am. Chem. Soc.* **1978**, *100*, 3443-3448.

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