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PPh_3 Mediated Reductive Annulation Reaction between Isatins and Electron Deficient Dienes to Construct Spirooxindole Compounds

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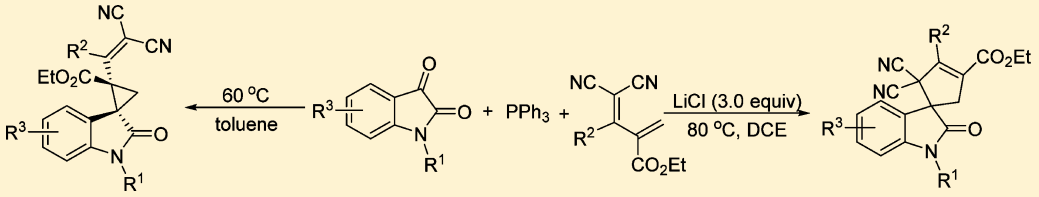
Supporting Information

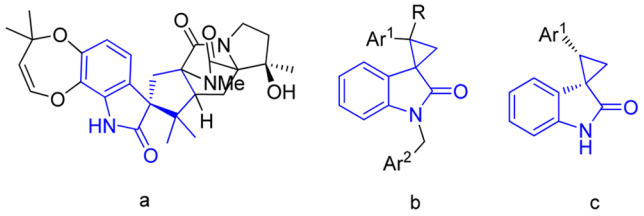


ABSTRACT: A PPh_3 mediated reductive annulation reaction between isatins and 4,4-dicyano-2-methylenebut-3-enoates was developed. The reaction provided an alternative method for constructing five- and three-membered all-carbon spirooxindole compounds. Lithium chloride as a Lewis acid played a key role in the synthesis of spirocyclopentenyl oxindole compounds.

INTRODUCTION

Spirooxindole moiety is an important framework present in a variety of pharmaceutical molecules[1] and natural products.[2] As representative compounds, compound **a** in Scheme 1 is a natural product that contains the spirooxindole framework, while compounds **b** and **c** are two pharmaceutical molecules which show distinct antitumor activities[1] because the strained spiro-cyclopropane at the C3 position of oxindoles plays an important role in their biological activities. So far, the spirooxindole framework has attracted great interest from chemists due to its biological importance and the challenge of its synthesis.[3] Isatins have been widely used as raw materials in the synthesis of spirooxindole compounds;[4] however, to the best of our knowledge, isatins are rarely reported as a C1 synthon in the construction of all-carbon spirooxindole compounds[5] because the deoxygenation step is needed.

Scheme 1. Representative Natural Products and Pharmaceutical Molecules



In the early reports, α-dicarbonyl compounds could be reduced by phosphine[6] with one of the carbonyls deoxygenated, and a carboxylic ester could be synthesized by a reductive coupling of α-keto ester with a carboxylic acid.[7] It is commonly believed that either a five-coordinate 1,3,2-dioxaphospholene intermediate or a dipolar ion (a in Scheme 2) is formed between the α-dicarbonyl compound and phosphine.[8] In our preliminary study, it was found that isatins could undergo a reductive coupling reaction at the C3 position with a carboxylic acid, and a benzoate at C3 position of isatins could be obtained, which also proved that a Kukhtin−Ramirez intermediate was formed between the *N*-methyl protected isatin and triphenylphosphine (a in Scheme 2).[7c,8b] In this process, the intermediate underwent a two-step process: first, the intermediate accepted a proton from the acid, and then the carboxylic ion attacked the C−O bond of the intermediate. Triphenylphosphine oxide departed, and the ester was finally formed. Considering the feature of the above reaction, this intermediate of isatins might have potential in the synthesis of spirooxindole compounds with another synthon. With our ongoing interest in the exploration of heterocyclic scaffold construction through organocatalysis,[9] we used triphenylphos-

Scheme 2. Different PPh_3 Involved Intermediates

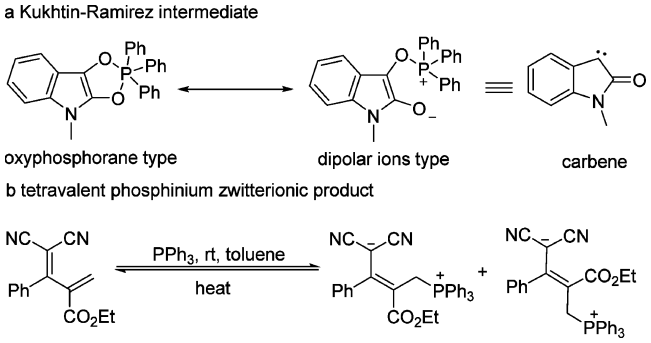


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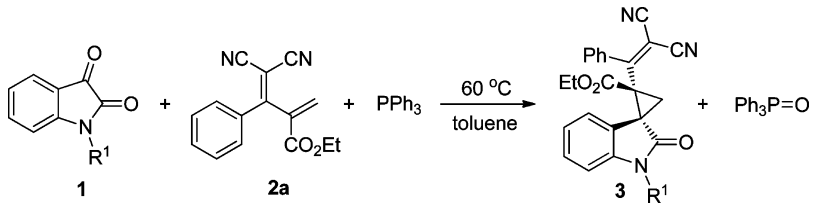
Table 1. Scope of N-Protected Isatins[a]



entry	R^1	P reagent	temp (°C)	time (h)	dr[b]	yield[c](%)
1	Me	PPh_3	60	24	>20:1	20
2	Boc	PPh_3	60	24		n.r.
3	Ac	PPh_3	60	20	>20:1	51
4	Bn	PPh_3	60	42	>20:1	73
5	Ts	PPh_3	60	24	6:1	83
6	Ts	$P(NMe_2)_3$	0	1	6:1	32
7	Ts	PBu_3	60	6	6:1	43
8	Ts	Ph_2MeP	60	14	6:1	51

[a]Standard procedure: substrate **1** (0.15 mmol) and substrate **2a** (0.1 mmol) were added into a reaction tube containing the solvent (0.6 mL); PR_3 solution (1.5 equiv) in the solvent (0.4 mL) was then added slowly into the tube with stirring at room temperature under N_2 atmosphere, and then the reaction tube was heated at 60 °C in an oil bath with the reaction monitored by TLC. [b]Determined by ^{1}H NMR analysis. [c]Isolated yield of the major product.

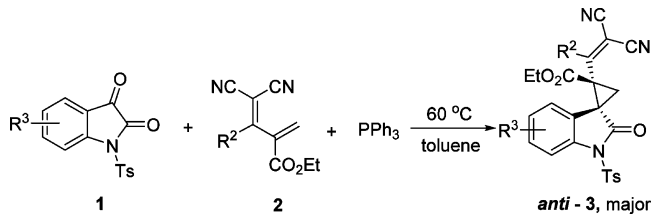
phine as a deoxygenation regent and developed a new reaction in which isatins could react directly with electron deficient dienes and produce various spiro-oxindole compounds.

RESULTS AND DISCUSSION

In our initial investigation, ethyl 4,4-dicyano-2-methylene-3-phenylbut-3-enoate **2a**,[10,11] PPh_3, and an *N*-methyl protected isatin were used as substrates. When stoichiometric amount of PPh_3 was added, a yellow solid of tetravalent phosphinium zwitterion (b in Scheme 2) was formed immediately. An unexpected cyclopropanation compound was produced after heating for 24 h (Table 1, entry 1). The cyclopropanation product could also be obtained with the separated tetravalent phosphinium zwitterions and the *N*-methyl protected isatin under the same conditions. To improve the efficiency of this process, a series of N-protected isatins were tested. When the electron donating group protected isatins were used, the dimerization of isatins was observed; phosphorus ylides of isatins were also formed in the reaction system, and the excessive PPh_3 was consumed by isatins. Finally, it was found that tosyl group was the best N-protection group for the reaction (Table 1, entries 1−5). The solvents were then screened, and it was found that toluene performed the best. Polar protic solvents were not favorable for this process, and no product was observed when MeOH was used as the solvent (see Supporting Information, Table S1). Other polar solvents showed moderate yields in this process. Further tests showed that PPh_3 was the optimal trivalent phosphorus reagent; $P(NMe_2)_3$ (Table 1, entry 6) could cause side reactions due to its high activity, and PBu_3 and $MePh_2P$ produced only moderate yields (Table 1, entries 7 and 8).

The generality of this reductive cyclopropanation was further explored under the optimized conditions. A variety of substituted dienes **2** (Table 2) were tested to react with *N*-tosyl protected isatin. Dienes **2** with the electron-donating and electron-withdrawing group substituted phenyls performed differently in this cyclopropanation reaction. Dienes **2** with electron-donating group substituted phenyls afforded the products in high yields (Table 2, entries 11 and 12), while those with electron deficient aryl groups provided moderate

Table 2. Substrate Scope of the Cyclopropanation Reaction[a]



entry	R^2	R^3	time (h)	dr[b]	yield[c](%)
1	Ph (**2a**)	H (**1a**)	20	6:1	**3a**, 83
2	2-MeC_6H_4 (**2b**)	H	20	6:1	**3b**, 75
3	3-MeC_6H_4 (**2c**)	H	20	10:1	**3c**, 90
4	4-MeC_6H_4 (**2d**)	H	20	6:1	**3d**, 83
5	4-$OMeC_6H_4$ (**2e**)	H	32	8:1	**3e**, 80
6	2-FC_6H_4 (**2f**)	H	20	>20:1	**3f**, 66
7	2-ClC_6H_4 (**2g**)	H	72	10:1	**3g**, 57
8	3-ClC_6H_4 (**2h**)	H	20	10:1	**3h**, 60
9	4-ClC_6H_4 (**2i**)	H	72	8:1	**3i**, 60
10	4-BrC_6H_4 (**2j**)	H	20	>20:1	**3j**, 52
11	4-*t*-BuC_6H_4 (**2k**)	H	6	>20:1	**3k**, 92
12	3,4-diMe C_6H_3 (**2l**)	H	20	>20:1	**3l**, 95
13	Ph (**2a**)	5-Cl (**1b**)	4	>20:1	**3m**, 96
14	Ph (**2a**)	5-Me (**1c**)	20	10:1	**3n**, 83

[a]Unless noted otherwise, the reaction was operated under the standard procedure A in the Experimental Section. [b]Determined by ^{1}H NMR analysis. [c]Isolated yield of the major product.

yields (Table 2, entries 8−10). Due to the steric hindrance, dienes **2** with the ortho substituted phenyls afforded the products in low yields (Table 2, entries 2, 6, and 7): no cyclopropanation product was isolated with 1-napth-phenyl diene **2**; the furyl substituted diene **2** produced a mixture of cyclporpanation products with dr ratio 1:1, which could not be separated by silicagel column. Dienes **2** with *meta*- and *para*-substituted phenyls did not show any difference in the cyclopropanation reaction (Table 2, entries 8 and 9). The substituent effect of isatins **1** was also investigated. Electron poor isatin produced the product in excellent yield (Table 2, entry 13), and the electron rich group substituted isatin **1** also

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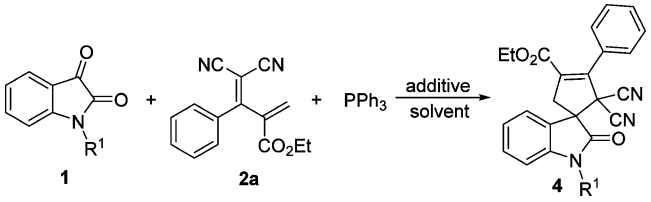
showed good activity in the process (Table 2, entry 14). We believed that isatins with electron-withdrawing groups could form the intermediates[8b] more easily and therefore cause less side reactions of isatins.

When we were optimizing the conditions for the cyclopropanation process, several Lewis acids were also tested to improve the yield. However, when anhydrous LiCl was used as an additive, the expected cyclopropanation did not occur: a cyclopentene annulation product was produced instead. Further research showed that only lithium salt was favorable for this reaction; other Lewis acids such as scandium trifluoromethanesulfonate and magnesium trifluoromethanesulfonate gave only cyclopropanation products. This is probably because the coordination between lithium and PPh_3 was weaker than those between other Lewis acids and PPh_3. With this interesting result obtained, we started to optimize the conditions of this [4 + 1] annulation reaction. It was found that an excessive amount of lithium salt was needed to improve the yield (Table 3), DCE was the optimal solvent, and 80 °C

Table 3. Screening of Additives



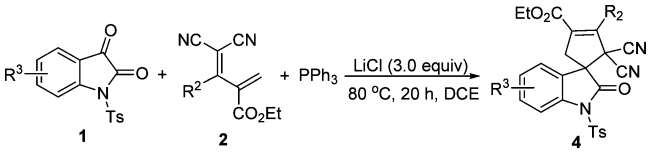
entry	R^1	additives (equiv)	solvent	temp (°C)	time (h)	yield[a] (%)
1	Me	LiCl (0.2)	toluene	70	20	18
2	Ts	LiCl (0.2)	toluene	70	20	55
3	Ts	LiCl (2.0)	toluene	70	20	66
4	Ts	LiBr (2.0)	toluene	70	20	65
5	Ts	$LiBF_4$ (2.0)	toluene	70	20	21
6	Ts	LiOH (2.0)	toluene	70	20	n.r.
7	Ts	LiCl (3.0)	toluene	80	20	68
8	Ts	LiCl (3.0)	DCE	80	20	83
9	Ts	LiCl (3.0)	toluene	100	20	57
10	Ts	LiCl (3.0)	DCE	100	20	75

[a]Isolated yield of the major product.

was the most favorable temperature. Only small amount of cyclopropanation product was produced in the initial stage, and under the reaction conditions, the cyclopropanation product rearranged to form cyclopentene. An array of aryl substituted ethyl 4,4-dicyano-2-methylene-3-phenylbut-3-enoates **2** was used to construct the cyclopentene annulation products (Table 4). The results showed that substrates **2** with electron deficient group substituted phenyls (Table 4, entries 4 and 5) and the furan substituted substrate (Table 4, entry 6) resulted in moderate yields, while substrates **2** with electron rich group substituted phenyls (Table 4, entries 2, 3, 7, and 8) resulted in high yields. The electron deficient substrates **2** showed reactivities in cyclopentene annulation processes lower than those in the cyclopropanation reactions.

All of the cyclopropanation and cyclopentene annulation products were characterized by ^1H, ^{13}C NMR, and HRMS-ESI measurements. The structures of representative cyclopropanation and cyclopentene annulation products were determined by single-crystal X-ray diffraction analysis (CCDC no. 1424174 for **3j** and 1424175 for **4a**). The major diastereomers of

Table 4. Substrate Scope of the [4 + 1] Annulations[a]



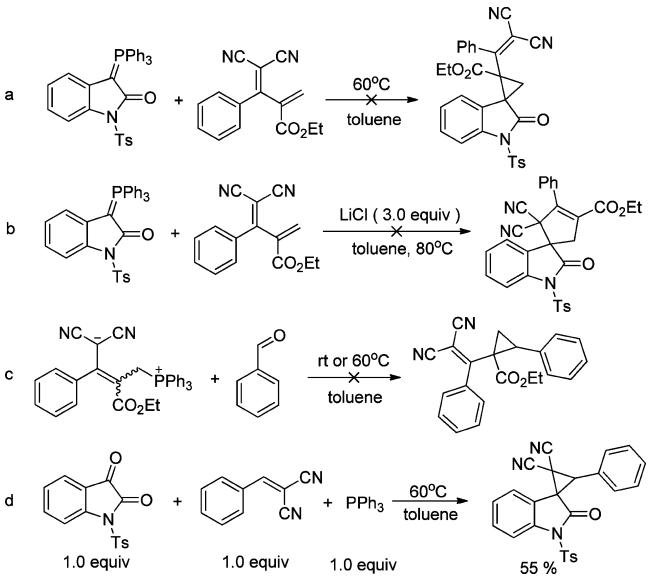
entry	R^2	R^3	yield[b] (%)
1	Ph (**2a**)	H (**1a**)	**4a**, 83
2	4-Me-C_6H_4 (**2d**)	H	**4d**, 77
3	4-OMe-C_6H_4 (**2e**)	H	**4e**, 78
4	3-Cl-C_6H_4 (**2h**)	H	**4h**, 60
5	3-Br-C_6H_4 (**2o**)	H	**4o**, 65
6	2-furyl (**2p**)	H	**4p**, 58
7	4-*t*-Bu-C_6H_4 (**2k**)	H	**4k**, 76
8	3,4-diMe-C_6H_3 (**2l**)	H	**4l**, 70
9	Ph	5-Cl (**1b**)	**4m**, 86
10	Ph	5-Me (**1c**)	**4n**, 81

[a]Unless noted otherwise, the reaction was operated under the standard procedure B in the Experimental Section. [b]Isolated yield of the major product.

cyclopropantion compounds were made in analogy with representative **3j**.

During our study, efforts were also made to understand the reaction mechanism. The N-protected isatin and triphenylphosphine can generate phosphorus ylide (as in Scheme 5, A), and the ylide may attack substrate **2** via a tandem S_N2 Michael addition to form product either **3** or **4**. However, it was found that the phosphorus ylide of N-protected isatin did not react with substrate **2** under either standard procedure A (a in Scheme 3) or standard procedure B (b in Scheme 3), and the

Scheme 3. Mechanism Study



tetravalent phosphinium zwitterions (b in Scheme 2) did not react with benzaldehyde (c in Scheme 3) either. These experiments demonstrated that the reaction did not occur by a phosphorus ylide intermediate mechanism or a wittig reaction mechanism, and further experiments showed that N-protected isatin reacted with 2-benzylidenemalononitrile to produce a cyclopropanation product under the standard procedure A (d

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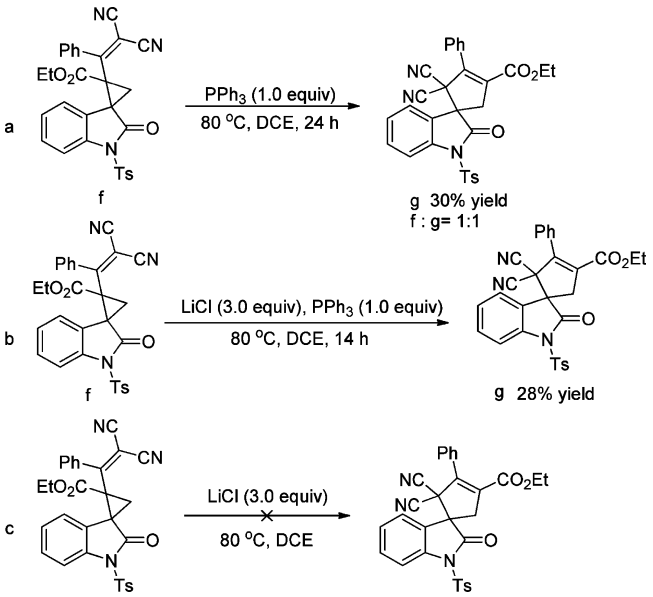
in Scheme 3), which suggested that the reaction might proceed via a Michael addition process.

Further investigation proved that the isolated cyclopropanation product could be rearranged by PPh_3 in DCE, and the rearrangement reached equilibrium by using PPh_3 after heating for 24 h (a in Scheme 4). On the contrary, using both lithium chloride and PPh_3 resulted in a complete conversion: **f** completely disappeared even though the isolated yield of the product **g** was only 28% (b in Scheme 4). No rearrangement was observed using lithium chloride alone (c in Scheme 4). The rearrangement was not observed at 60 °C in the cyclopropanation process either; the reason might be that the low temperature was not favorable for the rearrangement. The rearrangement proceeded under the standard procedure B in a yield of only 28% (b in Scheme 4), and most of the spirocyclopropane was decomposed in this process, which proved that the main reaction pathway of the cyclopentene product is not the rearrangement of cyclopropanation product.

Scheme 4. Rearrangement Investigation

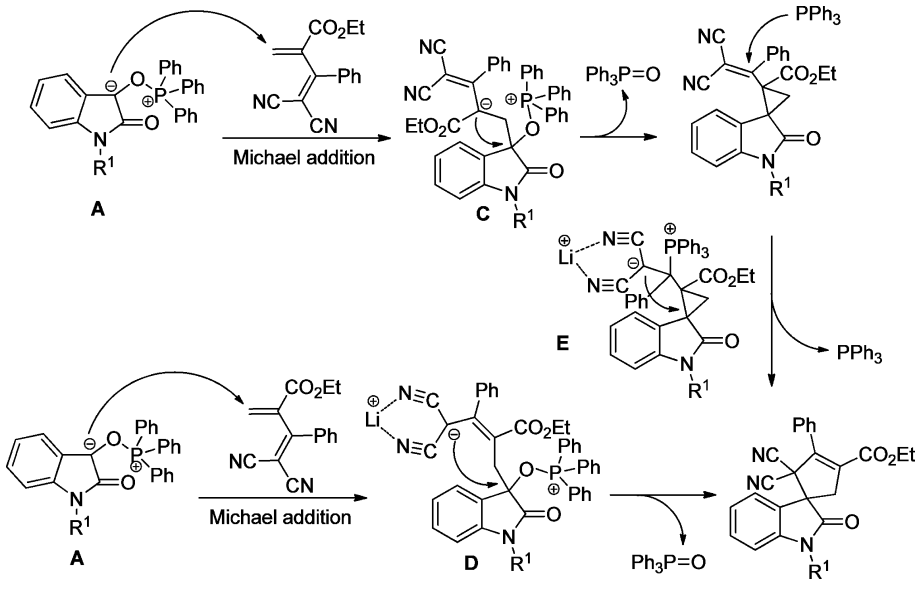


On the basis of this study and the early related reports,[5,8] a reasonable mechanism for the cyclopropanation and [4 + 1]-type annulation process is proposed (Scheme 5). First, isatins and triphenylphosphine form the unstable intermediate **A** in the solvent. In the cyclopropanation process, **A** reacts with substrate **2** by a Michael addition process to produce the carbanion **C**, and **C** then undergoes the replacement reaction via an intramolecular S_N2 process where the C−O bond is broken, triphenylphosphine oxide departs, and the cyclopropanation product is formed. In the [4 + 1]-type annulation process, the carbanion **C** formed after the Michael addition is stabilized by Li^+ to afford the new carbanion **D** (*E*-isomer is favorable). An intramolecular S_N2 process occurs in **D** with the C3 position on the indole ring of **A** attacked by Li^+ activated diene; then, triphenylphosphine oxide departs, and the cyclopentene annulation product is formed. In the Li^+ promoted rearrangement process, PPh_3 attacks the electron deficient olefinic bond of cyclopropanation product to form carbanion **E**, and then another intramolecular S_N2 process occurs in **E** with the C−C bond of cyclopropane attacked, thereby opening the ring. PPh_3 is then eliminated, and the cyclopentene is obtained. According to our study, the cyclopentene product is mainly produced via carbanion **D**, not carbanion **E**.

CONCLUSION

In conclusion, we developed an alternative method to construct spirocyclopropyl oxindole compounds and spirocyclopentenyl oxindole compounds. PPh_3 acted as a reductant and activated electronic deficient olefinic bonds in the rearrangement process. Lithium chloride as a Lewis acid activated 4,4-dicyano-2-methylenebut-3-enoates in the [4 + 1] annulation process. In addition, a plausible reaction mechanism was proposed, and the key intermediate of this reaction was proved to be the Kukhtin−Ramirez intermediate.

Scheme 5. Proposed Mechanism



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EXPERIMENTAL SECTION

All reagents were purchased from commercial vendors and used as received unless otherwise noted. 1,2-Dichloroethane was dried over P_2O_5 for 12 h prior to use. Toluene was dried over sodium. ^1H, ^{13}C, and ^{31}P NMR spectra were recorded on a Bruker JNM-ECS 400M. ^1H NMR chemical shifts are given in ppm with respect to the solvent residual peak ($CDCl_3$, δ = 7.26); ^{13}CNMR shifts are given in ppm with respect to $CDCl_3$ (δ = 77.2 ppm), and ^{31}P shifts are given in ppm with respect to an external sample of 85% H_3PO_4 (δ = 0.0). HRMS spectra were acquired in the ESI mode (positive ion) with the mass analyzer of Obitrap used. Coupling constants are reported as J values in Hz. Column chromatography was performed using 200−300 mesh silica gel as the stationary phase. 4,4-Dicyano-2-methylenebut-3-enoate **2** was prepared according to a procedure in the literature.[11a] *N*-Tosyl protected isatin **1** was prepared according to the procedure below: isatin (1.47 g) was dissolved in DMF (10 mL) in a 50 mL round-bottom flask at 0 °C, and sodium hydride (0.48 g) was added slowly into the flask. After the mixture was stirred for 1 h, tosyl chloride (2.28 g) was added slowly into this flask, and the mixture was then stirred for 3 h at room temperature. Then, the flask was heated at 70 °C for 8 h, removed from the heat, and cooled to room temperature; water was then added into the mixture, and the product was precipitated, filtrated under reduced pressure, and washed with EtOH and Et_2O. *N*-Tosyl protected isatin was obtained in 90% yield.

Standard procedure A: *N*-tosyl protected isatin **1** (0.15 mmol) and 4,4-dicyano-2-methylenebut-3-enoate **2** (0.1 mmol) were added into toluene (1 mL) in a reaction tube. PPh_3 (0.15 mmol) was then added, and the reaction was heated at 60 °C under N_2 atmosphere and monitored by TLC until the starting material disappeared. The solvent was removed under reduced pressure, and the residue was isolated by silica gel column chromatography (petroleum ether/ethyl acetate 5/1) to give product **3**.

Standard procedure B: *N*-tosyl protected isatin (0.15 mmol) and 4,4-dicyano-2-methylenebut-3-enoate (0.1 mmol) were added into DCE (1 mL) in a flask. PPh_3 (0.15 mmol) and LiCl (0.3 mmol) were then added, and the reaction was heated at 80 °C under N_2 atmosphere for 20 h. The solvent was removed, and the residue was isolated by silica gel column chromatography (petroleum ether/ethyl acetate 4/1) to give product **4**.

Ethyl 2-(2,2-Dicyano-1-phenylvinyl)-2′-oxo-1′-tosylspiro-[cyclopropane-1,3′-indoline]-2-carboxylate (3a). White solid, 44.5 mg, 83% yield; mp 88−90 °C; IR (KBr) cm^{-1}: 2983, 2230, 1734, 1597, 1462, 1380, 1254, 1238, 1190, 1177, 1086, 961, 910, 734, 665, 575, 542; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.11 (d, 2H, J = 8.3 Hz), 8.08 (d, 1H, J = 8.8 Hz), 7.46−7.42 (m, 2H), 7.54−7.49 (m, 5H), 7.39 (d, 1H, J = 7.0 Hz), 7.37 (d, 1H, J = 6.5 Hz), 7.14 (t, 1H, J = 7.6 Hz), 4.39−4.18 (m, 2H, CH_2), 2.76 (d, 1H, J = 5.6 Hz), 2.49 (s, 3H), 1.71(d, 1H, J = 5.5 Hz), 1.19 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.3, 169.8, 164.1, 146.5, 140.7, 134.8, 134.1, 132.1, 129.8, 129.7, 129.0, 128.8, 128.2, 124.6, 123.9, 122.8, 113.8, 112.3, 111.8, 90.6, 64.0, 47.0, 44.2, 27.5, 21.8, 13.9; HRMS (ESI) calcd for $C_{30}H_{23}N_3O_5S_1Na_1$ $[M + Na]^+$: 560.1251; found: 560.1245.

Ethyl 2-(2,2-Dicyano-1-(*o*-tolyl)vinyl)-2′-oxo-1′-tosylspiro-[cyclopropane-1,3′-indoline]-2-carboxylate (3b). White solid, 41.3 mg, 75% yield; mp 158−160 °C; IR (KBr) cm^{-1}: 2925, 2853, 2232, 1733, 1598, 1462, 1381, 1253, 1238, 1190, 1177, 1086, 910, 733, 665, 575, 542 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.14 (d, 1H, J = 8.2 Hz), 8.08 (d, 1H, J = 8.1 Hz), 7.67 (d, 1H, J = 7.3 Hz), 7.45 (d, 2H, J = 8.2 Hz), 7.39 (t, 3H, J = 8.0 Hz), 7.25 (t, 2H, J = 8.0 Hz), 7.13 (t, 1H, J = 7.6 Hz), 4.35−4.15 (m, 2H, CH_2), 2.71 (d, 1H, J = 5.6 Hz), 2.19 (s, 3H), 2.48 (s, 3H, CH_3), 1.80 (d, 1H, J = 5.6 Hz), 1.19 (t, 3H, J = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.4, 170.2, 163.7, 146.5, 140.6, 134.6, 134.1,131.2, 131.1, 130.1, 129.9, 129.8, 128.9, 128.1, 124.48, 124.46, 122.8, 122.7, 113.8, 111.7, 111.5, 94.6, 63.9, 47.6, 44.2, 25.6, 21.8, 20.0, 13.8; HRMS (ESI) calcd for $C_{31}H_{26}N_3O_5S_1$ $[M + H]^+$: 552.1588; found: 552.1583.

Ethyl 2-(2,2-Dicyano-1-(*m*-tolyl)vinyl)-2′-oxo-1′-tosylspiro-[cyclopropane-1,3′-indoline]-2-carboxylate (3c). White solid, 52.4 mg, 95% yield; mp 158−160 °C; IR (KBr) cm^{-1}: 2983, 2961, 2257, 2230, 1734, 1598, 1463, 1381, 1239, 1190, 1177, 1086, 962, 910, 734, 665, 575, 542; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.11 (d, 2H, J = 8.2 Hz), 8.07 (d, 1H, J = 8.2 Hz), 7.46−7 0.42 (m, 2H), 7.40−7.33 (m, 4H), 7.28 (s, 2H), 7.14 (t, J = 7.6 Hz), 4.40−4.18 (m, 2H), 2.77 (d, 1H, J = 5.7 Hz), 2.49 (s, 3H), 2.44 (s, 3H), 1.73 (d, 1H, J = 5.7 Hz), 1.18 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.3, 169.9, 164.2, 146.5, 140.6, 139.0, 134.8, 134.1, 133.0, 129.8, 128.9, 128.8, 128.5, 125.4, 124.5, 122.92, 122.87, 113.8, 112.4, 111.9, 90.4, 63.9, 47.0, 44.0, 27.5, 21.8, 21.4, 13.9; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_5S_1Na_1$ $[M + Na]^+$: 574.1407; found: 574.1403.

Ethyl 2-(2,2-Dicyano-1-(*p*-tolyl)vinyl)-2′-oxo-1′-tosylspiro-[cyclopropane-1,3′-indoline]-2-carboxylate (3d). White solid, 45.7 mg, 83% yield, mp 162−164 °C; IR (KBr) cm^{-1}: 2984, 2950, 2256, 2229, 1734, 1606, 1574, 1553, 1462, 1380, 1255, 1237, 1190, 1177, 1086, 961, 909, 815, 753, 732, 665, 574, 542; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.11−8.06 (m, 3H), 7.44 (d, 2H, J = 8.0 Hz), 7.36−7.40 (m, 4H), 7.33 (d, 2H, J = 7.6 Hz), 7.14 (t, 1H, J = 7.5 Hz), 4.36−4.18 (m, 2H), 2.77 (d, 1H), 2.49 (s, 3H), 2.43 (s, 3H), 1.73 (d, 1H, J = 5.4 Hz), 1.17 (t, 3H, J = 7.0 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.2, 169.7, 164.3, 146.5, 143.3, 140.6, 134.0, 132.0, 129.8, 129.77, 129.7, 128.8, 128.3, 124.5, 122.91, 122.86, 113.8, 112.7, 112.0, 89.4, 63.9, 47.0, 44.0, 27.6, 21.8, 21.7, 13.9; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_5S_1Na_1$ $[M + Na]^+$: 574.1407; found: 574.1401.

Ethyl 2-(2,2-Dicyano-1-(4-methoxyphenyl)vinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3e). White solid, 45.3 mg, 80% yield, mp 68−70 °C; IR (KBr) cm^{-1}: 2982, 2934, 2256, 2227, 1733, 1603, 1510, 1494, 1462, 1381, 1262, 1238, 1189, 1177, 1153, 1086, 1027, 961, 909, 837, 733, 665, 575, 542; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.09 (d, 2H, J = 8.4 Hz), 8.06 (d, 1H, J = 8.4 Hz), 7.50 (d, 2H, J = 8.8 Hz), 7.44−7.35 (m, 4H), 7.13 (t, 1H, J = 7.6 Hz), 6.99 (d, 2H, J = 8.9 Hz), 4.37−4.16 (m, 2H), 3.87 (s, 3H), 2.78 (d, 1H, J = 5.6 Hz), 2.48 (s, 3H), 1.74 (d, 1H, J = 5.6 Hz), 1.17 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.2, 168.7, 164.4, 162.9, 146.4, 140.6, 134.1, 131.2, 130.6, 129.7, 128.8, 127.0, 124.4, 123.0, 122.8, 114.4, 113.8, 113.0, 112.3, 87.7, 63.8, 55.5, 46.9, 43.8, 27.8, 21.7,13.9; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_6S_1Na_1$ $[M + Na]^+$: 590.1356; found: 590.1348.

Ethyl 2-(2,2-Dicyano-1-(2-fluorophenyl)vinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3f). White solid, 36.8 mg, 66% yield, mp 163−165 °C; IR (KBr) cm^{-1}: 2984, 2926, 2257, 2232, 1736, 1610, 1462, 1381, 1254, 1238, 1190, 1177, 1154, 1087, 962, 909, 754, 733, 665, 576, 542; ^1HNMR (400 MHz, $CDCl_3$, TMS): δ 7.68 (t, 1H, J = 6.4 Hz), 7.58−7.52 (m, 1H), 7.45 (d, 2H, J = 8.2 Hz), 7.42−7.38 (m, 2H), 7.34 (t, 1H, J = 7.6 Hz), 7.19−7.12 (m, 2H), 4.33−4.20 (m, 2H), 2.76 (d, 1H, J = 5.4 Hz), 2.49 (s, 3H), 1.70 (d, 1H, J = 5.4 Hz), 1.20 (t, 3H, J = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.6, 166.6, 163.1, 158.8 (d, $1J_{C-F}$ = 250.4 Hz), 146.6, 140.6, 134.2, 134.1 (d, $3J_{C-F}$ = 8.7 Hz), 131.7, 129.8, 128.9, 124.9 (d, $4J_{C-F}$ = 3.4 Hz), 124.6, 123.2, 122.9, 122.6, 122.5, 116.2 (d, $2J_{C-F}$ = 21.0 Hz), 113.8, 111.7, 111.3, 93.4, 63.7, 47.0, 44.2, 26.4, 21.8, 13.9; HRMS (ESI) calcd for $C_{30}H_{22}F_1N_3O_5S_1Na_1$ $[M + Na]^+$: 578.1156; found: 578.1149

Ethyl 2-(1-(2-Chlorophenyl)-2,2-dicyanovinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3g). White solid, 32.5 mg, 57% yield, mp 164−166 °C; IR (KBr) cm^{-1}: 2984, 2926, 2256, 2234, 1736, 1597, 1463, 1380, 1311, 1238, 1190, 1178, 1087, 962, 910, 812, 733, 665, 575, 541; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.13 (d, 2H, J = 8.3 Hz), 8.08 (d, 1H, J = 8.3 Hz), 7.78 (t, 1H, J = 3.0 Hz), 7.49−7.43 (m, 5H), 7.40 (d, 1H, J = 8.0 Hz), 7.33 (d, 1H, J = 7.6 Hz), 7.14 (t, 1H, J = 7.6 Hz), 4.33−4.14 (m, 2H), 2.78 (d, 1H, J = 5.9 Hz), 2.48 (s, 3H), 1.70 (d, 1H, J = 5.9 Hz) 1.19 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.5, 168.8,163.4, 146.6, 140.5, 134.0, 133.4, 133.2, 132.7, 131.3, 130.3, 129.9, 129.8, 128.9, 127.4, 124.6, 123.1, 122.8, 113.8, 111.6, 111.2, 95.2, 63.7, 47.3, 44.7, 25.8, 21.8,13.9; HRMS (ESI) calcd for $C_{30}H_{22}Cl_1N_3O_5S_1Na_1$ $[M + Na]^+$: 594.0861; found: 594.0855.

Ethyl 2-(1-(3-Chlorophenyl)-2,2-dicyanovinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3h). White solid, 34.2 mg, 60% yield, mp 76−78 °C; IR (KBr) cm^{-1}: 2982, 2927, 2232, 1732, 1603, 1565, 1462, 1385, 1308, 1249, 1179, 1086, 960, 906, 861, 806, 754, 695, 572; ^1H NMR (400 MHz, $CDCl_3$,

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TMS): δ 8.12−8.07 (m, 3H), 7.53−7.51 (m, 1H), 7.49−7.44 (m, 3H), 7.42−7.38 (m, 4H), 7.16 (t, 1H, *J* = 7.6 Hz), 4.40−4.19 (m, 2H), 2.77 (d, 1H, *J* = 5.8 Hz), 2.49 (s, 3H), 1.72 (d, 1H, *J* = 5.8 Hz),1.20 (t, 3H, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.3, 168.4, 163.8, 146.6, 140.6, 136.3, 136.1, 134.0, 132.0, 130.4, 130.0, 129.8, 128.8, 127.7, 126.5, 124.6, 123.1, 122.6, 113.9, 111.8, 111.4, 91.8, 64.2, 46.7, 44.4, 27.3, 21.8, 13.9; HRMS(ESI) calcd for $C_{30}H_{22}Cl_1N_3O_5S_1Na_1$ [M + Na]$^+$: 594.0861; found: 594.0851.

Ethyl 2-(1-(4-Chlorophenyl)-2,2-dicyanovinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3i). White solid, 34.2 mg, 60% yield, mp 82−84 °C; IR (KBr) cm^{-1}: 2935, 2232, 1737, 1598, 1461, 1381, 1243, 1089, 960, 909, 821, 745, 664, 573; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.10−8.06 (m, 3H), 7.49 (d, 2H, *J* = 8.5 Hz), 7.44−7.41 (m, 5H), 7.39−7.36 (m, 1H), 7.15 (t, 1H, *J* = 7.6 Hz), 4.39−4.17 (m, 2H), 2.77 (d, 1H, *J* = 5.7 Hz), 2.49 (s, 3H), 1.69 (d, 1H, *J* = 5.7 Hz), 1.19 (t, 3H, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.3, 168.6, 163.9, 146.6, 140.6, 138.6, 134.0, 133.0, 130.0, 129.8, 129.6, 129.4, 128.8, 124.6, 123.0, 122.6, 113.9, 112.1, 111.6, 90.9, 64.1, 46.7, 44.3, 27.4, 21.8, 13.9; HRMS (ESI) calcd for $C_{30}H_{22}Cl_1N_3O_5S_1Na_1$ [M + Na]$^+$: 594.0861; found: 594.0855.

Ethyl 2-(1-(4-Bromophenyl)-2,2-dicyanovinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3j). White solid, 31.9 mg, 52% yield, mp 81−84 °C; IR (KBr) cm^{-1}: 2983, 2928, 2256, 2230, 1735, 1596, 1585, 1462, 1381, 1237, 1177, 1086, 1010, 961, 813, 752, 665, 574, 542; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): 8.06−8.10 (m, 3H), 7.65 (d, 2H, *J* = 8.32 Hz), 7.44−7.40(m, 3H), 7.39−7.34 (m, 3H), 7.14 (t, 1H, *J* = 7.56 Hz), 4.39−4.18 (m), 2.75 (d, *J* = 5.6 Hz), 2.48 (s, 3H), 1.69 (d, 1H, *J* = 5.6 Hz), 1.19 (t, 3H, *J* = 7.12 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.3, 168.7, 164.0, 146.6, 140.7, 134.1, 133.5, 132.4, 131.4, 130.0, 129.7, 128.8, 127.0, 124.6, 123.0, 122.7, 113.9, 112.1, 111.6, 91.0, 64.1, 46.7, 44.4, 27.4, 21.8, 13.9; HRMS (ESI) calcd for $C_{30}H_{22}Br_1N_3O_5S_1Na_1$ [M + Na]$^+$: 638.0356; found: 638.0350.

Ethyl 2-(1-(4-(*tert*-Butyl)phenyl)-2,2-dicyanovinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3k). White solid, 54.5 mg, 92% yield, mp 178−180 °C; IR (KBr) cm^{-1}: 2966, 2906, 2870, 2256, 2229, 1734, 1605, 1462, 1382, 1255, 1238, 1190, 1177, 1086, 910, 734, 664, 573, 542; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.10 (d, 2H, *J* = 8.4 Hz), 8.07 (d, 1H, *J* = 8.4 Hz), 7.51 (d, 2H, *J* = 8.5 Hz), 7.46−7.41 (m, 4H), 7.40−7.37 (m, 2H), 7.14 (t, 1H, *J* = 7.3 Hz), 4.37−4.16 (m, 2H), 2.78 (d, 1H, *J* = 5.7 Hz), 2.49 (s, 3H), 1.75 (d, 1H, *J* = 5.7 Hz), 1.34 (s, 9H), 1.18 (t, 3H, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.3, 169.5, 169.3, 164.3, 156.3, 146.5, 146.5, 140.7, 134.2, 131.9, 129.8, 129.7, 128.9, 128.3, 126.0, 124.5, 123.0, 123.9, 122.9, 113.8, 112.8, 112.2, 89.2, 63.9, 46.9, 44.0, 35.2, 31.0, 27.8, 21.8, 13.9; HRMS (ESI) calcd for $C_{34}H_{31}N_3O_5S_1Na_1$ [M + Na]$^+$: 616.1877; found: 616.1873.

Ethyl 2-(2,2-Dicyano-1-(3,4-dimethylphenyl)vinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3l). White solid, 53.6 mg, 95% yield, mp 84−86 °C; IR (KBr) cm^{-1}: 2982, 2924, 2256, 2229, 1734, 1605, 1462, 1380, 1256, 1238, 1190, 1177, 1086, 962, 910, 814, 753, 733, 665, 574, 542; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.11 (d, *J* = 8.2 Hz), 8.06 (d, 1H, *J* = 8.2 Hz), 7.45 (d, 2H), 7.35−7.42 (m, 2H), 7.25 (d, 3H, *J* = 4.1 Hz), 7.14 (t, 1H, *J* = 7.6 Hz), 4.17−4.38 (m, 2H), 2.78 (d, 1H, *J* = 5.7 Hz), 2.49 (s, 3H), 2.34 (s, 3H), 2.33 (s, 3H), 1.74 (d, 1H, *J* = 5.7 Hz), 1.17 (t, 3H, *J* = 7.12 Hz,); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.2, 169.7, 164.2, 146.4, 142.1, 140.5, 137.5, 134.0, 132.3, 130.2, 129.7, 129.0, 128.7, 125.9, 124.5, 122.9, 122.8, 113.7, 112.7, 112.1, 89.1, 63.9, 47.0, 43.8, 27.6, 21.8, 20.0, 19.9, 13.9; HRMS (ESI) calcd for $C_{32}H_{27}N_3O_5S_1Na_1$ [M + Na]$^+$: 588.1564; found: 588.1559.

Ethyl 5′-Chloro-2-(2,2-dicyano-1-phenylvinyl)-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3m). White solid, 54.8 mg, 96% yield, mp 176−178 °C; IR (KBr) cm^{-1}: 2983, 2927, 2256, 2231, 1734, 1597, 1582, 1460, 1383, 1254, 1238, 1190, 1178, 1088, 910, 819, 733, 663, 581, 543; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.08 (d, 2H, *J* = 8.1 Hz), 8.02 (d, 1H, *J* = 8.7 Hz), 7.56−7.49 (m, 3H), 7.47−7.45 (m, 4H), 7.41−7.37 (m, 2H), 4.44−4.21 (m, 2H), 2.77 (d, 1H, *J* = 5.7 Hz), 2.50 (s, 3H), 1.74 (d, 1H, *J* = 5.7 Hz), 1.23 (t, 3H, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 169.8, 169.6, 164.0, 146.8, 139.1, 134.5, 133.7, 132.3, 130.3, 129.8, 129.1, 128.9, 128.2, 124.6, 123.5, 114.9, 112.2, 111.8, 90.5, 64.3, 47.2, 43.7, 27.8, 21.8, 13.9; HRMS (ESI) calcd for $C_{30}H_{22}Cl_1N_3O_5S_1Na_1$ [M + Na]$^+$: 594.0861; found: 594.0853

Ethyl 2-(2,2-Dicyano-1-phenylvinyl)-5′-methyl-2′-oxo-1′-tosylspiro[cyclopropane-1,3′-indoline]-2-carboxylate (3n). White solid, 45.1 mg, 82% yield, mp 160−162 °C; IR (KBr) cm^{-1}: 2961, 2927, 2257, 1754, 1719, 1596, 1485, 1383, 1262, 1237, 1191, 1178, 1021, 911, 815, 734, 664, 569, 545; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.09 (d, 1H, *J* = 8.2 Hz), 7.94 (d, 1H, *J* = 8.4 Hz), 7.55−7.50 (m, 5H), 7.44 (d, 2H, *J* = 8.2 Hz), 7.20 (d, 1H, *J* = 8.4 Hz), 7.16 (s,1H), 4.40−4.18 (m, 2H), 2.74 (d, 1H, *J* = 5.6 Hz), 2.48 (s, 3H), 2.32 (s, 3H), 1.69 (d, 2H, *J* = 5.6 Hz), 1.20 (t, 3H, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 170.4, 170.0, 164.2, 146.4, 138.2, 134.7, 134.3, 134.1, 132.1, 130.3, 129.8, 128.7, 128.2, 123.4, 122.8, 113.5, 112.4, 111.8, 90.4, 64.0, 46.9, 44.1, 27.5, 21.8, 21.2, 13.9; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_5S_1Na_1$ [M + Na]$^+$: 574.1407; found: 574.1404

Ethyl 2,2-Dicyano-2′-oxo-3-phenyl-1′-tosylspiro-[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4a). Red solid, 44.5 mg, 83% yield, mp 202−204 °C; IR (KBr) cm^{-1}: 2979, 2959, 2869, 2249, 2230, 1958, 1755, 1730, 1605, 1596, 1465, 1374, 1326, 1239, 1226, 1179, 1157, 1102, 1088, 1018, 962, 767, 717, 666, 572, 545; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, *J* = 8.3 Hz), 8.00 (d, 2H, *J* = 8.4 Hz), 7.56−7.52 (m, 1H), 7.47−7.43 (m, 5H), 7.35−7.31 (m, 3H), 4.07 (q, 2H, *J* = 7.1 Hz), 3.30 (dd, 2H, *J* = 64.3 Hz, 17.6 Hz), 2.40 (s, 3H), 1.03 (t, 3H, *J* = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 162.2, 146.5, 142.7, 139.3, 135.2, 134.1, 131.7, 130.1, 130.0, 128.5, 128.1, 125.8, 124.7, 123.4, 114.4, 111.1, 110.1, 61.6, 58.1, 54.0, 42.3, 21.7, 13.6; HRMS (ESI) calcd for $C_{30}H_{23}N_3O_5S_1Na_1$ [M + Na]$^+$: 560.1251; found: 560.1245.

Ethyl 2,2-Dicyano-2′-oxo-3-(*p*-tolyl)-1′-tosylspiro[cyclopent-[3]ene-1,3′-indoline]-4-carboxylate (4d). Red solid, 42.4 mg, 77% yield, mp 64−66 °C; IR (KBr) cm^{-1}: 2983, 2925, 2257, 1754, 1717, 1603, 1475, 1383, 1237, 1191, 1178, 1150, 1088, 1018, 959, 911, 815, 733, 661, 569, 544; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, *J* = 8.2 Hz), 7.99 (d, 2H, *J* = 8.4 Hz), 7.69−7.67 (m, 1H), 7.53 (td,1H, *J* = 8.3 Hz, 1.0 Hz), 7.36−7.30(m, 5H), 7.24 (d, 2H, 9.0 Hz), 4.09 (q, 2H, *J* = 7.1 Hz), 3.28 (dd, 2H, *J* = 17.6 Hz, 68.7 Hz), 2.40 (s, 3H), 2.38 (s, 3H), 1.08 (t, 3H, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 162.2, 146.4, 143.0, 140.4, 139.2, 134.5, 134.1, 131.7, 130.0, 129.2, 128.2, 128.1, 127.2, 125.7, 124.7, 123.5, 114.4, 111.1, 110.2, 61.5, 58.0, 53.9, 42.3, 21.7, 21.4, 13.7; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_5S_1Na_1$ [M + Na]$^+$: 574.1407; found: 574.1400.

Ethyl 2,2-Dicyano-3-(4-methoxyphenyl)-2′-oxo-1′-tosylspiro[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4e). Yellow solid, 44.2 mg, 78% yield, mp 44−46 °C; IR (KBr) cm^{-1}: 2982, 2961, 2257, 2227, 1754, 1728, 1605, 1511, 1463, 1383, 1295, 1253, 1237, 1178, 1151, 1088, 1024, 960, 910, 841, 813, 733, 661, 569, 544; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, *J* = 8.3 Hz), 7.99 (d, 2H, *J* = 8.4 Hz), 7.67(dd, 1H, *J* = 0.9 Hz, 7.7 Hz), 7.53 (td, 1H, *J* = 1.2 Hz, 8.2 Hz), 7.43−7.41 (m, 2H), 7.33−7.29 (m, 3H), 6.95 (d, 2H, *J* = 8.8 Hz), 4.10 (q, 2H, *J* = 7.1 Hz), 3.83 (s, 3H), 3.37 (dd, 2H, *J* = 68.7 Hz, 17.6 Hz), 2.40 (s, 3H), 1.11(t, 3H, *J* = 7.2 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 162.4, 161.1, 146.5, 142.9, 139.3, 134.2, 133.9, 131.7, 130.1, 130.0, 128.1, 125.7, 124.7, 123.6, 122.3, 114.4, 114.0, 61.6, 58.0, 55.3, 42.4, 21.8, 18.4, 13.8; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_6S_1Na_1$ [M + Na]$^+$: 590.1356; found: 590.1348.

Ethyl 3-(3-Chlorophenyl)-2,2-dicyano-2′-oxo-1′-tosylspiro-[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4h). Red solid, 34.2 mg, 60% yield, mp 60−62 °C; IR (KBr) cm^{-1}: 2926, 2256, 2234, 1736, 1597, 1463, 1380, 1238, 1178, 1087, 962, 910, 812, 733, 665, 575, 541; ^{1}H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, *J* = 8.3 Hz), 8.00 (d, 2H, *J* = 8.4 Hz), 7.69 (d, 1H, *J* = 7.69 Hz), 7.55 (td, 1H, *J* = 7.3 Hz, 1.0 Hz), 7.46−7.44 (m, 2H), 7.42−7.38 (m, 1H), 7.36−7.32 (m, 4H), 4.09 (q, 2H, *J* = 7.12 Hz), 3.38 (dd, 2H, *J* = 56.5 Hz, 17.7 Hz), 2.40 (s, 3H), 1.07 (t, 3H, *J* = 7.16 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 161.8, 146.6, 141.0, 139.3, 136.6, 134.0,

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131.89, 131.86, 130.3, 130.1, 129.9, 128.7, 128.1, 126.4, 125.8, 124.8, 122.9, 114.4, 110.9, 109.9, 61.8, 58.2, 53.7, 42.2, 21.8, 13.6; HRMS (ESI) calcd for $C_{30}H_{22}Cl_1N_3O_5S_1Na_1$ $[M + Na]^+$: 594.0861; found: 594.0853.

Ethyl 3-(3-Bromophenyl)-2,2-dicyano-2′-oxo-1′-tosylspiro-[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4o). Red solid, 39.9 mg, 65% yield, mp 62−66 °C; IR (KBr) cm^{-1}: 2983, 2926, 2258, 1763, 1720, 1599, 1464, 1384, 1237, 1191, 1179, 1151, 1088, 959, 910, 732, 661, 569, 544; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, J = 8.3 Hz), 8.00 (d, 2H, J = 8.4 Hz), 7.69 (d, 1H, J = 7.6 Hz), 7.61−7.59 (m, 2H), 7.55 (td, 1H, J = 8.4 Hz, 11.3 Hz), 7.41−7.39 (m, 1H), 7.36−7.31 (m,4H), 4.08 (q, 2H, J = 7.1 Hz), 3.37 (dd, 2H, J = 17.5 Hz, 70.2 Hz), 2.41 (s, 3H), 1.33 (s, 9H), 1.03 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 161.8, 146.6, 140.9, 139.4, 136.3, 134.0, 133.3, 132.1, 131.9, 131.5, 130.1, 130.1, 128.2, 126.8, 125.8, 124.8, 122.9, 114.4, 110.9, 109.9, 61.8, 58.2, 53.7, 42.2, 21.8, 13.6; HRMS (ESI) calcd for $C_{30}H_{22}Br_1N_3O_5S_1Na_1$ $[M + Na]^+$: 638.0356; found: 638.0348

Ethyl 2,2-Dicyano-3-(furan-2-yl)-2′-oxo-1′-tosylspiro-[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4p). Red liquid, 30.5 mg, 58% yield, IR (KBr) cm^{-1}: 2959, 2926, 2256, 2228, 1752, 1723, 1607, 1598, 1460, 1382, 1236, 1187, 1157, 1087, 910, 734, 661, 568, 543; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.06 (d, 1H, J = 8.2 Hz), 7.99 (d, 2H, J = 8.4 Hz), 7.75 (d, 1H, J = 3.6 Hz), 7.66 (dd, 1H, J = 0.7 Hz, 7.7 Hz), 7.51−7.58 (m, 2H), 7.29−7.34 (m, 3H), 4.24−4.32 (m, 2H), 3.39 (dd, J = 17.9 Hz, 32.7 Hz), 2.41 (s, 3H), 1.31 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 162.2, 149.5, 146.4, 145.1, 144.0, 143.0, 139.5, 134.0, 131.8, 131.1, 130.0, 128.4, 128.3, 125.6, 125.0, 123.2, 119.3, 114.3, 112.9, 113.4, 110.7, 61.8, 57.6, 50.5, 42.8, 21.8, 14.1; HRMS (ESI) calcd for $C_{28}H_{21}N_3O_6S_1Na_1$ $[M + Na]^+$:550.1043; found: 550.1037

Ethyl 3-(4-(*tert*-Butyl)phenyl)-2,2-dicyano-2′-oxo-1′-tosylspiro[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4k). Red solid, 54.5 mg, 92% yield, mp 62−64 °C; IR (KBr) cm^{-1}: 2965, 2869, 2257, 1754, 1718, 1603, 1464, 1384, 1237, 1179, 1150, 1088, 1017, 958, 910, 733, 661, 568, 543; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, J = 8.3 Hz), 8.00 (d, 2H, J = 8.4 Hz), 7.68 (d, 1H, J = 7.16 Hz), 7.53 (td, 1H, J = 8.0 Hz, 1.0 Hz), 7.42 (dd, 4H, J = 8.4 Hz, 22.6 Hz), 7.35−7.30 (m, 3H), 4.07 (q, 2H, J = 7.1 Hz), 3.37 (dd, 2H, J = 17.5 Hz, 70.2 Hz), 2.40 (s, 3H), 1.33 (s, 9H), 1.03 (t, 3H, J = 7.1 Hz, CH_3); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 162.3, 153.5, 146.4, 143.0, 139.3, 134.5, 134.1, 131.7, 130.0, 128.1, 127.1, 125.7, 125.4, 124.7, 123.6, 114.4, 111.2, 110.3, 61.5, 58.0, 53.9, 42.3, 31.1, 21.8, 13.5; HRMS (ESI) calcd for $C_{34}H_{31}N_3O_5S_1Na_1$ $[M + Na]^+$: 616.1877; found: 616.1873

Ethyl 2,2-Dicyano-3-(3,4-dimethylphenyl)-2′-oxo-1′-tosylspiro[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4l). Red solid, 53.6 mg, 95% yield, mp 61−63 °C; IR (KBr) cm^{-1}: 2981, 2924, 2257, 1756, 1723, 1603, 1464, 1384, 1327, 1238, 1191, 1178, 1151, 1088, 1039, 959, 911, 813, 729, 681, 661, 570, 544; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.04 (d, 1H, J = 8.3 Hz), 8.00 (d, 2H, J = 8.3 Hz), 7.68 (d, 1H, J = 7.3 Hz), 7.55−7.51 (m, 1H), 7.34−7.30 (m, 3H), 7.21−7.19 (m, 3H), 4.09 (q, 2H, J = 7.1 Hz), 3.36 (dd, 2H, J = 71.0 Hz, 17.5 Hz), 2.40 (s, 3H), 2.28 (s, 6H), 1.09 (t, 3H, J = 7.1 Hz),^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.8, 162.3, 146.4, 143.1, 139.21, 139.16, 136.8, 136.1, 134.1, 131.7, 130.0, 129.7, 129.3, 128.1, 127.6, 125.72, 125.70, 124.7, 123.6, 114.4, 111.2, 110.3, 61.5, 58.1, 53.9, 42.3, 21.7, 19.8, 13.7; HRMS (ESI) calcd for $C_{32}H_{27}N_3O_5S_1Na_1$ $[M + Na]^+$: 588.1564; found: 588.1561;

Ethyl 5′-Chloro-2,2-dicyano-2′-oxo-3-phenyl-1′-tosylspiro-[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4m). Red solid, 49.1 mg, 86% yield, mp 58−60 °C; IR (KBr) cm^{-1}: 2983, 2929, 2366, 2258, 1889, 1757, 1717, 1656, 1596, 1463, 1444, 1385, 1341, 1283, 1236, 1179, 1191, 1155, 1109, 1088, 1021, 958, 911, 814, 734, 700, 663, 581, 553, 544; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 8.00 (d, 1H, J = 8.9 Hz, 1H), 7.97 (d, 2H, J = 8.4 Hz), 7.66 (d, 1H, J = 2.08 Hz), 7.53−7.50 (m, 1H), 7.47−7.44 (m, 5H), 7.34 (d, 2H, J = 8.2 Hz), 4.07 (q, 2H, J = 7.1 Hz), 3.38 (dd, 2H, J = 71.1 Hz, 17.1 Hz), 2.40 (s, 3H), 1.04 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 171.2, 161.9, 146.8, 142.6, 137.7, 134.9, 133.7, 131.8, 131.4, 130.2, 130.1, 130.0, 128.6, 128.3, 128.1, 125.1, 125.0, 115.0, 110.8, 109.8, 61.6, 57.8, 53.8, 42.1, 21.8, 13.6; HRMS (ESI) calcd for $C_{30}H_{22}Cl_1N_3O_5S_1Na_1$ $[M + Na]^+$: 594.0861; found: 594.0871

Ethyl 2,2-Dicyano-5′-methyl-2′-oxo-3-phenyl-1′-tosylspiro-[cyclopent[3]ene-1,3′-indoline]-4-carboxylate (4n). Red solid, 44.6 mg, 81% yield, mp 54−56 °C; IR (KBr) cm^{-1}: 3061, 2982, 2961, 2927, 2871, 2257, 2231, 1754, 1719, 1656, 1596, 1485, 1444, 1383, 1340, 1298, 1262, 1237, 1191, 1178, 1155, 1113, 1089, 1021, 958, 911, 847, 815, 734, 699, 664, 569, 545; ^1H NMR (400 MHz, $CDCl_3$, TMS): δ 7.98 (d, 1H, J = 8.4 Hz), 7.90 (d, 2H, J = 8.4 Hz), 7.48 (s, 1H), 7.47−7.42 (m, 5H), 7.33−7.31 (m, 3H), 4.07 (q, 2H, J = 7.1 Hz), 3.36 (dd, 2H, J = 59.9 Hz, 17.6 Hz), 2.41 (s, 3H), 2.39 (s, 3H), 1.04 (t, 3H, J = 7.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$, TMS): δ 172.0, 162.2, 146.4, 142.9, 136.9, 135.8, 135.1, 134.2, 132.3, 130.4, 130.1, 130.0, 128.6, 128.4, 128.1, 125.3, 123.3, 114.2, 111.2, 110.2, 61.6, 58.2, 54.0, 42.4, 21.8, 21.2,13.6; HRMS (ESI) calcd for $C_{31}H_{25}N_3O_5S_1Na_1$ $[M + Na]^+$:574.1407; found: 574.1398

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.7b00595.

Control experiments and NMR spectra (PDF)
Crystallographic information of **3j** (CIF)
Crystallographic information of **4a** (CIF)

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Notes

The authors declare no competing financial interest.

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