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$Cu(OAc)_2$-Promoted Cascade Carboamination/Oxidative Cyclization of *C*-Acylimines with Alkenes

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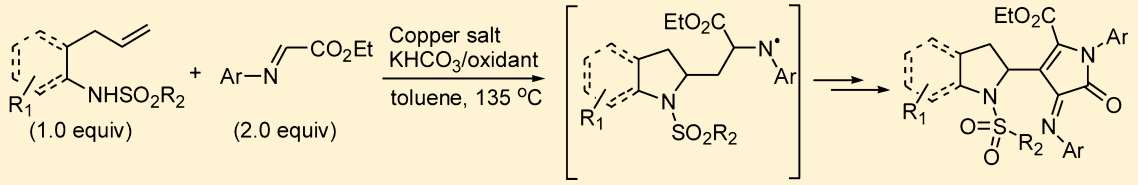
Supporting Information



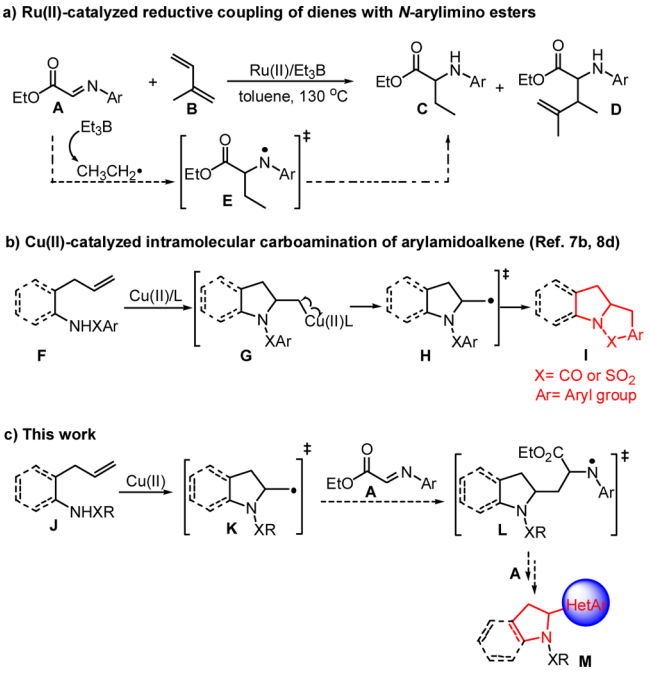
ABSTRACT: A $Cu(OAc)_2$-promoted cascade carboamination/oxidative cyclization of alkenes with α-imino esters has been explored. This transformation provides a concise approach to rapid assembly of 2-oxo-3-iminopyrrole derivatives in moderate to good yields.

INTRODUCTION

The development of synthetic transformations that allow for the rapid construction of heterocycles is a great challenging subject in organic chemistry. Transition-metal-catalyzed carboaminations of olefins represent one of the most efficient and atom-economical approaches to the assembly of such kind of products.[1] Consequently, many efforts have been invested in the exploration of various reaction systems for this demanding transformation. The most recent trend has been focused on the use of different carbon source substrates, which can lead to the simultaneous formation of C−N and C−C bonds. Since the Pd-catalyzed aminocarbonylation of alkenes/CO gas system has been reported by Hegedus and Tamaru,[2] transition-metal-catalyzed intermolecular carboamination of alkene with aryl bromide,[3] alkene/arylboronic acid,[4] alkene/*N*-aryl urea,[5] alkene/arene,[6] alkene/alkene,[7] and intramolecular carboamination of alkene[8] were well developed to furnish different classes of mono- or fused heterocyclic systems. To date, however, although zirconium- or titanium-catalyzed carboamination of imines with alkynes were developed to afford α,β-unsaturated imines by Bergman and Mindiola, respectively,[9] no studies have been reported for transition-metal-catalyzed carboamination of alkene/imine system, which will possibly offer a promising synthetic strategy to access complex nitrogen heterocycles.

On the other hand, as the versatile acceptors of nucleophiles, acylimines and their corresponding addition reactions with organometallic reagents and Mannich donors, etc., are widely utilized in many crucial steps.[10] Recently, we realized the ruthenium(II)-catalyzed regioselective reductive coupling of unactivated dienes with α-imino esters via an addition of alkyl ruthenium intermediate to acylimine C═N bond to furnish α-branched allylic α-amino acid derivatives (**D**) (Scheme 1a).[11] In the course of this study, we discovered that Ru(II)/Et_3B system could produce the unexpected ethylation byproduct (**C**) possibly via a radical process;[11,12] this result implied that acylimine could be easily trapped by carbon radical intermediates. Considering that the Cu(II)-catalyzed intramolecular carboamination of arylsulfonamidoalkenes (**F**)

Scheme 1. Reactions of Alkyl Radicals with *C*-Acylimines



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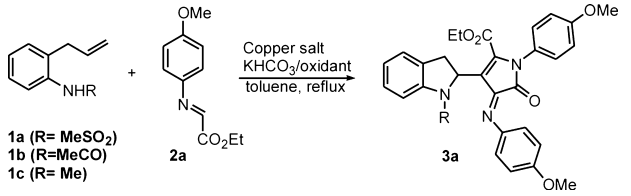
reported by Chemler involved in a key β-aminoalkyl radical (**H**), which derived from the C−Cu(II) homolysis of organocopper intermediate (**G**), and carbon radical (**H**) could further react with aryl ring (Ar) via an intramolecular coupling to give the fused heterocyclic product (**I**) (Scheme 1b),[8d] we therefore envisioned that the alkyl (*R*)-substituted sulfonylamidoalkene (**J**)/α-imino ester (**A**) partner could also first produce a carbonyl radical (**K**) under the copper(II) salt system, and then the radical (**K**) could possibly prefer attacking the imino carbon instead of the alkyl group (*R*) from **J** and lead to the formation of nitrogen radical **L**, which could likely further react with the second α-imino ester molecule **A** to provide structurally complex heterocycle (**M**) via a cascade process (Scheme 1c). To test this hypothesis, herein we described the first example of $Cu(OAc)_2$-promoted cascade carboamination/oxidative cyclization (Cu-PCCOC) of α-imino esters with alkenes for the rapid assembly of indoline-substituted-2-oxo-3-iminopyrrole (ISOIP) derivatives, and most of ISOIP analogues are potent and selective galanin GAL_3 receptor antagonists and DNA gyrase inhibitors.[13]

RESULTS AND DISCUSSION

To begin our study, *N*-(2-allyl-phenyl)-methanesulfonamide (**1a**, 0.18 mmol) was first employed to react with α-imino ester **2a** (0.36 mmol) in toluene (3.0 mL) at 120 °C for 48 h under an Ar atmosphere for screening various copper salts (Table 1,

Table 1. Optimization of the Cu(II)-PCCOC[a]



entry	copper salts	R	temp (°C)	oxidant	yield (%)[b]
1	$Cu(OTf)_2$	$MeSO_2$	120	–	0
2	CuOAc	$MeSO_2$	120	–	21
3	$CuBr_2$	$MeSO_2$	120	–	0
4	$Cu(OAc)_2$	$MeSO_2$	120	–	45
5	$Cu(OAc)_2$	$MeSO_2$	135	–	48
6	$Cu(OAc)_2$	$MeSO_2$	120	O_2	38
7	$Cu(OAc)_2$	$MeSO_2$	120	PhIO	0
8	$Cu(OAc)_2$	$MeSO_2$	120	$Na_2S_2O_8$	54
9	$Cu(OAc)_2$	$MeSO_2$	120	MnO_2	64
10	$Cu(OAc)_2$	$MeSO_2$	135	MnO_2	71[c]
11	$Cu(OAc)_2$	$MeSO_2$	135	MnO_2	0[d]
12	$Cu(OAc)_2$	MeCO	135	MnO_2	0[c]
13	$Cu(OAc)_2$	Me	135	MnO_2	0[c]

[a]Unless otherwise noted, the reactions were carried out using alkenes (**1**) (0.18 mmol) and α-imino ester (**2a**) (0.36 mmol) with copper salts (3.0 equiv) in the presence of oxidant (1.0 equiv) and $KHCO_3$ (1.0 equiv) in solvent (3.0 mL) at 120 °C for 48 h under Ar in a sealed reaction tube, followed by flash chromatography on SiO_2. [b]Isolated yield. [c]Reaction time of 24 h. [d]$KHCO_3$ was not used.

entries 1−4). To our delight, we quickly found that 3.0 equiv of $Cu(OAc)_2$ could provide 45% yield of the desired indoline-substituted-2-oxo-3-iminopyrrole (**3a**), whose structure was already unambiguously assigned by its single crystal X-ray analysis (see Supporting Information (SI) for more details) (entry 4). Albeit the yield of **3a** at 135 °C is still a little lower (entry 5), this positive result encouraged us to further optimize the reaction conditions for achieving satisfying yields. Then, we investigated the effect of various oxidants (1.0 equiv) on the Cu-PCCOC. Among the tested oxidants (entries 6−9), MnO_2 could bring us an improved yield of **3a** (entry 9, 64% yield). Finally, the best yield (71% yield of **3a**) was obtained using 1.0 equiv of MnO_2 at 135 °C for 24 h (entry 10). By the way, it is worth noting that no cyclization product **3a** was formed in the absence of $KHCO_3$ (entry 11). Moreover, when methanesulfonyl group of **1a** was switched to acetyl or methyl group (entries 12 and 13), no product was obtained, possibly because of poorer pK_a values from *N*-acetyl or methyl amino group (see SI for more details).

Having established optimized reaction conditions that enable the smooth Cu-PCCOC of **1a** with **2a**, we next investigated its scope with regard to the substituted *N*-sulfonyl-2-allylaniline (**1**) coupling partner. As illustrated in Table 2, the substitution on the benzene ring (R_1) of **1** showed no significant electronic effects, the *N*-methanesulfonyl-2-allylaniline derivatives with *para*-electron-donating group or halide (4-Me, 4-MeO, 4-Cl, 4-Br, 4-F) on the phenyl ring afforded the ISOIP derivatives in moderate to good yields (52−71%, entries 1−6), and electron-poor substrates with nitro group or ethoxylcarbonyl group on the phenyl ring underwent slightly worse conversion and provided lower yield of desired products (40−53%, entries 7−9). Compared with the *N*-methylsulfonyl-2-allylaniline (**1a**), the Cu-PCCOC of *N*-tosyl-2-allylaniline with **2a** provided 50% yield of ISOIP derivative **3j** and 42% yield of byproduct **3k**, which was directly derived from the intramolecular carboamination of alkene (entry 10). In addition, unactivated *N*-tosyl-(2,2-dimethyl)-pent-4-enylamine was also a suitable substrate for this transformation and provided 49% yield of the desired product **3l** and 40% yield of the intramolecular carboamination product **3m** (entry 11). The scope of the procedure with regard to α-imino ester coupling partner was then explored with particular **1a**. Electron-rich, electron-poor, and halide-substituted *N*-phenyl α-imino esters underwent smooth conversion when common functionalities, such as methyl, acetamido, halide, and alkoxylcarbonyl groups, were present as *para*- or *meta*-substituent on the benzene ring, with the formation of compounds **3n**−**3s** in moderate to good yield (entries 12−17). Worthy of note was that no ISOIP product was observed for the *N*-alkyl substituted α-imino ester, and only 59% yield of hydroamination product **3t** from alkene was obtained (entry 18). Finally, we also ran the Cu(II)-promoted cascade carboamination/cross-oxidative cyclization of **1a** (1.0 equiv) with *N*-(4-methoxylphenyl)imino ester (1.0 equiv) and *N*-(4-methylphenyl)imino ester (1.0 equiv). As expected, we got the corresponding cross-oxidative cyclization product **3u** (50% yield, entry 19) besides **3a** (14% yield) and **3n** (17% yield).

Taking previous reports on copper(II)-mediated carboamination into account, and in combination with the byproduct and intermediate derived from the Cu-PCCOC of alkene **1a** with α-imino ester **2a**, we proposed a plausible reaction mechanism for this novel transformation (Figure 1). It is well-known that the *syn*-aminocupraion of alkene **1a** gave organocopper intermediate **1a-1**, and subsequent C−Cu(II) homolysis furnished β-aminoalkyl radical **1a-2**.[7b,8d] Then alkyl radical **1a-2** attacked the imine carbon[14] of **2a** and generated the nitrogen radical intermediate **2a-1**, and the following oxidation of *N*-radical (**2a-1**) with either Cu(II) or MnO_2 and successive deprotonation could lead to imine **2a-2**, which then tautomerized to form enamine **2a-3**. By the way, the active

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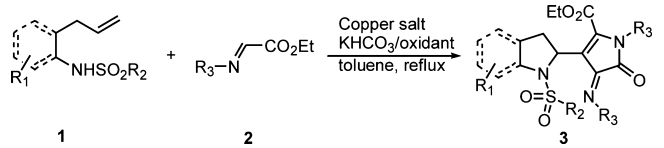
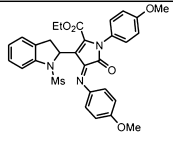
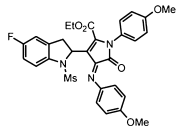
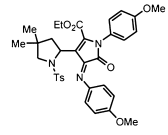
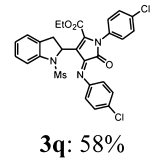
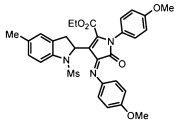
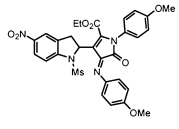
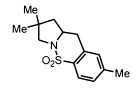
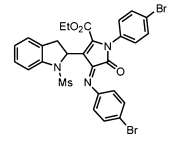
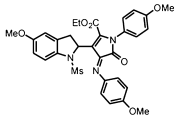
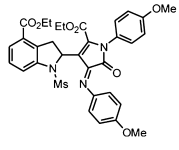
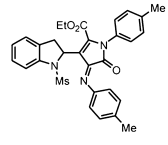
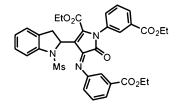
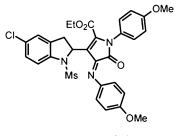
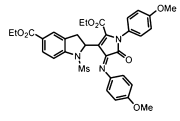
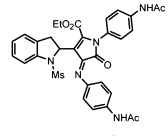
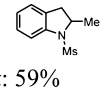
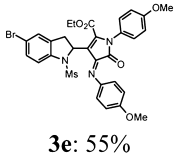
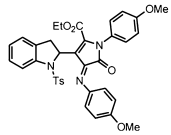
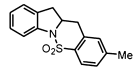
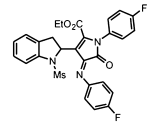
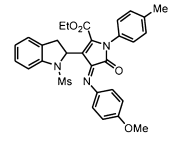
Table 2. Copper- Mediated Cascade Carboamination/Oxidative Cyclization of Alkenes with α-Imino Ester[a,b]



entry	product (yield)	entry	product (yield)	entry	product (yield)	entry	product (yield)
1	 **3a**: 71%	6	 **3f**: 54%	11	 **3l**: 49%	15	 **3q**: 58%
2	 **3b**: 52%	7	 **3g**: 44%		 **3m**: 40%	16	 **3r**: 52%
3	 **3c**: 64%	8	 **3h**: 53%	12	 **3n**: 73%	17	 **3s**: 53%
4	 **3d**: 61%	9	 **3i**: 40%	13	 **3o**: 21%	18	 **3t**: 59%
5	 **3e**: 55%	10	 **3j**: 50%  **3k**: 42%	14	 **3p**: 64%	19	 **3u**: 50%

[a]All the reactions were carried out using **1** (0.18 mmol) and **2** (0.36 mmol) with $Cu(OAc)_2$ (3.0 equiv) in the presence of MnO_2 (1.0 equiv) and $KHCO_3$ (1.0 equiv) in solvent (3.0 mL) at 135 °C for 24 h under Ar in a sealed reaction tube, followed by flash chromatography on SiO_2. [b]Isolated yield.

alkyl radical **2a-1** was also trapped partially by reaction medium to form byproduct **2a-7**.[15] Once the enamine **2a-3** is produced, it would react with another α-imino ester **2a** and provided imine **2a-4**. Once again, the second imine/enamiane isomerization process occurred to form enamine intermediate **2a-5**. Subsequently, a intramolecular nucleophilic cyclization from **2a-5** resulted in the formation of **2a-6**.[16] It is worth noting that when the reaction progress of Cu-PCCOC of alkene (**1a**) with α-imino ester (**2a**) was monitored by mass spectrometry experiment, the ESI/MS showed a peak at *m/z* 578.1826, which corresponds to $[\mathbf{2a\text{-}6} + H]^+$ (see SI for more details).[17] Finally, the oxidative dehydrogenation of **2a-6** further led to the desired ISOIP **3a**.

In conclusion, we have developed the first copper(II)-mediated cascade carboamination/oxidative cyclization of alkenes with α-imino esters. The transformation provided a concise access to complex ISOIP derivatives. Further investigation of their possible biological activities will make these compounds even more valuable and is also currently underway in our laboratory.

EXPERIMENTAL SECTION

General Information. All reactions were carried out in flame-dried sealed tubes with magnetic stirring. Unless otherwise noted, all experiments were performed under argon atmosphere. Solvents were treated with 4 Å molecular sieves or sodium and distilled prior to use. Flash chromatography was performed on silica gel (40−63 mm) by standard technique. ^1H and ^{13}C NMR spectra were recorded on a 400 MHz spectrometer at room temperature with tetramethylsilane (TMS) as internal standard. Chemical shifts are reported in parts per million (ppm), and coupling constants are reported as Hertz (Hz). Splitting patterns are designated as singlet (s), doublet (d), triplet (t), quartet (q). Splitting patterns that could not be interpreted or easily visualized are designated as multiple (m). High resolution exact mass measurements (HRMS) were performed on a TOF spectrometer (Micromass). Infrared spectra (IR) were reported as wavelength numbers (cm^{-1}). Infrared spectra were recorded by preparing a KBr

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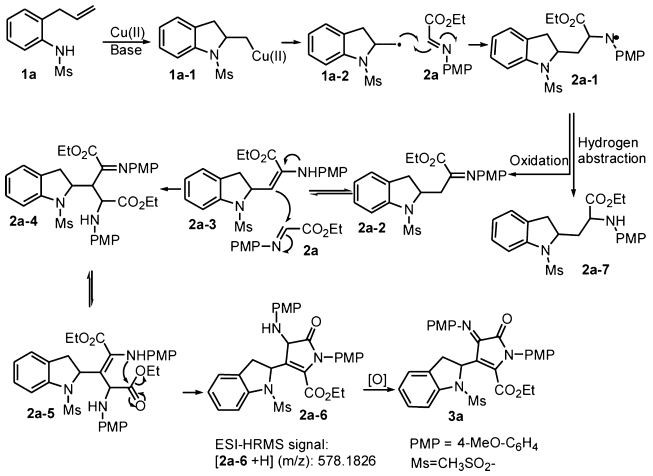

Figure 1. Proposed mechanism for the copper-mediated cascade transformation.

pellet containing the title compound. Crystal data were obtained by employing graphite monochromated Mo Kα radiation (λ = 0.71073 Å) at 293 (2) K and operating in the $\varphi-\omega$scan mode. The structure was solved by direct methods SHELXS-97. All the α-imino esters including (4-methoxy-phenylimino)-acetic acid ethyl ester (**2a**),[10f] *p*-tolylimino-acetic acid ethyl ester (**2b**),[10f] (4-acetylamino-phenylimino)-acetic acid ethyl ester (**2c**),[10f] (4-fluoro-phenylimino)-acetic acid ethyl ester (**2d**),[10f] (4-chloro-phenylimino)-acetic acid ethyl ester (**2e**),[10f] (4-bromo-phenylimino)-acetic acid ethyl ester (**2f**),[10f] (3-ethoxycarbonyl-phenylimino)-acetic acid ethyl ester (**2g**,)[10f] and cyclohexylimino-acetic acid ethyl ester (**2h**)[10f] were prepared using the previous reported procedure.[10f]

Procedures for the Preparation of Olefin Substrates (1a–1m). Procedure A[18] (Synthesis of 1a, 1b, 1d–1m). 2-Allyl phenylamine (0.55 g, 4.09 mmol, 1.0 equiv) was dissolved in dry CH_2Cl_2 (20.5 mL), and the solution was treated with pyridine (1.0 mL, 12.3 mmol, 1.0 equiv) and acyl chloride (4.90 mmol, 1.2 equiv). After, the corresponding reaction mixture was stirred at room temperature overnight, diluted with H_2O (30 mL), and extracted with Et_2O (3 × 30 mL). The combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. Chromatography of the resulting crude product on SiO_2 (using Et_2O/hexanes as eluent) afforded the corresponding olefin substrates.

*N-Methylsulfonyl-2-allylaniline (**1a**).*[18] Yellow liquid; 0.78 g, 90% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, J = 8.0 Hz, 1H), 7.22 (m, 3H), 6.62 (s, 1H), 5.96 (m, 1H), 5.17 (d, J = 10.1 Hz, 1H), 5.07 (dd, J = 12.0, 16.0 Hz, 1H), 3.45 (d, J = 6.0 Hz, 2H), 3.00 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 136.0, 134.9, 132.9, 130.9, 127.8, 126.5, 123.8, 116.9, 39.9, 35.9; IR(KBr) 3630, 3077, 2978, 2930, 1843, 1638, 1584, 1493, 1454, 1396, 1329, 971, 750, 655, 515 cm^{-1}; MS (ESI) m/z 234.7 $[M + Na]^+$.

*N-Acetyl-2-allyl aniline (**1b**).*[19] White solid; 0.62 g, 86% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (d, J = 7.8 Hz, 1H), 7.42 (s, 1H), 7.23 (t, J = 7.4 Hz, 1H), 7.16 (d, J = 7.0 Hz, 1H), 7.10 (t, J = 7.3 Hz, 1H), 5.95 (m, 1H), 5.15 (d, J = 10.0 Hz, 1H), 5.08 (d, J = 17.2 Hz, 1H), 3.36 (d, J = 6.1 Hz, 2H), 2.12 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.5, 136.4, 136.0, 130.5, 130.1, 127.4, 125.4, 124.1, 116.49, 36.8, 24.2; IR (KBr) 3277, 1655, 1586, 1535, 1481, 1449, 969, 752, 606, 533 cm^{-1}; MS (ESI) m/z 175.2 $[M]^+$.

Procedure B (Synthesis of 1c). This preparation is a modification of a literature procedure.[20] A 100 mL round-bottom flask was charged with *o*-allylaniline (6.03 g, 45.3 mmol) and tetrahydrofuran (40 mL). To this was added di-*tert*-butyl-dicarbonate (9.80 g, 44.9 mmol) and triethylamine (6.3 mL, 45.5 mmol). After the solution was heated at reflux temperature for 24 h, the solvent was removed under reduced pressure, and ethyl acetate (100 mL) was added to the corresponding residue. Then the solution was washed with 1 M citric acid (aq) (3 × 70 mL) and saturated NaCl (aq) (50 mL). The organic layer was dried over anhydrous $MgSO_4$ and filtered, and volatiles were removed under reduced pressure to give a mixture of a white solid and oil. The crude mixture was extracted with hexane, and the white solid removed by filtration. The hexane was removed under reduced pressure to yield pale yellow oil, which was distilled at 140 °C, 10–3 mmHg, to give 80% yield of clear oil (8.40 g). Then a 100 mL round-bottom flask was charged with *N*-(*tert*-butoxycarbonyl)-*o*-allylaniline (4.00 g, 17.2 mmol) and tetrahydrofuran (50 mL), and then $LiAlH_4$ (2.00 g, 52.6 mmol) was cautiously added, and the reaction mixture was heated at reflux temperature for 24 h. The reaction mixture was cooled to 0 °C in an ice bath, and water (10 mL) was added dropwise followed by 2 M NaOH (aq) (10 mL). The mixture was then extracted with diethyl ether (2 × 50 mL), and the combined organic extracts were dried over anhydrous $MgSO_4$ and filtered. Volatiles were removed under reduced pressure, and the residue was purified by column chromatography (hexane:diethyl ether = 15:1).

*N-Methyl-2-allylaniline (**1c**).*[20] Colorless oil; 1.50 g, 59% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.18 (m, 1H), 7.03 (d, J = 7.3 Hz, 1H), 6.70 (m, 1H), 6.63 (d, J = 8.1 Hz, 1H), 5.93 (m, 1H), 5.14–5.04 (m, 2H), 3.74(s, 1H), 3.26 (d, J = 6.1 Hz, 2H), 2.83 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.5, 136.2, 129.7, 127.8, 123.6, 117.2, 116.2, 109.9, 36.4, 30.8; IR (KBr) 3025, 2924, 1636, 1603, 1487, 963, 747, 715, 605, 464 cm^{-1}; MS (ESI) m/z 147.2 $[M]^+$.

*N-Methylsulfonyl-4-methyl-2-allylaniline (**1d**).*[21] White solid; 0.70 g, 76% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.39 (d, J = 8.1 Hz, 1H), 7.12–7.04 (m, 2H), 6.33 (s, 1H), 5.97 (m, 1H), 5.19 (d, J = 12.0 Hz, 1H), 5.09 (d, J = 16.0 Hz, 1H), 3.43 (d, J = 5.9 Hz, 2H), 3.00 (s, 3H), 2.34 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 136.5, 136.1, 133.0, 132.2, 131.5, 128.4, 124.4, 116.8, 39.8, 36.1, 20.9; IR (KBr) 3619, 3277, 2925, 1638, 1611, 1501, 973, 762, 583, 504 cm^{-1}; MS (ESI) m/z 248.7 $[M + Na]^+$.

*N-Methylsulfonyl-4-methoxy-2-allylaniline (**1e**).*[18] White solid; 0.83 g, 84% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, J = 9.3 Hz, 1H), 6.77 (d, J = 7.0 Hz, 2H), 6.50 (s, 1H), 5.94 (m, 1H), 5.14 (d, J = 10.1 Hz, 1H), 5.07 (d, J = 17.1 Hz, 1H), 3.78 (s, 3H), 3.45 (d, J = 5.8 Hz, 2H), 2.96 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 158.6, 136.6, 135.8, 127.4, 127.2, 117.0, 116.1, 112.6, 55.5, 39.7, 36.3; IR (KBr) 3610, 3273, 2935, 1638, 1582, 1499, 1433, 1390, 974, 917, 761, 603, 517 cm^{-1}; MS (ESI) m/z 264.0 $[M + Na]^+$.

*N-Methylsulfonyl-4-chloro-2-allylaniline (**1f**).*[22] White solid; 0.65 g, 65% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.45 (d, J = 8.4 Hz, 1H), 7.25 (d, J = 13.4 Hz, 2H), 6.41 (s, 1H), 5.93 (m, 1H), 5.23 (d, J = 10.0 Hz, 1H), 5.09 (d, J = 17.1 Hz, 1H), 3.41 (d, J = 5.5 Hz, 2H), 3.00 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 134.9, 133.5, 131.8, 130.7, 127.8, 124.9, 124.6, 117.7, 40.0, 35.8; IR (KBr) 3634, 3291, 3080, 2927, 1639, 1595, 1484, 970, 754, 517, 453 cm^{-1}; MS (ESI) m/z 268.7 $[M + Na]^+$.

*N-Methylsulfonyl-4-bromine-2-allylaniline (**1g**).* White solid; mp 78–79 °C; 0.85 g, 72% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 (d, J = 6.5 Hz, 2H), 7.38 (s, 1H), 6.52 (s, 1H), 5.92 (m, 1H), 5.22 (d, J = 10.0 Hz, 1H), 5.09 (d, J = 17.2 Hz, 1H), 3.40 (d, J = 5.6 Hz, 2H), 3.00 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 134.7, 134.2, 133.7, 130.9, 124.5, 119.4, 117.9, 40.1, 36.1; IR (KBr) 3286, 3079, 2929, 1638, 1591, 973, 762, 677, 549, 517 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{10}H_{12}BrNO_2S$ 288.9767, found 288.9768.

*N-Methylsulfonyl-4-fluoro-2-allylaniline (**1h**).*[22] White solid; 0.63 g, 67% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (dd, J = 8.0, 8.0 Hz, 1H), 6.95 (m, 2H), 6.59 (s, 2H), 5.93 (m, 2H), 5.19 (d, J = 9.4 Hz, 1H), 5.09 (d, J = 17.1 Hz, 1H), 3.45 (d, J = 6.0 Hz, 2H), 2.99 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 136.3, 135.0, 130.5, 126.8, 126.7, 117.6, 114.5, 117.3, 114.6, 114.4, 39.9, 36.1; IR (KBr) 3643, 3273, 2924, 1631, 1591, 967, 758, 501 cm^{-1}; MS (ESI) m/z 252.0 $[M + Na]^+$.

*N-Methylsulfonyl-4-nitro-2-allylaniline (**1i**).* Pink solid; mp 86–87 °C; 0.73 g, 70% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.13 (d, J = 11.6 Hz, 2H), 7.71 (s, 1H), 5.99 (m, 1H), 5.30 (d, J = 9.8 Hz, 1H), 5.15 (d, J = 17.2 Hz, 1H), 3.52 (d, J = 5.9 Hz, 2H), 3.15 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.0, 141.5, 133.8, 129.8, 126.2, 123.7, 119.2, 118.6, 40.6, 35.8; IR (KBr) 3440, 2924, 1639, 1519, 967 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{10}H_{12}N_2O_4S$ 256.0512, found 256.0512.

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*N-Methylsulfonyl-3-ethyl formate-2-allylaniline (**1j**).* Yellow liquid; 1.03 g, 89% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.747.66 (m, 2H), 7.34 (t, J = 8.0 Hz, 1H), 6.07−5.95 (m, 1H), 5.17 (d, J = 12.0 Hz, 1H), 5.02 (d, J = 16.0 Hz, 1H), 4.36 (q, J = 7.1 Hz, 2H), 3.76 (d, J = 5.6 Hz, 2H), 3.01 (s, 3H), 1.38 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.5, 136.5, 135.6, 132.9, 127.8, 127.5, 126.4, 116.6, 61.4, 40.3, 32.6, 14.2; IR (KBr) 3616, 3209, 2929, 1636, 1585, 1460, 979, 756, 655, 515 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{13}H_{17}NO_4S$ 283.0873, found 283.0870.

*N-Methylsulfonyl-4-ethyl formate-2-allylaniline (**1k**).* Yellow liquid; 0.93 g, 80% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.12 (d, J = 1.3 Hz, 1H), 7.86 (d, J = 7.9 Hz, 1H), 7.32 (d, J = 8.0 Hz, 1H), 6.82 (s, 1H), 5.95 (m, 1H), 5.20 (d, J = 12.0 Hz, 1H), 5.08 (d, J = 16.0 Hz, 1H), 4.38 (q, J = 7.1 Hz, 2H), 3.53 (d, J = 6.0 Hz, 2H), 3.07 (s, 3H), 1.39 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 165.9, 137.8, 135.18, 134.9, 130.9, 130.4, 127.4, 124.5, 117.7, 61.3, 40.4, 36.2, 14.3; IR (KBr) 3894, 3559, 3275, 3080, 2981, 1639, 1611, 1575, 974, 761, 661, 515 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{13}H_{17}NO_4S$ 283.0873, found 283.0870.

*N-Tosyl-2-allylaniline (**1l**).*[8a] White solid; 1.12 g, 95% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60 (d, J = 8.1 Hz, 2H), 7.39 (d, J = 7.9 Hz, 1H), 7.23−7.16 (m, 3H), 7.14−7.04 (m, 2H), 6.62 (s, 1H), 5.84−5.70 (m, 1H), 5.10 (d, J = 10.1 Hz, 1H), 4.94 (d, J = 16.0 Hz, 1H), 3.03 (d, J = 5.9 Hz, 2H), 2.38 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.8, 136.8, 135.6, 135.0, 132.0, 130.5, 129.6, 127.7, 127.1, 126.3, 124.5, 117.1, 36.2, 21.5; IR (KBr) 3283, 3071, 2978, 2922, 1637, 1596, 1492, 996, 711, 665, 566 cm^{-1}; MS (ESI) m/z 287.1 $[M]^+$.

*N-Tosyl-(2,2-dimethyl)-pent-4-enylamine (**1m**).*[8a] White solid; 0.79 g, 72% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (d, J = 8.2 Hz, 2H), 7.30 (d, J = 8.0 Hz, 2H), 5.72 (m, 1H), 5.04−4.95 (m, 2H), 4.46 (t, 1H, J = 9.0 Hz), 2.67 (d, 2H, J = 6.0 Hz), 2.42 (s, 3H), 1.96 (d, J = 7.4 Hz, 2H), 0.85 (s, 6H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.3, 137.0, 134.3, 129.7, 127.1, 117.8, 52.9, 43.9, 34.1, 24.8, 21.5; IR 3287, 3072, 2964, 1639, 1598, 1422, 997, 666, 556 cm^{-1}; MS (ESI) m/z 268.3 $[M + 1]^+$.

General Procedure for the Synthesis of the Compound 3a−3u. $Cu(OAc)_2$ (0.54 mmol, 3.0 equiv), $KHCO_3$ (0.18 mmol, 1.0 equiv), MnO_2 (0.18 mmol, 1.0 equiv), sulfonamide substrate (0.18 mmol, 1.0 equiv), and α-imino ester (0.36 mmol, 2.0 equiv) were dissolved in 2.0 mL of toluene in a tube, and then the tube was sealed under Ar and heated at 135 °C in an oil bath for 24 h. The reaction progress was monitored by TLC method, after the starting material disappeared; the corresponding reaction mixture was then cooled down and filtrated. Removal of the solvent in vacuo and chromatography on SiO_2 (using ethyl acetate/hexane as eluent) afforded the corresponding desired products.

*Ethyl-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3a**).* Red solid; mp 68−69 °C; 73.0 mg, 71% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.42 (d, J = 8.2 Hz, 1H), 7.35 (d, J = 8.7 Hz, 2H), 7.24 (t, J = 6.5 Hz, 2H), 7.17 (d, J = 8.6 Hz, 2H), 7.11 (t, J = 7.4 Hz, 1H), 6.92 (d, J = 8.6 Hz, 2H), 6.79 (d, J = 8.7 Hz, 2H), 5.78 (q, 1H), 4.23−4.09 (m, 1H), 4.09−3.98 (m, 1H), 3.81 (d, J = 6.2 Hz, 6H), 3.75−3.69 (m, 1H), 3.47 (m, 1H), 2.85 (s, 3H), 0.98 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 159.0, 156.2, 148.7, 142.3, 140.1, 131.4, 128.3, 127.7, 127.4, 127.2, 124.8, 124.1, 121.5, 114.2, 113.5, 62.1, 56.1, 55.5, 55.5, 35.6, 35.6, 13.5; IR (KBr) 3748, 3646, 2934, 1725, 1606, 1510, 973, 587, 549, 512, 421 cm^{-1}; HRMS (ESI-TOF) calcd for $[M+H]^+$ $C_{30}H_{30}N_3O_7S$ 576.1799, found 576.1799.

*Ethyl-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-3-(5-methyl-1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3b**).* Red solid; mp 73−75 °C; 55.0 mg, 52% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, J = 8.8 Hz, 2H), 7.30−7.25 (m, 1H), 7.14 (d, J = 8.7 Hz, 2H), 7.02 (d, J = 9.6 Hz, 2H), 6.89 (d, J = 8.8 Hz, 2H), 6.78 (d, J = 8.9 Hz, 2H), 5.68 (dd, J = 4.0, 4.0 Hz, 1H), 4.16−4.06 (m, 1H), 4.05−3.95 (m, 1H), 3.79 (s, 6H), 3.66 (m, 1H), 3.40 (dd, J = 16.0, 16.0 Hz, 1H), 2.80 (s, 3H), 2.33 (s, 3H), 0.95 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 160.3, 159.0, 156.1, 149.1, 140.2, 139.9, 133.9, 131.4, 128.2, 127.5, 126.8, 125.5, 121.2, 114.5, 114.2, 113.5, 62.1, 56.4, 55.5, 35.7, 34.9, 20.9, 13.5; IR (KBr) 3861, 3656, 3053, 2930, 1729, 1607, 1511, 1463, 1375, 1249, 974, 703, 566, 423 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + Na]^+$ $C_{31}H_{31}N_3O_7SNa$ 612.1744, found 612.1775.

*Ethyl-3-(5-methoxy-1-(methylsulfonyl)indolin-2-enyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3c**).* Red oil; 69.7 mg, 64% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (m, 3H), 7.14 (d, J = 8.9 Hz, 2H), 6.89 (d, J = 8.9 Hz, 2H), 6.82−6.71 (m, 4H), 5.68 (dd, J = 8.0, 4.0 Hz, 1H), 4.12 (m, 1H), 4.02 (m, 1H), 3.80 (d, J = 2.2 Hz, 9H), 3.67 (m, 1H), 3.41 (dd, J = 4.0, 8.0 Hz, 1H), 2.79 (s, 3H), 0.96 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.6, 160.2, 159.0, 157.2, 156.1, 149.1, 140.4, 140.2, 135.7, 132.9, 127.5, 126.7, 120.8, 115.8, 114.2, 113.5, 112.8, 110.9, 62.1, 56.6, 55.8, 55.5, 35.8, 34.61, 13.5; IR (KBr) 3743, 3641, 2928, 1725, 1607, 1511, 1464, 973, 770, 551, 516 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + Na]^+$ $C_{31}H_{31}N_3O_8SNa$ 628.1724, found 628.1740.

*Ethyl-3-(5-chloro-1-(methylsulfonyl)indolin-2-enyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3d**).* Red oil; 66.9 mg, 61% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (t, J = 8.2 Hz, 3H), 7.16 (m, 4H), 6.90 (d, J = 8.7 Hz, 2H), 6.78 (d, J = 8.8 Hz, 2H), 5.79 (dd, J = 4.0, 8.0 Hz, 1H), 4.16−4.01 (m, 2H), 3.80 (m, 6H), 3.68 (m, 1H), 3.44 (d, J = 16.4 Hz, 1H), 2.83 (s, 3H), 0.97 (t, J = 7.0 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.6, 160.4, 159.1, 156.1, 141.0, 140.2, 133.5, 1287.4, 124.9, 121.1, 115.3, 114.2, 113.6, 62.1, 56.4, 55.5, 35.7, 35.2, 29.7, 13.5. IR (KBr) 3657, 3060, 2927, 1725, 1607, 1510, 973, 736, 557, 427 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{30}H_{28}ClN_3O_7S$ 609.1331, found 609.1324.

*Ethyl-3-(5-bromo-1-(methylsulfonyl)indolin-2-enyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3e**).* Red oil; 64.7 mg, 55% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (d, J = 8.5 Hz, 4H), 7.27 (d, J = 3.9 Hz, 1H), 7.14 (d, J = 8.1 Hz, 2H), 6.91 (d, J = 8.3 Hz, 2H), 6.79 (d, J = 8.4 Hz, 2H), 5.79 (dd, J = 4.0, 4.0 Hz, 1H), 4.16−4.00 (m, 2H), 3.80 (s, 6H), 3.68 (m, 1H), 3.44 (m, 1H), 2.83 (s, 3H), 0.97 (t, J = 6.9 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.7, 160.4, 159.1, 156.1, 148.4, 141.6, 140.0, 133.9, 130.5, 128.3, 127.8, 127.4, 121.1, 116.6, 115.7, 114.2, 113.6, 62.1, 56.3, 55.5, 35.8, 35.2, 29.7, 13.5; IR (KBr) 3645, 2925, 1724, 1610, 1510, 1468, 972, 551, 430 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{30}H_{28}BrN_3O_7S$ 653.0826, found 653.0822.

*Ethyl-3-(5-fluoro-1-(methylsulfonyl)indolin-2-enyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3f**).* Red oil; 57.6 mg, 54% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.25 (m, 3H), 7.06 (d, J = 8.4 Hz, 2H), 6.84 (m, 4H), 6.70 (d, J = 8.0 Hz, 2H), 5.70 (dd, J = 4.0, 4.0 Hz, 1H), 4.05 (m, 1H), 3.95 (m, 1H), 3.71 (d, J = 3.6 Hz, 6H), 3.61 (m, 1H), 3.36 (m, 1H), 2.73 (s, 3H), 0.89 (t, J = 7.0 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 160.4, 159.1, 156.1, 148.6, 140.2, 140.0, 138.3, 133.6, 128.2, 127.4, 127.1, 121.0, 115.5, 115.4, 114.2, 113.6, 112.2, 111.9, 62.1, 56.6, 55.5, 35.4, 35.3, 29.7, 13.5; IR (KBr) 3746, 3644, 2925, 1724, 1607, 1511, 1442, 975, 569, 430 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{30}H_{29}FN_3O_7S$ 594.1705, found 594.1713.

*Ethyl-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-3-(1-(methylsulfonyl)-5-nitroindolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3g**).* Red solid; 49.1 mg, 44% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.15 (d, J = 8.8 Hz, 1H), 8.07 (s, 1H), 7.42 (d, J = 8.9 Hz, 1H), 7.27 (d, J = 8.9 Hz, 2H), 7.14 (d, J = 8.7 Hz, 2H), 6.92 (d, J = 8.8 Hz, 2H), 6.74 (d, J = 8.9 Hz, 2H), 6.04 (dd, J = 8.0, 4.0 Hz, 1H), 4.12 (m, 2H), 3.81 (s, 3H), 3.77 (s, 3H), 3.74 (d, J = 11.8 Hz, 1H), 3.53 (d, J = 16.0 Hz, 1H), 2.92 (s, 3H), 1.00 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 161.1, 160.1, 159.2, 156.1, 148.1, 147.9, 143.8, 140.4, 139.7, 132.9, 128.3, 127.6, 127.4, 124.6, 120.7, 120.4, 114.3, 113.7, 112.5, 62.2, 56.9, 55.5, 37.9, 34.6, 29.7, 13.6; IR (KBr) 3754, 2927, 1724, 1605, 1514, 972, 559, 514 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{30}H_{28}N_4O_9S$ 620.1572, found 620.1565.

*Ethyl-2-(2-(ethoxycarbonyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrol-3-enyl)-1-(methylsulfonyl)indoline-4-carboxylate (**3h**).* Red oil; 61.7 mg, 53% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78 (d, J = 7.8 Hz, 1H), 7.58 (d, J = 8.0 Hz, 1H), 7.32 (d, J = 7.9 Hz, 1H), 7.29−7.25 (d, J = 7.9 Hz, 1H), 7.14 (d, J = 8.8 Hz, 2H), 6.91 (d, J = 8.9 Hz, 2H), 6.75 (d, J = 9.0

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Hz, 2H), 5.84 (dd, *J* = 8.0, 4.0 Hz, 1H), 4.36 (q, *J* = 7.1 Hz, 2H), 4.17−4.10 (m, 1H), 4.09−3.99 (m, 2H), 3.80 (s, 3H), 3.78 (s, 3H), 3.73 (m, 1H), 2.84 (s, 3H), 1.39 (t, *J* = 7.1 Hz, 3H), 0.97 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.1, 160.5, 160.4, 159.0, 156.2, 148.5, 143.5, 139.9, 134.4, 128.3, 127.9, 127.4, 127.3, 127.0, 125.4, 121.6, 118.1, 114.2, 113.5, 62.0, 61.1, 56.3, 55.5, 55.5, 36.9, 35.9, 14.4, 13.6; IR (KBr) 3736, 2928, 1715, 1607, 1512, 1454, 956, 588, 513 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{33}H_{33}N_3O_9S$ 647.1932, found 647.1927.

Ethyl-2-(2-(ethoxycarbonyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrol-3-enyl)-1-(methylsulfonyl)indoline-5-carboxylate (**3i**). Red oil; 46.6 mg, 40% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, *J* = 8.5 Hz, 1H), 7.89 (s, 1H), 7.40 (d, *J* = 8.4 Hz, 1H), 7.30 (d, *J* = 8.9 Hz, 2H), 7.14 (d, *J* = 8.7 Hz, 2H), 6.91 (d, *J* = 8.8 Hz, 2H), 6.75 (d, *J* = 8.9 Hz, 2H), 5.89 (dd, *J* = 8.0, 8.0 Hz, 1H), 4.37 (m, 2H), 4.16−4.02 (m, 2H), 3.81 (s, 3H), 3.78 (s, 3H), 3.74−3.69 (m, 1H), 3.49 (d, *J* = 16.0 Hz, 1H), 2.87 (s, 3H), 1.40 (t, *J* = 7.1 Hz, 3H), 0.97 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.3, 160.7, 160.3, 159.1, 156.2, 146.4, 140.1, 139.9, 131.5, 130.2, 128.4, 127.5, 127.4, 126.1, 125.9, 121.4, 114.2, 113.6, 112.9, 62.1, 60.9, 56.5, 55.5, 36.7, 35.0, 29.7; IR (KBr) 3748, 3379, 2959, 2853, 1714, 1608, 1513, 973, 736, 588, 557, 515 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{33}H_{33}N_3O_9S$ 647.1932, found 647.1927.

Ethyl-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-3-(1-tosylindolin-2-enyl)-4,5-dihydro-1H-pyrrole-2-carboxylate (**3j**). Red oil; 58.6 mg, 50% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.63 (m, 3H), 7.25−7.19 (m, 2H), 7.17−7.11 (m, 4H), 7.05 (m, 3H), 6.92 (d, *J* = 8.6 Hz, 2H), 6.75 (d, *J* = 8.7 Hz, 2H), 5.71 (dd, *J* = 8.0, 4.0 Hz, 1H), 4.22−4.08 (m, 2H), 3.81 (d, *J* = 8.4 Hz, 6H), 3.35 (m, 1H), 3.25 (m, 1H), 2.33 (s, 3H), 1.02 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 158.9, 156.1, 148.3, 143.8, 142.6, 139.9, 135.0, 131.9, 129.5, 127.6, 127.3, 127.3, 124.4, 123.7, 121.8, 115.1, 114.2, 113.4, 62.1, 55.5, 35.3, 29.7, 21.5, 14.1, 13.6; IR (KBr) 3849, 3582., 2922, 1713, 1604, 1511, 1461, 812, 751, 574, 543, 449 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + Na]^+$ $C_{36}H_{33}N_3O_7SNa$ 674.1931, found 674.1931.

8-Methyl-10a,11-dihydro-10H-5-thia-4b-aza-benzo[b]fluorine-5,5-dioxide (**3k**).[8d] Colorless solid; 21.6 mg, 42% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 (d, *J* = 7.9 Hz, 1H), 7.47 (d, *J* = 7.9 Hz, 1H), 7.11−6.97 (m, 4H), 6.89 (t, *J* = 7.3 Hz, 1H), 4.87−4.74 (m, 1H), 3.38−3.28 (m, 1H), 3.25−3.24 (m, 1H), 3.02−2.93 (m, 1H), 2.85−2.81 (m, 1H), 2.28 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 143.2, 142.2, 135.7, 134.6, 130.1, 129.8, 128.1, 127.9, 124.8, 124.0, 115.9, 61.2, 36.1, 33.6, 21.5; IR (KBr) 2920, 1659, 1600, 1512, 1474, 974, 699, 666, 526, 451, 427 cm^{-1}; MS (ESI) *m*/*z* 286.7 $[M + 1]^+$.

Ethyl-3-(4,4-dimethyl-1-tosylpyrrolidin-2-enyl)-1-(4-methoxyphenyl)-4-(4-methoxyphenylimino)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3l**). Red oil; 55.7 mg, 49% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (d, *J* = 7.9 Hz, 2H), 7.19 (d, *J* = 6.6 Hz, 2H), 7.10 (d, *J* = 7.9 Hz, 2H), 7.01 (d, *J* = 8.8 Hz, 2H), 6.83 (d, *J* = 8.8 Hz, 2H), 6.75 (d, *J* = 8.8 Hz, 2H), 5.21 (m, 1H), 4.22−4.08 (m, 2H), 3.74 (d, *J* = 7.1 Hz, 6H), 3.35 (m, 2H), 2.46−2.34 (m, 1H), 2.29 (s, 3H), 1.86 (dd, *J* = 8.0, 8.0 Hz, 1H), 1.18 (s, 6H), 1.02 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.4, 159.9, 158.9, 155.8, 142.7, 141.1, 140.2, 129.4, 128.4, 127.0, 125.7, 114.2, 113.3, 62.04, 61.0, 55.5, 53.2, 38.8, 29.7, 25.9, 25.6, 21.5, 13.7; IR (KBr) 3376, 2924, 1729, 1607, 1512, 1463, 914, 685, 545 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{34}H_{38}N_3O_7S$ 632.2425, found 632.2437.

2,2,7-Trimethyl-2,3,9,9a-tetrahydro-1H-4-thia-3a-aza-cyclopenta[b]naphthalene-4,4- dioxide (**3m**).[23] Colorless oil; 19.1 mg, 40% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.70 (d, *J* = 7.8 Hz, 1H), 7.20 (d, *J* = 7.8 Hz, 1H), 7.09 (s, 1H), 4.35−4.26 (m, 1H), 3.48−3.43 (m, 1H), 3.17 (d, *J* = 9.1 Hz, 1H), 2.69 (d, *J* = 15.1 Hz, 1H), 2.55 (d, *J* = 9.1 Hz, 1H), 2.40 (s, 3H), 1.81 (dd, *J* = 8.0, 8.0 Hz, 1H), 1.28−1.24 (m, 1H), 1.15 (s, 3H), 0.95 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.9, 134.9, 134.3, 130.5, 127.7, 124.7, 61.7, 58.6, 45.9, 36.8, 31.6, 25.9, 21.6; IR (KBr) 2959, 1729, 1604, 1575, 1468, 954, 687, 645, 585 cm^{-1}; MS (ESI) *m*/*z* 266.8 $[M + 1]^+$.

Ethyl-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-1-p-tolyl-4-(p-tolylimino)-4,5-dihydro-1H-pyrrole-2-carboxylate (**3n**). Red oil; 71.4 mg, 73% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (d, *J* = 7.8 Hz, 1H), 7.24−7.12 (m, 5H), 7.07 (d, *J* = 7.6 Hz, 4H), 7.00 (d, *J* = 8.2 Hz, 2H), 5.66 (dd, *J* = 8.0, 4.0 Hz, 1H), 4.11 (m, 1H), 4.04−3.91 (m, 1H), 3.71−3.67 (m, 1H), 3.46−3.43 (m, 1H), 2.83 (s, 3H), 2.31 (d, *J* = 10.5 Hz, 6H), 0.91 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.4, 155.32, 151.3, 145.0, 142.0, 141.9, 137.7, 137.6, 132.4, 130.9, 129.5, 129.0, 127.8, 124.9, 124.3, 121.9, 62.2, 56.2, 35.8, 35.2, 21.2, 21.1, 13.4; IR (KBr) 3799, 2924, 1713., 1648, 1601, 1539, 1513, 971, 544 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + Na]^+$ $C_{30}H_{29}N_3O_5SNa$ 566.1720, found 566.1704.

Ethyl-1-(4-acetamidophenyl)-4-(4-acetamidophenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3o**). Red oil; 23.8 mg, 21% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 (d, *J* = 8.4 Hz, 2H), 7.39 (t, *J* = 7.6 Hz, 5H), 7.23 (d, *J* = 7.6 Hz, 2H), 7.18−7.07 (m, 5H), 5.68 (dd, *J* = 4.0, 4.0 Hz, 1H), 4.12−4.08 (m, 1H), 3.98−3.96 (m, 1H), 3.72−3.69 (m, 1H), 3.45−3.42 (m, 1H), 2.84 (s, 3H), 2.12 (d, *J* = 6.4 Hz, 6H), 0.93 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.4, 160.3, 142.0, 131.0, 127.9, 126.5, 124.9, 124.4, 119.9, 119.3, 114.5, 62.4, 56.1, 35.7, 35.1, 29.7, 24.6, 13.5; IR (KBr) 3363, 2925, 1669, 1602, 1514, 973, 548 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{32}H_{32}N_5O_7S$ 630.2017, found 630.2018.

Ethyl-1-(4-fluorophenyl)-4-(4-fluorophenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3p**). Red oil; 63.5 mg, 64% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, J = 8.1 Hz, 1H), 7.24−7.17 (m, 4H), 7.08 (m, 5H), 6.95 (t, *J* = 8.5 Hz, 2H), 5.66 (dd, J = 4.0, 8.0 Hz, 1H), 4.13 (m, 1H), 4.0−3.93 (m, 1H), 3.71−3.68 (m, 1H), 3.45−3.42 (m, 1H), 2.84 (s, 3H), 0.93 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.1, 160.6, 160.1, 155.4, 151.4, 143.3, 141.9, 141.8, 130.8, 127.9, 127.9, 127.8, 124.9, 124.4, 124.1, 124.0, 121.1, 116.1, 115.9, 115.4, 115.2, 114.6, 62.4, 56.0, 35.6, 34.9, 13.4; IR (KBr) 3630, 3373, 2925, 1730, 1600, 1507, 1455, 972, 544 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{28}H_{24}F_2N_3O_5S$ 552.1399, found 552.1404.

Ethyl-1-(4-chlorophenyl)-4-(4-chlorophenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3q**). Red oil; 60.9 mg, 58% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, *J* = 8.1 Hz, 1H), 7.35 (d, *J* = 8.4 Hz, 2H), 7.25−7.19 (m, 4H), 7.16−7.07 (m, 3H), 6.96 (d, *J* = 8.3 Hz, 2H), 5.63 (dd, *J* = 8.0, 4.0 Hz, 1H), 4.13 (m, 1H), 4.05−3.95 (m, 1H), 3.71−3.68 (m, 1H), 3.45−3.42 (m, 1H), 2.83 (s, 3H), 0.94 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.0, 154.9, 152.1, 145.9, 142.3, 141.9, 133.7, 133.3, 132.6, 130.6, 129.2, 128.6, 128.0, 126.9, 124.9, 124.5, 122.3, 121.1, 114.6, 62.6, 55.9, 35.6, 34.9, 13.4; IR (KBr) 3650, 2928, 1732, 1642, 1598, 1490, 1461, 972, 658 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + Na]^+$ $C_{28}H_{23}N_3O_5SCl_2Na$ 606.0628, found 606.0632.

Ethyl-1-(4-bromophenyl)-4-(4-bromophenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3r**). Red oil; 62.9 mg, 52% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50 (d, *J* = 8.6 Hz, 2H), 7.40 (t, *J* = 8.5 Hz, 3H), 7.22 (t, *J* = 6.9 Hz, 2H), 7.08−7.06 (m, 3H), 6.88 (d, *J* = 8.5 Hz, 2H), 5.62 (dd, *J* = 4.0, 4.0 Hz, 1H), 4.19−4.08 (m, 1H), 4.05−3.95 (m, 1H), 3.71−3.68 (m, 1H), 3.45−3.42 (m, 1H), 2.84 (s, 3H), 0.95 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.0, 154.8, 152.1, 146.5, 142.1, 141.9, 133.8, 132.2, 131.6, 130.6, 128.1, 127.2, 124.9, 124.5, 122.4, 121.6, 121.1, 120.5, 114.6, 62.6, 55.9, 35.6, 34.8, 13.4; IR (KBr) 3651, 2923, 1735, 1655, 1598, 1490, 972, 548 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{28}H_{24}Br_2N_3O_5S$ 673.9783, found 673.9769.

Ethyl-1-(3-(ethoxycarbonyl)phenyl)-4-(3-(ethoxycarbonyl)-phenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-4,5-dihydro-1H-pyrrole-2-carboxylate (**3s**). Red oil; 62.9 mg, 53% yield: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (d, *J* = 7.3 Hz, 1H), 7.83 (d, *J* = 8.3 Hz, 2H), 7.61 (s, 1H), 7.44−7.40 (m, 3H), 7.36 (t, *J* = 7.9 Hz, 1H), 7.26−7.19 (m, 2H), 7.16 (d, *J* = 7.9 Hz,1H), 7.09 (t, *J* = 7.4 Hz, 1H), 5.65 (dd, *J* = 8.0, 4.0 Hz, 1H), 4.36−4.34 (m, 2H), 4.33−4.30 (m, 2H), 4.12 (m, 1H), 3.95 (m, 1H), 3.74−3.71 (m, 1H), 3.51−3.48 (m, 1H), 2.86 (s, 3H), 1.37−1.35 (m, 6H), 0.90 (t, *J* = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.1, 165.4, 159.9, 154.8, 152.9, 148.3, 142.9, 141.9, 134.9, 131.6, 131.1, 130.5, 130.2, 129.1, 129.0, 128.6, 128.1, 127.2, 126.6, 125.1, 124.5, 123.7, 120.9, 120.7, 114.6, 62.6, 61.3, 61.1, 56.1, 35.7, 34.8, 14.3, 14.3, 13.4; IR (KBr) 3649, 3372, 3065,

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2983, 1734, 1647, 1586, 1482, 1353, 972, 622 cm^{-1}; HRMS (ESI-TOF) calcd for $[M]^+$ $C_{34}H_{33}N_3O_9S$ 659.1932, found 659.1934.

*1H-Indole,2,3-dihydro-2-methyl-1-(methylsulfonyl) (**3t**).*[24] White solid; 22.2 mg, 59% yield: ^1H NMR (400 MHz, $CDCl_3$) δ 7.42 (d, J = 8.0 Hz, 1H), 7.21 (t, J = 7.3 Hz, 2H), 7.05 (t, J = 7.4 Hz, 1H), 4.47–4.43 (m, 1H), 3.49–3.42 (m, 1H), 2.84 (s, 3H), 2.74–2.66 (m, 1H), 1.46 (d, J = 6.4 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 141.0, 130.5, 127.9, 125.5, 124.1, 115.2, 58.8, 36.5, 36.3, 23.3.

*Ethyl-4-(4-methoxyphenylimino)-3-(1-(methylsulfonyl)indolin-2-enyl)-5-oxo-1-p-tolyl-4,5-dihydro-1H-pyrrole-2-carboxylate (**3u**).* Red oil; 50.3 mg, 50% yield: ^1H NMR (400 MHz, $CDCl_3$) δ 7.39 (d, J = 8.2 Hz, 1H), 7.31 (d, J = 8.9 Hz, 2H), 7.24–7.16 (m, 4H), 7.13–7.06 (m, 3H), 6.76 (d, J = 8.9 Hz, 2H), 5.76 (dd, J = 4.0, 8.0 Hz, 1H), 4.11–4.06 (m, 1H), 4.06–3.97 (m, 1H), 3.79 (s, 3H), 3.72–3.68 (m, 1H), 3.45–3.42 (m, 1H), 2.83 (s, 3H), 2.35 (s, 3H), 0.93 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 160.5, 155.9, 148.6, 142.3, 140.0, 137.6, 132.9, 131.3, 129.5, 127.7, 127.2, 125.7, 124.8, 123.9, 121.9, 114.4, 113.5, 62.0, 56.1, 55.5, 35.6, 29.7, 21.1, 13.4; IR (KBr) 3361, 2925, 1726, 1605, 1514, 1461, 973, 736, 583 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{30}H_{30}N_3O_6S$ 560.1850, found 560.1850.

General Procedure for the Preparation of Intermediate (2a-7). $Cu(OAc)_2$ (0.54 mmol, 3.0 equiv), $KHCO_3$ (0.18 mmol, 1.0 equiv), *N*-methylsulfonyl-2-allylaniline **1a** (0.18 mmol, 1.0 equiv), and α-imino ester **2a** (0.36 mmol, 2.0 equiv) were dissolved in 2.0 mL of toluene in a tube, and then the tube was sealed and heated at 135 °C under Ar in an oil bath for 8 h. Then the reaction mixture was cooled down and filtrated. The corresponding filtrate was concentrated in vacuo to give crude residue, and the further chromatography on SiO_2 (20% ethyl acetate in hexanes) afforded the purified product **2a-7**.

*Ethyl-2-(4-methoxyphenylamino)-3-(1-(methylsulfonyl)indolin-2-enyl)propanoate (**2a-7**).* Yellow oil; 9.0 mg, 12% yield: ^1H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, J = 8.5 Hz, 1H), 7.25–7.19 (m, 2H), 7.09 (t, J = 7.4 Hz, 1H), 6.77 (d, J = 8.8 Hz, 2H), 6.64 (d, J = 8.9 Hz, 2H), 4.64 (m, 1H), 4.14 (m, 3H), 3.74 (s, 3H), 3.44–3.41 (m, 1H), 2.92–2.90 (m, 1H), 2.77 (s, 3H), 2.34–2.32 (m, 1H), 2.17–2.09 (m, 1H), 1.18 (t, J = 7.1 Hz, 3H); ^{13}C NMR (101 MHz, $CDCl_3$) δ 173.4, 152.9, 140.9, 130.9, 128.2, 125.6, 124.9, 116.4, 115.5, 114.9, 61.3, 59.9, 55.7, 55.1, 39.90, 35.8, 34.5, 29.7, 14.1; IR (KBr) 3861, 3850, 2925, 1732, 1598, 1514, 1463, 1347, 824, 753, 634 cm^{-1}; HRMS (ESI-TOF) calcd for $[M + H]^+$ $C_{21}H_{28}N_2O_5S$ 419.1635, found 419.1638.

Notes: When equal amounts of both alkene **1a** (0.18 mmol, 1.0 equiv) and α-imino ester **2a** (0.18 mmol, 1.0 equiv) were subjected to react under the same conditions, only 7% yield of **2a-7** (5.3 mg) was obtained.

General Procedure for Monitoring the Reaction Progress Using HPLC Method. The HPLC-MS spectra about the $[$**2a-6** + H$]^+$ was obtained in absence of MnO_2 under the following reaction conditions: The mixture of $Cu(OAc)_2$ (0.54 mmol, 3.0 equiv), $KHCO_3$ (0.18 mmol, 1.0 equiv), *N*-methylsulfonyl-2-allylaniline **1a** (0.18 mmol, 1.0 equiv), and α-imino ester **2b** (0.36 mmol, 2.0 equiv) were dissolved in 2.0 mL of toluene in tube, and then the tube was sealed and heated at 135 °C in an oil bath for 8 h. Then the corresponding mixture was monitored by HPLC–MS to get the corresponding MS spectra of **2a-6**.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Details for experiments conditions, characterization data, copies of ^1H and ^{13}C NMR spectra for all isolated compounds, crystallographic data for **3a** (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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