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Bicyclization of Isocyanides with Alkenoyl Bis(ketene dithioacetals): Access to 6,7-Dihydro-1*H*-indol-4(5*H*)-ones

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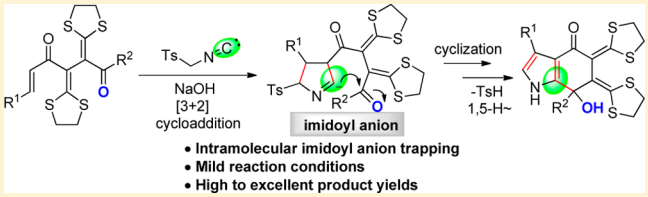
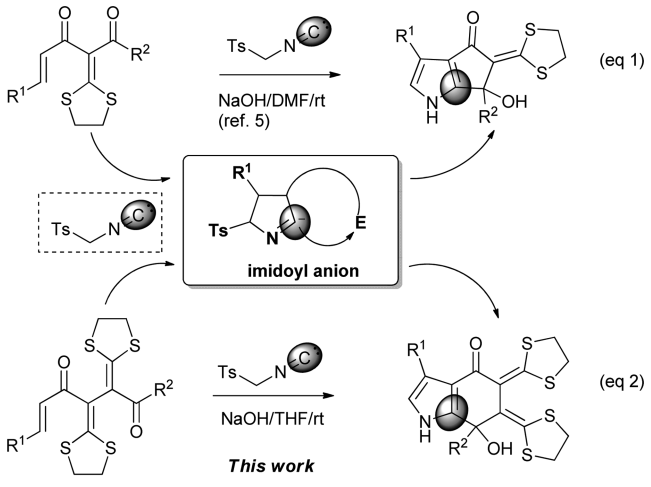
Supporting Information

ABSTRACT: The tandem [3 + 2] cycloaddition/intramolecular imidoyl anion trapping strategy has been successfully applied for the synthesis of 6,7-dihydro-1*H*-indol-4(5*H*)-ones from alkenoyl bis(ketene dithioacetals) and tosylmethyl isocyanide. The reaction proceeded smoothly under mild reaction conditions to afford bicyclization products in high to excellent yields in a single step.



Functionalized ketene dithioacetals are versatile intermediates in organic synthesis.[1,2] In our recent research on the heterocyclization based on the reactions of α-acidic isocyanides with functionalized ketene dithioacetals leading to nitrogen heterocycles,[1,3−5] we were able to show that cyclopenta[*b*]-pyrrole derivatives can be constructed from the reaction of alkenoyl ketene dithioacetals with tosylmethyl isocyanide (TosMIC) under mild metal-free conditions in a single run.[5] In this reaction, the successful trapping of the incipient imidoyl anion species in situ generated from the [3 + 2] cycloaddition (Scheme 1, eq 1)[5] as the key feature of the bicyclization reaction.[5] The literature search gave only a few relevant references for the preparation of bis(ketene-dithioacetals) (Scheme 2)[7] including, for example: (1) first obtained by Krespan in 1961 from the reaction of sulfur and hexafluoro-2-butyne in the presence of iodine at 200 °C under pressure, which suggested a *p*-dithiinodihydro-*p*-dithiin structure,[7a] later assigned as 2,2′-bi[2,4,5-tris(trifluoromethyl)-1,3-dithiole] **A** (obtained in 35% yield by treating potassium sulfide with 2,3-dichlorohexafluoro-2-butene in purified DMF at 25 °C for 6 days);[7b] (2) treatment of dimethyl acetylenedicarboxylate with carbon disulfide in a Carius tube at 100 °C for 18 h giving tetramethyl 2,2′-(1,4-dimethoxy-1,4-dioxobutane-2,3-diylidene) bis(1,3-dithiole-4,5-dicarboxylate) **B** as a minor product in only 4.8% yield;[7c] and (3) bis(ketene- dithioacetals) **C** and **D** by diazo transfer reaction of 2-(trimethylsilyl)-l,3-dithiane with tosyl azide at −70 °C via probably a bisalkylthiocarbene intermediate.[7d−f]

Scheme 1. Imidoyl Anion Trapping Strategy



promoted us to further explore the bicyclization strategy. Herein, we describe the efficient synthesis of 6,7-dihydro-1*H*-indol-4(5*H*)-ones from the bicyclization of alkenoyl bis(ketene-dithioacetals) **3** with TosMIC (Scheme 1, eq 2).[6]

The present research started with the synthesis of bis(ketene-dithioacetals), for example, **2a**, as an acyclic precursor for the bicyclization reaction.[5] The literature search gave only a few relevant references for the preparation of bis(ketene-dithioacetals) (Scheme 2)[7] including, for example: (1) first obtained by Krespan in 1961 from the reaction of sulfur and hexafluoro-2-butyne in the presence of iodine at 200 °C under pressure, which suggested a *p*-dithiinodihydro-*p*-dithiin structure,[7a] later assigned as 2,2′-bi[2,4,5-tris(trifluoromethyl)-1,3-dithiole] **A** (obtained in 35% yield by treating potassium sulfide with 2,3-dichlorohexafluoro-2-butene in purified DMF at 25 °C for 6 days);[7b] (2) treatment of dimethyl acetylenedicarboxylate with carbon disulfide in a Carius tube at 100 °C for 18 h giving tetramethyl 2,2′-(1,4-dimethoxy-1,4-dioxobutane-2,3-diylidene) bis(1,3-dithiole-4,5-dicarboxylate) **B** as a minor product in only 4.8% yield;[7c] and (3) bis(ketene- dithioacetals) **C** and **D** by diazo transfer reaction of 2-(trimethylsilyl)-l,3-dithiane with tosyl azide at −70 °C via probably a bisalkylthiocarbene intermediate.[7d−f]

In our research, it was found, after a series of tests, that bis(ketene-dithioacetal), 3,4-di(1,3-dithiolan-2-ylidene)hexane-2,5-dione **2a**, could be readily prepared in 70% yield by treatment of α-acetyl ketene dithioacetal **1a** (1.0 mmol) with ceric ammonium nitrate (CAN, 2.3 mmol)[8] as the oxidant in methanol at 0 °C within 30 min (Scheme 2). The above result indicates that a single-electron-transfer (SET) of **1a** and subsequent homocoupling process could account for the formation of bis(ketene-dithioacetal) **2a** (Scheme 2),[8] which provides an easy access to bis(ketene-dithioacetals).[7] Under similar reaction conditions, bis(ketene-dithioacetal) **2b** (2,3-di(1,3-dithiolan-2-ylidene)-1,4-diphenylbutane-1,4-dione) was obtained in 72% yield from 2-(1,3-dithiolan-2-ylidene)-1-phenylethanone **1b** (Scheme 2). However, a complicated mixture was obtained from the reaction of 1-(1,3-dithian-2-ylidene)propan-2-one **1c**, indicating a significant effect of the alkylthio group of ketene dithioacetals on the reaction.[1]

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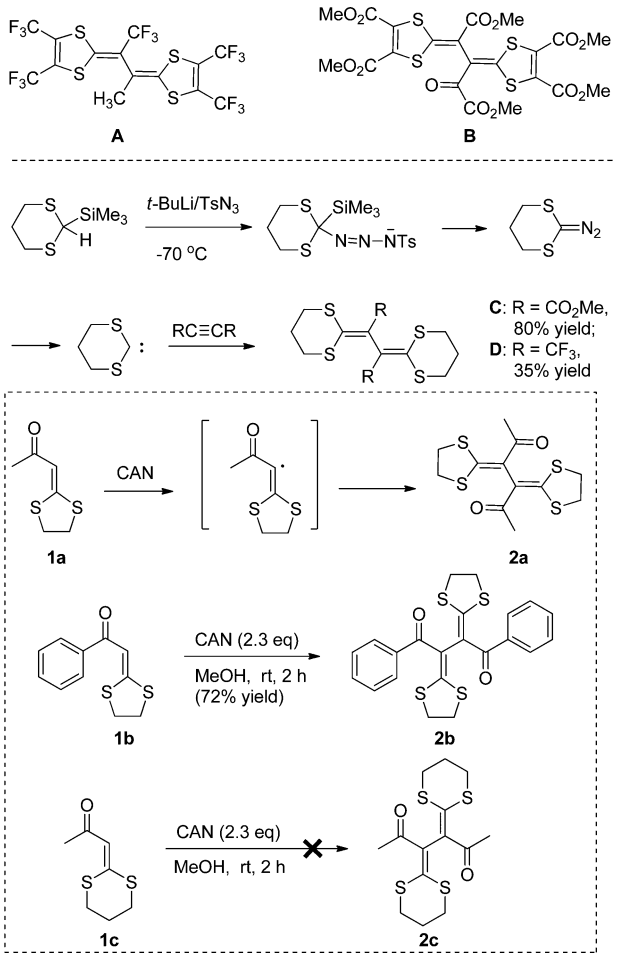
Scheme 2. Preparation of Bis(ketene dithioacetals)



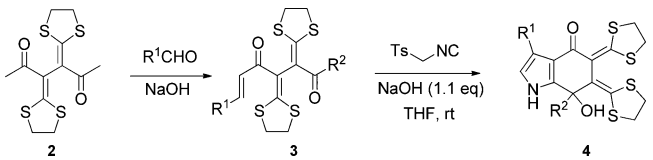
The condensation of bis(ketene dithioacetal) **2a** with various aldehydes under basic conditions led to the formation of either dialkenoyl bis(ketene-dithioacetals) **3a–g** (Table 1, entries 1–7) or monoalkenoyl bis(ketene-dithioacetal)s **3h–j** (Table 1, entries 8–10) in high to excellent yields.

Next, the reaction of **3a** with TosMIC was examined to investigate the bicyclization of alkenoyl bis(ketene-dithioacetals) for the synthesis of 6,7-dihydro-1*H*-indol-4(5*H*)-ones. Fortunately, the desired 1*H*-indol-4(5*H*)-one **4a** was prepared in 76% yield by treating the reaction mixture of **3a** (247 mg, 0.5 mmol) and TosMIC (117 mg, 0.6 mmol) with NaOH (22 mg, 0.55 mmol) in DMF at room temperature for 6 h. Further optimization of the reaction conditions showed that THF was more suitable than DMF as solvent, and the yield of **4a** increased to 93% (Table 1, entry 11).

Under identical reaction conditions as above, the scope of this tandem [3 + 2] cycloaddition/intramolecular imidoyl anion trapping reaction was investigated (Table 1, entries 11–20). The dialkenoyl bis(ketene-dithioacetals) **3a–g** having a phenyl (entry 11), electron-deficient aryl (entry 12), electron-rich aryl (entries 13 and 14), 2-naphthyl (entry 15), heteroaryl (entry 16), or alkyl (entry 17) group at the *β*-position of the enone moiety afforded the corresponding indol-4(5*H*)-ones **4a–g** in high to excellent yields. In addition, the monoalkenoyl bis(ketene-dithioacetals) bearing an alkyl R^2 group could also lead to the desired indol-4(5*H*)-ones **4h–j** in high yields (entries 18–20).

The successful synthesis of indol-4(5*H*)-ones **4** provides an efficient access to indole derivatives in a single operation.[6,9] From our previous[5] and present results (Table 1) a plausible mechanism for the formation of indol-4(5*H*)-ones **4** is proposed in Scheme 3. The overall process involves (i) a formal [3 + 2] cycloaddition of the C=C double bond of the alkenoyl moiety of bis(ketene-dithioacetals) **3** with TosMIC under basic conditions to provide intermediate imidoyl anion **I**;[3] (ii) intramolecular trapping of the resulting anion **I** by the tethered terminal carbonyl group (**I** → **II**) followed by elimination of tosylic acid (**II** → **III**);[5] and finally (iii) spontaneous aromatization of **III** to furnish indol-4(5*H*)-ones **4**.[10] Therefore, the key feature of this tandem process for the one-pot construction of 6,7-dihydro-1*H*-indol-4(5*H*)-ones **4** is the selective intramolecular trapping of the incipient imidoyl

Table 1. Synthesis of Di-/Monoalkenoyl Bis(ketene dithioacetals) 3 and Indol-4(5*H*)-ones 4



2 3 4

entry[a,b]	yield of 3[c] (%)	R^1	R^2	time (h)	yield of 4[c] (%)	entry[d]
1	**3a** (95)	Ph	PhCH=CH	6	**4a** (93)	11
2	**3b** (90)	4-ClC_6H_4	4-ClC_6H_4CH=CH	5	**4b** (95)	12
3	**3c** (86)	4-$CH_3OC_6H_4$	4-$CH_3OC_6H_4$CH=CH	8	**4c** (89)	13
4	**3d** (89)	4-$CH_3C_6H_4$	4-$CH_3C_6H_4$CH=CH	8	**4d** (90)	14
5	**3e** (88)	2-naphthyl	2-naphthylCH=CH	6	**4e** (88)	15
6	**3f** (82)	2-furyl	2-furylCH=CH	6	**4f** (80)	16
7	**3g** (80)	*t*-Bu	*t*-BuCH=CH	12	**4g** (74)	17
8	**3h** (65)	4-ClC_6H_4	Me	5	**4h** (75)	18
9	**3i** (60)	4-$CH_3OC_6H_4$	Me	6	**4i** (70)	19
10	**3j** (63)	*t*-Bu	Me	12	**4j** (65)	20

[a]Conditions for **3a–g** (entries 1–7): **2** (1.0 mmol), R^1CHO (2.2 equiv) and NaOH (4.0 equiv) in EtOH/CH_2Cl_2 (10:1, v/v, 25 mL) at 30 °C for 12–18 h. [b]Conditions for **3h–j** (entries 8–10): **2** (1.0 mmol), R^1CHO (1.1 equiv) and NaOH (2.0 equiv) in H_2O at 45 °C for 12 h. [c]Yield of isolated products. [d]Conditions: **3** (0.5 mmol), TosMIC (0.6 mmol, 1.2 equiv), and NaOH (0.55 mmol, 1.1 equiv) in THF (10 mL) at room temperature.

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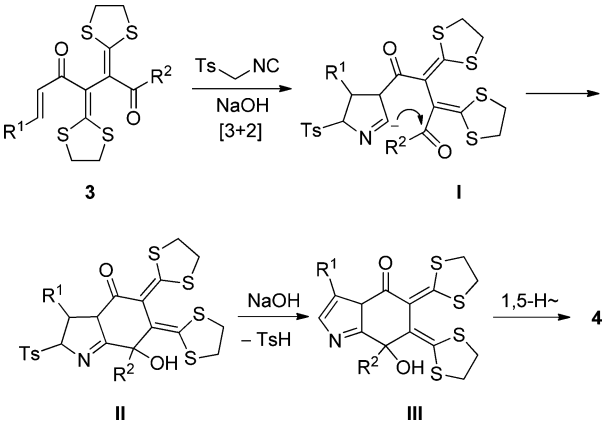
Scheme 3. Proposed Mechanism for Formation of Indol-4(5*H*)-ones 4



anion species **I** by the electrophilic terminal carbonyl carbon to form the six-membered ring.

In conclusion, we have described a simple oxidative dimerization reaction of α-acetal ketene dithioacetal, which enables the direct synthesis of bis(ketene dithioacetal) as the precursor of alkenoyl bis(ketene-dithioacetals) via a SET and subsequent homocoupling process in the presence of CAN as oxidant. The reaction of alkenoyl bis(ketene-dithioacetals) with TosMIC provides a simple access to indole derivatives in a single operation under very mild reaction conditions via a tandem [3 + 2] cycloaddition/intramolecular imidoyl anion trapping process. This strategy provides an easy access to pyrrole-fused heterocycles from readily available acyclic precursors in a single operation.

EXPERIMENTAL SECTION

General Information. All reagents were commercially available and used without further purification, unless otherwise indicated. Chromatography was carried on flash silica gel (300−400 mesh). All reactions were monitored by TLC, which was performed on precoated aluminum sheets of silica gel 60 (F254). Melting points were uncorrected. The ^{1}H NMR and ^{13}C NMR spectra were determined at 500 and 125 MHz (TMS as internal standard), respectively. High-resolution mass spectra (HRMS) were obtained using a micro TOF spectrometer (ESI).

General Procedure for the Synthesis of 2. To the solution of **1** (160 mg, 1.0 mmol) in MeOH (25 mL) was added ceric ammonium nitrate (CAN) (1261 mg, 2.3 mmol) at 0 °C. The reaction mixture was stirred at this temperature until the substrate **1** was consumed as indicated by TLC. The resulting mixture was then poured into brine (30 mL) and extracted with dichloromethane (15 mL × 3). The combined organic phase was washed with water (15 mL × 3), dried over anhydrous $MgSO_4$, and concentrated in vacuum. The crude product was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 2:1) to give **2** as a yellow solid.

3,4-Di(1,3-dithiolan-2-ylidene)hexane-2,5-dione (**2a**): yellowish solid (111 mg, 70% yield); mp 149−151 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.12 (s, 6H), 3.29−3.32 (m, 4H), 3.50−3.54 (m, 4H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.1, 35.3, 40.1, 124.0, 168.2, 193.4; HRMS (ESI-TOF) calcd for $C_{12}H_{15}O_2S_4^+$ ([M + H]) 318.9949, found 318.9956.

2,3-Di(1,3-dithiolan-2-ylidene)-1,4-diphenylbutane-1,4-dione (**2b**). The reaction was performed at room temperature: yellowish solid (159 mg, 72% yield); mp 194−196 °C. ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.35 (d, J = 7.5 Hz, 4H), 3.52 (t, J = 8.0 Hz, 4H), 7.15−7.20 (m, 2H), 7.29−7.34 (m, 8H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.4, 40.1, 124.1, 127.5, 130.4, 139.5, 171.5, 189.3; HRMS (ESI-TOF) Calcd for $C_{22}H_{19}O_2S_4^+$ ([M + H]$^+$) 443.0262, found 443.0258.

General Procedure for the Synthesis of Dialkenoyl Bisketene Dithioacetals 3a−g (Taking 3a as an Example). To the mixture of **2a** (318 mg, 1.0 mmol) and benzaldehyde (0.224 mL, 2.2 mmol) in EtOH/CH_2Cl_2 (10:1, v/v, 25 mL) was added NaOH (160 mg, 4.0 mmol). The reaction mixture was stirred at 30 °C until the substrate **2a** was consumed as indicated by TLC. The resulting mixture was then poured into brine (30 mL) and extracted with dichloromethane (15 mL × 3). The combined organic phase was washed with water (15 mL × 3), dried over anhydrous $MgSO_4$, and concentrated in vacuum. The crude product was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 2:1) to give **3a** (470 mg, 95%) as a yellow solid.

(1*E*,7*E*)-4,5-Di(1,3-dithiolan-2-ylidene)-1,8-diphenylocta-1,7-diene-3,6-dione (**3a**): yellow solid (470 mg, 95% yield); mp 125−127 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.29−3.32 (m, 4H), 3.55−3.58 (m, 4H), 6.87 (d, J = 15.5 Hz, 2H), 7.31−7.32 (m, 6H), 7.45−7.47 (m, 4H), 7.78 (d, J = 15.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.5, 40.2, 122.0, 123.7, 128.4, 128.7, 130.0, 135.2, 143.6, 170.8, 184.2; HRMS (ESI-TOF) calcd for $C_{26}H_{23}O_2S_4^+$ ([M + H]$^+$) 495.0575, found 495.0578.

(1*E*,7*E*)-1,8-Bis(4-chlorophenyl)-4,5-di(1,3-dithiolan-2-ylidene)-octa-1,7-diene-3,6-dione (**3b**): yellow solid (507 mg, 90% yield); mp 133−135 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.33 (d, J = 5.0 Hz, 4H), 3.57 (d, J = 6.0 Hz, 4H), 6.81 (d, J = 15.5 Hz, 2H), 7.28 (d, J = 8.5 Hz, 4H), 7.38 (d, J = 8.5 Hz, 4H), 7.71 (d, J = 15.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.6, 40.2, 122.4, 123.4, 128.9, 129.5, 133.6, 135.9, 142.2, 171.4, 183.9; HRMS (ESI-TOF) calcd for $C_{26}H_{21}Cl_2O_2S_4^+$ ([M + H]$^+$) 562.9796, found 562.9785.

(1*E*,7*E*)-4,5-Di(1,3-dithiolan-2-ylidene)-1,8-bis(4-methoxyphenyl)-octa-1,7-diene-3,6-dione (**3c**): yellow solid (477 mg, 86% yield); mp 136−138 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.28−3.31 (m, 4H), 3.53−3.56 (m, 4H), 3.80 (s, 6H), 6.75 (d, J = 15.5 Hz, 2H), 6.83 (d, J = 8.5 Hz, 4H), 7.42 (d, J = 8.5 Hz, 4H), 7.75 (d, J = 15.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz)δ 35.5, 40.1, 55.3, 114.1, 119.8, 123.9, 127.9, 130.1, 143.4, 161.2, 169.8, 184.3; HRMS (ESI-TOF) calcd for $C_{28}H_{27}O_4S_4^+$ ([M + H]$^+$) 555.0787, found 555.0787.

(1*E*,7*E*)-4,5-Di(1,3-dithiolan-2-ylidene)-1,8-di-*p*-tolylocta-1,7-diene-3,6-dione (**3d**): yellow solid (465 mg, 89% yield); mp 122−124 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.32 (s, 6H), 3.28−3.30 (m, 4H), 3.54−3.57 (m, 4H), 6.83 (d, J = 15.5 Hz, 2H), 7.11 (d, J = 8.0 Hz, 4H), 7.36 (d, J = 8.0 Hz, 4H), 7.76 (d, J = 15.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 21.5, 35.5, 40.2, 121.1, 123.9, 128.4, 129.4, 132.5, 140.5, 143.7, 170.3, 184.4; HRMS (ESI-TOF) calcd for $C_{28}H_{27}O_2S_4^+$ ([M + H]$^+$) 523.0888, found 523.0896.

(1*E*,7*E*)-4,5-Di(1,3-dithiolan-2-ylidene)-1,8-di(naphthalen-2-yl)-octa-1,7-diene-3,6-dione (**3e**): yellow solid (523 mg, 88% yield); mp 137−139 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.31−3.34 (m, 4H), 3.58−3.60 (m, 4H), 7.01 (d, J = 15.5 Hz, 2H), 7.46 (dd, J = 7.0, 4.0 Hz, 4H), 7.58 (dd, J = 8.5, 1.5 Hz, 2H), 7.74 (d, J = 8.5 Hz, 2H), 7.76−7.78 (m, 2H), 7.81−7.83 (m, 2H), 7.90 (s, 2H), 7.97 (d, J = 15.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.6, 40.2, 122.2, 123.8, 123.9, 126.5, 127.0, 127.7, 128.4, 128.5, 130.3, 132.7, 133.2, 134.1, 143.8, 171.0, 184.2; HRMS (ESI-TOF) calcd for $C_{34}H_{27}O_2S_4^+$ ([M + H]$^+$) 595.0888, found 595.0896.

(1*E*,7*E*)-4,5-Di(1,3-dithiolan-2-ylidene)-1,8-di(furan-2-yl)octa-1,7-diene-3,6-dione (**3f**): yellow solid (389 mg, 82% yield); mp 135−137 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.29−3.31 (m, 4H), 3.54−3.56 (m, 4H), 6.41 (dd, J = 3.5, 2.0 Hz, 2H), 6.73 (d, J = 15.5 Hz, 2H), 7.40 (d, J = 1.0 Hz, 2H), 7.51 (d, J = 15.0 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.5, 40.2, 112.3, 115.4, 119.9, 123.8, 129.7, 144.4, 152.0, 170.4, 184.0; HRMS (ESI-TOF) calcd for $C_{22}H_{19}O_4S_4^+$ ([M + H]$^+$) 475.0161, found 475.0163.

(3*E*,9*E*)-6,7-Di(1,3-dithiolan-2-ylidene)-2,2,11,11-tetramethyldodeca-3,9-diene-5,8-dione (**3g**): yellow solid (363 mg, 80% yield); mp 140−142 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 0.99 (s, 18H), 3.26−3.30 (m, 4H), 3.48−3.52 (m, 4H), 6.10 (d, J = 15.5 Hz, 2H), 6.97 (d, J = 15.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 28.7, 33.7, 35.4, 40.0, 120.7, 123.5, 157.7, 169.3, 185.1; HRMS (ESI-TOF) calcd for $C_{22}H_{31}O_2S_4^+$ ([M + H]$^+$) 455.1201, found 455.1207.

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General Procedure for the Synthesis of Monoalkenoyl Bisketene Dithioacetals 3h–j (Taking 3h as an Example). To the mixture of **2a** (318 mg, 1.0 mmol) and 4-chlorobenzaldehyde (154 mg, 1.1 mmol) in H_2O (25 mL) was added NaOH (80 mg, 2.0 mmol). The reaction mixture was stirred at 45 °C until the substrate **2a** was consumed as indicated by TLC. The resulting mixture was then poured into brine (30 mL) and extracted with dichloromethane (15 mL × 3). The combined organic phase was washed with water (15 mL × 3), dried over anhydrous $MgSO_4$, and concentrated in vacuum. The crude product was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 2:1) to give **3h** (285 mg, 65%) as a yellow solid.

(*E*)-7-(4-Chlorophenyl)-3,4-di(1,3-dithiolan-2-ylidene)hept-6-ene-2,5-dione (**3h**): yellow solid (285 mg, 65% yield); mp 120–122 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.11 (s, 3H), 3.26–3.34 (m, 4H), 3.50–3.57 (m, 4H), 6.79 (d, J = 16.0 Hz, 1H), 7.31 (d, J = 8.5 Hz, 2H), 7.41 (d, J = 8.5 Hz, 2H), 7.71 (d, J = 15.5 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.4, 35.4, 35.4, 40.1, 40.1, 122.0, 122.8, 124.3, 128.9, 129.4, 133.4, 135.8, 142.1, 170.7, 183.5, 193.6; HRMS (ESI-TOF) calcd for $C_{19}H_{18}ClO_2S_4^+$ ([M + H]$^+$) 440.9873, found 440.9868.

(*E*)-3,4-Di(1,3-dithiolan-2-ylidene)-7-(4-methoxyphenyl)hept-6-ene-2,5-dione (**3i**): yellow solid (262 mg, 60% yield); mp 118–120 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.12 (s, 3H), 3.27–3.34 (m, 4H), 3.50–3.55 (m, 4H), 3.83 (s, 3H), 6.72 (d, J = 15.5 Hz, 1H), 6.87 (d, J = 8.5 Hz, 2H), 7.45 (d, J = 9.0 Hz, 2H), 7.76 (d, J = 15.5 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.4, 35.3, 35.4, 40.1, 40.1, 55.3, 114.2, 119.3, 123.2, 124.7, 127.8, 130.1, 143.6, 161.3, 168.4, 169.3, 184.0, 193.8; HRMS (ESI-TOF) calcd for $C_{20}H_{21}O_3S_4^+$ ([M + H]$^+$) 437.0368, found 437.0371.

(*E*)-3,4-Di(1,3-dithiolan-2-ylidene)-8,8-dimethylnon-6-ene-2,5-dione (**3j**): yellow solid (243 mg, 63% yield); mp 125–127 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.00 (s, 9H), 2.06 (s, 3H), 3.25–3.29 (m, 4H), 3.47–3.52 (m, 4H), 6.11 (d, J = 15.5 Hz, 1H), 7.00 (d, J = 15.5 Hz, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.2, 28.7, 33.7, 35.2, 35.4, 40.0, 120.1, 123.0, 124.2, 158.2, 168.0, 169.2, 184.7, 193.5; HRMS (ESI-TOF) calcd for $C_{17}H_{23}O_2S_4^+$ ([M + H]$^+$) 387.0575, found 387.0565.

General Procedure for the Synthesis of Indol-4(5*H*)-ones 4 (Taking 4a as an Example). To the mixture of **3a** (247 mg, 0.5 mmol) and TosMIC (117 mg, 0.6 mmol) in THF (10 mL) was added NaOH (22 mg, 0.55 mmol). The reaction mixture was stirred at room temperature until the substrate **3a** was consumed as indicated by TLC. The resulting mixture was then poured into brine (30 mL) and extracted with dichloromethane (15 mL × 3). The combined organic phase was washed with water (15 mL × 3), dried over anhydrous $MgSO_4$, and concentrated in vacuum. The crude product was purified by flash chromatography on silica gel (petroleum ether/EtOAc = 3:1) to give **4a** (248 mg, 93%) as a yellow solid.

(*E*)-5,6-Di(1,3-dithiolan-2-ylidene)-7-hydroxy-3-phenyl-7-styryl-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4a**): yellow solid (248 mg, 93% yield); mp 160–162 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.06–3.15 (m, 2H), 3.18–3.26 (m, 2H), 3.27 (s, 1H), 3.29–3.37 (m, 2H), 3.38–3.42 (m, 2H), 6.32 (d, J = 16.0 Hz, 1H), 6.40 (d, J = 16.0 Hz, 1H), 6.77 (d, J = 2.0 Hz, 1H), 7.19 (t, J = 7.0 Hz, 1H), 7.23–7.30 (m, 5H), 7.34 (t, J = 8.0 Hz, 2H), 7.67 (d, J = 8.0 Hz, 2H), 8.95 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.5, 35.9, 38.6, 39.4, 77.6, 116.9, 118.7, 125.2, 125.4, 126.5, 126.7, 126.8, 127.7, 127.9, 128.4, 128.5, 128.7, 129.1, 134.0, 135.6, 136.4, 143.1, 158.3, 181.1; HRMS (ESI-TOF) calcd for $C_{28}H_{24}NO_2S_4^+$ ([M + H]$^+$) 534.0684, found 534.0687.

(*E*)-3-(4-Chlorophenyl)-7-(4-chlorostyryl)-5,6-di(1,3-dithiolan-2-ylidene)-7-hydroxy-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4b**): yellow solid (286 mg, 95%); mp 170–172 °C; ^{1}H NMR ($CDCl_3$, 500 MHz)δ 3.07–3.19 (m, 2H), 3.21 (s, 1H), 3.22–3.47 (m, 6H), 6.26 (d, J = 15.5 Hz, 1H), 6.32 (d, J = 16.0 Hz, 1H), 6.76 (d, J = 2.5 Hz, 1H), 7.20 (dd, J = 14.0, 8.5 Hz, 4H), 7.30–7.31 (m, 2H), 7.60–7.61 (m, 2H), 8.91 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.6, 36.0, 38.7, 39.4, 77.5, 116.9, 118.7, 124.2, 125.1, 126.3, 127.9, 128.0, 128.1, 128.6, 129.0, 129.9, 132.4, 132.4, 133.4, 134.9, 136.0, 143.1, 158.9, 181.0; HRMS (ESI-TOF) calcd for $C_{28}H_{22}Cl_2NO_2S_4^+$ ([M + H] $^+$) 601.9905, found 601.9911.

(*E*)-5,6-Di(1,3-dithiolan-2-ylidene)-7-hydroxy-3-(4-methoxyphenyl)-7-(4-methoxystyryl)-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4c**): yellow solid (264 mg, 89%); mp 197–199 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.05–3.25 (m, 4H), 3.27–3.36 (m, 5H), 3.77 (s, 3H), 3.80 (s, 3H), 6.20 (d, J = 16.0 Hz, 1H), 6.33 (d, J = 15.5 Hz, 1H), 6.73 (d, J = 2.5 Hz, 1H), 6.77 (d, J = 9.0 Hz, 2H), 6.89 (d, J = 9.0 Hz, 2H), 7.20 (d, J = 9.0 Hz, 2H), 7.61 (d, J = 9.0 Hz, 2H), 8.91 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.5, 35.9, 38.6, 39.4, 55.2, 55.2, 77.7, 113.4, 113.8, 116.8, 117.9, 125.0, 125.6, 126.6, 127.1, 128.0, 128.8, 129.2, 129.8, 135.3, 143.1, 157.9, 158.4, 159.3, 181.1; HRMS (ESI-TOF) calcd for $C_{30}H_{28}NO_4S_4^+$ ([M + H]$^+$) 594.0896, found 594.0878.

(*E*)-5,6-Di(1,3-dithiolan-2-ylidene)-7-hydroxy-7-(4-methylstyryl)-3-(*p*-tolyl)-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4d**): yellow solid (253 mg, 90%); mp 166–168 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.29 (s, 3H), 3.33 (s, 3H), 3.04–3.20 (m, 4H), 3.25 (s, 1H), 3.33–3.40 (m, 4H), 6.26 (d, J = 15.5 Hz, 1H), 6.34 (d, J = 15.5 Hz, 1H), 6.71 (s, 1H), 7.04 (d, J = 8.0 Hz, 2H), 7.15 (t, J = 8.0 Hz, 4H), 7.55 (d, J = 7.5 Hz, 2H), 8.99 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 21.2, 35.5, 35.8, 38.6, 39.4, 77.6, 116.9, 118.5, 125.1, 125.6, 126.7, 127.0, 127.6, 128.6, 128.7, 129.1, 131.1, 133.6, 135.4, 136.1, 137.5, 143.1, 158.0, 181.2; HRMS (ESI-TOF) calcd for $C_{30}H_{28}NO_2S_4^+$ ([M + H] $^+$) 562.0997, found 562.0989.

(*E*)-5,6-Di(1,3-dithiolan-2-ylidene)-7-hydroxy-3-(naphthalen-2-yl)-7-(2-(naphthalen-2-yl)vinyl)-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4e**): yellow solid (279 mg, 88%); mp 148–150 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.96–3.05 (m, 2H), 3.15–3.24 (m, 3H), 3.27–3.34 (m, 2H), 3.37–3.41 (m, 2H), 6.44 (d, J = 15.5 Hz, 1H), 6.49 (d, J = 16.0 Hz, 1H), 6.74 (d, J = 2.5 Hz, 1H), 7.38–7.40 (m, 4H), 7.41–7.46 (m, 1H), 7.60 (s, 1H), 7.66–7.78 (m, 6H), 7.79–7.83 (m, 1H), 8.07 (s, 1H), 9.14 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.6, 35.8, 38.6, 39.4, 77.7, 117.2, 119.3, 123.8, 125.1, 125.2, 125.5, 125.6, 125.9, 126.2, 126.6, 126.8, 127.0, 127.2, 127.5, 127.6, 127.8, 128.0, 128.1, 128.9, 129.3, 131.7, 132.4, 132.9, 133.4, 133.5, 133.9, 135.7, 143.3, 158.4, 181.3; HRMS (ESI-TOF) calcd for $C_{36}H_{28}NO_2S_4^+$ ([M + H] $^+$) 634.0997, found 634.1017.

(*E*)-5,6-Di(1,3-dithiolan-2-ylidene)-3-(furan-2-yl)-7-(2-(furan-2-yl)-vinyl)-7-hydroxy-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4f**): yellow solid (205 mg, 80%); mp 155–157 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.14–3.24 (m, 5H), 3.31–3.34 (m, 2H), 3.41–3.44 (m, 2H), 6.17 (d, J = 3.0 Hz, 1H), 6.26(d, J = 8.5 Hz, 2H), 6.31 (dd, J = 3.5, 1.5 Hz, 1H), 6.43 (dd, J = 3.5, 2.0 Hz, 1H), 7.12 (d, J = 2.0 Hz, 1H), 7.29 (d, J = 1.5 Hz, 1H), 7.32 (d, J = 1.0 Hz, 1H), 7.51 (d, J = 3.5 Hz, 1H), 8.74 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 35.6, 36.0, 38.5, 39.4, 77.3, 108.8, 109.0, 111.2, 111.5, 115.3, 115.8, 117.9, 125.4, 126.1, 126.9, 136.2, 140.3, 142.2, 142.6, 149.0, 152.0, 158.1, 181.0; HRMS (ESI-TOF) calcd for $C_{24}H_{20}NO_4S_4^+$ ([M + H]$^+$) 514.0270, found 514.0272.

(*E*)-3-*tert*-Butyl-7-(3,3-dimethylbut-1-en-1-yl)-5,6-di(1,3-dithiolan-2-ylidene)-7-hydroxy-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4g**): yellow solid (183 mg, 74%); mp 142–144 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 0.93 (s, 9H), 1.41 (s, 9H), 2.88 (s, 1H), 3.15–3.23 (m, 4H), 3.28–3.38 (m, 2H), 3.40–3.45 (m, 2H), 5.38 (d, J = 15.5 Hz, 1H), 5.56(d, J = 15.5 Hz, 1H), 6.51 (d, J = 2.0 Hz, 1H), 8.32 (s, 1H); HRMS (ESI-TOF) calcd for $C_{24}H_{32}NO_2S_4^+$ ([M + H] $^+$) 494.1310, found 494.1317.

3-(4-Chlorophenyl)-5,6-di(1,3-dithiolan-2-ylidene)-7-hydroxy-7-methyl-6,7-dihydro-1*H*-indol-4(5*H*)-one (4h): yellow solid (180 mg, 75%); mp 157–159 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.64 (s, 3H), 2.84 (s, 1H), 3.19–3.24 (m, 2H), 3.25–3.30 (m, 2H), 3.33–3.41 (m, 2H), 3.44–3.49 (m, 2H), 6.79 (d, J = 2.5 Hz, 1H), 7.30 (d, J = 8.5 Hz, 2H), 7.60 (d, J = 8.5 Hz, 2H), 8.66 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.4, 35.5, 35.9, 38.8, 39.3, 75.3, 115.6, 118.2, 124.0, 125.9, 128.0, 128.7, 129.9, 132.2, 132.5, 134.2, 146.3, 157.9, 180.9; HRMS (ESI-TOF) calcd for $C_{21}H_{19}ClNO_2S_4^+$ ([M + H]$^+$) 479.9982, found 479.9976.

5,6-Di(1,3-dithiolan-2-ylidene)-7-hydroxy-3-(4-methoxyphenyl)-7-methyl-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4i**): yellow solid (166 mg, 70%); mp 155–157 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.62 (d, J = 1.5 Hz, 3H), 2.96 (s, 1H), 3.14–3.23 (m, 2H), 3.24–3.29 (m, 2H),

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3.34−3.41 (m, 2H), 3.42−3.50 (m, 2H), 3.80 (s, 3H), 6.70 (d, J = 2.5 Hz, 1H), 6.88 (d, J = 9.0 Hz, 2H), 7.58 (d, J = 9.0 Hz, 2H), 8.80 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.4, 35.5, 35.9, 38.7, 39.3, 55.2, 75.3, 113.4, 115.6, 117.6, 124.8, 126.1, 126.6, 129.0, 133.9, 146.0, 157.2, 158.4, 181.0; HRMS (ESI-TOF) calcd for $C_{22}H_{22}NO_3S_4^+$ ([M + H] $^+$) 476.0477, found 476.0492.

3-*tert*-Butyl-5,6-di(1,3-dithiolan-2-ylidene)-7-hydroxy-7-methyl-6,7-dihydro-1*H*-indol-4(5*H*)-one (**4j**): yellow solid (138 mg, 65%); mp 181−183 °C; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.39 (s, 9H), 1.59 (s, 3H), 3.02 (s, 1H), 3.10−3.14 (m, 1H), 3.17−3.21 (m, 1H), 3.24−3.29 (m, 3H), 3.35−3.40 (m, 2H), 3.45−3.49 (m, 1H), 6.49 (d, J = 2.0 Hz, 1H), 8.59 (s, 1H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 27.4, 30.1, 31.4, 35.5, 35.9, 38.6, 39.2, 75.3, 115.0, 116.4, 126.6, 129.2, 133.2, 135.3, 146.7, 155.9, 180.7; HRMS (ESI-TOF) calcd for $C_{19}H_{24}NO_2S_4^+$ ([M + H]$^+$) 426.0684, found 426.0690.

■ ASSOCIATED CONTENT

Supporting Information

Copies of ^{1}H and ^{13}C NMR spectra for all new products. 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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