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1,6-Conjugated Addition-Mediated [2+1] Annulation: Approach to Spiro[2.5]octa-4,7-dien-6-one

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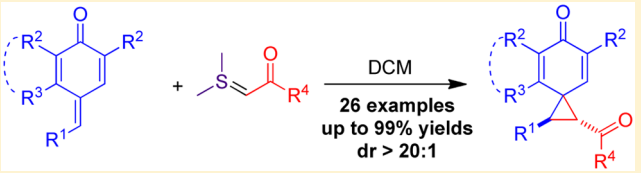
Supporting Information

ABSTRACT: A formal 1,6-conjugated addition-mediated [2+1] annulation to synthesize spiro[2.5]octa-4,7-dien-6-one with *p*-quinone methides and sulfur ylides has been described. This domino-type process was highly diastereoselective and exhibited good functional group tolerance and scalability without the use of metals and bases.



Spiro-cyclopropanes, as a privileged class of spiro compounds, are embedded in a large quantity of natural products and bioactive molecules.[1] In addition, they could act as key synthetic intermediates in organic synthetic chemistry and material chemistry.[2] Among them, spiro[2.5]octa-4,7-dien-6-one structural motifs have attracted an increasing amount of attention because of their presence in natural products as antitumor antibiotics working by alkylation of DNA.[3] In general, one frequently used synthetic approach to spiro[2.5]-octa-4,7-dien-6-ones should be distinguished. In the 1980s, Becker[4] and Field[5] constructed them with quinone diazides and olefins under lighting conditions. Recently, Baran[6] achieved the core structure successfully with the same materials by employing Rh catalysts. However, the commonality of all these syntheses is that they need well-designed quinone diazides as starting materials or harsh reaction conditions such as the use of heavy metals. Therefore, the development of a promising strategy for synthesizing spiro[2.5]octa-4,7-dien-6-one from simple starting materials under mild conditions remains highly desirable.

p-Quinone methide (*p*-QM) containing a cyclohexadiene moiety in *para* conjugation with a carbonyl group has been known as a reactive intermediate for chemical, medicinal, and biological processes[7] because of its aromatic zwitterionic resonances.[8] Recently, two pioneering works of *p*-QMs offering diarylmethines through 1,6-conjugated addition have been reported by Fan and Jørgensen (Scheme 1a).[9] Taking their zwitterionic resonances into consideration, we envisaged that after the addition of a nucleophile, the carbon atom at the *para* position of the phenolic hydroxyl still exhibits sufficient nucleophilicity to realize nucleophilic addition or the nucleophilic substitution reaction, thus leading to the preparation of spiro-cyclohexadiene compounds (Scheme 1b).[10] This strategy could offer us an easy way to construct the spiro[2.5]octa-4,7-dien-6-one with *p*-QMs and appropriately designed substrates.

Sulfur ylides[11] have been well employed as outstanding synthons for the construction of epoxides, aziridines, and cyclopropanes with aldehydes, imines, and α,β-unsaturated aldehydes or ketones.[12] Recently, Zhou[13] and co-workers developed a 1,4-addition and dearomatization reaction of 2-methyl-substituted arenesulfonylindole and sulfonium bromide to the synthesis of 5-azaspiro[2.4]hept-4-ene derivatives. Herein, we will describe our method for the synthesis of spiro[2.5]octa-4,7-dien-6-one through 1,6-conjugated addition-mediated [2+1] annulation with *p*-quinone methides and sulfur ylides (Scheme 1c).

We commenced our research by screening the reaction between *p*-quinone methide **1a** and sulfonium bromide **2a** in the presence of 1 equiv of base. To our delight, **4aa** was achieved in 55% yield (Table 1, entries 1−6). The structure was confirmed by ^{1}H and ^{13}C NMR spectroscopy, mass spectrometry, and single-crystal X-ray diffraction analysis[14] (Figure S1). Then we employed sulfur ylide **3a** instead of sulfonium bromide **2a** to improve the reaction efficiency. When K_2CO_3 or NaOAc was tested, **4aa** was obtained in 90 or 82% yield, respectively (Table 1, entries 7 and 8). The reaction proceeded with low yields when Cs_2CO_3, DBU, KOH, and KO^{t}Bu were used (Table 1, entries 9−12). A control experiment without base was also conducted, and the yield of **4aa** was further increased to 95% (Table 1, entry 13). Additionally, several solvents were evaluated, and all of them failed to give a better result (Table 1, entries 14−17).

With the optimized conditions in hand, we then explored the scope and generality of *p*-quinone methides and sulfur ylides, and the results are shown in Table 2. Most of the *p*-quinone methides employed in the reaction delivered the corresponding products in moderate to good yields with high diastereoselectivity. *p*-QMs bearing a halogen group (-Cl or -Br) or an electron-withdrawing group (-CF_3) at the *para* position of the benzene ring afforded **4ba**−**4da** in 82−98% yields. **1e** with a methyl group at the *para* position produced **4ea** in 69% yield. *p*-QMs with -MeO and -Cl at the *meta* position gave **4fa** and **4ga** in 97 and 92% yields, respectively. *ortho*-Chloride- or

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Scheme 1. Reactions of *p*-Quinone Methide (*p*-QM)

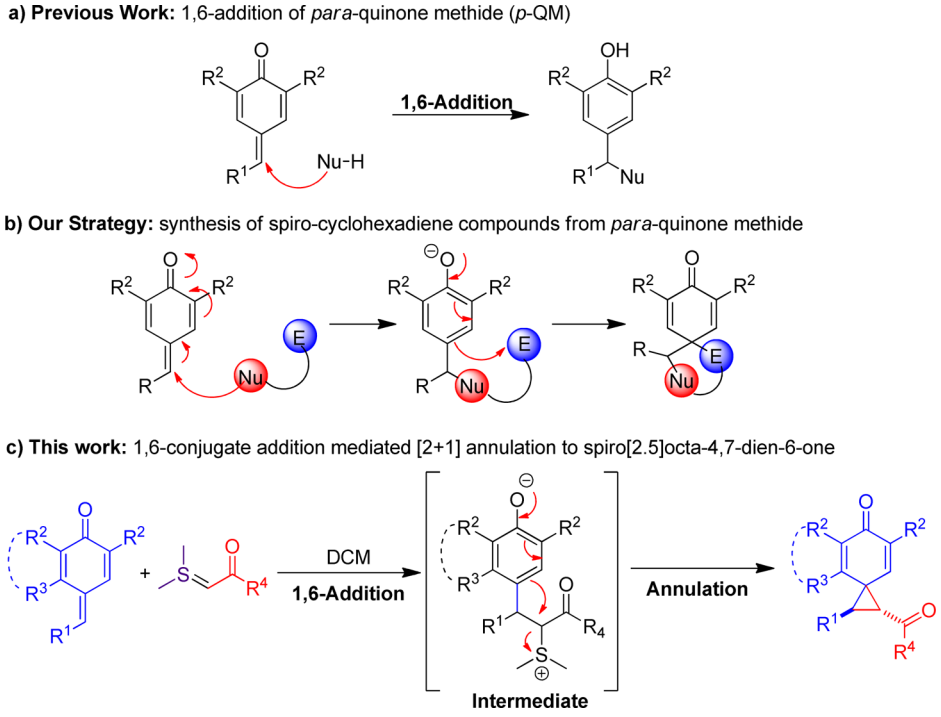
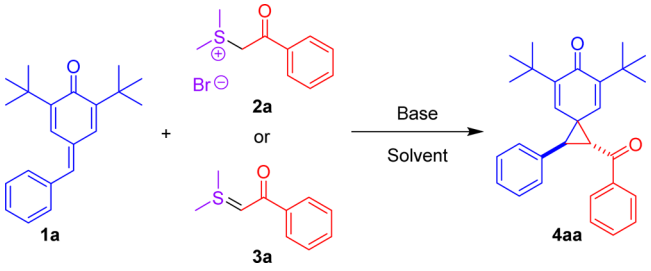


Table 1. Optimization of Reaction Conditions[a]



entry	2a or 3a	base	solvent	yield (%)[b]	dr[b]
1	**2a**	K_2CO_3	DCM	5	–
2	**2a**	NaOAc	DCM	<5	–
3	**2a**	Cs_2CO_3	DCM	47	>20:1
4	**2a**	DBU	DCM	37	>20:1
5	**2a**	KO^{t}Bu	DCM	55	>20:1
6	**2a**	KOH	DCM	33	>20:1
7	**3a**	K_2CO_3	DCM	90	>20:1
8	**3a**	NaOAc	DCM	82	>20:1
9	**3a**	Cs_2CO_3	DCM	44	>20:1
10	**3a**	DBU	DCM	5	–
11	**3a**	KO^{t}Bu	DCM	13	–
12	**3a**	KOH	DCM	5	–
13	**3a**	/	**DCM**	**95 (91)**[c]	**>20:1**
14	**3a**	/	CH_3CN	87	>20:1
15	**3a**	/	DMF	93	>20:1
16	**3a**	/	THF	89	>20:1
17	**3a**	/	EtOH	94	>20:1

[a]All reactions were performed with **1a** (0.1 mmol), **2a** or **3a** (0.1 mmol), base (0.1 mmol), and solvents (0.50 mL) at ambient temperature for 12 h. [b]The yields and dr values were determined by ^{1}H NMR analysis with trioxane as an internal standard. [c]Isolated yield reported in parentheses.

-bromide-substituted **1h** and **1i** produced **4ha** and **4ia** in 99 and 91% yields, respectively. For functionalized *p*-QMs with alkynyl or alkenyl groups, the corresponding reactions also proceeded smoothly to give **4ja** and **4ka** in 68 and 80% yields, respectively. Substrates carrying naphthyl offered **4la** in 91% yield. (*E*)-4-Benzylidene-naphthalen-1(4*H*)-one (**1m**) produced product **4ma** in 85% yield. The relative configuration of the structure was determined by single-crystal X-ray diffraction analysis.[14] Varying the R^1 group of *p*-QMs with alkyl groups, such as methyl, ethyl, *iso*-propyl, and *tert*-butyl groups, led to products **4na**–**4qa** in 33–97% yields. Subsequently, we explored the scope of sulfur ylides. 4-Halogen-substituted sulfur ylides produced **4ab**–**4ad** in 80, 68, and 86% yields, respectively. When sulfur ylides contain methyl and methoxyl at the *para* position, the corresponding products **4ae** and **4af** were produced in 80 and 92% yields, respectively. **3g** and **3h** with 3-methoxyl and 3,4-methylenedioxyl produced **4ag** and **4ah** in 91 and 99% yields, respectively. Substrates with naphthyl and thienyl could also produce **4ai** and **4aj** in 61 and 74% yields, respectively. R^4 groups of methyl or methoxyl group failed to produce the corresponding product. Finally, we set this protocol in gram scale (5 mmol), and model product **4aa** could be obtained in 86% yield (1.77 g) without a decrease of diastereoselectivity.

To gain insight into the utility of the reaction, spiro[2.5]octa-4,7-dien-6-one **4aa** was further transformed. Treatment of **4aa** with *p*-toluenesulfonic acid and water gave 3-hydroxy-2-(4-hydroxyphenyl)-1,3-diphenylpropan-1-one **5aa** in 92% yield (Scheme 2). Under the basic conditions, **4aa** could be transformed into 1,2,3-triphenylprop-2-en-1-one derivative **6aa** in 97% yield (2:1 *Z*:*E*), which is an important class of organic compounds present in natural and bioactive molecules and potential intermediates in numerous organic and medicinal syntheses.[15]

To achieve the optically active spiro[2.5]octa-4,7-dien-6-one, we employed the known chiral sulfur ylides **7** developed by

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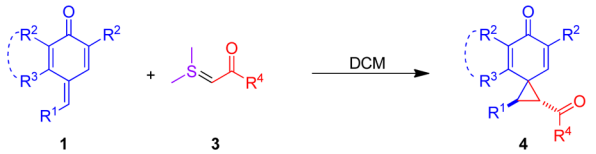
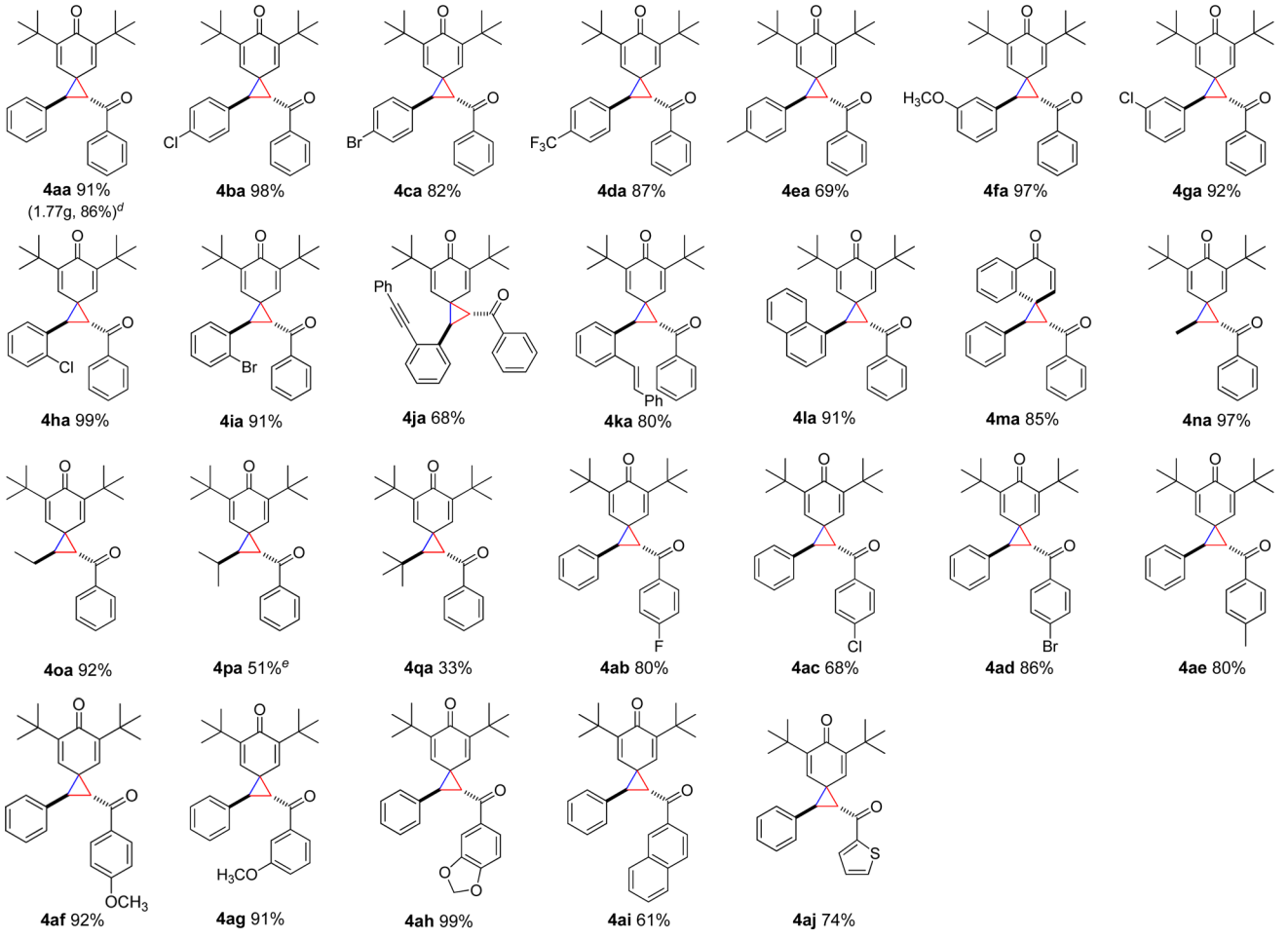
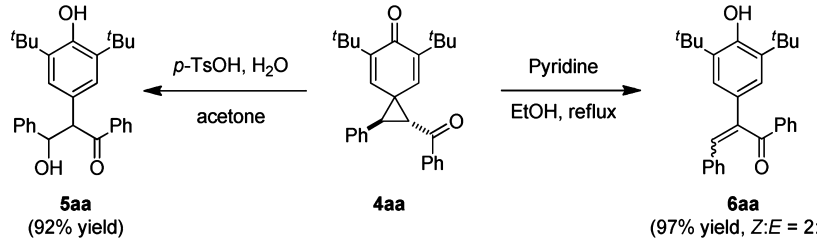
Table 2. Substrate Scope[a−c]





[a]All reactions were performed with **1** (0.1 mmol) and **3** (0.1 mmol) in CH_2Cl_2 (0.50 mL) at ambient temperature for 12 h. [b]Isolated yields. [c]dr values of >20:1. [d]Total of 5.0 mmol. [e]dr of 3:1.

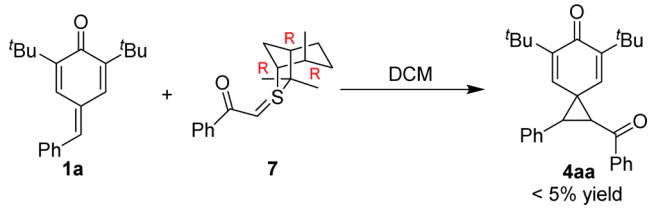
Scheme 2. Transformation of 4aa



Aggarwal[16] instead of **3a** to conduct our reaction (Scheme 3). Unfortunately, only trace **4aa** could be detected.

According to the literature,[9,12n,17] a reasonable mechanism is described in Scheme 4. The first step involved nucleophilic attack of sulfur ylide **3** on *p*-QMs **1** through 1,6-conjugated addition to give two intermediates, **A** and **B**, through paths a and b. Because of steric hindrance, intermediate **A** was more stable than **B** and easier to transform into major product **4** through the S_N2 nucleophilic substitution reaction.

Scheme 3. Attempt To Synthesize Enantiopure 4aa



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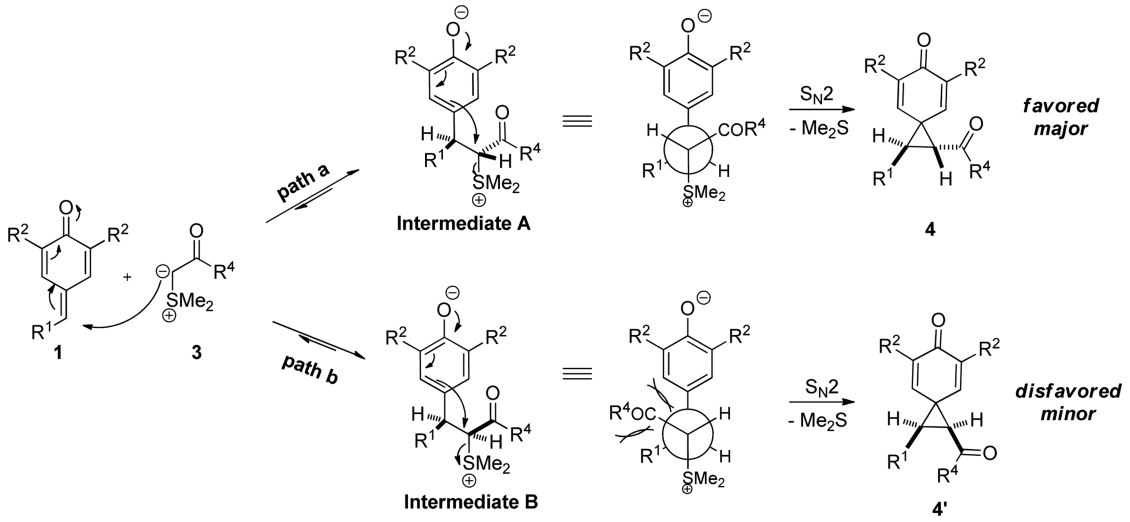
Scheme 4. Plausible Mechanism



In conclusion, we have developed a new strategy for synthesizing spiro[2.5]octa-4,7-dien-6-one through 1,6-conjugated addition-mediated [2+1] annulation of *p*-QMs with sulfur ylides. This domino-type process was highly diastereoselective and exhibited good functional group tolerance and scalability without the use of metals and bases.

EXPERIMENTAL SECTION

General Information. ^{1}H and ^{13}C NMR spectra were recorded on a 300 MHz spectrometer using $CDCl_3$ as a solvent. Infrared (IR) spectra were recorded using a thin film supported on KBr disks. High-resolution mass measurement was performed with an electrospray ionization (ESI) method on a Q-TOF mass spectrometer operating in positive ion mode. Melting points were measured on a microscopic melting point apparatus. Tetrahydrofuran (THF) was distilled from sodium/benzophenone, *N*,*N*-dimethylformamide (DMF) from calcium hydride, and dichloromethane (DCM) from phosphorus pentoxide. PE refers to petroleum ether (bp 60−90 °C), and EA refers to ethyl acetate. Flash column chromatography was conducted using commercially available 200−300 mesh under pressure unless otherwise indicated. Gradient flash chromatography was conducted eluting with PE and EA. All other starting materials and solvents were commercially available and were used without further purification unless otherwise stated.

General Procedure for the Preparation of *p*-Quinone Methides. Aldehydes (10 mmol) were added to a solution of phenols (10 mmol) in toluene (40 mL). The reaction mixture was heated in a Dean−Stark apparatus to reflux. Piperidine (20 mmol) was added dropwise over 1 h, and the reaction mixture continued to reflux for 3 h. After the mixture had cooled just below the boiling point of toluene, acetic anhydride (20 mmol) was added, and then the solution was stirred for 15 min. The residue was extracted three times with dichloromethane. The combined organic layers were washed with water and brine sequentially, dried over Na_2SO_4, filtered, and concentrated. The crude product was purified by flash chromatography on silica gel to afford the corresponding product. **1a−1l** were synthesized by the general procedure.[18a] **1m**,[9a] **1n**,[18b] **1o−1q**,[9a] were prepared using the corresponding literature procedures.

General Procedure for the Preparation of Sulfonium Bromide. Dimethyl sulfide (10 mmol) was added to a solution of 2-bromoacetophenone (10 mmol) in acetone (15 mL). After the mixture had been stirred for 12 h, the residue was filtered and washed with acetone. The solid product was used as sulfonium bromide without further purification. **2a−2j** was prepared by the general procedure.[19]

General Procedure for the Preparation of Sulfur Ylides. Corresponding sulfonium bromide was added to a solution of NaOH (10 mmol) in water (10 mL). The solution was stirred for 30 min and then extracted several times with dichloromethane. The combined organic layers were washed with water and brine sequentially, dried over Na_2SO_4, filtered, and concentrated. The sulfur ylides obtained can be used directly without further purification. **3a−3j** were prepared by the general procedure.[19]

General Procedure for the Preparation of Spiro[2.5]octa-4,7-dien-6-ones. A sealed tube was charged with *p*-quinone methide (0.1 mmol, 1 equiv), sulfur ylide (0.1 mmol, 1 equiv), and dichloromethane (0.5 mL). The reaction mixture was stirred at ambient temperature for 12 h. Then the reaction mixture was concentrated *in vacuo* and purified by careful chromatography on silica gel to afford the desired product.

*1-Benzoyl-5,7-di-tert-butyl-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4aa**).* White solid: 37.6 mg, 91% yield; mp 166−168 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87 (d, J = 7.2 Hz, 2H), 7.60 (t, J = 7.3 Hz, 1H), 7.48 (t, J = 7.5 Hz, 2H), 7.38−7.23 (m, 5H), 6.62 (d, J = 2.7 Hz, 1H), 6.03 (d, J = 2.7 Hz, 1H), 4.09 (d, J = 7.5 Hz, 1H), 3.96 (d, J = 7.5 Hz, 1H), 1.16 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.6, 185.6, 150.1, 149.8, 138.5, 137.6, 137.5, 135.2, 133.5, 129.1, 128.8, 128.6, 128.2, 127.7, 40.8, 40.4, 40.0, 35.2, 29.3; IR (KBr) 3062, 3003, 2956, 2903, 2865, 1668, 1646, 1620, 1450, 725, 695 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{32}O_2 + H]^+$ 413.2475, found 413.2474.

*1-Benzoyl-5,7-di-tert-butyl-2-(4-chlorophenyl)spiro[2.5]octa-4,7-dien-6-one (**4ba**).* White solid: 43.6 mg, 98% yield; mp 197−199 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (d, J = 7.3 Hz, 2H), 7.60 (t, J = 7.3 Hz, 1H), 7.48 (t, J = 7.5 Hz, 2H), 7.33 (d, J = 8.3 Hz, 2H), 7.21 (d, J = 8.2 Hz, 2H), 6.57 (d, J = 2.5 Hz, 1H), 5.99 (d, J = 2.5 Hz, 1H), 4.03 (d, J = 7.4 Hz, 1H), 3.89 (d, J = 7.4 Hz, 1H), 1.15 (s, 9H), 1.15 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.3, 185.5, 150.5, 150.0, 137.9, 137.2, 133.8, 133.6, 130.5, 128.9, 128.8, 128.2, 40.8, 40.2, 39.1, 35.2, 35.2, 29.3, 29.2; IR (KBr) 3056, 3009, 2959, 2909, 2866, 1663, 1645, 1619, 1597, 1495, 1450, 1288, 882, 737, 685 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}ClO_2 + H]^+$ 447.2085, found 447.2084.

*1-Benzoyl-2-(4-bromophenyl)-5,7-di-tert-butylspiro[2.5]octa-4,7-dien-6-one (**4ca**).* White solid: 40.3 mg, 82% yield; mp 201−203 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.85 (d, J = 7.4 Hz, 2H), 7.60 (s, 1H), 7.53−7.40 (m, 4H), 7.15 (d, J = 8.0 Hz, 2H), 6.56 (d, J = 1.9 Hz, 1H), 5.99 (s, 1H), 4.00 (d, J = 7.3 Hz, 1H), 3.88 (d, J = 7.4 Hz, 1H), 1.15 (s, 9H), 1.14 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.3, 185.5, 150.5, 150.0, 137.8, 137.2, 134.3, 133.6, 131.7, 130.8, 128.8, 128.2, 126.9, 121.7, 40.7, 40.1, 39.1, 35.2, 29.3, 29.2; IR (KBr) 3056, 2959, 2867, 1663, 1643, 1619, 1491, 1450, 1288, 1215, 1012, 882, 736, 688 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}BrO_2 + H]^+$ 491.1580, found 491.1577.

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*1-Benzoyl-5,7-di-tert-butyl-2-[4-(trifluoromethyl)phenyl]spiro-[2.5]octa-4,7-dien-6-one (**4da**).* White solid: 41.6 mg, 87% yield; mp 158−160 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.87 (d, J = 7.3 Hz, 2H), 7.62 (d, J = 8.0 Hz, 3H), 7.49 (t, J = 7.5 Hz, 2H), 7.41 (d, J = 8.0 Hz, 2H), 6.57 (d, J = 2.6 Hz, 1H), 5.96 (d, J = 2.6 Hz, 1H), 4.10 (d, J = 7.3 Hz, 1H), 3.94 (d, J = 7.5 Hz, 1H), 1.15 (s, 9H), 1.14 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.1, 185.4, 150.7, 150.3, 139.4, 137.5, 137.2, 137.0, 133.7, 129.6, 128.9, 128.2, 125.6, 125.5, 40.6, 40.0, 39.1, 35.2, 35.2, 29.2, 29.2; IR (KBr) 3062, 3009, 2962, 2926, 2861, 1659, 1620, 1450, 1327, 1289, 1129, 1068, 883, 730, 689 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{31}F_3O_2 + H]^+$ 481.2349, found 481.2347.

*1-Benzoyl-5,7-di-tert-butyl-2-(p-tolyl)spiro[2.5]octa-4,7-dien-6-one (**4ea**).* White solid: 29.5 mg, 69% yield; mp 178−180 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (d, J = 7.2 Hz, 2H), 7.59 (t, J = 7.3 Hz, 1H), 7.48 (t, J = 7.5 Hz, 2H), 7.14 (s, 4H), 6.61 (d, J = 2.7 Hz, 1H), 6.06 (d, J = 2.7 Hz, 1H), 4.05 (d, J = 7.4 Hz, 1H), 3.92 (d, J = 7.5 Hz, 1H), 2.35 (s, 3H), 1.15 (s, 9H), 1.15 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.7, 185.7, 150.0, 149.6, 138.7, 137.8, 137.6, 137.4, 133.5, 132.1, 129.3, 128.9, 128.8, 128.2, 41.0, 40.6, 39.9, 35.2, 29.3, 21.26; IR (KBr) 3012, 2962, 2920, 2863, 1657, 1645, 1620, 1484, 1450, 1044, 883, 734, 689, 635 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{34}O_2 + H]^+$ 427.2632, found 427.2631.

*1-Benzoyl-5,7-di-tert-butyl-2-(3-methoxyphenyl)spiro[2.5]octa-4,7-dien-6-one (**4fa**).* White solid: 43.0 mg, 97% yield; mp 123−131 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (d, J = 7.3 Hz, 2H), 7.58 (d, J = 7.3 Hz, 1H), 7.48 (t, J = 7.5 Hz, 2H), 7.26 (t, J = 7.9 Hz, 2H), 6.85 (d, J = 7.9 Hz, 2H), 6.79 (s, 1H), 6.60 (d, J = 2.5 Hz, 1H), 6.07 (d, J = 2.5 Hz, 1H), 4.06 (d, J = 7.4 Hz, 1H), 3.93 (d, J = 7.5 Hz, 1H), 3.80 (s, 3H), 1.15 (s, 18H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.6, 159.7, 150.1, 149.8, 138.5, 137.5, 136.8, 133.5, 129.6, 128.8, 128.2, 121.3, 114.9, 113.1, 55.3, 40.9, 40.4, 40.0, 35.2, 29.3; IR (KBr) 3056, 2997, 2958, 2914, 1658, 1643, 1619, 1491, 1450, 1256, 883, 810, 732, 689 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{34}O_3 + H]^+$ 443.2581, found 443.2582.

*1-Benzoyl-5,7-di-tert-butyl-2-(3-chlorophenyl)spiro[2.5]octa-4,7-dien-6-one (**4ga**).* Light yellow solid: 41.0 mg, 92% yield; mp 145−147 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.94−7.79 (m, 2H), 7.60 (t, J = 7.4 Hz, 1H), 7.48 (t, J = 7.5 Hz, 2H), 7.34−7.21 (m, 3H), 7.16 (dd, J = 4.3, 1.2 Hz, 1H), 6.57 (d, J = 2.7 Hz, 1H), 6.00 (d, J = 2.7 Hz, 1H), 4.04 (d, J = 7.4 Hz, 1H), 3.91 (d, J = 7.4 Hz, 1H), 1.16 (s, 9H), 1.15 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.2, 185.5, 150.5, 150.1, 137.9, 137.4, 137.3, 137.1, 134.5, 133.7, 129.8, 129.3, 128.9, 128.2, 128.0, 127.4, 40.6, 40.1, 39.1, 35.2, 35.18, 29.3, 29.2; IR (KBr) 2997, 2957, 2850, 1661, 1647, 1619, 1598, 1478, 1449, 886, 786, 733, 689, 653 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}ClO_2 + H]^+$ 447.2085, found 447.2086.

*1-Benzoyl-5,7-di-tert-butyl-2-(2-chlorophenyl)spiro[2.5]octa-4,7-dien-6-one (**4ha**).* White solid: 44.3 mg, 99% yield; mp 176−178 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.91 (d, J = 7.2 Hz, 2H), 7.61 (t, J = 7.4 Hz, 1H), 7.50 (t, J = 7.5 Hz, 2H), 7.43−7.34 (m, 1H), 7.30−7.25 (m, 3H), 6.67 (d, J = 2.7 Hz, 1H), 5.86 (d, J = 2.7 Hz, 1H), 4.02 (d, J = 7.5 Hz, 1H), 3.93 (d, J = 7.5 Hz, 1H), 1.17 (s, 9H), 1.12 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.4, 185.6, 150.5, 150.1, 137.8, 137.4, 137.1, 136.4, 133.8, 133.6, 130.0, 129.7, 129.1, 128.9, 128.2, 126.6, 40.8, 40.3, 38.6, 35.2, 35.1, 29.3, 29.2; IR (KBr) 3044, 2962, 2897, 2861, 1670, 1647, 1619, 1593, 1446, 1060, 754, 736, 698 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}ClO_2 + H]^+$ 447.2085, found 447.2082.

*1-Benzoyl-2-(2-bromophenyl)-5,7-di-tert-butylspiro[2.5]octa-4,7-dien-6-one (**4ia**).* White solid: 44.5 mg, 91% yield; mp 175−177 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.91 (d, J = 7.4 Hz, 2H), 7.66−7.56 (m, 2H), 7.49 (t, J = 7.6 Hz, 2H), 7.34−7.23 (m, 2H), 7.19 (dd, J = 10.1, 4.5 Hz, 1H), 6.68 (d, J = 2.6 Hz, 1H), 5.84 (d, J = 2.6 Hz, 1H), 4.00 (d, J = 7.5 Hz, 1H), 3.94 (d, J = 7.5 Hz, 1H), 1.18 (s, 9H), 1.12 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.3, 185.6, 150.6, 150.2, 137.7, 137.4, 137.2, 135.6, 133.6, 133.0, 130.2, 129.3, 128.9, 128.2, 127.3, 126.6, 40.9, 40.9, 40.5, 35.2, 35.1, 29.3, 29.1; IR (KBr) 3044, 2991, 2962, 2897, 2855, 1668, 1646, 1620, 1597, 1448, 1217, 1051, 752, 733, 686, 645 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}BrO_2 + H]^+$ 491.1580, found 491.1579.

*1-Benzoyl-5,7-di-tert-butyl-2-[2-(phenylethynyl)phenyl]spiro[2.5]-octa-4,7-dien-6-one (**4ja**).* Brown oil: 34.7 mg, 68% yield; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.85−7.75 (m, 2H), 7.59−7.51 (m, 2H), 7.41 (dd, J = 10.5, 4.6 Hz, 2H), 7.31 (ddd, J = 7.5, 5.1, 1.9 Hz, 4H), 7.26 (s, 1H), 7.25−7.22 (m, 2H), 6.67 (d, J = 2.7 Hz, 1H), 6.01 (d, J = 2.7 Hz, 1H), 4.25 (d, J = 7.6 Hz, 1H), 3.96 (d, J = 7.6 Hz, 1H), 1.15 (s, 9H), 1.01 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.6, 185.7, 150.0, 149.9, 138.3, 137.9, 137.5, 137.4, 133.4, 132.7, 131.5, 129.1, 128.7, 128.4, 128.2, 128.2, 127.7, 125.4, 125.0, 122.7, 94.7, 86.8, 41.3, 40.7, 39.4, 35.1, 35.0, 29.2, 29.1; IR (KBr) 3061, 2998, 2956, 2865, 1673, 1645, 1619, 1494, 1484, 1449, 756, 725, 689 cm^{-1}; HRMS (ESI) calcd for $[C_{37}H_{36}O_2 + H]^+$ 513.2788, found 513.2785.

*1-Benzoyl-5,7-di-tert-butyl-2-{2-[(E)-styryl]phenyl}spiro[2.5]octa-4,7-dien-6-one (**4ka**).* Light yellow solid: 41.1 mg, 80% yield; mp 167−169 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.91 (d, J = 7.3 Hz, 2H), 7.68 (d, J = 7.6 Hz, 1H), 7.60 (t, J = 7.3 Hz, 1H), 7.49 (t, J = 7.5 Hz, 2H), 7.35−7.19 (m, 8H), 6.94 (q, J = 16.2 Hz, 2H), 6.76 (d, J = 2.6 Hz, 1H), 5.91 (d, J = 2.6 Hz, 1H), 4.09 (d, J = 7.4 Hz, 1H), 3.96 (d, J = 7.4 Hz, 1H), 1.20 (s, 9H), 1.03 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.8, 185.5, 150.7, 150.5, 138.7, 138.1, 137.5, 137.2, 137.0, 133.6, 133.4, 130.8, 129.6, 128.9, 128.7, 128.3, 127.9, 127.5, 126.6, 125.3, 124.9, 41.5, 40.6, 39.0, 35.3, 35.1, 29.4, 29.1; IR (KBr) 2954, 2865, 1664, 1644, 1619, 1596, 1481, 1448, 1215, 1015, 958, 761, 722, 691 cm^{-1}; HRMS (ESI) calcd for $[C_{37}H_{38}O_2 + H]^+$ 515.2945, found 515.2942.

*1-Benzoyl-5,7-di-tert-butyl-2-(naphthalen-1-yl)spiro[2.5]octa-4,7-dien-6-one (**4la**).* Light yellow solid: 42.0 mg, 91% yield; mp 184−186 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.02−7.92 (m, 2H), 7.88−7.77 (m, 2H), 7.64 (t, J = 7.4 Hz, 1H), 7.59−7.49 (m, 3H), 7.49−7.35 (m, 4H), 6.83 (d, J = 2.7 Hz, 1H), 5.76 (d, J = 2.7 Hz, 1H), 4.35 (d, J = 7.3 Hz, 1H), 4.11 (d, J = 7.4 Hz, 1H), 1.25 (s, 9H), 0.84 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.8, 185.4, 150.6, 150.1, 138.8, 137.5, 137.0, 133.7, 133.5, 132.9, 132.4, 128.9, 128.6, 128.5, 128.3, 126.5, 126.2, 126.2, 125.0, 124.0, 41.3, 40.5, 38.3, 35.4, 34.9, 29.4, 28.8; IR (KBr) 3056, 3021, 2968, 2944, 2850, 1678, 1642, 1613, 1598, 1449, 804, 781, 724, 689, 650, 594 cm^{-1}; HRMS (ESI) calcd for $[C_{33}H_{34}O_2 + H]^+$ 463.2632, found 463.2630.

*2-Benzoyl-3-phenyl-4′H-spiro[cyclopropane-1,1′-naphthalen]-4′-one (**4ma**).* Light yellow solid: 29.7 mg, 85% yield; mp 159−161 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.19 (d, J = 7.9 Hz, 1H), 7.64 (d, J = 7.4 Hz, 2H), 7.50−7.25 (m, 11H), 6.67 (d, J = 10.1 Hz, 1H), 6.53 (d, J = 10.2 Hz, 1H), 4.54 (d, J = 8.1 Hz, 1H), 3.91 (d, J = 8.1 Hz, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.6, 184.7, 148.9, 138.8, 136.6, 135.3, 133.7, 133.2, 132.2, 129.7, 129.2, 128.9, 128.8, 128.1, 128.0, 127.4, 127.3, 123.8, 44.7, 39.0, 38.6; IR (KBr) 3050, 2950, 2903, 1672, 1653, 1598, 1481, 1449, 1304, 1215, 1013, 764, 700, 603 cm^{-1}; HRMS (ESI) calcd for $[C_{25}H_{18}O_2 + Na]^+$ 373.1199, found 373.1198.

*1-Benzoyl-5,7-di-tert-butyl-2-methylspiro[2.5]octa-4,7-dien-6-one (**4na**).* White solid: 34.0 mg, 97% yield; mp 126−128 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.78 (d, J = 7.2 Hz, 2H), 7.56 (t, J = 7.3 Hz, 1H), 7.44 (t, J = 7.5 Hz, 2H), 6.49 (d, J = 2.6 Hz, 1H), 6.46 (d, J = 2.6 Hz, 1H), 3.32 (d, J = 7.3 Hz, 1H), 2.82 (d, J = 6.7 Hz, 1H), 1.46 (d, J = 6.4 Hz, 3H), 1.31 (d, J = 9.6 Hz, 9H), 1.12 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.2, 185.7, 150.8, 149.1, 138.8, 137.6, 137.5, 133.3, 128.7, 128.0, 44.7, 39.7, 35.3, 35.0, 31.5, 29.4, 29.2, 14.0; IR (KBr) 3015, 2955, 2867, 1660, 1642, 1615, 1481, 1041, 880, 724, 691, 653 cm^{-1}; HRMS (ESI) calcd for $[C_{24}H_{30}O_2 + H]^+$ 351.2319, found 351.2317.

*1-Benzoyl-5,7-di-tert-butyl-2-ethylspiro[2.5]octa-4,7-dien-6-one (**4oa**).* White solid: 33.5 mg, 92% yield; mp 141−143 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.79 (d, J = 7.1 Hz, 2H), 7.55 (d, J = 6.7 Hz, 1H), 7.46 (d, J = 7.0 Hz, 2H), 6.49 (s, 2H), 3.36 (d, J = 7.0 Hz, 1H), 2.74 (d, J = 7.1 Hz, 1H), 1.92−1.61 (m, 2H), 1.32 (s, 9H), 1.12 (s, 9H), 1.04 (t, J = 7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.1, 185.6, 150.6, 148.9, 138.9, 137.6, 133.2, 128.7, 128.1, 43.8, 39.6, 38.9, 35.3, 35.0, 29.3, 29.2, 22.7, 13.3; IR (KBr) 2997, 2950, 2920, 1663, 1638, 1618, 1555, 1224, 1122, 1042, 733, 689 cm^{-1}; HRMS (ESI) calcd for $[C_{25}H_{32}O_2 + H]^+$ 365.2475, found 365.2482.

*1-Benzoyl-5,7-di-tert-butyl-2-iso-propylspiro[2.5]octa-4,7-dien-6-one (**4pa**).* White solid: 19.4 mg, 51% yield; dr 3:1; mp 109−111 °C;

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^{1}H NMR (300 MHz, $CDCl_3$) δ 7.80 (d, J = 7.6 Hz, 2H), 7.55 (d, J = 7.3 Hz, 1H), 7.50−7.39 (m, J = 7.5 Hz, 2H), 6.49 (d, J = 4.4 Hz, 2H), 3.37 (d, J = 7.3 Hz, 1H), 2.59−2.48 (m, J = 10.5, 7.5 Hz, 1H), 1.80−1.70 (m, 1H), 1.32 (s, 9H), 1.17−1.08 (m, J = 7.3 Hz, 12H), 0.96 (d, J = 6.6 Hz, 3H) (major); ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.0, 185.6, 150.6, 148.8, 143.5, 138.8, 137.7, 133.2, 128.7, 128.1, 45.0, 43.5, 35.3, 35.0, 29.9, 29.5, 29.2, 22.6, 21.9 (major); IR (KBr) 2959, 2920, 2850, 1663, 1639, 1618, 1449, 1384, 1252, 1087, 1046, 880, 730, 692 cm^{-1}; HRMS (ESI) calcd for $[C_{26}H_{34}O_2 + H]^+$ 379.2632, found 379.2638.

1-Benzoyl-2,5,7-tri-tert-butylspiro[2.5]octa-4,7-dien-6-one (**4qa**). White solid: 13.1 mg, 33% yield; mp 113−115 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.81 (d, J = 6.9 Hz, 2H), 7.56 (d, J = 6.8 Hz, 1H), 7.47 (d, J = 6.7 Hz, 2H), 6.76 (s, 1H), 6.42 (s, 1H), 3.58 (d, J = 8.0 Hz, 1H), 2.73 (d, J = 8.2 Hz, 1H), 1.32 (s, 9H), 1.12 (s, 9H), 1.10 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 195.1, 185.8, 149.6, 148.6, 139.4, 137.6, 137.5, 133.3, 128.7, 128.1, 48.5, 41.2, 41.1, 35.3, 35.0, 31.6, 30.0, 29.4, 29.2; IR (KBr) 3003, 2956, 2914, 2867, 1654, 1641, 1618, 1540, 1366, 1253, 1226, 1038, 1017, 880, 780, 731, 689 cm^{-1}; HRMS (ESI) calcd for $[C_{27}H_{36}O_2 + H]^+$ 393.2788, found 393.2792.

5,7-Di-tert-butyl-1-(4-fluorobenzoyl)-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ab**). White solid: 34.3 mg, 80% yield; mp 136−138 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.98−7.82 (m, 2H), 7.39−7.23 (m, 5H), 7.16 (dd, J = 11.9, 5.3 Hz, 2H), 6.58 (d, J = 2.7 Hz, 1H), 6.02 (d, J = 2.7 Hz, 1H), 4.08 (d, J = 7.4 Hz, 1H), 3.90 (d, J = 7.5 Hz, 1H), 1.16 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 193.0, 185.5, 167.7, 164.3, 150.2, 149.9, 138.3, 137.4, 135.1, 133.9, 130.9, 130.8, 129.1, 128.6, 127.8, 116.1, 115.8, 40.7, 40.3, 40.0, 35.2, 29.2; IR (KBr) 2958, 2910, 2857, 1670, 1655, 1620, 1601, 1506, 1482, 882, 746, 696 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}FO_2 + H]^+$ 431.2381, found 431.2385.

5,7-Di-tert-butyl-1-(4-chlorobenzoyl)-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ac**). White solid: 30.4 mg, 68% yield; mp 151−153 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.80 (d, J = 8.7 Hz, 2H), 7.46 (d, J = 8.6 Hz, 2H), 7.38−7.29 (m, 3H), 7.28−7.22 (m, 2H), 6.57 (d, J = 2.7 Hz, 1H), 6.01 (d, J = 2.7 Hz, 1H), 4.07 (d, J = 7.5 Hz, 1H), 3.88 (d, J = 7.5 Hz, 1H), 1.15 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 191.8, 183.9, 148.6, 148.3, 138.5, 136.6, 135.6, 134.1, 133.4, 127.9, 127.5, 127.4, 127.0, 126.1, 39.1, 38.8, 38.4, 33.6, 28.7, 27.6; IR (KBr) 2957, 1662, 1644, 1619, 1587, 1484, 1458, 1217, 1090, 744, 696, 650 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}ClO_2 + H]^+$ 447.2085, found 447.2087.

1-(4-Bromobenzoyl)-5,7-di-tert-butyl-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ad**). White solid: 42.0 mg, 86% yield; mp 149−151 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.73 (d, J = 8.5 Hz, 2H), 7.62 (d, J = 8.5 Hz, 2H), 7.33 (t, J = 8.0 Hz, 3H), 7.27 (s, 1H), 7.24 (s, 1H), 6.57 (d, J = 2.5 Hz, 1H), 6.01 (d, J = 2.5 Hz, 1H), 4.08 (d, J = 7.4 Hz, 1H), 3.88 (d, J = 7.4 Hz, 1H), 1.16 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 193.6, 185.5, 150.3, 150.0, 138.2, 137.2, 136.2, 135.0, 132.2, 129.6, 129.1, 128.8, 128.6, 127.8, 40.7, 40.4, 40.0, 35.2, 29.2; IR (KBr) 2956, 2909, 1658, 1646, 1620, 1586, 1481, 1008, 886, 774, 742, 698 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{31}BrO_2 + H]^+$ 491.1580, found 491.1584.

5,7-Di-tert-butyl-1-(4-methylbenzoyl)-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ae**). White solid: 34.0 mg, 80% yield; mp 148−150 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.78 (d, J = 8.2 Hz, 2H), 7.44−7.18 (m, 7H), 6.61 (d, J = 2.6 Hz, 1H), 6.03 (d, J = 2.6 Hz, 1H), 4.08 (d, J = 7.4 Hz, 1H), 3.94 (d, J = 7.5 Hz, 1H), 2.41 (s, 3H), 1.15 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.1, 185.7, 150.0, 149.7, 144.5, 138.7, 137.8, 135.4, 135.0, 129.5, 129.1, 128.6, 128.3, 127.7, 40.7, 40.3, 40.0, 35.1, 29.3, 21.7; IR (KBr) 2956, 2909, 2864, 1658, 1644, 1619, 1607, 1487, 1456, 1287, 1045, 742, 696 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{34}O_2 + H]^+$ 427.2632, found 427.2634.

5,7-Di-tert-butyl-1-(4-methoxybenzoyl)-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4af**). White solid: 40.8 mg, 92% yield; mp 166−168 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (d, J = 8.8 Hz, 2H), 7.38−7.23 (m, 5H), 6.95 (d, J = 8.7 Hz, 2H), 6.61 (d, J = 2.3 Hz, 1H), 6.02 (d, J = 2.3 Hz, 1H), 4.07 (d, J = 7.4 Hz, 1H), 3.91 (d, J = 7.5 Hz, 1H), 3.87 (s, 3H), 1.15 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.7, 185.6, 163.9, 149.9, 149.6, 138.7, 137.9, 135.4, 130.5, 129.1, 128.5, 127.6, 114.0, 55.5, 40.6, 40.1, 39.9, 35.1, 29.3; IR (KBr) 2960, 2903, 1647, 1621, 1601, 1511, 1481, 1233, 754, 704 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{34}O_3 + H]^+$ 443.2581, found 443.2580.

5,7-Di-tert-butyl-1-(3-methoxybenzoyl)-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ag**). White solid: 40.2 mg, 91% yield; mp 144−146 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.52−7.19 (m, 8H), 7.13 (d, J = 7.3 Hz, 1H), 6.59 (s, 1H), 6.04 (s, 1H), 4.08 (d, J = 7.3 Hz, 1H), 3.93 (d, J = 7.4 Hz, 1H), 3.82 (s, 3H), 1.16 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.5, 185.6, 159.9, 150.1, 149.9, 138.8, 138.5, 137.7, 135.2, 129.8, 129.1, 128.6, 127.7, 120.7, 120.1, 112.3, 55.4, 41.1, 40.4, 40.0, 35.2, 29.2; IR (KBr) 3056, 2957, 2861, 1665, 1644, 1619, 1603, 1581, 1484, 878, 771, 742, 695 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{34}O_3 + H]^+$ 443.2581, found 443.2577.

1-(Benzo[d][1,3]dioxole-5-carbonyl)-5,7-di-tert-butyl-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ah**). White solid: 45.0 mg, 99% yield; mp 181−183 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.44 (dd, J = 8.2, 1.6 Hz, 1H), 7.39−7.36 (m, 1H), 7.35−7.21 (m, 5H), 6.85 (d, J = 8.1 Hz, 1H), 6.59 (d, J = 2.6 Hz, 1H), 6.04 (s, 2H), 6.02 (d, J = 2.6 Hz, 1H), 4.06 (d, J = 7.4 Hz, 1H), 3.88 (d, J = 7.5 Hz, 1H), 1.17 (s, 9H), 1.13 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 192.3, 185.6, 152.2, 150.0, 149.7, 148.4, 138.6, 137.8, 135.3, 132.3, 129.1, 128.6, 127.7, 124.7, 108.1, 107.9, 102.0, 40.6, 40.2, 39.9, 35.1, 29.3, 29.3; IR (KBr) 2961, 2909, 1665, 1644, 1618, 1506, 1491, 1455, 1434, 1253, 1098, 1040, 868, 743, 696 cm^{-1}; HRMS (ESI) calcd for $[C_{30}H_{32}O_4 + Na]^+$ 479.2193, found 479.2195.

1-(2-Naphthoyl)-5,7-di-tert-butyl-2-phenylspiro[2.5]octa-4,7-dien-6-one (**4ai**). White solid: 28.1 mg, 61% yield; mp 139−141 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.29 (s, 1H), 7.92 (dt, J = 16.9, 8.0 Hz, 4H), 7.57 (dt, J = 15.1, 6.5 Hz, 2H), 7.42−7.27 (m, 5H), 6.64 (d, J = 2.4 Hz, 1H), 6.12 (d, J = 2.4 Hz, 1H), 4.15 (d, J = 7.5 Hz, 1H), 4.08 (d, J = 7.5 Hz, 1H), 1.19 (s, 9H), 1.12 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 194.5, 185.6, 150.2, 149.9, 138.5, 137.8, 135.7, 135.3, 134.8, 132.4, 130.2, 129.6, 129.2, 128.8, 128.8, 128.6, 127.9, 127.7, 127.1, 123.7, 41.1, 40.4, 40.0, 35.2, 35.1, 29.3, 29.2; IR (KBr) 2957, 1666, 1649, 1622, 1458, 821, 789, 748, 698 cm^{-1}; HRMS (ESI) calcd for $[C_{33}H_{34}O_2 + Na]^+$ 485.2451, found 485.2453.

5,7-Di-tert-butyl-1-phenyl-2-(thiophene-2-carbonyl)spiro[2.5]-octa-4,7-dien-6-one (**4aj**). White solid: 30.9 mg, 74% yield; mp 166−168 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.85−7.60 (m, 2H), 7.42−7.20 (m, 5H), 7.16 (s, 1H), 6.79 (s, 1H), 5.98 (s, 1H), 4.03 (d, J = 6.9 Hz, 1H), 3.87 (d, J = 7.0 Hz, 1H), 1.21 (s, 9H), 1.12 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.7, 185.7, 149.8, 149.6, 144.5, 138.5, 137.4, 135.1, 134.6, 132.5, 129.0, 128.6, 128.4, 127.8, 41.1, 40.4, 40.3, 35.2, 35.1, 29.3, 29.2; IR (KBr) 2956, 2865, 1645, 1629, 1619, 1518, 1484, 1421, 1253, 744, 721, 695 cm^{-1}; HRMS (ESI) calcd for $[C_{27}H_{30}O_2S + H]^+$ 419.2039, found 419.2038.

General Procedure for Preparing 3-Hydroxy-2-(4-hydroxyphenyl)-1,3-diphenylpropan-1-one. To a solution of **4aa** (0.3 mmol) in 6 mL of acetone were added *p*-TsOH (0.3 mmol) and water (0.3 mmol), and then the reaction mixture was stirred for 0.5 h. Then water was added and extracted three times with DCM. The combined organic layers were washed with water and brine sequentially, dried over Na_2SO_4, filtered, and concentrated. The crude product was purified by flash chromatography on silica gel to afford the corresponding rearomatized product **5aa** in 92% yield.

2-(3,5-Di-tert-butyl-4-hydroxyphenyl)-3-hydroxy-1,3-diphenylpropan-1-one (**5aa**). White solid: 118.6 mg, 92% yield; mp 141−143 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.04−7.86 (m, 2H), 7.44 (dd, J = 5.0, 3.7 Hz, 1H), 7.40−7.31 (m, 2H), 7.19−7.11 (m, 3H), 6.99 (dd, J = 6.5, 2.9 Hz, 2H), 6.65 (s, 2H), 5.25 (d, J = 9.0 Hz, 1H), 5.05 (s, 1H), 4.64 (d, J = 9.0 Hz, 1H), 3.28 (brs, 1H), 1.25 (s, 18H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 201.0, 153.0, 141.5, 137.1, 136.1, 133.0, 128.9, 128.5, 127.8, 127.3, 126.8, 125.8, 125.4, 77.1, 62.6, 34.2, 30.2; IR (KBr) 3622, 3562, 2953, 1665, 1436, 1189, 1148, 1040, 768, 704, 606 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{34}O_3 + Na]^+$ 453.2400, found 453.2398.

General Procedure for the Preparation of 2-(4-Hydroxyphenyl)-1,3-diphenylprop-2-en-1-one. To a solution of **4aa** (0.1 mmol) in 2 mL of ethanol was added 2 mL of pyridine. The reaction mixture was heated to reflux for 10 h. The crude product was concentrated and then purified by flash chromatography on silica gel

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to afford the corresponding product **6aa** in 97% yield with a *Z*:*E* ratio of 2:1.

*2-(3,5-Di-tert-butyl-4-hydroxyphenyl)-1,3-diphenylprop-2-en-1-one (**6aa**).* Brown oil: 40.0 mg, 97% yield; 2:1 *Z*:*E*; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.06−7.94 (m, major), 7.91−7.79 (m, minor) (2H), 7.57−6.97 (m, 11H), 5.30 (s, major), 5.24 (s, minor) (1H), 1.40 (s, major), 1.31 (s, minor) (18H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 200.3, 198.7, 154.2,153.8, 141.6, 141.5, 138.7, 138.6, 136.8, 136.2, 135.9, 135.6, 133.5, 132.1, 130.1, 129.9, 129.7, 129.5, 128.7, 128.6, 128.5, 128.4, 128.2, 128.1, 128.0, 127.6, 126.9, 126.8, 126.2, 123.4, 34.4, 34.3, 30.2, 30.1; IR (KBr) 3547, 2955, 2924, 2856, 1669, 1643, 1619, 1450, 1218, 1090, 732, 696 cm^{-1}; HRMS (ESI) calcd for $[C_{29}H_{32}O_2 + H]^+$ 413.2475, found 413.2470.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b01793.

^{1}H and ^{13}C NMR spectra for all new compounds (PDF)
X-ray crystallographic data for **4aa** (CIF)
X-ray crystallographic data for **4ma** (CIF)

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The authors declare no competing financial interest.

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