JOC The Journal of Organic Chemistry

Article

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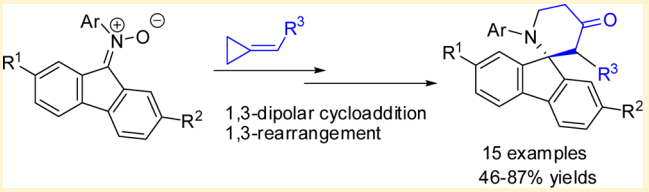
Cycloaddition of Fluorenone *N*-Aryl Nitrones with Methylenecyclopropanes and Sequential 1,3-Rearrangement: An Entry to Synthesis of Spirofluorenylpiperidin-4-ones

Xiao-Pan Ma, Jie-Feng Zhu, Si-Yi Wu, Chun-Hua Chen, Ning Zou, Cui Liang, Gui-Fa Su,* and Dong-Liang Mo*

State Key Laboratory for Chemistry and Molecular Engineering of Medicinal Resources, Ministry of Science and Technology of China; School of Chemistry & Pharmaceutical Sciences, Guangxi Normal University, 15 Yu Cai Road, Guilin 541004, China

Supporting Information

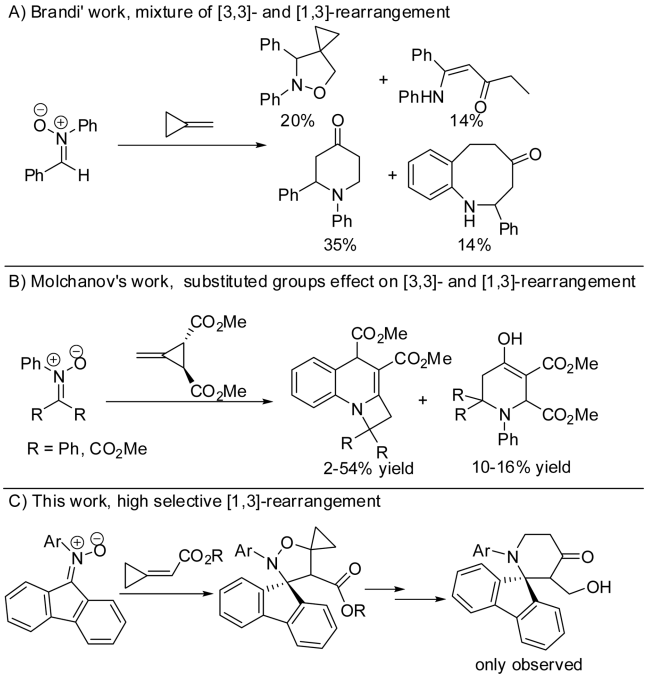
ABSTRACT: A facile synthesis of various spirofluorenylpiperidin-4-ones has been achieved in good yields from fluorenone *N*-aryl nitrones and methylenecyclopropanes. This method involved an initial cycloaddition to form a 5-spirocyclopropane-isoxazoline, which underwent a highly selective 1,3-rearrangement to give the desired product. The stereochemistry of the spirofluorenylpiperidin-4-one could be controlled by the cycloaddition and sequential rearrangement strategy. Furthermore, the spirofluorenylpiperidin-4-ones could be not only prepared in one-pot procedure but also converted to useful scaffolds by reduction or oxidation conditions.



INTRODUCTION

The development of new and efficient methods for synthesis of piperidinone derivatives represents an important research field because these piperidinone scaffolds showed the unique biological activities and served as valuable intermediates in organic synthesis.[1,2] 1,3-Dipolar cycloaddition of nitrones to the double bond of methylenecyclopropanes is one of the most extensively studied cycloaddition reactions due to the rich chemistry of 5-spirocyclopropane-isoxazoline cycloadducts formed in the reactions.[3,4] 5-Spirocyclopropane-isoxazolines could undergo Brandi−Guarna rearrangement to afford piperidin-4-ones or related compounds because of the highly strained spirocyclopropane ring.[5] In 1989, Brandi and co-workers found that the reaction of (*Z*)-*N*-aryl aldonitrones and methylenecyclopropane could form 4-spirocyclopropane-isoxazoline and 5-spirocyclopropane-isoxazoline which could be converted to a mixture of enamine, piperidin-4-one, and benzoazocinone (Scheme 1A).[6] A further study on the regioselective formation of 5-spirocyclopropane-isoxazoline and its 1,3- or 3,3-rearrangement was reported by Molchanov and co-workers (Scheme 1B).[7] The effect of substituted groups on both nitrones and methylenecyclopropanes to the N−O bond rearrangement was studied. Although the rearrangement of 5-spirocyclopropane-isoxazoline has been studied, the yields and selectivities observed in the 1,3- and 3,3-rearrangement of 5-spirocyclopropane-isoxazoline are generally poor for *N*-aryl nitrones. During the studies on the rearrangement of N−O bond in our group,[8] we envisaged that methylenecyclopropanes bearing an alkoxycarbonyl group would regioselectively react with *N*-aryl nitrones bearing a rigid and sterically encumbered 9-fluorenyl group to give 5-spirocyclopropane-isoxazolines, which might undergo a controllable rearrangement process.

Scheme 1. Rearrangement of N−O Cyclopropane Intermediates



Fluorenone nitrones are distinct from traditional nitrones because of the rigidity and steric hindrance of the fluorene.[9] This property can be exploited by N−O bond cleavage[10] to

Received: October 20, 2016
Published: December 16, 2016

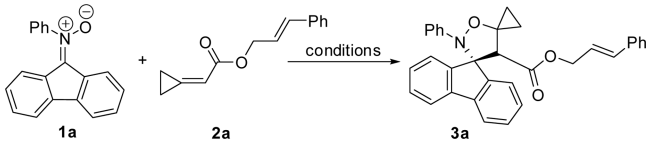
DOI: 10.1021/acs.joc.6b02544
J. Org. Chem. 2017, 82, 502−511

afford spirofluorenylpiperidinones that exhibit privileged scaffolds present in bioactive pharmaceuticals and organic materials.[11] Herein, we report a facile synthesis of spirofluorenylpiperidin-4-ones in good yields from fluorenone nitrones and methylenecyclopropanes (MCP) (Scheme 1C).

RESULTS AND DISCUSSION

We initially evaluated the formation of 5-spirocyclopropane-isoxazoline via the cycloaddition reaction of *N*-aryl fluorenone nitrone and methylenecyclopropane. *N*-Phenyl fluorenone nitrone **1a** and methylenecyclopropane **2a** were chosen as model substrates for this reaction. As shown in Table 1, the

Table 1. Optimization of the Cycloaddition Reaction Conditions[a]



1a 2a 3a

	solvent	*T* (°C)	**3a** yield (%)[b]
1	toluene	40	98
2	DCE	40	98
3	MeCN	40	96
4	THF	40	97
5	DMSO	40	79
6	MeOH	40	94
7	DCE	25	99[c]
8	DCE	60	84
9	DCE	80	<5

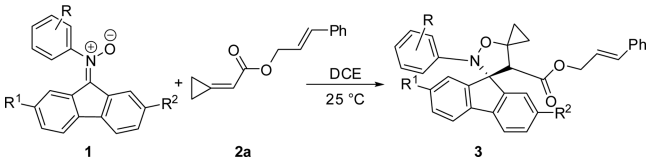
[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.4 mmol, 2.0 equiv), solvent (2 mL), 18−24 h. [b]Isolated yield. [c]Reaction time: 36 h.

desired cycloadduct **3a** was isolated in excellent yield from a variety of different solvents, including toluene, 1,2-dichloroethane (DCE), MeCN, THF, DMSO, and MeOH following 18−24 h at 40 °C (Table 1, entries 1−6). Reducing the reaction temperature to room temperature led to an increase in the yield of **3a** to 99%, albeit after extending the reaction time to 36 h (Table 1, entry 7). In contrast, increasing the reaction temperature to 60 °C led to a decrease in the yield of **3a** (Table 1, entry 8). Furthermore, no product **3a** was observed when the reaction was conducted at 80 °C, with the starting materials **1a** and **2a** being recovered unchanged (Table 1, entry 9).

The cycloaddition reactions of various *N*-aryl fluorenone nitrones **1** with methylenecyclopropane **2a** were conducted under the optimal conditions. As shown in Table 2, these reactions proceeded smoothly to afford the desired products in good to excellent yields. This reaction was found to be compatible with several useful functional groups on the nitrone substrates, including methoxy, bromide, ester, and nitro groups at the *para*, *ortho*, or *meta*-position. However, nitrones **1b** and **1k** bearing a *para*-methoxy and *ortho*-bromide, respectively, afforded low yields of the corresponding cycloadducts **3b** and **3k** (Table 2, entries 2 and 11). Notably, nitrone **1m** with a 1:1 ratio of *E*/*Z*-isomer gave product **3m** with a dr value of 1:1 when it reacted with **2a** under the optimal conditions (Table 2, entry 13).

In addition to the nitrone moiety, we also investigated a variety of different methylenecyclopropane substrates **2a−j** to determine the substituent effect on the cycloaddition reaction. All of these compounds provided the desired cycloadduct **3** in

Table 2. Scope of the Nitrones 1[a]



1 2a 3

	1	R, R^1, R^2	3	yield (%)[b]
1	**1a**	R = H, R^1, R^2 = H	**3a**	99
2	**1b**	R = 4-MeO, R^1, R^2 = H	**3b**	37
3	**1c**	R = 4-PhO, R^1, R^2 = H	**3c**	76
4	**1d**	R = 4-Me, R^1, R^2 = H	**3d**	79
5	**1e**	R = 4-*i*-Pr, R^1, R^2 = H	**3e**	86
6	**1f**	R = 4-Br, R^1, R^2 = H	**3f**	82
7	**1g**	R = 4-F, R^1, R^2 = H	**3g**	73
8	**1h**	R = 4-CO_2Me, R^1, R^2 = H	**3h**	62
9	**1i**	R = 3,5-Me_2, R^1, R^2 = H	**3i**	94
10	**1j**	R = 3-NO_2, R^1, R^2 = H	**3j**	92
11	**1k**	R = 2-Br, R^1, R^2 = H	**3k**	47
12	**1l**	R = H, R^1, R^2 = Br	**3l**	86
13	**1m**	R = H, R^1 = H, R^2 = Br	**3m**	93 (1:1)[c]

[a]Reaction conditions: **1** (0.2 mmol), **2a** (0.4 mmol, 2.0 equiv), solvent (2 mL), 18−36 h. [b]Isolated yield. [c]dr value.

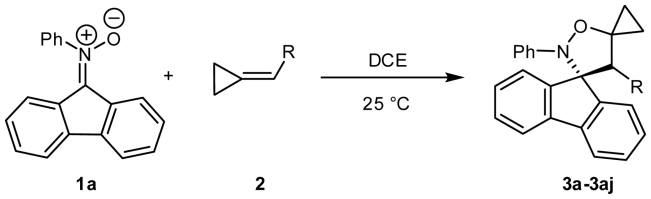
good to excellent yields (Table 3). Notably, when (−)-menthol methylenecyclopropane **2h** was evaluated as a substrate to explore the diastereoselectivity of the cycloaddition reaction, the corresponding product **3ah** was isolated in 58% yield with a dr value of 3.5:1, which was determined by ^{1}H NMR (Table 3, entry 8). This result revealed that the stereochemistry of the cycloadduct could be controlled by installing a chiral auxiliary in the methylenecyclopropane substrate. The ketone-substituted methylenecyclopropane **2i** gave the corresponding cycloadduct **3ai** in 73% yield (Table 3, entry 9). However, the reaction of methylenecyclopropane **2j** bearing a primary alcohol failed to afford the desired cycloadduct **3aj**, and nitrone **1a** and methylenecyclopropane **2j** were recovered unchanged (Table 3, entry 10).

Having fully evaluated the scope of the cycloaddition reaction, we proceeded to investigate the rearrangement of 5-spirocyclopropane-isoxazoline **3**. When **3a** was heated at 100 °C, the nitrone **1a** was recovered with 35% yield; *N*-(9*H*-fluoren-9-ylidene)aniline was isolated in 20% yield, and the enolated 1,3-rearrangement product **4a′** was obtained in 10% yield (Scheme 2-1). This experiment revealed that the cycloaddition reaction might be reversible, and the desired selective rearrangement could be achieved through improving the rigidity of cycloaddition intermediate. To inhibit the reversible reaction and promote the efficiency of the rearrangement process, the 5-spirocyclopropane-isoxazoline **3a** was reduced by $LiAlH_4$ to provide alcohol **3aj**. When **3aj** was heated at 40 °C for 36 h, no desired product **4a** was observed, and only starting material **3aj** was recovered. To our delight, only 1,3-rearrangement product **4a** was obtained in 64% yield while **3aj** was heated at 80 °C for 18 h, and the solvent played an important role on the yield of product **4a** (Scheme 2-2). The optimal conditions for the rearrangement of **3aj** to **4a** were in MeCN at 120 °C.

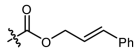
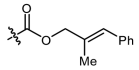
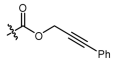
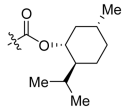
With the optimal conditions, we found that the reduction of **3a** with $LiAlH_4$, followed by the rearrangement of the resulting alcohol in MeCN at 120 °C afforded product **4a** in 70% isolated yield in two steps. As shown in Table 4, the

DOI: 10.1021/acs.joc.6b02544
J. Org. Chem. 2017, 82, 502−511

Table 3. Scope of the Methylenecyclopropane Substrate 2[a]



1a 2 3a-3aj

entry	2	R	3	yield (%)[b]
1	2a		3a	99
2	2b		3ab	75
3	2d		3ac	96
4	2d	CO_2Bn	3ad	97
5	2e	CO_2n-Bu	3ae	81
6	2f	CO_2Et	3af	90
7	2g	CO_2t-Bu	3ag	71
8	2h		3ah	58 (3.5 :1)[c]
9	2i		3ai	73
10	2j	CH_2OH	3aj	0

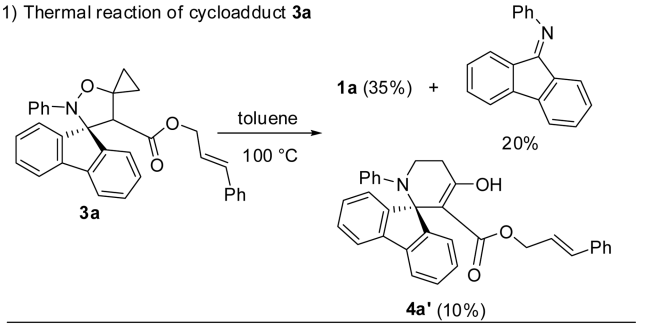
[a]Reaction conditions: **1a** (0.2 mmol), **2** (0.4 mmol, 2.0 equiv), DCE (2 mL), 18−36 h. [b]Isolated yield. [c]dr value.

rearrangement products **4** were obtained in yields of 46−87% from the corresponding cycloadduct **3** by sequential reduction and rearrangement reactions (method **A**) or sequential reduction, protection (with an alkyl bromide) and rearrangement reactions (method **B**) in a single-flask. The reaction was compatible with electron-withdrawing and electron-donating groups on the aryl rings. Furthermore, **3h** containing two ester groups reacted smoothly to give product **4h** in 73% yield bearing two hydroxyl groups (Table 4, entry 7), which indicated that the two ester groups of **3h** were reduced by $LiAlH_4$.

The stereochemistry of the cycloaddition and rearrangement steps was investigated using the reaction shown in Scheme 3. Reduction of cycloadduct **3ah** with $LiAlH_4$ afforded the corresponding alcohol **3aj** in 86% yield and 35% ee value. The desired rearrangement product **4a** was obtained in 89% yield and 37% ee value when chiral **3aj** was subjected to the optimal conditions. This result suggested that the absolute stereochemistry of the spiropiperidin-4-one could be controlled through this cycloaddition and rearrangement process.

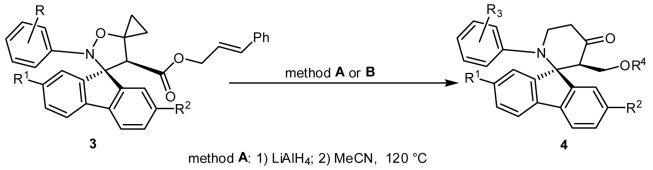
The types of nitrones were also examined to the cycloaddition and rearrangement process (Scheme 4). When fluorenone *N*-methyl nitrone **1n** reacted with methylenecyclopropane **2a** in DCE at room temperature followed by reduction

Scheme 2. Thermal Rearrangement Conditions of 3aj to 4a



solvent	temperature	**4a** yield%
toluene	40 °C	0%
toluene	80 °C	64%
toluene	100 °C	67%
toluene	120 °C	71%
DMF	120 °C	66%
dioxane	120 °C	44%
MeCN	120 °C	90%

Table 4. Scope of the Rearrangement of Cycloadduct 3[a]



method **A**: 1) $LiAlH_4$; 2) MeCN, 120 °C

method **B**: 1) $LiAlH_4$; 2) R^4Br, Et_3N, 3) MeCN, 120 °C

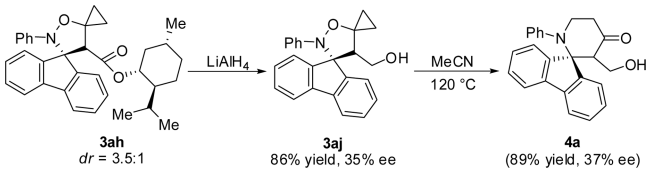
	3	R^3	R^4	method	4	yield (%)[b]
1	3a	H	H	A	4a	70
2	3c	4-PhO	H	A	4c	87
3	3d	4-Me	H	A	4d	74
4	3e	4-*i*-Pr	H	A	4e	77
5	3f	4-Br	H	A	4f	47
6	3g	4-F	H	A	4g	82
7	3h	4-CH_2OH	H	A	4h	73[c]
8	3i	3,5-Me_2	H	A	4i	63
9	3j	3-NO_2	H	A	4j	50
10	3k	2-Br	H	A	4k	56
11	3l	H	H	A	4l	65
12	3m	H	H	A	4m	46 (1:1)[d]
13	3a	H	Bn	B	4n	64
14	3a	H	allyl	B	4o	68

[a]Reaction conditions: method A: (1) **3** (0.2 mmol), $LiAlH_4$ (2.0 equiv), THF, 0 °C, 30 min; (2) MeCN (2 mL), 120 °C, 18−24 h. method B: (1) **3** (0.2 mmol), $LiAlH_4$ (2.0 equiv), THF, 0 °C, 10−30 min; (2) R^4Br (2.0 equiv), 2−10 h; (3) MeCN (2 mL), 120 °C, 18−24 h. [b]Isolated yield. [c]The methoxycarbonyl group in **3h** was also reduced. [d]dr value.

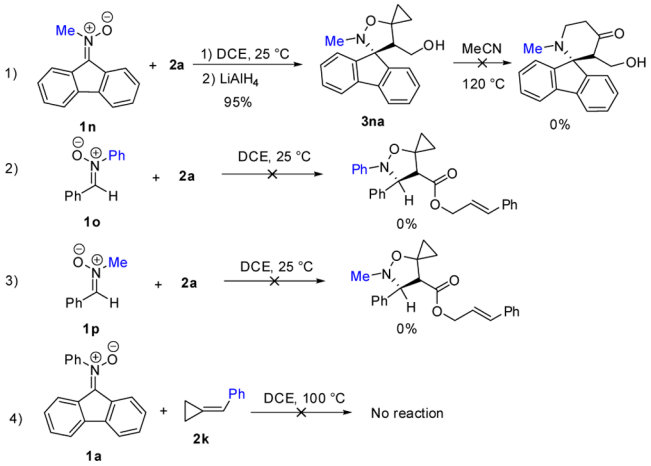
of $LiAlH_4$, the alcohol **3na** was obtained in 95% yield. However, the rearrangement of **3na** did not occur in the optimal conditions, and only the alcohol **3na** was recovered (Scheme 4-1). To our surprise, both (*Z*)-*N*-phenyl benzaldehyde nitrone

DOI: 10.1021/acs.joc.6b02544
J. Org. Chem. 2017, 82, 502−511

Scheme 3. Stereochemistry in the Rearrangement Step



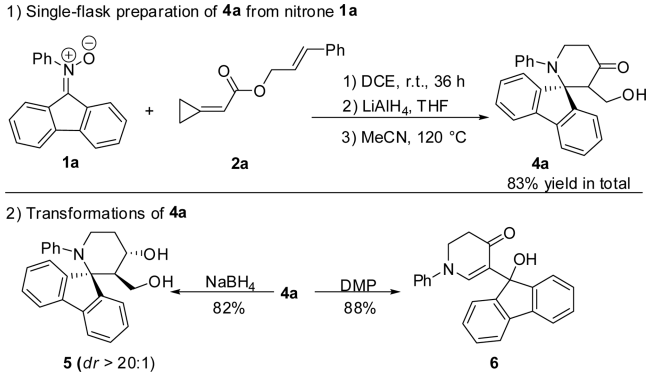
Scheme 4. Effect of Type of Nitrones and Methylenecyclopropanes on the Cycloaddition and Rearrangement



1o and (*Z*)-*N*-methyl benzaldehyde nitrone **1p** with **2a** could not provide the cycloadducts at room temperature, and the reaction turned messy (Scheme 4-2 and 4-3). When nitrone **1a** reacted with methylenecyclopropane **2k** at either room temperature or high temperature, no desired cycloadduct or rearrangement product was obtained with starting materials being recovered (Scheme 4-4). The results revealed that the types of nitrones and methylenecyclopropanes are important for these transformations.

To explore the utility of this cascade process, we further studied the efficiency of one-pot process and the usefulness of spiropiperidin-4-one. Pleasingly, spiropiperidin-4-one **4a** was prepared in 83% yield in a total of three steps via a one-pot reaction from nitrone **1a** and methylenecyclopropane **2a** (Scheme 5-1). Reduction of **4a** with $NaBH_4$ afforded the corresponding 1,3-diol **5** in 82% yield with a dr value of 20:1. Treatment of **4a** with Dess–Martin periodinane (DMP) gave compound **6** in 88% yield.[12] The ability to install useful functional groups on spiropiperidin-4-one will undoubtedly lead to these compounds in more applications.

Scheme 5. Transformation Studies



CONCLUSIONS

We developed an efficient synthesis of fluorenyl-substituted spiropiperidin-4-ones from *N*-aryl fluorenone nitrones and methylenecyclopropanes. This reaction involved initial cycloaddition, reduction and sequential thermal rearrangement steps to give spirofluorenylpiperidin-4-ones, and exhibited functional group compatibility toward halide, ester, alcohol, and nitro groups. The 1,3-rearrangement of the N–O bond could be controlled by the rigidity of the fluorenyl in the nitrone. Notably, this reaction allowed for the one-pot synthesis of spirofluorenylpiperidin-4-one, providing a powerful platform for the construction of numerous other diverse scaffolds.

EXPERIMENTAL SECTION

General Methods. All reactions were performed under an atmosphere of air. Commercially available reagents were used without further purification. The NMR spectra were recorded in $CDCl_3$ or DMSO-d_6 on 400 or 500 MHz instrument with TMS as the internal standard. NMR data are represented as follows: chemical shift (ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet), coupling constants in hertz (Hz), and integration. IR spectra were recorded on FT-IR spectrometer, and only major peaks are reported in cm^{-1}. HRMS were measured in ESI mode and the mass analyzer of the HRMS was TOF. Flash column chromatography was performed on silica gel (300–400 mesh).

General Procedure A for Synthesis of Cycloadduct ***3*** *(Tables 2 and 3).* In a Teflon-sealed reaction flask charged with nitrone **1** (0.2 mmol) and methylenecyclopropane **2** (0.4 mmol, 2.0 equiv) under air atmosphere, DCE (2.0 mL) was added via syringe. Then, the reaction vessel was sealed with a Teflon cap. The reaction mixture was stirred vigorously at 25 °C for 24–36 h until substrate **1** disappeared (monitored by TLC). At this time, the solvent was removed under reduced pressure, and the crude product was purified by flash chromatography (the crude residue was dry loaded with silica gel, 1/100 to 1/50, ethyl acetate/petroleum ether) to provide product **3**.

3a, a white solid, 0.096 g, 99% yield. Mp: 120–121 °C; ^{1}H NMR (400 MHz, DMSO-d_6): δ 7.84 (d, J = 6.4 Hz, 1H), 7.76 (d, J = 6.0 Hz, 1H), 7.61 (d, J = 5.6 Hz, 1H), 7.48–7.42 (m, 3H), 7.35–7.32 (m, 2H), 7.27–7.22 (m, 3H), 7.19–7.16 (m, 1H), 7.13 (t, J = 6.0 Hz, 1H), 6.83–6.80 (m, 2H), 6.66 (t, J = 6.0 Hz, 1H), 6.34 (d, J = 6.4 Hz, 2H), 6.14 (d, J = 12.8 Hz, 1H), 5.58–5.52 (m, 1H), 4.38 (s, 1H), 4.14–4.04 (m, 2H), 1.45–1.39 (m, 2H), 1.22–1.19 (m, 1H), 1.10–1.05 (m, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 168.3, 146.7, 145.6, 141.9, 140.9, 136.2, 132.8, 129.8, 129.3, 129.0, 128.7, 128.3, 128.1, 127.3, 126.8, 126.7, 126.6, 125.0, 123.1, 122.8, 120.8, 120.2, 116.9, 81.1, 64.5, 63.6, 61.3, 12.8, 9.0; IR (thin film) 3054, 2914, 2862, 1743, 1448, 1303, 1184, 969, 742, 693 cm^{-1}; HRMS (ESI) m/z calcd for $C_{33}H_{28}NO_3$ $(M + H)^+$ 486.2069, found 486.2053.

3b, a white solid, 0.038 g, 37% yield. Mp: 105–106 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.84–7.82 (m, 1H), 7.70–7.68 (m, 1H), 7.50–7.48 (m, 1H), 7.38–7.34 (m, 3H), 7.31–7.21 (m, 3H), 7.18 (d, J = 7.2 Hz, 2H), 7.12–7.10 (m, 2H), 6.48 (d, J = 8.8 Hz, 2H), 6.36 (d, J = 8.8 Hz, 2H), 6.12 (d, J = 16.0 Hz, 1H), 5.54–5.47 (m, 1H), 4.29 (s, 1H), 4.19–4.07 (m, 2H), 3.53 (s, 3H), 1.61–1.55 (m, 1H), 1.49–1.35 (m, 2H), 0.94–0.88 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.4, 155.6, 144.7, 141.4, 141.2, 140.7, 139.2, 136.1, 133.4, 129.1, 128.7, 128.4, 128.3, 127.8, 127.1, 126.9, 126.5, 124.5, 122.2, 119.9, 119.6, 119.4, 112.7, 81.7, 64.7, 63.1, 61.1, 55.0, 12.8, 9.0; IR (thin film) 3021, 2930, 2838, 1735, 1504, 1178, 966, 832, 741 cm^{-1}; HRMS (ESI) m/z calcd for $C_{34}H_{30}NO_4$ $(M + H)^+$ 516.2175, found 516.2160.

3c, a white solid, 0.088 g, 76% yield. Mp: 114–115 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82–7.80 (m, 1H), 7.65 (d, J = 6.4 Hz, 1H), 7.53–7.51 (m, 1H), 7.39–7.37 (m, 3H), 7.32–7.26 (m, 3H), 7.13–7.08 (m, 3H), 6.97 (t, J = 7.2 Hz, 1H), 6.68 (d, J = 8.0 Hz, 2H), 6.51–6.46 (m, 4H), 6.14 (d, J = 16.0 Hz, 1H), 5.54–5.47 (m, 1H), 4.27 (s,

DOI: 10.1021/acs.joc.6b02544
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1H), 4.20−4.08 (m, 2H), 1.60−1.56 (m, 1H), 1.52−1.46 (m, 1H), 1.43−1.37 (m, 1H), 0.97−0.91 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.3, 157.9, 152.0, 145.0, 142.2, 141.5, 141.1, 140.7, 136.1, 133.5, 129.3, 129.2, 128.8, 128.4, 128.0, 127.9, 127.0, 126.9, 126.5, 124.5, 122.3, 122.1, 120.0, 119.4, 119.0, 118.8, 117.6, 81.6, 64.8, 63.3, 61.2, 12.7, 9.0; IR (thin film) 3030, 2940, 1738, 1488, 1230, 1158, 965, 838, 739 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{39}H_{32}NO_4$ $(M + H)^+$ 578.2331, found 578.2319.

3d, a white solid, 0.079 g, 79% yield. Mp: 92−93 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.82 (d, *J* = 5.0 Hz, 1H), 7.66 (d, *J* = 6.0 Hz, 1H), 7.52−7.51 (m, 1H), 7.37−7.36 (m, 3H), 7.30−7.27 (m, 2H), 7.24−7.22 (m, 1H), 7.18 (d, *J* = 7.5 Hz, 2H), 7.12−7.09 (m, 2H), 6.61 (d, *J* = 8.5 Hz, 2H), 6.39 (d, *J* = 8.5 Hz, 2H), 6.12 (d, *J* = 16.0 Hz, 1H), 5.53−5.47 (m, 1H), 4.26 (s, 1H), 4.15−4.07 (m, 2H), 2.00 (s, 3H), 1.56−1.53 (m, 1H), 1.50−1.45 (m, 1H), 1.42−1.37 (m, 1H), 0.92−0.89 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.3, 145.2, 143.7, 141.7, 141.1, 140.7, 136.1, 133.5, 132.1, 129.1, 128.7, 128.3, 128.1, 127.9, 127.8, 127.1, 127.0, 126.5, 124.5, 122.2, 119.9, 119.3, 117.4, 81.3, 64.7, 63.1, 61.6, 20.5, 12.6, 9.1; IR (thin film) 3026, 2923, 2864, 1741, 1447, 1182, 967, 822, 737 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{34}H_{30}NO_3$ $(M + H)^+$ 500.2226, found 500.2208.

3e, a white solid, 0.091 g, 86% yield. Mp: 105−106 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.79 (d, *J* = 6.0 Hz, 1H), 7.64 (d, *J* = 6.0 Hz, 1H), 7.55 (d, *J* = 7.0 Hz, 1H), 7.40−7.35 (m, 3H), 7.31 (t, *J* = 7.0 Hz, 2H), 7.25−7.23 (m, 1H), 7.20 (d, *J* = 7.5 Hz, 2H), 7.13−7.08 (m, 2H), 6.68 (d, *J* = 8.0 Hz, 2H), 6.40 (d, *J* = 8.0 Hz, 2H), 6.14 (d, *J* = 16.0 Hz, 1H), 5.55−5.49 (m, 1H), 4.24 (s, 1H), 4.12−4.10 (m, 2H), 2.61−2.56 (m, 1H), 1.55−1.52 (m, 1H), 1.50−1.45 (m, 1H), 1.40−1.35 (m, 1H), 1.00 (d, *J* = 7.0 Hz, 6H), 0.93−0.86 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 168.4, 145.4, 144.0, 143.0, 141.8, 141.0, 140.7, 136.1, 133.4, 129.0, 128.7, 128.4, 127.9, 127.8, 127.0, 126.9, 126.5, 125.5, 124.5, 122.2, 119.9, 119.4, 117.2, 81.1, 64.7, 63.1, 61.8, 33.1, 23.8, 23.7, 12.6, 9.1; IR (thin film) 3022, 2949, 2866, 1733, 1448, 1164, 963, 832, 747 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{36}H_{34}NO_3$ $(M + H)^+$ 528.2539, found 528.2529.

3f, a white solid, 0.092 g, 82% yield. Mp: 119−120 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.78 (d, *J* = 6.4 Hz, 1H), 7.59 (d, *J* = 7.6 Hz, 1H), 7.55 (d, *J* = 6.8 Hz, 1H), 7.41−7.35 (m, 3H), 7.31−7.26 (m, 3H), 7.19 (d, *J* = 7.2 Hz, 2H), 7.15−7.07 (m, 2H), 6.92 (d, *J* = 8.8 Hz, 2H), 6.34 (d, *J* = 8.8 Hz, 2H), 6.13 (d, *J* = 15.6 Hz, 1H), 5.53−5.46 (m, 1H), 4.23 (s, 1H), 4.15−4.08 (m, 2H), 1.58−1.53 (m, 1H), 1.53−1.45 (m, 1H), 1.41−1.37 (m, 1H), 0.96−0.90 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.0, 145.5, 145.0, 141.3, 140.9, 140.6, 136.0, 133.6, 130.5, 129.3, 129.0, 128.3, 128.1, 127.9, 127.2, 126.6, 126.5, 124.3, 122.0, 120.1, 119.5, 118.6, 115.3, 81.1, 64.8, 63.3, 61.5, 12.4, 9.0; IR (thin film) 3026, 2936, 2877, 1738, 1480, 1172, 963, 830, 741 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{33}H_{27}BrNO_3$ $(M + H)^+$ 564.1174, found 564.1153.

3g, a white solid, 0.072 g, 73% yield. Mp: 117−118 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.82−7.80 (m, 1H), 7.64 (d, *J* = 7.5 Hz, 1H), 7.53 (d, *J* = 8.0 Hz, 1H), 7.40−7.36 (m, 3H), 7.31 (t, *J* = 7.5 Hz, 2H), 7.25−7.23 (m, 1H), 7.18 (d, *J* = 7.0 Hz, 2H), 7.13−7.08 (m, 2H), 6.52−6.49 (m, 2H), 6.47−6.44 (m, 2H), 6.12 (d, *J* = 15.5 Hz, 1H), 5.53−5.47 (m, 1H), 4.27 (s, 1H), 4.18−4.08 (m, 2H), 1.59−1.56 (m, 1H), 1.49−1.45 (m, 1H), 1.41−1.37 (m, 1H), 0.95−0.92 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 168.2, 159.7 (d, *J* = 239.2 Hz), 144.8, 142.1 (d, *J* = 2.5 Hz), 141.2, 141.1, 140.6, 136.1, 133.5, 129.3, 128.9, 128.3, 128.0, 127.9, 127.0 (d, *J* = 15.5 Hz), 126.5, 124.4, 122.1, 120.0, 119.5, 119.2, 119.1, 114.3 (d, *J* = 22.7 Hz), 81.6, 64.8, 63.3, 61.2, 12.7, 9.0; IR (thin film) 3027, 2941, 2875, 1743, 1501, 964, 834, 742 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{33}H_{27}FNO_3$ $(M + H)^+$ 504.1975, found 504.1957.

3h, a white solid, 0.051 g, 62% yield. Mp: 133−134 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.72 (d, *J* = 7.0 Hz, 1H), 7.60 (d, *J* = 7.0 Hz, 1H), 7.53 (d, *J* = 8.5 Hz, 3H), 7.46 (d, *J* = 7.5 Hz, 1H), 7.43−7.40 (m, 1H), 7.37−7.34 (m, 1H), 7.32 (t, *J* = 7.0 Hz, 2H), 7.25−7.23 (m, 1H), 7.20 (d, *J* = 7.0 Hz, 2H), 7.15−7.12 (m, 1H), 7.08 (t, *J* = 7.0 Hz, 1H), 6.42 (d, *J* = 8.5 Hz, 2H), 6.16 (d, *J* = 16.0 Hz, 1H), 5.55−5.49 (m, 1H), 4.20 (s, 1H), 4.13−4.12 (m, 2H), 3.72 (s, 3H), 1.59−1.54 (m, 1H), 1.53−1.48 (m, 1H), 1.43−1.41 (m, 1H), 0.99−0.96 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 167.9, 166.8, 150.6, 145.6, 141.7, 140.7, 136.1, 133.7, 129.7, 129.4, 129.1, 128.5, 128.4, 128.3, 127.9, 127.4, 126.5, 126.3, 124.1, 123.1, 122.0, 120.2, 119.6, 115.2, 80.6, 64.9, 63.6, 61.9, 51.5, 11.9, 9.1; IR (thin film) 3024, 2950, 2856, 1716, 1445, 1276, 1175, 964, 741 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{35}H_{30}NO_5$ $(M + H)^+$ 544.2124, found 544.2105.

3i, a white solid, 0.097 g, 94% yield. Mp: 100−101 °C; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.78 (d, *J* = 6.0 Hz, 1H), 7.62 (d, *J* = 6.5 Hz, 1H), 7.54 (d, *J* = 6.0 Hz, 1H), 7.39−7.37 (m, 3H), 7.31 (t, *J* = 7.0 Hz, 2H), 7.24−7.23 (m, 1H), 7.19 (d, *J* = 7.5 Hz, 2H), 7.12−7.09 (m, 2H), 6.30 (s, 1H), 6.13 (d, *J* = 16.0 Hz, 1H), 6.07 (s, 2H), 5.54−5.50 (m, 1H), 4.23 (s, 1H), 4.13−4.11 (m, 2H), 1.90 (s, 6H), 1.56−1.53 (m, 1H), 1.51−1.46 (m, 1H), 1.41−1.36 (m, 1H), 0.95−0.91 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 168.4, 146.2, 145.5, 141.8, 141.0, 140.7, 136.9, 136.1, 133.4, 129.0, 128.7, 128.3, 127.9, 127.8, 127.0, 126.8, 126.5, 124.4, 124.3, 122.2, 119.8, 119.2, 115.0, 81.1, 64.7, 63.1, 61.6, 21.2, 12.6, 9.1; IR (thin film) 3026, 2950, 2861, 1737, 1449, 1165, 967, 740, 688 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{35}H_{32}NO_3$ $(M + H)^+$ 514.2382, found 514.2366.

3j, a yellow solid, 0.097 g, 92% yield. Mp: 129−130 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77 (d, *J* = 7.2 Hz, 1H), 7.60 (d, *J* = 7.2 Hz, 1H), 7.57 (d, *J* = 7.2 Hz, 1H), 7.51−7.49 (m, 2H), 7.45−7.37 (m, 3H), 7.32−7.28 (m, 2H), 7.26−7.25 (m, 1H), 7.19 (d, *J* = 7.2 Hz, 1H), 7.15−7.06 (m, 2H), 6.90 (t, *J* = 8.0 Hz, 1H), 6.47 (d, *J* = 7.6 Hz, 1H), 6.16 (d, *J* = 16.0 Hz, 1H), 5.55−5.48 (m, 1H), 4.26 (s, 1H), 4.20−4.09 (m, 2H), 1.62−1.58 (m, 1H), 1.54−1.49 (m, 1H), 1.01−0.95 (m, 1H), 0.89−0.83 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.8, 147.8, 147.6, 144.7, 141.0, 140.8, 140.7, 136.0, 133.8, 129.7, 129.3, 128.5, 128.4, 128.3, 127.9, 127.5, 126.5, 126.4, 124.2, 122.0, 121.9, 120.3, 119.7, 116.9, 111.6, 81.1, 64.9, 63.8, 61.4, 12.2, 9.1; IR (thin film) 3029, 2949, 2860, 1740, 1521, 1342, 1168, 966, 738, 691 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{33}H_{27}N_2O_5$ $(M + H)^+$ 531.1920, found 531.1904.

3k, a white solid, 0.053 g, 47% yield. Mp: 38−39 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.75 (d, *J* = 7.2 Hz, 1H), 7.44 (d, *J* = 7.6 Hz, 2H), 7.38 (d, *J* = 7.6 Hz, 1H), 7.23−7.16 (m, 7H), 7.12 (d, *J* = 7.2 Hz, 2H), 7.08 (d, *J* = 7.6 Hz, 1H), 7.03 (t, *J* = 7.6 Hz, 1H), 6.90 (d, *J* = 7.6 Hz, 1H), 6.83 (t, *J* = 7.2 Hz, 1H), 6.06 (d, *J* = 16.0 Hz, 1H), 5.50−5.43 (m, 1H), 4.26 (s, 1H), 4.17−4.12 (m, 1H), 4.08−4.03 (m, 1H), 1.63−1.57 (m, 1H), 1.51−1.45 (m, 1H), 1.36−1.30 (m, 1H), 1.00−0.94 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.3, 145.4, 143.3, 142.1, 141.7, 140.2, 136.0, 133.8, 132.9, 129.0, 128.8, 128.4, 127.9, 127.5, 127.1, 127.0, 126.9, 126.6, 126.5, 125.0, 123.7, 122.0, 120.6, 119.6, 119.5, 81.1, 65.1, 64.8, 58.4, 10.8, 10.3; IR (thin film) 3058, 2927, 2852, 1737, 1451, 1221, 965, 740, 692 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{33}H_{27}BrNO_3$ $(M + H)^+$ 564.1174, found 564.1157.

3l, a white solid, 0.110 g, 86% yield. Mp: 143−144 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.91 (s, 1H), 7.77 (s, 1H), 7.52 (d, *J* = 7.6 Hz, 1H), 7.35−7.21 (m, 6H), 7.15 (s, 2H), 6.89−6.85 (m, 2H), 6.75 (t, *J* = 7.2 Hz, 1H), 6.48 (d, *J* = 8.0 Hz, 2H), 6.22 (d, *J* = 16.0 Hz, 1H), 5.63−5.56 (m, 1H), 4.32−4.27 (m, 1H), 4.22 (s, 1H), 4.16−4.11 (m, 1H), 1.53−1.47 (m, 2H), 1.42−1.36 (m, 1H), 0.98−0.92 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.7, 147.0, 145.7, 143.5, 139.0, 138.6, 136.0, 134.3, 132.5, 132.1, 130.0, 128.4, 128.1, 128.0, 127.9, 126.6, 123.4, 122.1, 121.7, 121.4, 121.2,120.7, 117.3, 80.9, 65.1, 63.3, 61.6, 12.6, 9.0; IR (thin film) 3023, 2926, 2867, 1752, 1595, 1184, 968, 814, 734 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{33}H_{26}Br_2NO_3$ $(M + H)^+$ 642.0279, found 642.0271.

3m (dr = 1:1), a white solid, 0.105 g, 93% yield, mp: 39−40 °C. Isomer 1: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93 (s, 1H), 7.79−7.76 (m, 2H), 7.38−7.18 (m, 8H), 7.12−7.09 (m, 2H), 6.86−6.82 (m, 4H), 6.20−6.12 (m, 1H), 5.64−5.56 (m, 1H), 4.32−4.26 (m, 2H), 4.21 (s, 1H), 1.52−1.46 (m, 2H), 1.42−1.37 (m, 1H), 0.96−0.93 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.9, 147.6, 146.1, 141.5, 140.1, 139.7, 136.1, 134.0, 132.3, 130.0, 129.0, 128.5, 128.0, 127.8, 127.5, 126.6, 124.5, 123.0, 122.0, 121.6, 120.8, 120.1, 117.3, 81.2, 65.0, 63.3, 61.7, 12.6, 9.1. Isomer 2: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.61−7.59 (m, 1H), 7.52−7.49 (m, 2H), 7.38−7.18 (m, 8H), 6.72−6.68 (m, 2H), 6.49−6.45 (m, 4H), 6.20−6.12 (m, 1H), 5.54−5.47 (m, 1H), 1.52−1.46 (m, 2H), 1.42−1.37 (m, 1H), 0.96−0.91 (m, 1H); ^{13}C NMR

DOI: 10.1021/acs.joc.6b02544
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(100 MHz, $CDCl_3$): δ 167.9, 146.0, 144.9, 143.8, 140.0, 139.6, 136.0, 133.8, 131.8, 130.0, 129.4, 128.4, 127.9, 127.7, 126.9, 126.5, 124.5, 122.9, 121.9, 121.3, 120.6, 119.5, 117.1, 81.1, 64.8, 63.2, 61.6, 12.4, 9.1; IR (thin film) 3026, 2925, 2854, 1742, 1596, 1172, 965, 744, 692 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{33}H_{27}BrNO_3$ $(M + H)^+$ 564.1174, found 564.1168.

3ab, a white solid, 0.075 g, 75% yield. Mp: 104−105 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.81−7.79 (m, 1H), 7.65 (d, *J* = 7.2 Hz, 1H), 7.55−7.53 (m, 1H), 7.44 (d, *J* = 7.2 Hz, 1H), 7.37−7.35 (m, 2H), 7.31−7.27 (m, 2H), 7.21−7.12 (m, 3H), 7.09 (d, *J* = 7.2 Hz, 2H), 6.84−6.80 (m, 2H), 6.69 (t, *J* = 7.2 Hz, 1H), 7.49 (d, *J* = 8.0 Hz, 2H), 6.00 (s, 1H), 4.30 (s, 1H), 4.13 (d, *J* = 12.0 Hz, 1H), 3.87 (d, *J* = 12.4 Hz, 1H), 1.58−1.54 (m, 1H), 1.51−1.47 (m, 1H), 1.43−1.37 (m, 1H), 1.35 (s, 3H), 0.95−0.93 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.3, 146.3, 145.3, 141.7, 141.0, 140.6, 136.8, 131.8, 129.1, 128.7, 128.2, 128.0, 127.9, 127.6, 127.1, 126.8, 126.6, 124.4, 122.7, 120.0, 119.4, 117.1, 81.3, 70.5, 63.2, 61.7, 15.0, 12.6, 9.1; IR (thin film) 3057, 2920, 2867, 1733, 1448, 1182, 1027, 741, 696 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{34}H_{30}NO_3$ $(M + H)^+$ 500.2226, found 500.2207.

3ac, a white solid, 0.093 g, 96% yield. Mp: 120−121 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.80 (d, *J* = 7.0 Hz, 1H), 7.63 (d, *J* = 7.5 Hz, 1H), 7.59 (d, *J* = 7.5 Hz, 1H), 7.47 (d, *J* = 7.0 Hz, 1H), 7.41−7.35 (m, 2H), 7.32−7.27 (m, 5H), 7.17 (t, *J* = 7.0 Hz, 1H), 7.12 (d, *J* = 7.0 Hz, 1H), 6.84 (t, *J* = 7.5 Hz, 2H), 6.69 (t, *J* = 7.0 Hz, 1H), 6.49 (d, *J* = 8.0 Hz, 2H), 4.44 (d, *J* = 15.5 Hz, 1H), 4.25 (s, 1H), 4.17 (d, *J* = 15.5 Hz, 1H), 1.52−1.49 (m, 2H), 1.43−1.41 (m, 1H), 0.99−0.94 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 168.0, 146.3, 145.2, 141.5, 140.9, 140.7, 131.8, 129.2, 128.8, 128.6, 128.1, 128.0, 127.6, 127.0, 126.8, 124.4, 122.7, 122.1, 120.1, 119.5, 117.1, 86.0, 82.2, 81.2, 63.2, 61.8, 52.5, 12.7, 9.1; IR (thin film) 3053, 2955, 2850, 1744, 1592, 1489, 1167, 744, 692 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{33}H_{26}NO_3$ $(M + H)^+$ 484.1913, found 484.1898.

3ad, a white solid, 0.089 g, 97% yield. Mp: 93−94 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.78 (d, *J* = 7.5 Hz, 1H), 7.63 (d, *J* = 7.5 Hz, 1H), 7.54 (d, *J* = 7.0 Hz, 1H), 7.41−7.33 (m, 3H), 7.20−7.09 (m, 5H), 6.83 (t, *J* = 7.5 Hz, 2H), 6.74 (d, *J* = 7.5 Hz, 2H), 6.69 (t, *J* = 7.0 Hz, 1H), 6.48 (d, *J* = 8.0 Hz, 2H), 4.60 (d, *J* = 13.0 Hz, 1H), 4.38 (d, *J* = 13.0 Hz, 1H), 4.27 (s, 1H), 1.53−1.45 (m, 2H), 1.41−1.37 (m, 1H), 0.94−0.89 (m, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 168.3, 146.3, 145.2, 141.6, 140.9, 140.6, 134.8, 129.1, 128.8, 128.1, 128.0, 127.8, 127.7, 127.6, 127.0, 126.8, 124.4, 122.7, 120.0, 119.5, 117.2, 81.3, 66.2, 63.2, 61.6, 12.6, 9.1; IR (thin film) 3031, 2946, 2890, 1738, 1447, 1168, 1015, 742, 692 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{31}H_{26}NO_3$ $(M + H)^+$ 460.1913, found 460.1895.

3ae, a white solid, 0.069 g, 81% yield. Mp: 87−88 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.78 (d, *J* = 6.8 Hz, 1H), 7.64−7.59 (m, 2H), 7.50 (d, *J* = 7.6 Hz, 1H), 7.42−7.34 (m, 2H), 7.22 (d, *J* = 7.6 Hz, 1H), 7.15 (t, *J* = 7.6 Hz, 1H), 6.84−6.80 (m, 2H), 6.69 (d, *J* = 7.2 Hz, 1H), 6.48 (d, *J* = 8.0 Hz, 2H), 4.23 (s, 1H), 3.49−3.46 (m, 2H), 1.56−1.52 (m, 1H), 1.48−1.37 (m, 2H), 0.97−0.87 (m, 3H), 0.85−0.78 (m, 2H), 0.66 (t, *J* = 6.8 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.5, 146.4, 145.3, 141.8, 141.0, 140.7, 129.1, 128.7, 128.0, 127.6, 127.0, 126.9, 124.4, 122.6, 119.9, 119.3, 117.1, 81.2, 64.1, 63.2, 61.5, 29.8, 18.6, 13.5, 12.4, 9.1; IR (thin film) 3042, 2957, 2871, 1730, 1450, 1187, 745, 690 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{28}H_{28}NO_3$ $(M + H)^+$ 426.2069, found 426.2050.

3af, a white solid, 0.071 g, 90% yield. Mp: 116−117 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.78 (d, *J* = 6.8 Hz, 1H), 7.63−7.61 (m, 2H), 7.51 (d, *J* = 7.6 Hz, 1H), 7.42−7.34 (m, 2H), 7.22 (d, *J* = 7.6 Hz, 1H), 7.14 (t, *J* = 7.2 Hz, 1H), 6.84−6.80 (m, 2H), 6.69 (d, *J* = 7.2 Hz, 1H), 6.48 (d, *J* = 8.0 Hz, 2H), 4.19 (s, 1H), 3.60−3.48 (m, 2H), 1.56−1.53 (m, 1H), 1.51−1.35 (m, 2H), 0.95−0.88 (m, 1H), 0.59 (t, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 168.4, 146.4, 145.5, 141.9, 140.9, 140.7, 129.1, 128.7, 128.0, 127.6, 127.0, 126.8, 124.4, 122.6, 119.9, 119.3, 117.0, 81.2, 63.2, 61.6, 60.2, 13.2, 12.4, 9.0; IR (thin film) 3065, 2985, 1733, 1449, 1193, 741, 696 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{26}H_{24}NO_3$ $(M + H)^+$ 398.1756, found 398.1741.

3ag, a white solid, 0.060 g, 71% yield. Mp: 107−108 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.67 (d, *J* = 7.2 Hz, 1H), 7.63 (d, *J* = 7.6 Hz, 1H), 7.52 (d, *J* = 6.8 Hz, 1H), 7.44 (d, *J* = 7.6 Hz, 1H), 7.33−7.25 (m, 2H), 7.17−7.13 (m, 1H), 7.09 (d, *J* = 7.6 Hz, 1H), 6.76−6.72 (m, 2H), 6.62 (t, *J* = 7.2 Hz, 1H), 6.42 (d, *J* = 8.0 Hz, 2H), 4.17 (s, 1H), 1.68−1.66 (m, 1H), 1.40−1.30 (m, 2H), 0.85−0.78 (m, 1H), 0.70 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.0, 146.4, 145.2, 142.2, 141.3, 140.9, 128.9, 128.6, 127.8, 127.5, 127.2, 127.1, 124.4, 122.6, 119.7, 119.2, 117.3, 81.2, 80.7, 63.0, 60.9, 27.0, 11.9, 8.9; IR (thin film) 3054, 2974, 1730, 1451, 1151, 844, 746, 694 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{28}H_{28}NO_3$ $(M + H)^+$ 426.2069, found 426.2052.

3ah (dr = 3.5/1), a white solid, 0.058 g, 58% yield, mp: 86−87 °C. Major isomer: ^1H NMR (400 MHz, $CDCl_3$): δ 7.65 (d, *J* = 7.2 Hz, 1H), 7.61 (d, *J* = 7.2 Hz, 1H), 7.53 (d, *J* = 7.2 Hz, 1H), 7.42 (d, *J* = 7.2 Hz, 1H), 7.31−7.24 (m, 2H), 7.18−7.13 (m, 1H), 7.09−7.05 (m, 1H), 6.77−6.73 (m, 2H), 6.63−6.59 (m, 1H), 6.43 (d, *J* = 8.0 Hz, 2H), 4.24 (s, 1H), 4.09−4.02 (m, 1H), 1.62−1.58 (m, 2H), 1.39−1.30 (m, 6H), 1.12−1.07 (m, 1H), 0.81−0.78 (m, 2H), 0.70−0.67 (m, 2H), 0.57−0.51 (m, 6H), 0.40 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.6, 146.4, 145.1, 142.3, 141.4, 141.1, 129.0, 128.6, 127.8, 127.5, 127.2, 126.8, 124.4, 122.7, 119.7, 119.4, 117.4, 80.9, 74.3, 63.2, 60.4, 46.1, 38.7, 33.8, 30.7, 25.9, 23.2, 21.7, 20.4, 16.1, 11.7, 9.0. Minor isomer: ^1H NMR (400 MHz, $CDCl_3$): δ 7.70 (d, *J* = 7.2 Hz, 1H), 7.69 (d, *J* = 7.2 Hz, 1H), 7.49 (d, *J* = 7.2 Hz, 1H), 7.37 (d, *J* = 7.2 Hz, 1H), 7.31−7.24 (m, 2H), 7.18−7.13 (m, 1H), 7.09−7.05 (m, 1H), 6.77−6.73 (m, 2H), 6.63−6.59 (m, 1H), 6.39 (d, *J* = 8.0 Hz, 2H), 4.33 (s, 1H), 4.09−4.02 (m, 1H), 1.62−1.58 (m, 2H), 1.43−1.40 (m, 6H), 1.10−1.07 (m, 1H), 0.81−0.78 (m, 2H), 0.68−0.67 (m, 2H), 0.57−0.51 (m, 6H), 0.43 (d, *J* = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 167.7, 146.0, 144.0, 142.3, 141.5, 140.4, 129.2, 128.7, 127.7, 127.5, 127.4, 127.0, 124.6, 123.0, 119.8, 119.3, 117.8, 81.7, 74.6, 63.7, 61.1, 46.1, 40.4, 33.9, 31.1, 26.8, 22.5, 21.8, 20.8, 15.3, 12.5, 9.5; IR (thin film) 3062, 2953, 2867, 1735, 1595, 1454, 1184, 747, 693 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{34}H_{38}NO_3$ $(M + H)^+$ 508.2852, found 508.2836.

3ai, a white solid, 0.063 g, 73% yield. Mp: 120−121 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 8.01 (d, *J* = 7.6 Hz, 1H), 7.47−7.45 (m, 1H), 7.41−7.39 (m, 3H), 7.21 (t, *J* = 7.6 Hz, 1H), 7.12−7.10 (m, 1H), 7.00−6.98 (m, 2H), 6.96−6.90 (m, 4H), 6.83−6.80 (m, 2H), 6.67−6.64 (m, 1H), 6.48 (d, *J* = 8.4 Hz, 2H), 4.92 (s, 1H), 1.69−1.66 (m, 1H), 1.43−1.37 (m, 2H), 0.94−0.88 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.0, 146.6, 146.2, 141.1, 141.0, 140.3, 137.1, 132.3, 129.2, 128.4, 128.3, 128.1, 127.7, 127.5, 127.4, 127.1, 124.5, 122.3, 120.0, 119.0, 116.7, 81.0, 64.5, 63.7, 13.5, 9.3; IR (thin film) 3066, 2957, 2857, 1727, 1680, 1597, 1213, 746, 692 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{30}H_{24}NO_2$ $(M + H)^+$ 430.1807, found 430.1792.

3aj, as a white solid, 0.065 g, 92% yield. Mp: 149−150 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.74 (d, *J* = 7.6 Hz, 1H), 7.70 (d, *J* = 7.2 Hz, 1H), 7.61 (d, *J* = 7.2 Hz, 1H), 7.56 (d, *J* = 7.2 Hz, 1H), 7.41−7.32 (m, 2H), 7.29−7.25 (m, 1H), 7.21−7.17 (m, 1H), 6.84−6.80 (m, 2H), 6.69 (t, *J* = 7.2 Hz, 1H), 6.49 (d, *J* = 8.0 Hz, 2H), 3.71−3.68 (m, 1H), 3.32−3.28 (m, 1H), 3.15−3.11 (m, 1H), 1.41−1.36 (m, 1H), 1.21−1.12 (m, 2H), 0.93−0.87 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.6, 144.9, 141.7, 140.6, 140.5, 129.0, 128.6, 128.0, 127.6, 127.1, 126.8, 124.8, 122.5, 120.0, 119.9, 117.2, 80.9, 65.1, 61.0, 57.0, 10.7, 7.2; IR (thin film) 3660, 3030, 2927, 2865, 1592, 1217, 740, 691 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{24}H_{22}NO_2$ $(M + H)^+$ 356.1651, found 356.1633.

*Direct Thermal Rearrangement of **3a** to **4a′** (Scheme 2-1).* A round-bottle flask was charged with **3a** (0.2 mmol) and toluene (2 mL). Then, the reaction mixture was stirred vigorously at 100 °C for 36 h until the substrate **3a** disappeared (monitored by TLC). At this time, the solvent was removed under reduced pressure, and the crude product was purified by flash chromatography (the crude residue was dry loaded with silica gel, 1/100 to 1/10, ethyl acetate/petroleum ether) to provide **1a** (0.020 g, 35% yield), *N*-(9*H*-fluoren-9-ylidene)aniline (0.010 g, 20% yield) and **4a′** (0.010 g, 10% yield).

*Cinnamyl4′-hydroxy-1′-phenyl-5′,6′-dihydro-1′H-spiro[fluorene-9,2′-pyridine]-3′-carboxylate (**4a′**).* A white solid, mp: 126−127 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 12.90 (s, 1H), 7.48 (d, *J* = 7.2 Hz, 2H), 7.30−7.04 (m, 11H), 6.67−6.59 (m, 3H), 6.20 (d, *J* = 7.2 Hz, 2H), 5.78 (d, *J* = 16.0 Hz, 1H), 5.19−5.12 (m, 1H), 4.05 (d, *J* = 7.0 Hz, 2H), 3.51 (t, *J* = 5.2 Hz, 2H), 2.79 (t, *J* = 5.2 Hz, 2H); ^{13}C NMR

DOI: 10.1021/acs.joc.6b02544
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(100 MHz, $CDCl_3$): δ 174.0, 170.8, 149.2, 148.2, 141.2, 136.3, 132.8, 128.3, 127.8, 127.6, 127.4, 126.7, 126.4, 124.2, 124.1, 122.1, 119.1, 100.9, 70.4, 63.8, 45.4, 31.2; IR (thin film) 3442, 3040, 2954, 2847, 1725, 1640, 1247, 1072, 740, 694 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{33}H_{28}NO_3$ $(M + H)^+$ 486.2069, found 486.2059.

General Procedure B for Preparation of Product ***4*** *(Table 4).* In a round-bottle flask charged with **3** (0.2 mmol) and THF (2 mL) was added $LiAlH_4$ (0.4 mmol, 2.0 equiv). Then, the reaction mixture was stirred vigorously at 25 °C for 1 h until the substrate **3** disappeared (monitored by TLC). At this time, the reaction was diluted with H_2O (10 mL) and exacted with Et_2O (3 × 10 mL). The combined organic layers were washed with brine (1 × 10 mL), dried over Na_2SO_4, and filtered. The solvent was removed under reduced pressure, and the crude product was used directly in the next step.

A Teflon-sealed reaction flask was charged with the above crude mixture and MeCN (2 mL). Then, the reaction mixture was stirred vigorously at 120 °C for 18−24 h until the substrate disappeared (monitored by TLC). At this time, the solvent was removed under reduced pressure, and the crude product was purified by flash chromatography (the crude residue was dry-loaded with silica gel, 1/20 to 1/4 ethyl acetate/petroleum ether) to provide product **4**.

*3′-(Hydroxymethyl)-1′-phenylspiro[fluorene-9,2′-piperidin]-4′-one (**4a**).* A white solid, 0.050 g, 70% yield. Mp: 116−117 °C; ^1H NMR (400 MHz, DMSO-d_6): δ 7.74 (d, *J* = 7.2 Hz, 2H), 7.63−7.61 (m, 1H), 7.40 (t, *J* = 7.2 Hz, 1H), 7.30−7.19 (m, 4H), 6.77 (t, *J* = 7.6 Hz, 2H), 6.61−6.58 (m, 1H), 6.35 (d, *J* = 7.6 Hz, 2H), 4.29−4.27 (m, 1H), 4.13 (brs, 1H), 3.85−3.82 (m, 1H), 3.67 (d, *J* = 7.2 Hz, 1H), 3.10−3.01 (m, 2H), 2.90−2.82 (m, 1H), 2.10 (d, *J* = 5.6 Hz, 1H); ^{13}C NMR (100 MHz, DMSO-d_6): δ 208.9, 149.4, 147.2, 146.3, 140.1, 139.9, 129.1, 128.8, 128.2, 128.1, 127.8, 125.0, 124.9, 122.5, 122.4, 120.9, 120.2, 73.7, 57.9, 55.7, 47.3, 42.8; IR (thin film) 3657, 3030, 2927, 2865, 1739, 1592, 1217, 740, 691 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{24}H_{22}NO_2$ $(M + H)^+$ 356.1651, found 356.1635.

*3′-(Hydroxymethyl)-1′-(4-phenoxyphenyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4c**).* A white solid, 0.077 g, 87% yield. Mp: 38−39 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.61 (d, *J* = 6.5 Hz, 1H), 7.54 (d, *J* = 7.0 Hz, 1H), 7.39−7.34 (m, 3H), 7.28−7.20 (m, 5H), 7.01 (t, *J* = 7.0 Hz, 1H), 6.71 (d, *J* = 7.5 Hz, 2H), 6.44 (t, *J* = 8.0 Hz, 2H), 6.41 (d, *J* = 8.0 Hz, 2H), 4.02−3.98 (m, 1H), 3.69−3.65 (m, 2H), 3.37−3.33 (m, 1H), 3.20−3.17 (m, 1H), 2.88 (d, *J* = 15.0 Hz, 1H), 2.59−2.58 (m, 1H), 2.27 (brs, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 211.8, 157.5, 153.5, 145.4, 143.8, 143.7, 140.7, 139.7, 129.4, 128.9, 128.7, 127.7, 127.3, 127.2, 124.9, 124.6, 122.7, 120.5, 119.5, 118.3, 118.0, 73.7, 58.5, 58.3, 49.4, 42.4; IR (thin film) 3439, 3034, 2930, 2851, 1708, 1621, 1231, 869, 741, 698 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{30}H_{26}NO_3$ $(M + H)^+$ 448.1913, found 448.1905.

*3′-(Hydroxymethyl)-1′-p-tolylspiro[fluorene-9,2′-piperidin]-4′-one (**4d**).* A white solid, 0.055 g, 74% yield. Mp: 40−41 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.61 (d, *J* = 7.5 Hz, 1H), 7.54 (d, *J* = 7.5 Hz, 1H), 7.38−7.34 (m, 3H), 7.29−7.18 (m, 3H), 6.59 (d, *J* = 7.5 Hz, 2H), 6.35 (d, *J* = 8.0 Hz, 2H), 4.05−3.99 (m, 1H), 3.72−3.68 (m, 1H), 3.64 (dd, *J* = 9.0 Hz, 3.0 Hz, 1H), 3.32−3.28 (m, 1H), 3.19−3.14 (m, 1H), 2.87 (dt, *J* = 15.0 Hz, 4.0 Hz, 1H), 2.56−2.54 (m, 1H), 2.25 (brs, 1H), 2.03 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 211.9, 145.7, 145.6, 144.3, 140.6, 139.6, 133.9, 128.7, 128.6, 128.3, 127.7, 127.2, 125.5, 124.9, 124.6, 120.4, 119.5, 73.5, 58.7, 58.3, 49.4, 42.5, 20.6; IR (thin film) 3440, 3060, 2929, 2851, 1709, 1622, 1215, 820, 739, 694 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{25}H_{23}NO_2Na$ $(M + Na)^+$ 392.1626, found 392.1609.

*3′-(Hydroxymethyl)-1′-(4-isopropylphenyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4e**).* A white solid, 0.061 g, 77% yield. Mp: 125−126 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.52 (d, *J* = 7.0 Hz, 1H), 7.48 (d, *J* = 7.5 Hz, 1H), 7.32−7.25 (m, 2H), 7.21−7.19 (m, 2H), 7.16−7.10 (m, 2H), 6.57 (d, *J* = 8.0 Hz, 2H), 6.29 (d, *J* = 8.5 Hz, 2H), 3.98−3.93 (m, 1H), 3.72−3.68 (m, 1H), 3.57−3.55 (m, 1H), 3.24−3.20 (m, 1H), 3.12−3.06 (m, 1H), 2.82 (dt, *J* = 15.0 Hz, 4.0 Hz, 1H), 2.55−2.49 (m, 2H), 2.17 (brs, 1H), 0.94 (d, *J* = 6.5 Hz, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.9, 145.9, 145.7, 144.5, 140.5, 139.6, 128.7, 128.5, 127.7, 127.2, 125.6, 125.0, 124.9, 124.8, 124.5, 120.4, 119.4, 73.4, 58.8, 58.2, 49.2, 42.5, 33.1, 23.7, 23.6; IR (thin film) 3446, 3030, 2963, 2875, 1711, 1616, 1047, 739, 668 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{27}H_{28}NO_2$ $(M + H)^+$ 398.2120, found 398.2105.

*1′-(4-Bromophenyl)-3′-(hydroxymethyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4f**).* A white solid, 0.041 g, 47% yield. Mp: 42−43 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.58−7.55 (m, 2H), 7.50−7.33 (m, 2H), 7.29−7.25 (m, 1H), 7.22−7.18 (m, 2H), 6.81−6.78 (m, 2H), 6.76−6.74 (m, 1H), 6.45 (d, *J* = 7.5 Hz, 2H), 4.07−4.02 (m, 1H), 3.84−3.79 (m, 1H), 3.67 (dd, *J* = 8.0 Hz, 2.5 Hz, 1H), 3.32−3.28 (m, 1H), 3.32−3.13 (m, 1H), 2.92 (dt, *J* = 15.5 Hz, 4.5 Hz, 1H), 2.56−2.51 (m, 1H), 2.23 (brs, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 211.7, 148.3, 145.6, 144.5, 140.4, 139.7, 128.8, 128.6, 127.7, 127.3, 125.0, 124.9, 124.8, 124.5, 124.1, 120.5, 119.5, 73.4, 58.7, 58.2, 48.8, 42.4; IR (thin film) 3415, 3059, 2927, 2877, 1715, 1593, 1486, 1035, 741, 697 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{24}H_{19}BrNO$ $(M - OH)^+$ 416.0650, found 416.0630.

*1′-(4-Fluorophenyl)-3′-(hydroxymethyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4g**).* A white solid, 0.062 g, 82% yield. Mp: 139−140 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.62 (d, *J* = 7.2 Hz, 1H), 7.54 (d, *J* = 7.2 Hz, 1H), 7.40−7.34 (m, 3H), 7.30−7.18 (m, 3H), 6.49−6.45 (m, 2H), 6.42−6.38 (m, 2H), 4.01−3.94 (m, 1H), 3.65−3.59 (m, 2H), 3.36−3.31 (m, 1H), 3.22−3.14 (m, 1H), 2.87 (dt, *J* = 14.8 Hz, 3.6 Hz, 1H), 2.59−2.54 (m, 1H), 2.25 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.6, 160.9 (d, *J* = 242.8 Hz), 145.2, 144.0, 143.6, 140.7, 139.6, 128.9 (d, *J* = 12.5 Hz), 127.8, 127.7, 127.6, 127.2, 124.9, 124.5, 120.5, 119.6, 114.4 (d, *J* = 21.9 Hz), 73.6, 58.5, 58.2, 49.6, 42.4; IR (thin film) 3474, 3057, 2930, 2850, 1708, 1617, 1211, 837, 739 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{24}H_{21}FNO_2$ $(M + H)^+$ 374.1556, found 374.1544.

*3′-(Hydroxymethyl)-1′-(4-(hydroxymethyl)phenyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4h**).* A white solid, 0.056 g, 73% yield. Mp: 47−48 °C; ^1H NMR (500 MHz, $CDCl_3$): δ 7.58−7.55 (m, 2H), 7.41−7.37 (m, 2H), 7.34−7.32 (m, 1H), 7.29−7.26 (m, 1H), 7.22−7.18 (m, 2H), 6.80 (d, *J* = 8.0 Hz, 2H), 6.44 (d, *J* = 8.0 Hz, 2H), 4.37 (s, 2H), 4.05−4.02 (m, 1H), 3.82−3.80 (m, 1H), 3.75−3.74 (m, 1H), 3.66 (dd, *J* = 9.0 Hz, 3.0 Hz, 1H), 3.30−3.26 (m, 1H), 3.17−3.14 (m, 1H), 2.92 (dt, *J* = 15.5, Hz, 4.5 Hz, 1H), 2.54−2.53 (m, 1H), 2.22 (brs 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.6, 147.9, 145.6, 144.4, 140.4, 139.6, 136.3, 128.8, 128.7, 127.8, 127.4, 126.6, 124.9, 124.8, 124.4, 120.5, 119.6, 73.4, 64.7, 58.7, 58.2, 48.8, 42.4; IR (thin film) 3419, 3054, 2926, 2862, 1712, 1611, 1509, 1261, 1028, 805, 739 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{25}H_{24}NO_3$ $(M + H)^+$ 386.1756, found 386.1739.

*1′-(3,5-Dimethylphenyl)-3′-(hydroxymethyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4i**).* A white solid, 0.049 g, 63% yield. Mp: 154−155 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.58 (d, *J* = 7.2 Hz, 1H), 7.54 (d, *J* = 7.6 Hz, 1H), 7.40−7.28 (m, 3H), 7.25−7.21 (m, 1H), 7.20−7.17 (m, 2H), 6.38 (s, 1H), 6.02 (s, 2H), 4.03−3.98 (m, 1H), 3.79−3.75 (m, 1H), 3.65−3.62 (m, 1H), 3.35−3.30 (m, 1H), 3.16−3.12 (m, 1H), 2.90−2.85 (m, 1H), 2.59 (d, *J* = 10.4 Hz, 1H), 2.23 (brs, 1H), 1.88 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.9, 148.1, 145.7, 144.5, 140.5, 139.7, 136.9, 128.7, 128.6, 127.6, 127.2, 125.6, 124.8, 124.5, 122.8, 120.2, 119.4, 73.4, 58.5, 58.3, 48.8, 42.5, 20.9; IR (thin film) 3432, 3045, 2928, 2854, 1711, 1614, 1045, 744 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{26}H_{26}NO_2$ $(M + H)^+$ 384.1964, found 384.1953.

*3′-(Hydroxymethyl)-1′-(3-nitrophenyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4j**).* A yellow liquid, 0.040 g, 50% yield. ^1H NMR (500 MHz, $CDCl_3$): δ 7.63 (d, *J* = 8.0 Hz, 1H), 7.56 (d, *J* = 8.0 Hz, 1H), 7.52 (d, *J* = 7.5 Hz, 1H), 7.51 (d, *J* = 7.0 Hz, 1H), 7.49−7.47 (m, 1H), 7.44−7.41 (m, 3H), 7.33−7.22 (m, 2H), 6.92 (t, *J* = 7.5 Hz, 1H), 6.61 (d, *J* = 7.0 Hz, 1H), 4.09−3.03 (m, 2H), 3.71−3.69 (m, 1H), 3.29−3.26 (m, 1H), 3.17−3.13 (m, 1H), 3.03−2.98 (m, 1H), 2.59−2.55 (m, 1H), 2.17 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 210.5, 149.3, 147.8, 144.9, 144.0, 139.9, 139.7, 129.4, 129.2, 128.8, 128.4, 128.3, 127.9, 124.4, 123.9, 120.8, 120.0, 117.6, 117.5, 73.1, 58.1, 58.0, 47.2, 41.9; IR (thin film) 3430, 3031, 2972, 2860, 1708, 1619, 1048, 738 cm^{-1}; HRMS (ESI) *m*/*z* calcd for $C_{24}H_{21}N_2O_4$ $(M + H)^+$ 401.1501, found 401.1493.

*1′-(2-Bromophenyl)-3′-(hydroxymethyl)spiro[fluorene-9,2′-piperidin]-4′-one (**4k**).* A white solid, 0.049 g, 56% yield. Mp: 69−70 °C; ^1H NMR (400 MHz, $CDCl_3$): δ 7.51−7.47 (m, 2H), 7.33−7.26 (m,

DOI: 10.1021/acs.joc.6b02544
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2H), 7.22−7.16 (m, 1H), 7.14−7.10 (m, 2H), 6.74−6.66 (m, 3H), 6.38 (d, J = 7.2 Hz, 2H), 4.01−3.94 (m, 1H), 3.78−3.72 (m, 1H), 3.60 (dd, J = 8.8 Hz, 3.2 Hz, 1H), 3.25−3.20 (m, 1H), 3.13−3.05 (m, 1H), 2.85−2.79 (m, 1H), 2.51 (d, J = 10.4 Hz, 1H), 2.14 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.7, 148.3, 145.6, 144.5, 140.4, 139.7, 128.8, 128.6, 127.7, 127.3, 125.0, 124.8, 124.5, 124.1, 120.5, 119.5, 73.4, 58.7, 58.2, 48.8, 42.4; IR (thin film) 3407, 3057, 2960, 2858, 1710, 1591, 1449, 1262, 1094, 804, 742 cm^{-1}; HRMS (ESI) m/z calcd for $C_{24}H_{21}BrNO_2$ $(M + H)^+$ 434.0756, found 434.0730.

*2,7-Dibromo-3′-(hydroxymethyl)-1′-phenylspiro[fluorene-9,2′-piperidin]-4′-one (**4l**).* A white solid, 0.066 g, 65% yield. Mp: 42−43 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.73 (s, 1H), 7.53 (d, J = 8.0 Hz, 1H), 7.46 (s, 1H), 7.37 (d, J = 8.0 Hz, 1H), 7.32 (d, J = 7.6 Hz, 1H), 7.21 (d, J = 8.0 Hz, 1H), 6.87−6.78 (m, 3H), 6.46 (d, J = 7.6 Hz, 2H), 3.99−3.93 (m, 1H), 3.83−3.77 (m, 1H), 3.59−3.57 (m, 1H), 3.36−3.31 (m, 1H), 3.17−3.10 (m, 1H), 2.93 (dt, J = 15.6 Hz, 4.4 Hz, 1H), 2.58−2.55 (m, 1H) 2.28 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 210.6, 147.6, 147.5, 146.4, 138.4, 137.6, 132.2, 132.0, 128.1, 128.0, 127.9, 125.2, 124.7, 121.9, 121.8, 121.7, 120.9, 73.4, 58.0, 57.9, 48.8, 42.3; IR (thin film) 3478, 3038, 2977, 2873, 1728, 1614, 1131, 880, 652 cm^{-1}; HRMS (ESI) m/z calcd for $C_{24}H_{20}Br_2NO_2$ $(M + H)^+$ 511.9861, found 511.9866.

*2-Bromo-3′-(hydroxymethyl)-1′-phenylspiro[fluorene-9,2′-piperidin]-4′-one (**4m**).* Dr = 1/1, a white solid, 0.040 g, 46% yield, mp: 37−38 °C. Isomer 1: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.74 (s, 1H), 7.57−7.46 (m, 2H), 7.36−7.19 (m, 4H), 6.82−6.73 (m, 3H), 6.44 (d, J = 7.6 Hz, 2H), 4.40−3.97 (m, 1H), 3.84−3.77 (m, 1H), 3.66−3.59 (m, 1H), 3.36−3.27 (m, 1H), 3.16−3.09 (m, 1H), 2.91−2.86 (m, 1H), 2.57−2.54 (m, 1H), 2.35 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.9, 148.3, 147.7, 145.6, 144.5, 140.5, 139.8, 132.1, 129.3, 128.8, 127.8, 125.2, 124.5, 121.7, 121.2, 120.5, 119.6, 73.4, 58.6, 58.1, 48.8, 42.4. Isomer 2: ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.57−7.46 (m, 3H), 7.36−7.19 (m, 4H), 6.82−6.73 (m, 3H), 6.44 (d, J = 7.6 Hz, 2H), 4.40−3.97 (m, 1H), 3.84−3.77 (m, 1H), 3.66−3.59 (m, 1H), 3.36−3.27 (m, 1H), 3.16−3.09 (m, 1H), 2.91−2.86 (m, 1H), 2.57−2.54 (m, 1H), 2.35 (brs, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 211.1, 148.0, 146.8, 145.4, 144.0, 139.4, 138.6, 131.7, 129.0, 128.6, 127.3, 124.8, 124.0, 121.4, 120.8, 120.4, 119.3, 73.3, 58.3, 58.0, 48.6, 42.3; IR (thin film) 3406, 3013, 2932, 2867, 1719, 1631, 1250, 877, 655 cm^{-1}; HRMS (ESI) m/z calcd for $C_{24}H_{21}BrNO_2$ $(M + H)^+$ 434.0756, found 434.0751.

*3′-(Benzyloxymethyl)-1′-phenylspiro[fluorene-9,2′-piperidin]-4′-one (**4n**).* A white solid, 0.057 g, 64% yield. Mp: 94−95 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63 (d, J = 7.2 Hz, 1H), 7.51 (d, J = 7.6 Hz, 1H), 7.37−7.32 (m, 3H), 7.25−7.16 (m, 6H), 7.00 (d, J = 6.4 Hz, 2H), 6.79−6.70 (m, 3H), 6.42 (d, J = 7.6 Hz, 2H), 4.21 (d, J = 12.0 Hz, 1H), 4.03 (d, J = 11.6 Hz, 1H), 3.97−3.94 (m, 1H), 3.89−3.83 (m, 1H), 3.78 (d, J = 6.0 Hz, 1H), 3.48 (t, J = 8.8 Hz, 1H), 3.18−3.11 (m, 1H), 2.92 (dt, J = 14.8 Hz, 4.8 Hz, 1H), 2.39 (d, J = 9.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 208.0, 148.5, 146.2, 144.5, 140.6, 139.8, 138.1, 128.7, 128.4, 128.0, 127.7, 127.6, 127.4, 127.3, 127.2, 125.1, 125.0, 124.6, 123.9, 120.2, 119.4, 74.1, 72.9, 64.7, 56.8, 49.1, 42.7; IR (thin film) 3060, 2925, 2859, 1713, 1595, 1489, 1100, 740, 698 cm^{-1}; HRMS (ESI) m/z calcd for $C_{31}H_{28}NO_2$ $(M + H)^+$ 446.2120, found 446.2114.

*3′-(Allyloxymethyl)-1′-phenylspiro[fluorene-9,2′-piperidin]-4′-one (**4o**).* A colorless liquid, 0.054 g, 68% yield. ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.57 (d, J = 6.8 Hz, 1H), 7.46 (d, J = 7.6 Hz, 1H), 7.32−7.24 (m, 2H), 7.20−7.12 (m, 3H), 6.72−6.65 (m, 3H), 6.35 (d, J = 7.2 Hz, 2H), 5.56−5.46 (m, 1H), 4.88−4.84 (m, 2H), 3.91−3.88 (m, 1H), 3.84−3.78 (m, 1H), 3.66 (d, J = 7.6 Hz, 1H), 3.58 (dd, J = 12.8 Hz, 5.6 Hz, 1H), 3.46 (dd, J = 12.8 Hz, 5.6 Hz, 1H), 3.31−3.26 (m, 1H), 3.11−3.04 (m, 1H), 2.84−2.78 (m, 1H), 2.22−2.20 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 208.1, 148.5, 146.2, 144.5, 140.6, 139.8, 134.4, 128.7, 128.4, 127.7, 127.6, 127.3, 125.1, 125.0, 124.6, 123.9, 120.2, 119.3, 116.5, 74.0, 71.8, 64.3, 56.8, 49.1, 42.7; IR (thin film) 3062, 2923, 2879, 1711, 1594, 1483, 1105, 741, 693 cm^{-1}; HRMS (ESI) m/z calcd for $C_{27}H_{26}NO_2$ $(M + H)^+$ 396.1964, found 396.1953.

*Enantioselective Synthesis of **3aj** and **4a** (Scheme 3).* Chiral **3aj** was prepared by general procedure B. **3ah** (0.030 g, 0.06 mmol) was stirred for 1 h at 25 °C. Purification using medium pressure chromatography (1/4 ethyl acetate/petroleum ether) afforded chiral **3aj** as a white solid (0.021 g, 86%). Ee = 35%, conditions: AD-H; hexane/i-PrOH = 85/15; flow rate 1.0 mL/min; λ = 254 nm; t (minor) = 36.4 min; t (major) = 43.2 min.

Chiral **4a** was prepared by general procedure B. Chiral **3aj** (0.021 g, 0.06 mmol) was stirred for 12 h at 120 °C. Purification using medium pressure chromatography (1/4 ethyl acetate/petroleum ether) afforded chiral **4a** as a white solid (0.016 g, 89%). The characteristic data was matched with that above. Ee = 37%, conditions: AD-H; hexane/i-PrOH = 85/15; flow rate 0.8 mL/min; λ = 254 nm; t (major) = 48.4 min; t (minor) = 102.0 min.

*General Procedure for Synthesis of **5**.* In a round-bottle flask charged with **4a** (0.2 mmol) and MeOH (2 mL), $NaBH_4$ (0.4 mmol, 2.0 equiv) was added. Then, the reaction mixture was stirred vigorously at 25 °C for 1 h until the substrate **4a** disappeared (monitored by TLC). At this time, the reaction was diluted with H_2O (10 mL) and exacted with Et_2O (3 × 10 mL). The combined organic layers were washed with brine (1 × 10 mL), dried over Na_2SO_4, and filtered. The solvent was removed under reduced pressure, and the crude product was purified by flash chromatography (the crude residue was dry loaded with silica gel, 1/20 to 1/4 ethyl acetate/petroleum ether) to provide product **5** as a white solid (0.058 g, 82%). Mp: 73−74 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.52−8.50 (m, 1H), 7.58−7.56 (m, 1H), 7.45−7.43 (m, 1H),7.39−7.37 (m, 1H), 7.30−7.21 (m, 4H), 7.74−7.69 (m, 3H), 6.47 (d, J = 7.2 Hz, 2H), 4.67 (d, J = 2.4 Hz, 1H), 4.27−4.21 (m, 1H), 3.54 (brs, 1H), 3.28−3.26 (m, 1H), 3.21−3.17 (m, 1H), 3.10−3.06 (m, 1H), 2.54−2.53 (m, 1H), 2.33−2.30 (m, 1H), 2.19 (dd, J = 13.6 Hz, 2.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 149.4, 149.1, 145.8, 140.7, 140.3, 128.8, 128.3, 128.1, 127.4, 127.1, 126.9, 126.5, 124.7, 123.7, 119.7, 119.2, 72.9, 67.4, 62.6, 49.2, 45.3, 33.6; IR (thin film) 3399, 3058, 2925, 2865, 1593, 1490, 1094, 803, 745 cm^{-1}; HRMS (ESI) m/z calcd for $C_{24}H_{24}NO_2$ $(M + H)^+$ 358.1807, found 358.1797.

*General Procedure for Synthesis of **6**.* To a solution of Dess−Martin periodinane (0.064 g, 0.15 mmol) in CH_2Cl_2 (1.0 mL) was added a solution of **4a** (0.036 g, 0.1 mmol) in CH_2Cl_2 (1.0 mL) with stirring overnight at room temperature. Once **4a** disappeared completely (about 15 h), the reaction mixture was diluted with diethyl ether (5 mL). Aqueous 1.0 M NaOH (2 mL) was added, and the solution was stirred for a further 20 min. The organic phase was then separated, and the aqueous phase was extracted with Et_2O (3 × 5 mL). The combined organic phases were dried over Na_2SO_4 and concentrated in vacuo. The crude product was purified by flash chromatography (the crude residue was dry loaded with silica gel, 1/20 to 1/4 ethyl acetate/petroleum ether) to provide product **6** as a light yellow solid (0.031 g, 88%). Mp: 176−177 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.63 (d, J = 7.2 Hz, 2H), 7.54 (d, J = 7.2 Hz, 2H), 7.28−7.16 (m, 6H), 7.01−6.96 (m, 2H), 6.76 (d, J = 8.0 Hz, 2H), 6.37 (brs, 1H), 3.87 (d, J = 7.6 Hz, 2H), 2.72−2.68 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 193.7, 149.0, 147.1, 144.8, 139.3, 129.5, 128.8, 128.2, 124.6, 124.5, 120.0, 118.2, 114.3, 83.3, 47.2, 36.3; IR (thin film) 3328, 3044, 2924, 2857, 1734, 1574, 1295, 743, 687 cm^{-1}; HRMS (ESI) m/z calcd for $C_{24}H_{18}NO$ $(M-H_2O)^+$ 336.1388, found 336.1371.

*General Procedure for Synthesis of Nitrone **1**.* A round-bottle flask, open to the air, was charged with fluoren-9-one oxime (0.5 mmol), CCl_4 (5 mL), and KOH (0.75 mmol, 1.5 equiv). The mixture was stirred vigorously at room temperature for 5 min. Then, diaryliodonium salt (0.75 mmol, 1.5 equiv) was added in one portion. The reaction was monitored by TLC until the oxime was consumed completely. At this time, the CCl_4 was removed under reduced pressure, and the crude product was purified by flash chromatography (the crude residue was dry loaded on silica gel; 1/10−1/4 ethyl acetate/petroleum ether) to provide nitrones **1** as yellow solid.

The nitrones **1a**,[9d] **1b**,[13] **1d**,[13] **1g**,[13] **1f**,[14] **1n**,[15] **1o**,[16] and **1p**[17] were prepared according to literature methods, and their spectral data matched literature values.

*N-(9H-Fluoren-9-ylidene)-4-phenoxyaniline oxide (**1c**).* A yellow solid, 0.040 g, 37% yield. Mp: 178−179 °C; ^{1}H NMR (400 MHz; $CDCl_3$): δ 8.84 (d, J = 7.2 Hz, 1H), 7.62−7.56 (m, 2H), 7.42−7.39 (m, 3H), 7.36−7.32 (m, 3H), 7.20−7.17 (m, 2H), 7.14−7.04 (m, 5H),

DOI: 10.1021/acs.joc.6b02544
J. Org. Chem. 2017, 82, 502−511

6.91 (t, J = 7.6 Hz, 1H), 6.05 (d, J = 8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 159.0, 155.9, 145.6, 142.0, 139.2, 139.0, 132.3, 131.2, 130.8, 130.0, 129.2, 128.8, 127.2, 127.0, 125.5, 124.4, 123.8, 120.2, 119.7, 119.6, 119.2; IR (thin film) 3058, 1586, 1487, 1245, 870, 727 cm^{-1}; HRMS (ESI) m/z calcd for $C_{25}H_{18}NO_2$ $(M + H)^+$ 364.1338, found 364.1321.

*N-(9H-Fluoren-9-ylidene)-4-isopropylaniline oxide (**1e**).* A yellow solid, 0.040 g, 43% yield. Mp: 95−96 °C; ^{1}H NMR (500 MHz; $CDCl_3$): δ 8.85 (d, J = 7.6 Hz, 1H), 7.61 (d, J = 7.6 Hz, 1H), 7.55 (d, J = 7.6 Hz, 1H), 7.40−7.31 (m, 6H), 7.16 (t, J = 7.6 Hz, 1H), 6.83−6.79 (m, 1H), 5.87 (d, J = 8.4 Hz, 1H), 2.98−2.94 (m, 1H), 1.25 (d, J = 6.8 Hz, 6H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 151.4, 145.3, 144.9, 139.1, 139.0, 132.3, 131.0, 130.8, 129.0, 128.7, 127.9, 127.1, 126.9, 123.8, 123.5, 120.0, 119.5, 33.9, 23.8; IR (thin film) 3054, 2957, 1534, 1498, 1253, 828, 730 cm^{-1}; HRMS (ESI) m/z calcd for $C_{22}H_{20}NO$ $(M + H)^+$ 314.1545, found 314.1534.

*N-(9H-Fluoren-9-ylidene)-4-(methoxycarbonyl)aniline oxide (**1h**).* A yellow solid, 0.042 g, 25% yield. Mp: 109−110 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.83 (d, J = 7.6 Hz, 1H), 8.22 (d, J = 8.4 Hz, 2H), 7.63 (d, J = 7.2 Hz, 1H), 7.58−7.53 (m, 3H), 7.45−7.41 (m, 1H), 7.37 (t, J = 7.6 Hz, 1H), 7.20−7.16 (m, 1H), 6.84 (t, J = 7.6 Hz, 1H), 5.85 (d, J = 8.0 Hz 1H), 3.93 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.7, 149.7, 145.9, 139.4, 139.1, 134.6, 132.1, 131.8, 131.6, 131.5, 130.3, 129.5, 128.9, 127.4, 127.1, 124.0, 123.7, 120.3, 119.7, 52.6; IR (thin film) 3055, 2953, 1718, 1537, 1441, 1282, 952, 727 cm^{-1}; HRMS (ESI) m/z calcd for $C_{21}H_{16}NO_3$ $(M + H)^+$ 330.1130, found 330.1116.

*N-(9H-Fluoren-9-ylidene)-3,5-dimethylaniline oxide (**1i**).* A yellow solid, 0.050 g, 56% yield. Mp: 171−172 °C; ^{1}H NMR (400 MHz; $CDCl_3$): δ 8.85 (d, J = 7.6 Hz, 1H), 7.63 (d, J = 7.2 Hz, 1H), 7.58 (d, J = 7.6 Hz, 1H), 7.43 (t, J = 7.2 Hz, 1H), 7.37 (t, J = 7.6 Hz, 1H), 7.20−7.15 (m, 2H), 7.05 (s, 2H), 6.88 (t, J = 7.6 Hz, 1H), 5.93 (d, J = 7.6 Hz, 1H), 2.33 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.9, 145.2. 140.2, 139.1, 139.0, 132.3, 131.7, 131.0, 130.8, 129.0, 128.8, 127.2, 127.0, 124.0, 121.1, 120.0, 119.5, 21.2; IR (thin film) 3036, 2917, 1533, 1445, 1246, 768, 722 cm^{-1}; HRMS (ESI) m/z calcd for $C_{21}H_{18}NO$ $(M + H)^+$ 300.1388, found 300.1375.

*N-(9H-Fluoren-9-ylidene)-3-nitroaniline oxide (**1j**).* A yellow solid, 0.067 g, 42% yield. Mp: 150−151 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.89 (d, J = 7.6 Hz, 1H), 8.51−8.45 (m, 2H), 7.92 (d, J = 8.0, 1H), 7.85−7.81 (m, 1H), 7.72−7.66 (m, 2H), 7.55−7.51 (m, 1H), 7.46 (t, J = 7.6 Hz, 1H), 7.31−7.26 (m, 1H), 6.93 (t, J = 7.6 Hz, 1H), 5.93 (d, J = 8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 148.9, 147.2, 146.3, 139.6, 139.2, 131.9, 131.8, 131.3, 130.0, 129.8, 129.1, 127.4, 127.2, 125.0, 123.2, 120.6, 119.9, 119.8; IR (thin film) 3055, 1600, 1531, 1447, 1346, 1250, 727 cm^{-1}; HRMS (ESI) m/z calcd for $C_{19}H_{13}N_2O_3$ $(M + H)^+$ 317.0926, found 317.0912.

*2-Bromo-N-(9H-fluoren-9-ylidene)aniline oxide (**1k**).* A yellow solid, 0.104 g, 59% yield. Mp: 62−63 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.87 (d, J = 7.2 Hz, 1H), 7.74 (d, J = 8.0 Hz, 1H), 7.63−7.56 (m, 2H), 7.49−7.33 (m, 5H), 7.21−7.17 (m, 1H), 6.86−6.82 (m, 1H), 5.71 (d, J = 8.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.3, 145.8, 139.4, 139.3, 134.3, 131.7, 131.5, 131.3, 130.2, 129.5 129.3, 128.9, 127.6, 127.4, 125.6, 122.9, 120.3, 119.6, 117.0; IR (thin film) 3061, 1601, 1541, 1451, 1255, 768, 729 cm^{-1}; HRMS (ESI) m/z calcd for $C_{19}H_{13}BrNO$ $(M + H)^+$ 350.0181, found 350.0167.

*N-(2,7-Dibromo-9H-fluoren-9-ylidene)aniline oxide (**1l**).* A yellow solid, 0.146 g, 57% yield. Mp: 220−221 °C; ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.06 (s, 1H), 7.66−7.60 (m, 4H), 7.52−7.45 (m, 4H), 7.37 (d, J = 8.0 Hz, 1H), 5.92 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.6, 143.4, 136.7, 136.6, 133.9, 133.5, 132.1, 131.9, 130.8, 130.3, 129.6, 127.0, 123.6, 123.5, 123.0, 121.3, 120.8; IR (thin film) 3022, 1536, 1432, 1251, 815, 765, 686 cm^{-1}; HRMS (ESI) m/z calcd for $C_{19}H_{12}Br_2NO$ $(M + H)^+$ 427.9286, found 427.9280.

*N-(2-Bromo-9H-fluoren-9-ylidene)aniline oxide (**1m**).* E/Z = 1/1, a yellow solid, 0.090 g, 43% yield, mp: 136−137 °C. Isomer 1: ^{1}H NMR (400 MHz, $CDCl_3$): δ 9.09 (s, 1H), 7.66−7.62 (m, 5H), 7.53−7.50 (m, 4H), 7.35 (d, J = 8.0 Hz, 1H), 5.91−5.88 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.9, 144.5, 138.1, 137.7, 133.8, 132.3, 131.7, 130.6, 130.5, 130.2, 129.6, 129.2, 126.9, 123.7, 122.5, 121.2, 120.2. Isomer 2: ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.89 (d, J = 7.6 Hz, 1H), 7.61−7.58 (m, 4H), 7.49−7.41 (m, 4H), 7.25−7.21 (m, 1H), 6.93 (t, J = 7.6 Hz, 1H), 5.91−5.88 (m, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 146.7, 144.4, 138.0, 137.6, 133.7, 132.0, 131.2, 130.4, 130.1, 129.1, 127.5, 126.8, 123.6, 123.5, 120.9, 120.7, 119.6; IR (thin film) 3054, 1603, 1534, 1440, 1345, 1252, 771 cm^{-1}; HRMS (ESI) m/z calcd for $C_{19}H_{13}BrNO$ $(M + H)^+$ 350.0181, found 350.0172.

*General Procedure for Synthesis of Methylenecyclopropane **2**.* Bromoacetyl bromide (2.61 mL, 30.0 mmol) was added dropwise to a solution of corresponding alcohol (30 mmol) and pyridine (2.4 mL, 30 mmol) in CH_2Cl_2 (40 mL) at 0 °C to form a white suspension that was stirred for 20 min at 0 °C and then an additional 30 min at 25 °C. At this time, H_2O (50 mL) was added to the reaction mixture, and the organic layer was separated. The aqueous layer was then extracted with CH_2Cl_2 (2 × 20 mL). The combined organic layers were washed with brine (50 mL) and dried over $MgSO_4$. The filtrate was then concentrated to give bromoester as a colorless liquid which was used directly without purification for the next step.

Bromoester was added dropwise to a toluene (100 mL) solution of triphenylphosphine (7.8 g, 30 mmol) to form a white precipitate. The resulting slurry was stirred overnight, filtered over a glass-fitted filter, and washed with toluene and hexane to give phosphonium salt as a white solid. The phosphonium salt was dissolved in H_2O (100 mL), and NaOH (2 M) was added to keep the aqueous pH > 7.0. A white solid appeared, and the mixture was stirred for 30 min before CH_2Cl_2 (50 mL) was added. The organic layer was separated and washed with brine (50 mL) and dried over $MgSO_4$. The filtrate was concentrated to give ylide as a white solid, which was used directly without further purification for the next step.

To a refluxing solution of ylide (10 mmol) and benzoic acid (122 mg, 10 mmol %) in benzene (50 mL) was added (1-ethoxycyclopropoxy)trimethylsilane (2 mL, 10 mmol) via syringe. After the addition was completed, the mixture was allowed to reflux at 80 °C for 18 h. After the mixture was cooled to room temperature, benzene was removed under reduced pressure, and the crude product was purified by flash chromatography (the crude residue was dry loaded on silica gel; 1/100−1/20 ethyl acetate/petroleum ether) to afford methylenecyclopropane **2** as a colorless oil.

The methylenecyclopropane **2d**,[18] **2e**,[19] **2f**,[19] **2g**,[19] **2h**,[20] **2i**,[21] **2j**,[22] and **2k**[23] were prepared according to literature methods, and their spectral data matched literature values.

*Cinnamyl-2-cyclopropylideneacetate (**2a**).* A colorless oil, 1.490 g, 69% yield. ^{1}H NMR (400 MHz; $CDCl_3$): δ 7.33 (d, J = 7.2 Hz, 2H), 7.27−7.23 (m, 2H), 7.20−7.16 (m, 1H), 6.63 (d, J = 16.0, 1H), 6.30−6.21 (m, 2H), 4.77 (d, J = 6.0, 2H), 1.44−1.39 (m, 2H), 1.21−1.16 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.8, 145.7, 136.3, 133.7, 128.5, 127.9, 126.5, 123.5, 110.7, 64.7, 4.6, 2.1; IR (thin film) 3031, 2988, 2881, 1713, 1601, 1494, 1170, 741, 695 cm^{-1}; HRMS (EI) m/z calcd for $C_{14}H_{14}O_2Na$ $(M + Na)^+$ 237.0891, found 237.0887.

*(E)-2-Methyl-3-phenylallyl-2-cyclopropylideneacetate (**2b**).* A colorless oil, 0.800 g, 35% yield. ^{1}H NMR (400 MHz; $CDCl_3$): δ 7.36−7.32 (m, 2H), 7.29−7.23 (m, 3H), 6.57 (s, 1H), 6.30 (s, 1H), 4.73 (s, 2H), 1.92 (s, 3H), 1.48−1.46 (m, 2H), 1.28−1.24 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.8, 145.5, 137.1, 133.0, 128.9, 128.1, 127.7, 126.6, 110.8, 69.6, 15.5, 4.6, 2.2; IR (thin film) 3056, 2981, 2872, 1716, 1600, 1491, 1254, 746, 699 cm^{-1}; HRMS (EI) m/z calcd for $C_{15}H_{16}O_2Na$ $(M + Na)^+$ 251.1048, found 251.1045.

*3-Phenylprop-2-ynyl-2-cyclopropylideneacetate (**2c**).* A colorless oil, 1.200 g, 57% yield. ^{1}H NMR (400 MHz; $CDCl_3$): δ 7.46−7.44 (m, 2H), 7.32−7.26 (m, 3H), 6.30 (s, 1H), 5.00 (s, 2H), 1.52−1.48 (m, 2H), 1.30−1.24 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 165.2, 146.8, 131.8, 128.6, 128.2, 122.2, 110.1, 86.1, 83.2, 52.4, 4.7, 2.2; IR (thin film) 3060, 2985, 2875, 1718, 1600, 1490, 1252, 759, 692 cm^{-1}; HRMS (EI) m/z calcd for $C_{14}H_{12}O_2Na$ $(M + Na)^+$ 235.0735, found 235.0732.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b02544.

DOI: 10.1021/acs.joc.6b02544
J. Org. Chem. 2017, 82, 502−511

Spectra of compounds **1**, **2**, **3**, **4**, **5**, and **6** and chromatograms of **3aj** and **4a** (PDF)

AUTHOR INFORMATION

Corresponding Authors

*E-mail: gfysglgx@163.com.

*E-mail: moeastlight@mailbox.gxnu.edu.cn.

ORCID

Dong-Liang Mo: 0000-0002-4005-2249

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

Financial support from the "Overseas 100 Talents Program" of Guangxi Higher Education and State Key Laboratory for Chemistry and Molecular Engineering of Medicinal Resources (Guangxi Normal University), Ministry of Science and Technology of China (Grants CMEMR2015-A05 and CMEMR2014-A01), the National Natural Science Foundation of China (Grants 21562005, 21602037, and 21462008), and the Natural Science Foundation of Guangxi (Grants 2015GXNSFCA139001 and 2016GXNSFFA380005) is greatly appreciated.

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