A Platinum Open Access Journal for Organic Chemistry

Paper

Free to Authors and Readers | DOAJ Seal | *Arkivoc* **2021**, part vii, 48-65

PhIO-Mediated oxidative dethioacetalization/dethioketalization under water-free conditions

Zhenyang Yu,[a] Yaxin Ouyang,[a] Xiaofan Wang,[a] Bingyue Zhao,[a] Xi Wang,[a] Yunfei Du,[a,*] and Kang Zhao[b,*]

[a] *Tianjin Key Laboratory for Modern Drug Delivery & High-Efficiency, School of Pharmaceutical Science and Technology, Tianjin University, Tianjin 300072, China*

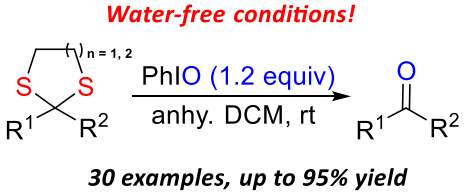
[b] *State Key Laboratory of Microbial Technology, Institute of Microbial Technology, Shandong University, Qingdao 266237, China*

Email: duyunfeier@tju.edu.cn , zhaokang@sdu.edu.cn

Received 03-31-2021 **Accepted Manuscript** 05-13-2021 **Published on line** 05-20-2021

Abstract

Treatment of thioacetals and thioketals with iodosobenzene in anhydrous DCM conveniently afforded the corresponding carbonyl compounds in high yields under water-free conditions. The mechanistic studies indicate that this dethioacetalization/dethioketalization process does not need water and the oxygen of the carbonyl products comes from the hypervalent iodine reagent.



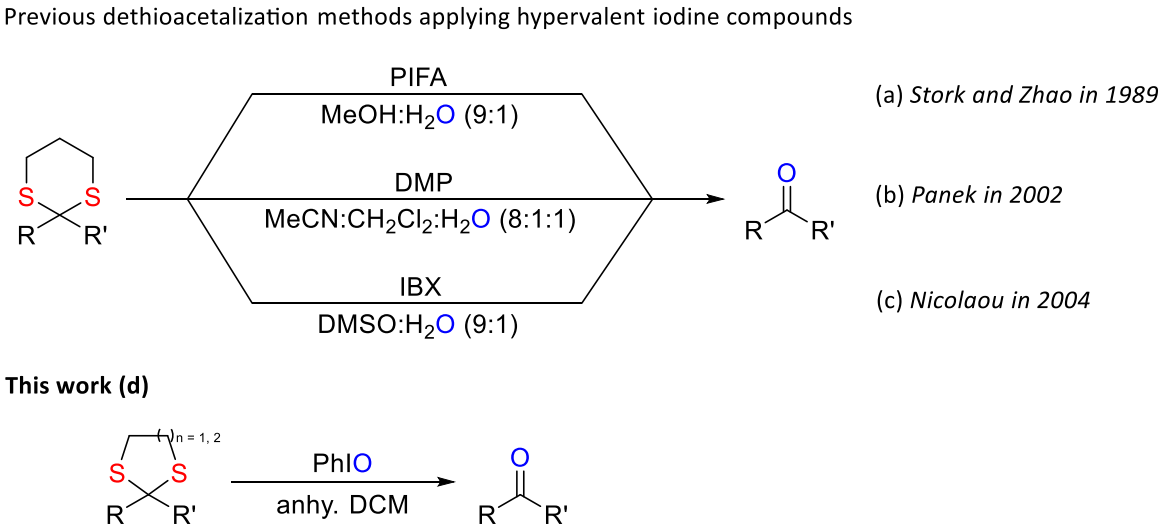
Keywords: Iodosobenzene, thioacetal, thioketal, dethioacetalization, carbonyl compound, hypervalent iodine reagent

Introduction

The protection of carbonyl compounds as thioacetals and thioketals has been widely applied[1-4] in organic synthesis, as the approach can enable the synthesis of useful synthetic building blocks via a protection/deprotection protocol. For a representative example, the lithium anions of aldehyde 1,3-dithianes could be utilized as nucleophiles for the formation of new C-C bonds, providing a practical umpolung approach for further alkylating of the substrates.[5-7] Cyclic thioacetals and thioketals, such as 1,3-dithiolanes and 1,3-dithianes, have been commonly used in various organic transformations due to their easy preparation and high stability against the acidic/basic conditions.[8] However, regeneration of the parent carbonyl species via removal of the thio moiety is often not an easy task. Generally, the existing deprotection can be achieved by using the traditional Hg(II)-based reagents[9,10] and other metal salts including $AgNO_3$,[11] $Fe(acac)_3$,[12] $Cu(NO_3)_2$,[13] $SbCl_5$,[14] $GaCl_3$[15] and $ZnCr_2O_7$.[16] It is obvious that most of the above methods are suffering from limits of potential environmental concerns caused by the metal pollution. With this context, the development of facile and 'greener' deprotection approaches for converting thioacetals and thioketals back to carbonyl compounds under convenient and environment-friendly conditions has been the increasing interest of organic chemists. Accordingly, the novel deprotection protocols continuously evolved and now the conversion can be realized by using hydrogen peroxide,[17] oxone,[18] selectfluor,[19] clay[20] and UV/visible light.[21] Furthermore, the electrophilicity of halonium ions also allows the oxidative cleavage of 1,3-dithianes by using halogenation reagents including NBS (*N*-bromosuccinimide)[22] and NCS (*N*-chlorosuccinimide).[23,24] It is worth noting that various oxidative systems involving the use of iodine reagents such as NH_4I/H_2O_2,[25] NaI/1,4-benzoquinone (BQ),[26] MeI,[27] I_2/H_2O_2[28] and IBr[29] have also been used for this dethioacetalization process.

Owing to their non-metallic and environment-benign characteristic as well as the moderate oxidizing property, hypervalent iodine compounds have also been explored for the oxidative dethioacetalization reactions. Until now, several of them have been attested to be efficient reagents for this deprotection process. In 1989, Stork and Zhao[30] reported a concise method for the deprotection of 1,3-dithianes by using bis(trifluoroacetoxy)iodobenzene (PIFA) as oxidant in acetonitrile/H_2O or MeOH/H_2O (Scheme 1a). During this transformation, the hypervalent iodine reagent can realize an efficient selective dethioacetalization as the functional groups including esters, alcohols, halides, secondary amides, acetals, alkenes and alkynes could be well tolerated under the conditions. The method has been widely applied in a series of organic transformations, including the synthesis of complicated naturally occurring compounds.[31,32] In 2002, Panek and coworkers reported that thioketals and thioacetals could be efficiently and chemoselectively deprotected by Dess-Martin periodinane (DMP) in mixed solvents containing acetonitrile, DCM and water (Scheme 1b). The method was equally compatible with a variety of functional groups involving nitriles, esters, lactones, aldehydes, ethers, and olefins.[33] In 2004, Nicolaou and colleagues reported that *o*-iodoxybenzoic acid (IBX) in DMSO/H_2O was also a powerful system for the cleavage of dithiane (Scheme 1c).[34] It is worth noting that Nicolaou proposed that IBX could directly provide oxygen atoms for the newly generated carbonyl groups. However, water was also used as a component of the mixed solvent as the reaction could be greatly promoted with the introduction of water, possibly due to the improved solvalysis of IBX in aqueous solvent. It is evident that all of the above methods applied water in their respective reaction systems, possibly for introducing the oxygen of the carbonyl compound via a presumed hydrolysis process. As it is obvious that the above hypervlaent iodine-mediated approaches are not applicable to compounds bearing water-sensitive moieties, it is highly desirable to develop a novel dethioacetalization process that does not require the participation of water. In this communication, we reported that iodosobenzene (PhIO) is another efficient hypervalent iodine reagent that can realize dethioacetalization/dethioketalization of 1,3-dithiolanes or 1,3-dithianes by using DCM as sole solvent (Scheme

1d). One striking of the current approach is that, differing from the above existing approaches, the reaction does not require the presence of water and the oxygen atoms of the regenerated carbonyl groups has been proved to be from the hypervalent iodine reagent.



Scheme 1. Dethioacetalization/dethioketalization mediated by hypervalent iodine reagents.

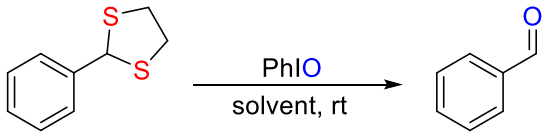
Results and Discussion

Based on previous research describing that PhIO could transfer oxygen atoms to ketene,[35] we were interested to investigate the feasibility of PhIO-mediated dethioacetalization as well as of the origin of the oxygen in the final carbonyl products. 2-Phenyl-1,3-dithiolane **1a** was used as the model substrate which was deprotected with 1.0 equiv of PhIO in anhydrous acetonitrile at room temperature. To our delight, thioacetal **1a** was converted to the corresponding aldehyde **2a** in 82% yield (entry 1, Table 1). Encouraged by this result, we further screened the reaction conditions by using different anhydrous solvents. The results indicated that the deprotection could occur smoothly when ethyl acetate (EtOAc) and DCM was used as solvent, with DCM being the best choice as the desired aldehyde **2a** was achieved in 85% yield (entries 2-3, Table 1). While the reaction using 1,2-dichloroethane (DCE), *n*-hexane, tetrahydrofuran (THF), *N*,*N*-dimethylformamide (DMF) or 1,4-dioxane as solvent was proved to be less efficient since aldehyde **2a** was obtained in relatively much lower yields (entries 4-8, Table 1). It was further observed that toluene and methanol (MeOH) were not appropriate solvents for this deprotection reaction because the yield of the target product **2a** was fairly low for both cases, even after a prolonged reaction time (entries 9-10, Table 1). Next, the dosage amount of PhIO was investigated to further improve the outcome of the deprotection reaction. With an increased amount of oxidant from 1.0 to 1.2 equiv, the reaction rate was obviously enhanced and the product could be achieved in 92% yield (entry 11, Table 1). However, the further application of 1.5 equiv was not necessary as the reaction afforded the deprotected product in an even lower yield, possibly due to the formation of some unidentified byproducts (entry 12, Table 1).

With the optimized conditions (entry 11, Table 1) in hand, we went on investigating the scope of this novel dethioacetalization/dethioketalization method with a diverse range of dithioacetals substrates. It was demonstrated that the new deprotection pathway was suitable for a plethora of substrates possessing versatile

electron-donating groups (EDG) or electron-withdrawing groups (EWG). Strikingly, the functional groups including ether, dimethylamino, ester, halogen atom, phenolic hydroxy and alkene were all well tolerated under the reaction conditions (Table 2). Specifically, electron-rich as well as neutral aromatic dithioacetals could be deprotected smoothly in anhydrous DCM within 30 min to afford the corresponding aldehydes in excellent yield (entries 1-7, Table 2). The method works equally well for dithioacetals bearing electron-deficient aromatic substituent as the corresponding products were obtained in good yield (entries 8-10, Table 2). It was further observed that dithioacetals derived from *α*, *β*-unsaturated, condensed-aromatic, heteroaromatic and aliphatic aldehydes were all converted to the corresponding deprotected aldehydes in good to excellent yields (entries 11-14, Table 2). Furthermore, the method was also well applicable to 1,3-dithianes, the six-membered analogue of the five-membered 1,3-dithiolanes, as the reaction delivered the parent aldehydes in equally good to excellent yields (entries 16-19, Table 2). It is worth noting that in all cases, no carboxylic acids, an-over oxidation product of aldehydes, was observed during this dethioacetalization process.

Table 1. Optimization of the reaction conditions[a]

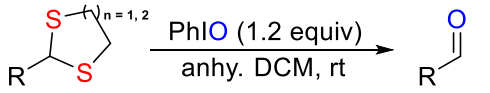


1a **2a**

Entry	Oxidant (equiv)	Solvent	Time (min)	Yield (%)[b]
1	PhIO (1.0)	MeCN	30	82
2	PhIO (1.0)	EtOAc	30	80
3	PhIO (1.0)	DCM	30	85
4	PhIO (1.0)	DCE	30	65
5	PhIO (1.0)	hexane	120	55
6	PhIO (1.0)	THF	25	78
7	PhIO (1.0)	DMF	30	77
8	PhIO (1.0)	1,4-dioxane	30	75
9	PhIO (1.0)	toluene	180	23
10	PhIO (1.0)	MeOH	300	40
11	PhIO (1.2)	DCM	20	92
12	PhIO (1.5)	DCM	20	88

[a]All reactions were carried out on a 1.0 mmol scale at rt with PhIO in anhydrous solvent under air.
[b]Isolated yield.

Table 2. Scope of PhIO-mediated dethioacetalization[a]



1a-p **2a-p**

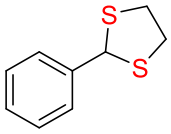
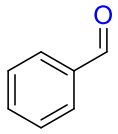
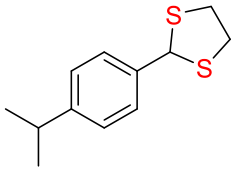
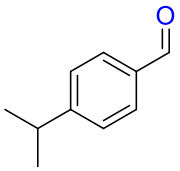
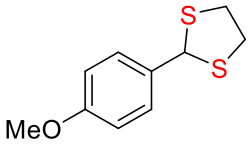
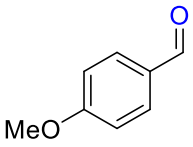
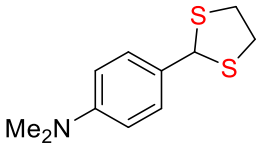
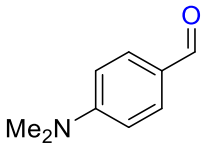
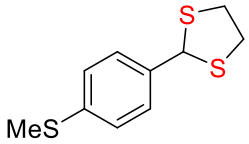
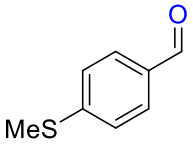
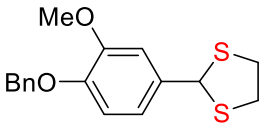
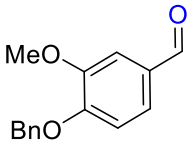
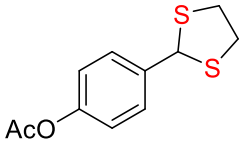
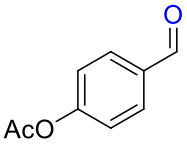
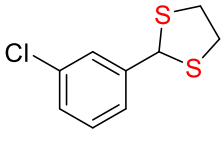
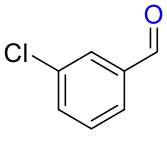
Entry	Substrates	Products	Time (min)	Yield (%)[b]
1	 **1a**	 **2a**	20	92
2	 **1b**	 **2b**	15	91
3	 **1c**	 **2c**	15	90
4	 **1d**	 **2d**	15	95
5	 **1e**	 **2e**	20	90
6	 **1f**	 **2f**	45	91
7	 **1g**	 **2g**	45	92
8	 **1h**	 **2h**	30	88

Table 2. Continued

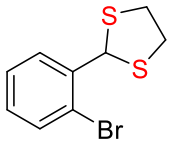
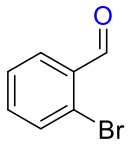
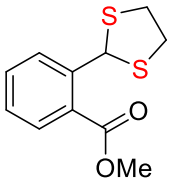
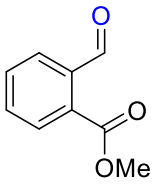
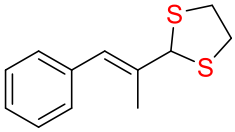
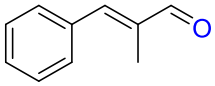
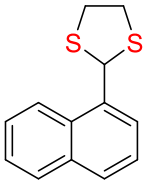
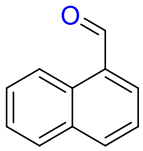
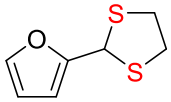
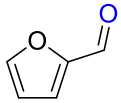
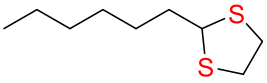
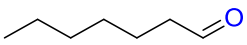
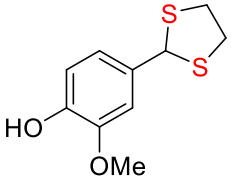
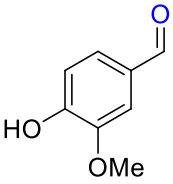
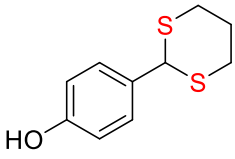
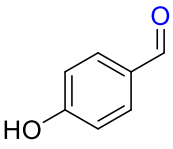
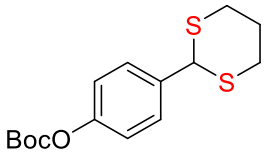
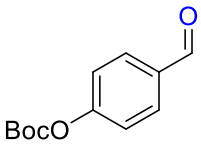
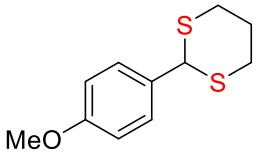
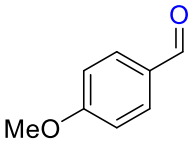
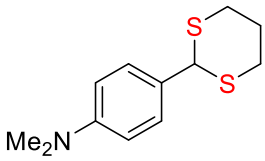
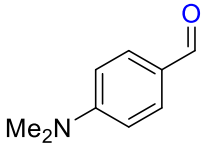
Entry	Substrates	Products	Time (min)	Yield (%)[b]
9	 **1i**	 **2i**	30	85
10	 **1j**	 **2j**	60	80
11	 **1k**	 **2k**	30	92
12	 **1l**	 **2l**	30	90
13	 **1m**	 **2m**	45	85
14	 **1n**	 **2n**	25	95
15	 **1o**	 **2o**	60	70
16	 **1p**	 **2p**	45	85

Table 2. Continued

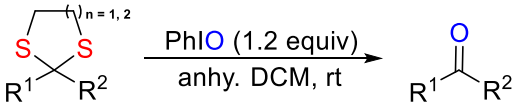
Entry	Substrates	Products	Time (min)	Yield (%)[b]
17	 **1q**	 **2q**	40	95
18	 **1c'**	 **2c**	20	94
19	 **1d'**	 **2d**	20	92

[a]All reactions were run on a 2.0 mmol scale with PhIO (1.2 equiv) in anhydrous DCM at rt.
[b]Isolated yield.

In addition, we explored the efficiency of this method on dithioketals involving aromatic, aliphatic and heteroaromatic substrates. The results indicated that all the reactions underwent a smooth deprotection to furnish the corresponding carbonyl compounds in good to excellent yields (entries 1-9, Table 3). It is worth noting that the amide moiety in dithioketal **1ab** could be well tolerated (entry 2, Table 3). Furthermore, dithioketal-protected estrone **1aj** also underwent facile deprotection to regenerate the parent carbonyl product, without any influence on the phenolic hydroxyl group (entry 10, Table 3).

To verify the feasibility of this method for the dethioacetalization of compounds bearing water-sensitive groups, we carried out a control experiment by subjecting (4-(1,3-dithian-2-yl)phenoxy)trimethylsilane **1r** to this PhIO-mediated water-free conditions. The result clearly showed that dithioacetal **1r** could be conveniently converted to the parent aldehyde **2r**, with the TMS group intact during the process. However, when substrate **1r** was deprotected by the known hypervalent iodine reagent-mediated approaches using water as a co-solvent, the dethioacetalization as well as the desilylation both occurred to afford product **2p**.

Table 3. Scope of PhIO-mediated dethioketalization[a]



1aa-aj **2aa-aj**

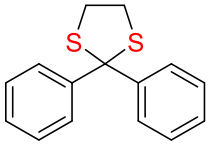
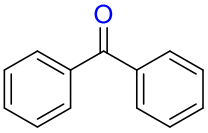
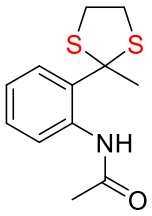
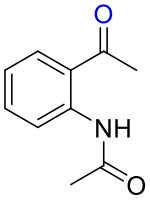
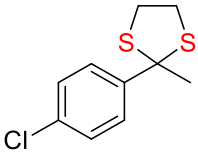
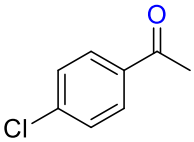
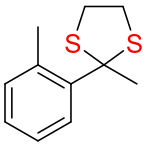
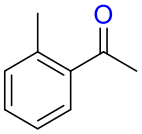
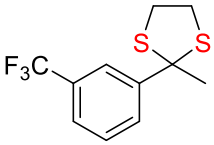
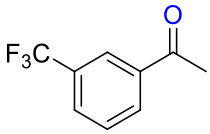
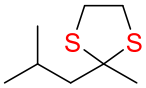
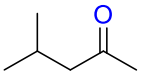
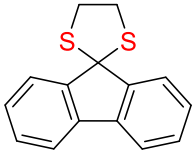
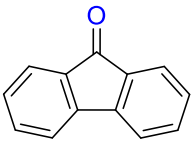
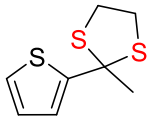
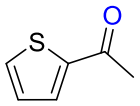
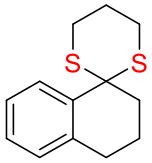
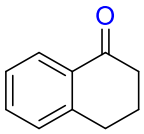
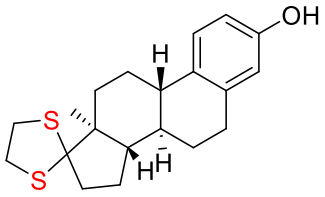
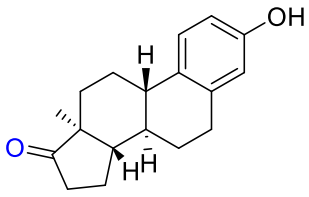
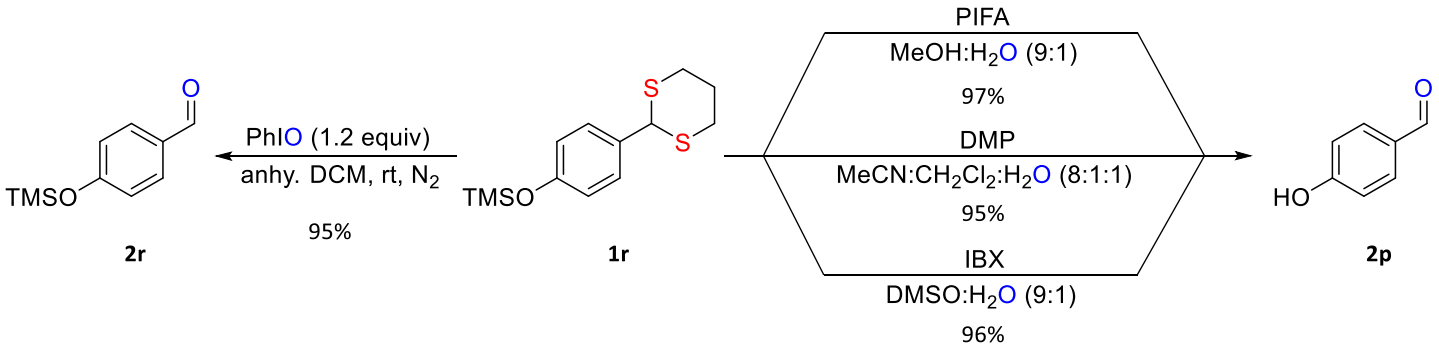
Entry	Substrates	Products	Time (min)	Yield (%)[b]
1	 **1aa**	 **2aa**	50	92
2	 **1ab**	 **2ab**	45	88
3	 **1ac**	 **2ac**	45	80
4	 **1ad**	 **2ad**	60	78
5	 **1ae**	 **2ae**	85	85
6	 **1af**	 **2af**	30	93
7	 **1ag**	 **2ag**	45	95

Table 3. Continued

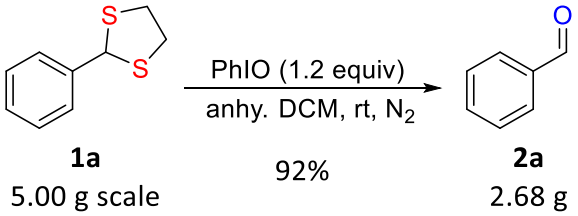
Entry	Substrates	Products	Time (min)	Yield (%)[b]
8	 **1ah**	 **2ah**	60	82
9	 **1ai**	 **2ai**	40	90
10	 **1aj**	 **2aj**	70	91

[a]All reactions were run on a 2.0 mmol scale with PhIO (1.2 equiv) in DCM at rt.
[b]Isolated yield.

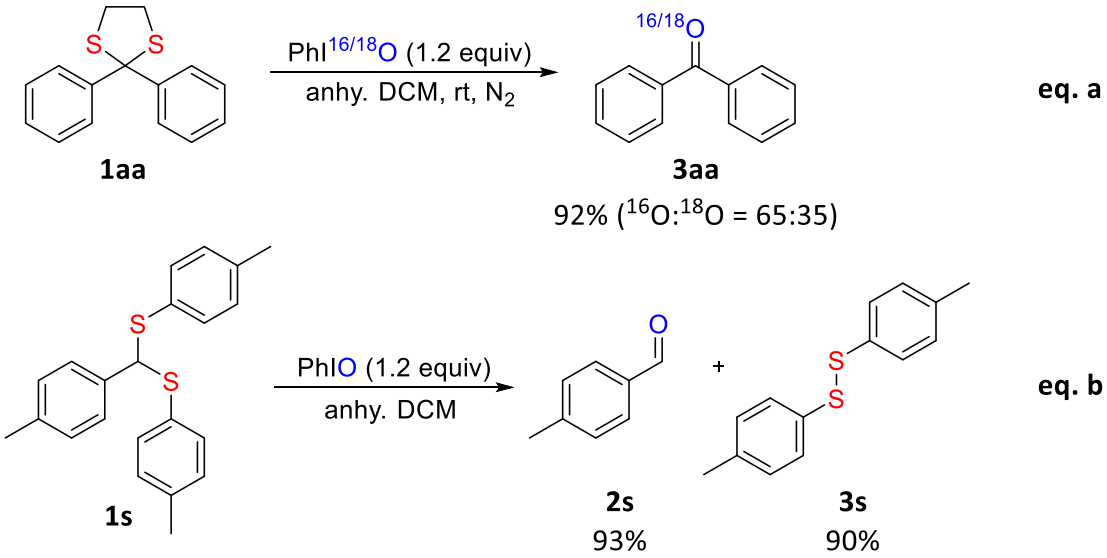


Scheme 2. Deprotection study for the substrate with a water-sensitive group.

To understand the exact source of the oxygen atom in the newly generated carbonyl compounds, we conducted two control experiments. First, the deprotection of 2-phenyl-1,3-dithiolane **1a** on a 5 grams scale in anhydrous DCM under N_2 atmosphere was carried out and the corresponding benzaldehyde **2a** was obtained in excellent yield (Scheme 3). This outcome could rule out the possibilities that the residual water in the solvent and the O_2 from air participated the deprotection process. Second, PhI^{18}O was prepared according to a literature procedure[36] and its reaction with 2,2-diphenyl-1,3-dithiolane **1aa** under the optimized conditions did afford the corresponding ^{18}O-labelled carbonyl product **3aa** (Scheme 4, eq. a), The outcome of this isotope-labelling experiment indicates that the oxygen atom of the carbonyl product could be originated from PhIO. Although the previous reports demonstrated that the thio moieties in the substrate was converted to disulfide during the deprotection process,[21,26] dithioacetal **1s** was prepared and subjected to the standard conditions to make further corroboration. Unsurprisingly, the reaction of **1s** with PhIO in DCM afforded disulfide **3s** in 90% yield, with isolation of 4-methylbenzaldehyde **2s** in 93% yield (Scheme 4, eq. b).

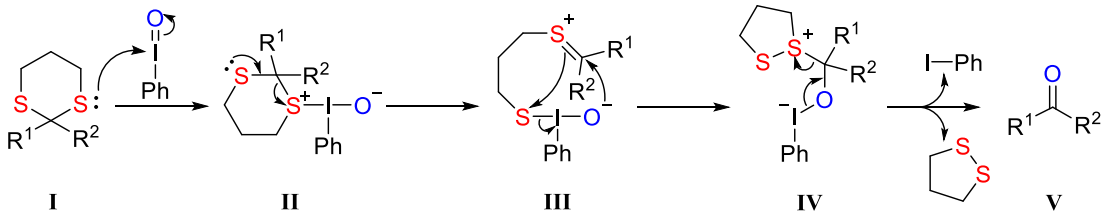


Scheme 3. Gram scale conversion.



Scheme 4. Control experiments.

Based on the above experimental results and the conclusions from previous reports,[34,35] a possible mechanism was proposed for this novel PhIO-mediated dethioacetalization/dethioketalization (Scheme 5). First, the reaction of 1,3-dithianes **I** with PhIO generates the sulfonium intermediates **II**, which undergo ring-opening to form sulfonium intermediates **III**. Then following the similar pathway proposed by Nicolaou,[34] the oxygen anion nucleophilicly attacks the carbon center of sulfonium moiety in **III**, with the concomitant formation of disulfide bond and the cleavage of S-I bond, to furnish intermediates **IV**. Finally, eliminations occur in intermediate **IV** to afford the final carbonyl products **V**, with removal of phenyl iodide and the cyclic disulfide as byproducts.



Scheme 5. Plausible mechanism.

Conclusions

In summary, we have developed a viable PhIO-mediated dethioacetalization/dethioketalization method by which 1,3-dithiolanes and 1,3-dithianes could be smoothly converted to the corresponding carbonyl products under water-free conditions. Significantly, differing from the existing hypervalent iodine mediated deprotection methods, the current approach does not require the participation of water and it is verified that PhIO can provide oxygen atoms for the regenerated carbonyl groups. This feature might render this method practical application to the dethioacetalization/dethioketalization of substrates that bear water-sensitive functional groups.

Experimental Section

General. Commercially available reagents and solvents were purchased as reagent grade and used without further purification. 1,3-Dithiolanes/dithianes substrates and PhIO were synthesized and purified according to the literature procedures.[37,38] All reactions were carried out at room temperature and stirred magnetically in anhydrous solvents. Thin layer chromatography (TLC) plates were visualized by exposures to the ultraviolet light (254 nm). Flash column chromatography was performed over silica gel (200-300 m) using a mixture of ethyl acetate (EtOAc) and petroleum ether (PE) as the eluent. Preparative high-performance liquid chromatography was conducted on a LC-20AP system and over a ZORBAX CN column (21.2 mm × 250 mm, 7 μm) using a mixture of dichloromethane (DCM) and hexane as the eluent. ^{1}H and ^{13}C NMR spectra were recorded on a 400 MHz spectrometer or a 600 MHz spectrometer at 25 °C. The values of chemical shifts are shown in ppm and referring to tetramethylsilane (TMS) as the internal standard whose chemical shift value is 0.00 ppm. The peaks are manifested as follows: chemical shift; s, singlet; d, doublet; t, triplet; q, quadruplet; m, multiplet; dd, doublet of doublets; and br, broad. The coupling constants (*J*) are reported in Hertz (Hz). Melting points were measured with a Micromelting point apparatus. The data of high-resolution mass spectrometry (HRMS) were collected on a Q-TOF micro spectrometer.

General procedure for the preparation of dithiolanes/dithianes.[37] To a round bottom flask (100 mL) were added aldehyde/ketone **2** (10 mmol, 1.0 equiv), 1,2-ethanedithiol/1,3-propanedithiol (12 mmol, 1.2 equiv) and $HClO_4$-SiO_2 (0.01 mmol of $HClO_4$, 1 mol%). The mixture was magnetically stirred at room temperature until TLC revealed a complete consumption of the aldehyde/ketone. Then the reaction mixture was diluted with EtOAc (30 mL) and filtered through the Celite and the residue was washed with EtOAc (10 mL × 3). The combined filtrate was concentrated to obtain a crude product which was further purified via flash column chromatography to furnish the desired dithiolanes/dithianes.

General procedure for the preparation of PhI$^{16/18}$O.[36] To the magnetically stirred and ice-cold $H_2{}^{18}O$ (1000 μL) were added small finely polished slices of sodium (69 mg, 3 mmol) slowly under a N_2 atmosphere. Then well vacuum-dried powder of PIDA (150 mg, 0.47 mmol) was prudently added. Then the mixture was stirred rigorously for 3 h at room temperature under N_2 atmosphere. A homogeneous dispersion was formed with the color changing from white to light yellow. Then the solid was carefully collected on a Büchner funnel, washed with unlabeled water, acetonitrile and finally diethyl ether, respectively. The isolated pale-yellow solid was vacuum-dried for 17 h and stored in cool and dry condition. The PhI$^{16/18}$O was characterized by HRMS (98%, ^{16}O:^{18}O = 70:30).

General procedure for the deprotection process. To a solution of 1,3-dithiolane/dithiane (2.0 mmol) in DCM (5.0 mL) was added the well ground PhIO (2.4 mmol) powder with stirring. The mixture was stirred at room temperature until TLC revealed a complete consumption of the substrates. Then the reaction solution was concentrated to afford the crude product, which was further purified by silica gel column chromatography to give the parent aldehyde/ketone.

2-Phenyl-1,3-dithiolane (1a).[39] Following the general procedure, **1a** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 1.80 g, 99%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58 – 7.49 (m, 2H), 7.36 – 7.24 (m, 3H), 5.65 (s, 1H), 3.57 – 3.45 (m, 2H), 3.42 – 3.31 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.3, 128.5, 128.1, 128.0, 56.3, 40.3. HRMS (ESI) calcd for $C_9H_{11}S_2^+$ [M + H$^+$] 183.0297, found 183.0303.

2-(4-Isopropylphenyl)-1,3-dithiolane (1b). Following the general procedure, **1b** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.23 g, 99%, a white solid, mp. 60-61 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, *J* 8.3 Hz, 2H), 7.19 (d, *J* 8.1 Hz, 2H), 5.65 (s, 1H), 3.60 – 3.44 (m, 2H), 3.41 – 3.28 (m, 2H), 2.90 (hept, *J* 6.9 Hz, 1H), 1.24 (dt, *J* 6.9, 1.5 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 148.9, 137.5, 127.9, 126.6, 56.2, 40.3, 33.9, 24.0. HRMS (ESI) calcd for $C_{12}H_{17}S_2^+$ [M + H$^+$] 225.0766, found 225.0763.

2-(4-Methoxyphenyl)-1,3-dithiolane (1c).[40] Following the general procedure, **1c** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.25 g, 99%, a white solid, mp. 60-62 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (d, *J* 8.7 Hz, 2H), 6.85 (d, *J* 8.7 Hz, 2H), 5.64 (s, 1H), 3.79 (s, 3H), 3.58 – 3.42 (m, 2H), 3.39 – 3.30 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.4, 131.8, 129.2, 113.9, 56.1, 55.4, 40.3. HRMS (ESI) calcd for $C_{10}H_{13}OS_2^+$ [M + H$^+$] 213.0402, found 213.0406.

4-(1,3-Dithiolan-2-yl)-*N,N*-dimethylaniline (1d).[41] Following the general procedure, **1d** was purified by silica gel chromatography (EtOAc/PE = 2/98). Yield: 2.14 g, 95%, a white solid, mp. 105-106 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.41 (d, *J* 7.9 Hz, 2H), 6.68 (d, *J* 8.8 Hz, 2H), 5.66 (s, 1H), 3.55 – 3.46 (m, 2H), 3.38 – 3.29 (m, 2H), 2.95 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.4, 128.8, 127.7, 112.4, 56.6, 40.7, 40.2. HRMS (ESI) calcd for $C_{11}H_{16}NS_2^+$ [M + H$^+$] 226.0719, found 226.0716.

2-(4-(Methylthio)phenyl)-1,3-dithiolane (1e).[42] Following the general procedure, **1e** was purified by silica gel chromatography (EtOAc/PE = 2/98). Yield: 2.17 g, 95%, a white solid, mp. 74-76 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.44 (d, *J* 8.3 Hz, 2H), 7.19 (d, *J* 8.4 Hz, 2H), 5.61 (s, 1H), 3.55 – 3.44 (m, 2H), 3.40 – 3.29 (m, 2H), 2.47 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.4, 137.0, 128.4, 126.5, 55.9, 40.3, 15.8. HRMS (ESI) calcd for $C_{10}H_{13}S_3^+$ [M + H$^+$] 229.0174, found 229.0177.

2-(4-(Benzyloxy)-3-methoxyphenyl)-1,3-dithiolane (1f).[43] Following the general procedure, **1f** was purified by silica gel chromatography (EtOAc/PE = 5/95). Yield: 3.03 g, 95%, a white solid, mp. 76-77 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (d, *J* 6.9 Hz, 2H), 7.36 (t, *J* 7.3 Hz, 2H), 7.30 (t, *J* 7.2 Hz, 1H), 7.13 (d, *J* 2.1 Hz, 1H), 6.98 (dd, *J* 8.3, 2.2 Hz, 1H), 6.79 (d, *J* 8.3 Hz, 1H), 5.62 (s, 1H), 5.15 (s, 2H), 3.91 (s, 3H), 3.56 – 3.44 (m, 2H), 3.39 – 3.28 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 149.6, 148.1, 137.1, 132.6, 128.6, 127.9, 127.2, 120.3, 113.4, 111.5, 71.0, 56.5, 56.0, 40.2. HRMS (ESI) calcd for $C_{17}H_{19}O_2S_2^+$ [M + H$^+$] 319.0821, found 319.0825.

4-(1,3-Dithiolan-2-yl)phenyl acetate (1g).[44] Following the general procedure, **1g** was purified by silica gel chromatography (EtOAc/PE = 2/98). Yield: 2.36 g, 98%, a white solid, mp. 95-97 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (d, *J* 8.6 Hz, 2H), 7.03 (d, *J* 8.6 Hz, 2H), 5.63 (s, 1H), 3.54 – 3.44 (m, 2H), 3.39 – 3.30 (m, 2H), 2.29 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 169.4, 150.3, 137.8, 129.1, 121.6, 55.7, 40.3, 21.2. HRMS (ESI) calcd for $C_{11}H_{13}O_2S_2^+$ [M + H$^+$] 241.0351, found 241.0354.

2-(3-Chlorophenyl)-1,3-dithiolane (1h).[45] Following the general procedure, **1h** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 2.15 g, 99%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.54 (s, 1H), 7.38 (pd, *J* 4.3, 1.8 Hz, 1H), 7.26 – 7.19 (m, 2H), 5.58 (s, 1H), 3.54 – 3.45 (m, 2H), 3.41 – 3.31 (m, 2H). ^{13}C NMR

(101 MHz, $CDCl_3$) δ 142.9, 134.3, 129.7, 128.2, 128.1, 126.2, 55.4, 40.3. HRMS (ESI) calcd for $C_9H_{10}{}^{37}ClS_2^+$ [M + H^+] 216.9907, found 216.9904.

2-(2-Bromophenyl)-1,3-dithiolane (1i).[46] Following the general procedure, **1i** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 2.48 g, 95%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (dd, *J* 7.9, 1.7 Hz, 1H), 7.53 (dd, *J* 8.0, 1.3 Hz, 1H), 7.31 (td, *J* 7.6, 1.3 Hz, 1H), 7.11 (td, *J* 7.6, 1.7 Hz, 1H), 6.05 (s, 1H), 3.50 – 3.42 (m, 2H), 3.42 – 3.33 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.3, 132.8, 129.4, 129.2, 127.8, 124.0, 55.0, 39.8. HRMS (ESI) calcd for $C_9H_{10}{}^{81}BrS_2^+$ [M + H^+] 260.9402, found 260.9405.

Methyl 2-(1,3-dithiolan-2-yl)benzoate (1j). Following the general procedure, **1j** was purified by silica gel chromatography (EtOAc/PE = 2/98). Yield: 2.20 g, 97%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (dd, *J* 8.0, 1.2 Hz, 1H), 7.85 (dd, *J* 7.8, 1.5 Hz, 1H), 7.50 (td, *J* 7.6, 1.5 Hz, 1H), 7.30 (td, *J* 7.6, 1.3 Hz, 1H), 6.59 (s, 1H), 3.92 (s, 3H), 3.49 – 3.40 (m, 2H), 3.40 – 3.31 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.7, 143.1, 132.3, 130.4, 129.1, 128.9, 127.4, 52.4, 52.1, 39.8. HRMS (ESI) calcd for $C_{11}H_{13}O_2S_2^+$ [M + H^+] 241.0351, found 241.0355.

(*E*)-2-(1-Phenylprop-1-en-2-yl)-1,3-dithiolane (1k). Following the general procedure, **1k** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.21 g, 99%, a white solid, mp. 36-38 °C. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.37 – 7.30 (m, 2H), 7.30 – 7.26 (m, 2H), 7.25 – 7.19 (m, 1H), 6.62 (s, 1H), 5.41 (s, 1H), 3.41 – 3.33 (m, 2H), 3.33 – 3.24 (m, 2H), 2.08 – 2.00 (m, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 137.2, 136.4, 129.1, 128.1, 127.8, 126.8, 61.7, 40.1, 14.0, 14.0. HRMS (ESI) calcd for $C_{12}H_{15}S_2^+$ [M + H^+] 223.0610, found 223.0614.

2-(Naphthalen-1-yl)-1,3-dithiolane (1l).[41] Following the general procedure, **1l** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.3 g, 99%, a white solid, mp. 107-109 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (d, *J* 1.8 Hz, 1H), 7.87 – 7.76 (m, 3H), 7.70 (dd, *J* 8.6, 1.9 Hz, 1H), 7.55 – 7.40 (m, 2H), 5.83 (s, 1H), 3.62 – 3.49 (m, 2H), 3.46 – 3.35 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 137.6, 133.2, 133.0, 128.6, 127.9, 127.7, 126.6, 126.3, 126.3, 125.9, 56.5, 40.4. HRMS (ESI) calcd for $C_{13}H_{13}S_2^+$ [M + H^+] 233.0453, found 233.0457.

2-(1,3-Dithiolan-2-yl)furan (1m).[41] Following the general procedure, **1m** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 1.7 g, 99%, colorless oil, mp. 86-88 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 – 7.27 (m, 1H), 6.41 – 6.17 (m, 2H), 5.62 (s, 1H), 3.47 – 3.37 (m, 2H), 3.36 – 3.26 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 154.3, 142.7, 110.4, 107.1, 47.5, 39.2. HRMS (ESI) calcd for $C_7H_9OS_2^+$ [M + H^+] 173.0089, found 173.0085.

2-Hexyl-1,3-dithiolane (1n).[47] Following the general procedure, **1n** was purified by silica gel chromatography (EtOAc/PE = 0/99). Yield: 1.88 g, 99%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.46 (t, *J* 7.1 Hz, 1H), 3.29 – 3.11 (m, 4H), 1.86 – 1.75 (m, 2H), 1.47 – 1.37 (m, 2H), 1.35 – 1.20 (m, 6H), 0.91 – 0.83 (m, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ53.9, 39.4, 38.4, 31.7, 29.3, 28.9, 22.6, 14.1. HRMS (ESI) calcd for $C_9H_{19}S_2^+$ [M + H^+] 191.0923, found 191.0926.

4-(1,3-Dithiolan-2-yl)-2-methoxyphenol (1o).[48] Following the general procedure, **1o** was purified by silica gel chromatography (EtOAc/PE = 10/90). Yield: 2.05 g, 90%, a white solid, mp. 85-86 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.10 (d, *J* 2.1 Hz, 1H), 7.00 (dd, *J* 8.2, 2.1 Hz, 1H), 6.83 (d, *J* 8.2 Hz, 1H), 5.63 (s, 2H), 3.90 (d, *J* 6.5 Hz, 3H), 3.56 – 3.43 (m, 2H), 3.40 – 3.09 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.5, 145.6, 131.3, 121.1, 114.0, 110.3, 56.7, 56.0, 40.2. HRMS (ESI) calcd for $C_{10}H_{13}O_2S_2^+$ [M + H^+] 229.0351, found 229.0356.

4-(1,3-Dithian-2-yl)phenol (1p).[44] Following the general procedure, **1p** was purified by silica gel chromatography (EtOAc/PE = 15/85). Yield: 2.08 g, 98%, a white solid, mp. 156-158 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.28 (m, 2H), 6.85 – 6.66 (m, 2H), 5.12 (s, 1H), 4.98 (s, 1H), 3.11 – 2.99 (m, 2H), 2.89 (ddd, *J* 14.5, 4.3, 3.0 Hz, 2H), 2.16 (dtt, *J* 13.9, 4.6, 2.5 Hz, 1H), 1.91 (dtt, *J* 14.1, 12.4, 3.1 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 155.6, 131.4, 129.2, 115.6, 50.7, 32.2, 25.0. HRMS (ESI) calcd for $C_{10}H_{13}OS_2^+$ [M + H^+] 213.0402, found 213.0406.

4-(1,3-Dithian-2-yl)phenyl *tert*-butyl carbonate (1q). Following the general procedure, **1q** was purified by silica gel chromatography (EtOAc/PE = 15/85). Yield: 3.06 g, 98%, a white solid, mp. 148-150 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.52 – 7.43 (m, 2H), 7.20 – 7.08 (m, 2H), 5.15 (s, 1H), 3.04 (ddd, J 14.7, 12.2, 2.4 Hz, 2H), 2.90 (ddd, J

14.6, 4.3, 3.0 Hz, 2H), 2.16 (dtt, J 14.0, 4.7, 2.5 Hz, 1H), 2.01 – 1.84 (m, 1H), 1.55 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.7, 150.9, 136.6, 128.9, 121.5, 83.7, 50.7, 32.0, 27.7, 25.0. HRMS (ESI) calcd for $C_{15}H_{21}O_3S_2^+$ [M + H^+] 313.0927, found 313.0931.

2-(4-Methoxyphenyl)-1,3-dithiane (1c').[49] Following the general procedure, **1c'** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.22 g, 99%, a white solid, mp. 116-118 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.39 (d, *J* 8.7 Hz, 2H), 6.86 (d, *J* 8.7 Hz, 2H), 5.13 (s, 1H), 3.79 (s, 3H), 3.05 (ddd, *J* 14.6, 12.5, 2.4 Hz, 2H), 2.89 (dt, *J* 14.3, 4.2 Hz, 2H), 2.15 (dtt, *J* 13.9, 4.6, 2.4 Hz, 1H), 1.98 – 1.85 (m, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 159.6, 131.4, 128.9, 114.1, 55.3, 50.8, 32.2, 25.1. HRMS (ESI) calcd for $C_{11}H_{15}OS_2^+$ [M + H^+] 227.0559, found 227.0556.

4-(1,3-Dithian-2-yl)-*N, N*-dimethylaniline (1d').[1] Following the general procedure, **1d'** was purified by silica gel chromatography (EtOAc/PE = 2/98). Yield: 2.37 g, 99%, a white solid, mp. 118-120 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 (d, *J* 8.8 Hz, 2H), 6.68 (d, *J* 8.3 Hz, 2H), 5.12 (s, 1H), 3.09 – 3.00 (m, 2H), 2.94 (s, 6H), 2.88 (ddd, *J* 14.4, 4.2, 2.9 Hz, 2H), 2.20 – 2.09 (m, 1H), 1.98 – 1.82 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 153.1, 128.5, 124.7, 112.4, 50.9, 40.5, 32.3, 25.2. HRMS (ESI) calcd for $C_{12}H_{18}NS_2^+$ [M + H^+] 240.0875, found 240.0878.

(4-(1,3-Dithian-2-yl)phenoxy)trimethylsilane (1r). Following the general procedure, **1r** was purified by preparative high-performance liquid chromatography (DCM/Hexane = 10/90, 10 mL/min). Yield : 2.79 g, 98%, a white solid, mp. 50-52 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 – 7.28 (m, 2H), 6.85 – 6.73 (m, 2H), 5.12 (s, 1H), 3.05 (ddd, J 14.7, 12.4, 2.4 Hz, 2H), 2.95 – 2.85 (m, 2H), 2.16 (dtt, J 13.9, 4.6, 2.5 Hz, 1H), 1.99 – 1.84 (m, 1H), 0.25 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 155.0, 131.7, 128.7, 120.0, 50.6, 32.0, 24.9, 0.0. HRMS (ESI) calcd for $C_{13}H_{21}OS_2Si^+$ [M + H^+] 285.0798, found 285.0794.

(*p*-Tolylmethylene)bis(*p*-tolylsulfane) (1s).[49] Following the general procedure, **1s** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 3.33 g, 95%, a white solid, mp. 72-74 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.27 – 7.23 (m, 6H), 7.15 – 6.98 (m, 6H), 5.36 – 5.27 (m, 1H), 2.32 (dd, *J* 7.2, 2.3 Hz, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 137.8, 137.6, 137.0, 132.9, 131.2, 129.6, 129.1, 127.8, 61.1, 21.2. HRMS (ESI) calcd for $C_{22}H_{23}S_2^+$ [M + H^+] 351.1236, found 351.1231.

2,2-Diphenyl-1,3-dithiolane (1aa).[50] Following the general procedure, **1aa** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.53 g, 98%, a white solid, mp. 104-106 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 – 7.53 (m, 4H), 7.31 – 7.25 (m, 4H), 7.24 – 7.18 (m, 2H), 3.41 (s, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.6, 128.2, 128.0, 127.2, 40.2. HRMS (ESI) calcd for $C_{15}H_{15}S_2^+$ [M + H^+] 259.0610, found 259.0615.

***N*-(2-(2-Methyl-1,3-dithiolan-2-yl)phenyl)acetamide (1ab).** Following the general procedure, **1ab** was purified by silica gel chromatography (EtOAc/PE = 20/80). Yield: 2.51 g, 99%, a white solid, mp. 88-90 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.74 (s, 1H), 7.92 – 7.58 (m, 2H), 7.33 (t, *J* 8.0 Hz, 1H), 7.20 – 7.07 (m, 1H), 3.61 – 3.33 (m, 4H), 2.20 (dd, *J* 18.8, 2.8 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.9, 135.9, 132.3, 128.9, 128.0, 126.6, 124.9, 67.0, 39.8, 32.4, 24.8. HRMS (ESI) calcd for $C_{12}H_{16}NOS_2^+$ [M + H^+] 254.0668, found 254.0664.

2-(4-Chlorophenyl)-2-methyl-1,3-dithiolane (1ac).[47] Following the general procedure, **1ac** was purified by silica gel chromatography (EtOAc/PE = 2/98). Yield: 2.26 g, 98%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 – 7.68 (m, 2H), 7.32 – 7.27 (m, 2H), 3.54 – 3.44 (m, 2H), 3.43 – 3.33 (m, 2H), 2.15 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 144.7, 132.9, 128.4, 128.1, 68.0, 40.5, 33.6. HRMS (ESI) calcd for $C_{10}H_{12}ClS_2^+$ [M + H^+] 231.0063, found 231.0068.

2-Methyl-2-(o-tolyl)-1,3-dithiolane (1ad).[51] Following the general procedure, **1ad** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 2.06 g, 98%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (dd, *J* 6.8, 1.9 Hz, 1H), 7.26 – 7.12 (m, 3H), 3.52 – 3.42 (m, 2H), 3.40 – 3.30 (m, 2H), 2.69 (s, 3H), 2.21 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.5, 136.3, 132.9, 127.4, 126.8, 125.6, 69.5, 39.8, 33.3, 22.7. HRMS (ESI) calcd for $C_{11}H_{15}S_2^+$ [M + H^+] 211.0610, found 211.0615.

2-Methyl-2-(3-(trifluoromethyl)phenyl)-1,3-dithiolane (1ae). Following the general procedure, **1ae** was purified by silica gel chromatography (EtOAc/PE = 5/95). Yield: 2.51 g, 95%, colorless oil. ^{1}H NMR (400 MHz,

$CDCl_3$) δ 8.04 (dd, *J* 2.4, 1.3 Hz, 1H), 7.99 – 7.92 (m, 1H), 7.53 – 7.47 (m, 1H), 7.47 – 7.40 (m, 1H), 3.54 – 3.44 (m, 2H), 3.41 – 3.32 (m, 2H), 2.16 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 147.4, 130.4, 130.3(q, $^2J_{C-F}$ = 29.4 Hz), 130.1, 124.0(q, $^3J_{C-F}$ = 3.7 Hz), 123.6(q, $^3J_{C-F}$ = 3.9 Hz), 124.1(q, $^1J_{C-F}$ = 270.7 Hz), 68.0, 40.5, 33.5. HRMS (ESI) calcd for $C_{11}H_{12}F_3S_2^+$ [M + H$^+$] 265.0327, found 265.0322.

2-Isobutyl-2-methyl-1,3-dithiolane (1af).[52] Following the general procedure, **1af** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 1.59 g, 90%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.41 – 3.21 (m, 4H), 1.92 (d, *J* 5.7 Hz, 2H), 1.83 (dtd, *J* 13.4, 6.6, 5.2 Hz, 1H), 1.75 (d, *J* 1.0 Hz, 3H), 0.99 (dd, *J* 6.6, 0.9 Hz, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ66.7, 53.5, 39.5, 32.9, 27.1, 24.4. HRMS (ESI) calcd for $C_8H_{17}S_2^+$ [M + H$^+$] 177.0766, found 177.0763.

Spiro[fluorene-9,2'-[1,3]dithiolane] (1ag).[53] Following the general procedure, **1ag** was purified by silica gel chromatography (EtOAc/PE = 1/99). Yield: 2.54 g, 99%, a white solid, mp. 123-125 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.77 – 7.67 (m, 2H), 7.66 – 7.58 (m, 2H), 7.41 – 7.29 (m, 4H), 3.79 (s, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.5, 138.5, 128.6, 128.4, 125.2, 119.8, 68.5, 42.3. HRMS (ESI) calcd for $C_{15}H_{13}S_2^+$ [M + H$^+$] 257.0453, found 257.0457.

2-Methyl-2-(thiophen-2-yl)-1,3-dithiolane (1ah).[54] Following the general procedure, **1ah** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 2.00 g, 99%, colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.19 (dd, *J* 5.2, 1.3 Hz, 1H), 7.11 (dd, *J* 3.6, 1.3 Hz, 1H), 6.89 (dd, *J* 5.2, 3.6 Hz, 1H), 3.50 (s, 4H), 2.24 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 153.6, 126.7, 125.2, 124.8, 64.3, 40.9, 34.0. HRMS (ESI) calcd for $C_8H_{11}S_3^+$ [M + H$^+$] 203.0017, found 203.0013.

3,4-Dihydro-2H-spiro[naphthalene-1,2'-[1,3]dithiane] (1ai).[53] Following the general procedure, **1ai** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 2.34 g, 99%, a white solid, mp. 87-89 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.99 (dt, *J* 7.5, 2.2 Hz, 1H), 7.25 – 7.12 (m, 2H), 7.10 – 7.03 (m, 1H), 3.27 – 3.15 (m, 2H), 2.82 (t, *J* 6.4 Hz, 2H), 2.75 – 2.68 (m, 2H), 2.65 – 2.58 (m, 2H), 2.24 – 2.12 (m, 1H), 2.05 – 1.91 (m, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 137.7, 137.7, 129.9, 129.1, 127.9, 126.2, 52.3, 36.2, 30.0, 28.0, 25.1, 20.2. HRMS (ESI) calcd for $C_{13}H_{17}S_2^+$ [M + H$^+$] 237.0766, found 237.0762.

(8*R*,9*S*,13*S*,14*S*)-13-Methyl-6,7,8,9,11,12,13,14,15,16 decahydrospiro[cyclopenta-[a]phenanthrene-17,2'-[1,3]dithiolan]-3-ol (1aj). Following the general procedure, **1aj** was purified by silica gel chromatography (EtOAc/PE = 20/80). Yield: 3.29 g, 95%, a white solid, mp. 278-280 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.17 (dd, *J* 8.5, 1.1 Hz, 1H), 6.63 (dd, *J* 8.4, 2.8 Hz, 1H), 6.57 (d, *J* 2.7 Hz, 1H), 4.71 (s, 1H), 3.42 – 3.04 (m, 4H), 2.83 (td, *J* 6.9, 3.2 Hz, 2H), 2.58 (ddd, *J* 14.6, 11.8, 4.4 Hz, 1H), 2.48 – 2.29 (m, 2H), 2.23 (td, *J* 11.0, 4.0 Hz, 1H), 2.02 – 1.92 (m, 1H), 1.92 – 1.77 (m, 2H), 1.74 – 1.65 (m, 2H), 1.53 – 1.45 (m, 1H), 1.41 – 1.35 (m, 2H), 1.35 – 1.27 (m, 1H), 0.97 (d, *J* 0.8 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 153.3, 138.3, 132.7, 126.6, 115.2, 112.7, 80.6, 51.5, 49.4, 43.4, 43.0, 40.2, 39.7, 39.3, 32.2, 29.7, 27.4, 26.4, 23.6, 17.3. HRMS (ESI) calcd for $C_{20}H_{27}OS_2^+$ [M + H$^+$] 347.1498, found 347.1493.

1,2-Di-*p*-tolyldisulfane (3s).[55] Following the general procedure, **3s** was purified by silica gel chromatography (EtOAc/PE = 0/100). Yield: 222 mg, 90%, a white solid, mp. 46-48 °C. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.39 (d, *J* 7.3 Hz, 4H), 7.11 (d, *J* 7.9 Hz, 4H), 2.32 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 137.5, 134.0, 129.8, 128.6, 77.2, 77.0, 76.8, 21.0. HRMS (ESI) calcd for $C_{14}H_{15}S_2^+$ [M + H$^+$] 247.0610, found 247.0615.

Acknowledgements

Y. Du acknowledges the National Natural Science Foundation of China (#22071175) and K. Zhao acknowledges National Key R&D Program of China (2019YFA0905104) for the financial support.

Supplementary Material

HRMS spectra and NMR spectra (^{1}H and ^{13}C) can be found in the supplementary material file.

References

1. Vale, J. R.; Rimpiläinen, T.; Sievänen, E.; Rissanen, K.; Afonso, C. A. M.; Candeias, N. R. *J. Org. Chem.* **2018**, *83*, 1948. https://doi.org/10.1021/acs.joc.7b02896
2. Liu, C.; Gu, Y. *J. Org. Chem.* **2014**, *79*, 9619. https://doi.org/10.1021/jo5017234
3. Sakamoto, S.; Sakazaki, H.; Hagiwara, K.; Kamada, K.; Ishii, K.; Noda, T.; Inoue, M.; Hirama, M. *Angew. Chem. Int. Ed.* **2004**, *43*, 6505. https://doi.org/10.1002/anie.200461802
4. Nicolaou, K. C.; Frederick, M. O.; Petrovic, G.; Cole, K. P.; Loizidou, E. Z. *Angew. Chem. Int. Ed.* **2006**, *45*, 2609. https://doi.org/10.1002/anie.200600295
5. Corey, E. J.; Seebach, D. *Angew. Chem. Int. Ed.* **1965**, *4*, 1077. https://doi.org/10.1002/anie.196510752
6. Seebach, D.; Corey, E. J. *J. Org. Chem.* **1975**, *40*, 231. https://doi.org/10.1021/jo00890a018
7. Myles, L.; Gathergood, N.; Connon, S. J. *Eur. J. Org. Chem.* **2015**, *2015*, 188. https://doi.org/10.1002/ejoc.201402947
8. Firouzabadi, H.; Iranpoor, N.; Karimi, B. *Synthesis* **1999**, *1999*, 58. https://doi.org/10.1055/s-1999-3679
9. Corey, E. J.; Bock, M. G. *Tetrahedron Lett.* **1975**, *16*, 2643. https://doi.org/10.1016/S0040-4039(00)75203-8
10. Mahesh, S. K.; Nanubolu, J. B.; Sudhakar, G. *J. Org. Chem.* **2019**, *84*, 7815. https://doi.org/10.1021/acs.joc.9b00679
11. Reece, C. A.; Rodin, J. O.; Brownlee, R. G.; Duncan, W. G.; Silverstein, R. M. *Tetrahedron* **1968**, *24*, 4249.
12. Kirihara, M.; Suzuki, S.; Ishizuka, Y.; Yamazaki, K.; Matsushima, R.; Suzuki, T.; Iwai, T. *Tetrahedron Lett.* **2013**, *54*, 5477.
13. Oksdath-Mansilla, G.; Peñéñory, A. B. *Tetrahedron Lett.* **2007**, *48*, 6150.
14. Kamata, M.; Otogawa, H.; Hasegawa, E. *Tetrahedron Lett.* **1991**, *32*, 7421. https://doi.org/10.1016/0040-4039(91)80123-N
15. Saigo, K.; Hashimoto, Y.; Kihara, N.; Umehara, H.; Hasegawa, M. *Chem. Lett.* **1990**, *19*, 831. https://doi.org/10.1246/cl.1990.831
16. Firouzabadi, H.; Iranpoor, N.; Hassani, H.; Sobhani, S. *Synth. Commun.* **2004**, *34*, 1967. https://doi.org/10.1081/SCC-120037908
17. Ganguly, N. C.; Datta, M. *J. Chem. Res.* **2005**, *2005*, 218. https://doi.org/10.3184/0308234054213555
18. Desai, U. V.; Pore, D. M.; Tamhankar, B. V.; Jadhav, S. A.; Wadgaonkar, P. P. *Tetrahedron Lett.* **2006**, *47*, 8559. https://doi.org/10.1016/j.tetlet.2006.09.138
19. Liu, J.; Wong, C.-H. *Tetrahedron Lett.* **2002**, *43*, 4037.

https://doi.org/10.1016/S0040-4039(02)00740-2
20. Ganguly, N. C.; Datta, M. *Synlett* **2004**, *2004*, 659.
21. Dharpure, P. D.; Bhowmick, A.; Warghude, P. K.; Bhat, R. G. *Tetrahedron Lett.* **2020**, *61*, 151407. https://doi.org/10.1016/j.tetlet.2019.151407
22. Fürstner, A.; Thiel, O. R.; Kindler, N.; Bartkowska, B. *J. Org. Chem.* **2000**, *65*, 7990. https://doi.org/10.1021/jo0009999
23. Sakthivel, S.; Kothapalli, R. B.; Balamurugan, R. *Org. Biomol. Chem.* **2016**, *14*, 1670. https://doi.org/10.1039/C5OB02172C
24. Corey, E. J.; Erickson, B. W. *J. Org. Chem.* **1971**, *36*, 3553. https://doi.org/10.1021/jo00822a019
25. Ganguly, N. C.; Mondal, P. *Synth. Commun.* **2011**, *41*, 2374. https://doi.org/10.1080/00397911.2010.502995
26. Inamoto, K.; Yamada, T.; Kato, S.-I.; Kikkawa, S.; Kondo, Y. *Tetrahedron* **2013**, *69*, 9192. https://doi.org/10.1016/j.tet.2013.08.061
27. Nakagita, T.; Ishida, A.; Tachrim, Z. P.; Wang, L.; Misaka, T.; Hashimoto, M. *Molecules* **2020**, *25*, 2790. https://doi.org/10.3390/molecules25122790
28. Ganguly, N.; Barik, S. *Synthesis* **2009**, *2009*, 1393. https://doi.org/10.1055/s-0028-1088023
29. Takikawa, Y.; Shimada, K.; Makabe, T.; Takizawa, S. *Chem. Lett.* **1983**, *12*, 1503. https://doi.org/10.1246/cl.1983.1351
30. Stork, G.; Zhao, K. *Tetrahedron Lett.* **1989**, *30*, 287. https://doi.org/10.1016/S0040-4039(00)95181-5
31. Cox, C. D.; Siu, T.; Danishefsky, S. J. *Angew. Chem. Int. Ed.* **2003**, *42*, 5625. https://doi.org/10.1002/anie.200352591
32. Nicolaou, K. C.; Gray, D. L. F.; Tae, J. *J. Am. Chem. Soc.* **2004**, *126*, 613. https://doi.org/10.1021/ja030498f
33. Langille, N. F.; Dakin, L. A.; Panek, J. S. *Org. Lett.* **2003**, *5*, 575. https://doi.org/10.1021/ol027518n
34. Nicolaou, K. C.; Mathison, C. J. N.; Montagnon, T. *J. Am. Chem. Soc.* **2004**, *126*, 5192. https://doi.org/10.1021/ja0400382
35. Moriarty, R. M.; Gupta, S. C.; Hu, H.; Berenschot, D. R.; White, K. B. *J. Am. Chem. Soc.* **1981**, *103*, 686. https://doi.org/10.1021/ja00393a040
36. De Sousa, D. P.; Wegeberg, C.; Vad, M. S.; Mørup, S.; Frandsen, C.; Donald, W. A.; McKenzie, C. J. *Chem. Eur. J.* **2016**, *22*, 3810. https://doi.org/10.1002/chem.201503112
37. Rudrawar, S.; Besra, R. C.; Chakraborti, A. K. *Synthesis* **2006**, *2006*, 2767. https://doi.org/10.1055/s-2006-942474
38. Dauban, P.; Sanière, L.; Tarrade, A.; Dodd, R. H. *J. Am. Chem. Soc.* **2001**, *123*, 7707. https://doi.org/10.1021/ja010968a
39. Xing, Z.; Yang, M.; Sun, H.; Wang, Z.; Chen, P.; Liu, L.; Wang, X.; Xie, X.; She, X. *Green Chem.* **2018**, *20*, 5117. https://doi.org/10.1039/C8GC02237B
40. Arakawa, Y.; Mihara, T.; Fujii, H.; Minagawa, K.; Imada, Y. *Chem. Commun.* **2020**, *56*, 5661. https://doi.org/10.1039/D0CC01960G
41. Nishino, K.; Minato, K.; Miyazaki, T.; Ogiwara, Y.; Sakai, N. *J. Org. Chem.* **2017**, *82*, 3659.

https://doi.org/10.1021/acs.joc.7b00170
42. Kiselyov, A. S.; Strekowski, L.; Semenov, V. V. *Tetrahedron* **1993**, *49*, 2151. https://doi.org/10.1016/S0040-4020(01)80359-8
43. Mandal, P. K.; Roy, S. C. *Tetrahedron* **1995**, *51*, 7823. https://doi.org/10.1016/0040-4020(95)00399-S
44. Naik, S.; Gopinath, R.; Goswami, M.; Patel, B. K. *Org. Biomol. Chem.* **2004**, *2*, 1670. https://doi.org/10.1039/b402648a
45. Hajipour, A. R.; Zarei, A.; Khazdooz, L.; Zahmatkesh, S.; Ruoho, A. E. *Phosphorus Sulfur* **2006**, *181*, 387. https://doi.org/10.1080/104265091000877
46. Rohde, V. H. G.; Pommerening, P.; Klare, H. F. T.; Oestreich, M. *Organometallics* **2014**, *33*, 3618. https://doi.org/10.1021/om500570d
47. Hajipour, A. R.; Pourmousavi, S. A.; Ruoho, A. E. *Phosphorus Sulfur* **2007**, *182*, 921. https://doi.org/10.1080/10426500601088739
48. Jung, N.; Grässle, S.; Lütjohann, D. S.; Bräse, S. *Org. Lett.* **2014**, *16*, 1036. https://doi.org/10.1021/ol403313h
49. Taylor, W. H. *J. Am. Chem. Soc.* **1935**, *57*, 1065. https://doi.org/10.1021/ja01309a027
50. Nozawa-Kumada, K.; Ito, S.; Noguchi, K.; Shigeno, M.; Kondo, Y. *Chem. Commun.* **2019**, *55*, 12968. https://doi.org/10.1039/C9CC06775B
51. Aoyama, T.; Suzuki, T.; Nagaoka, T.; Takido, T.; Kodomari, M. *Synth. Commun.* **2013**, *43*, 553. https://doi.org/10.1080/00397911.2011.604458
52. Rao, C. N. R.; Venkataraghavan, R.; Kasturi, T. R. *Can. J. Chem.* **1964**, *42*, 36. https://doi.org/10.1139/v64-006
53. Zhao, G.; Yuan, L.-Z.; Alami, M.; Provot, O. *Adv. Synth. Catal.* **2018**, *360*, 2522. https://doi.org/10.1002/adsc.201800437
54. Rudrawar, S.; Besra, R. C.; Chakraborti, A. K. *Synthesis* **2006**, *2006*, 2767. https://doi.org/10.1055/s-2006-942474
55. Zhu, R.-H.; Shi, X.-X. *Synth. Commun.* **2012**, *42*, 1108. https://doi.org/10.1080/00397911.2010.535947