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Straightforward access to aryl-substituted/fused 1,3dithiole-2-chalcogenones by Cu-catalyzed C–S coupling between aryl iodides and zinc–thiolate complex (TBA)₂[Zn(DMIT)₂][†]

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The Cu-catalyzed C–S coupling between iodoaryl and a zincthiolate complex was achieved. This protocol provides a facile and efficient synthetic approach for aryl-substituted/fused 1,3dithiole-2-chalcogenones, which can be converted to TTFs.

The extension of π -electron conjugation of tetrathiafulvalene (TTF) offers a powerful opportunity to adapt TTFs for different applications.¹ In this context, the peripheral substitution/fusion of aromatic system to TTF framework is one promising method because the aryls can(1) influence the electronic nature of parent TTF through the extension of π -conjugation, and (2) lead to new packing motifs by π - π interaction. To date, the aryls and TTF are mainly connected *via* the C-C bond,² whereas few reports concern their connection via the sulphur bridge due to the synthetic difficulty.³ It is known that the most effective synthetic method for TTFs is the phosphate-mediated coupling reaction of 1,3-dithiole-2-chalcogenones.⁴ Thus, the key step for the synthesis of arylsubstituted/fused TTFs via sulphur bridge is to prepare the corresponding 1,3-dithiole-2-chalcogenones. Unfortunately, the reported methods for the incorporation of aryls onto 1,3dithiole-2-chalcogenones via sulphur bridge suffer from the narrow scope and low yield.³ It is therefore highly desirable to solve this synthetic problem.

The copper-catalyzed C–S coupling has attracted considerable attention.⁵ We envisioned that this reaction would be applicable to synthesize the aryl-substituted/fused 1,3-dithiole-2-thiones *via* sulphur bridge. Herein, we disclose the Cu-catalyzed C–S coupling between aryl halides and a readily available zinc–thiolate complex $(TBA)_2[Zn(DMIT)_2]^6$ (see Scheme 1), which is further employed to the preparation of a variety of aryl-substituted/fused 1,3-dithiole-2-

thiones. It should be noted that the sulphur sources in most of the C–S coupling reactions are limited to thiols or their precursors.⁵ Therefore, the present protocol, using ambient stable and odourless zinc–thiolate as a sulphur source, would be attractive from the synthetic viewpoint.

We carried out the Cu₂O-catalyzed C–S coupling reaction between halogenobenzene and $(TBA)_2[Zn(DMIT)_2]$ under similar conditions to those reported for the typical C–S coupling reaction (in DMF at 120 °C).^{5e} It was found that chlorobenzene and bromobenzene did not afford the desired product **1a**, thus iodobenzene was used to optimize the reaction conditions as summarized in Table 1. Since $(TBA)_2[Zn(DMIT)_2]$ has four thiolate anions, the molar ratio of $(TBA)_2[Zn(DMIT)_2]$: iodobenzene was set as 1 : 4.4. Further increasing the amount of iodobenzene did not afford better yield of **1a**. The ratio of Cu₂O : ligand was set as 1 : 2.^{5e}

Several ligands (L1–L5) were screened with Cu₂O (20%) (Table 1, Entries 1–5), among which ethyl acetoacetate (L2) gave the best result (isolated yield of **1a**, 77%). Surprisingly, **1a** can also be obtained in 50% even without adding any ligands (Entry 6). On the other hand, when (TBA)₂[Cu(DMIT)₂] was directly used as reactant without adding Cu₂O and ligand, **1a** was obtained only in 25%. The reaction was run with different copper salts other than Cu₂O (Entries 7–14), but the yield of **1a** was less than 60%. Additionally, the amount of Cu₂O showed significant influence on this reaction (Entries 15–19). The reaction did not take place in the absence of Cu₂O. The yield of **1a** became higher as the amount of Cu₂O increased and reached to the maximum of 77% when Cu₂O was 20%, but it could not be further improved by increasing Cu₂O to over 25%.

The influence of the reaction temperature (Entries 20–23) and time (Entries 24–27) were also examined. The yield of **1a** dropped dramatically when the temperature was below 100 $^{\circ}$ C or the reaction time was shorter than 10 h. However, the yield of **1a** did not improve any more by further increasing the temperature to more than 120 $^{\circ}$ C or extending reaction time to more than 10 h. This reaction also took place in DMSO with the yield of **1a** (65%) lower than in DMF. By contrast, the reaction did not proceed in

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Scheme 1 Synthetic approach for the aryl-substituted/fused 1,3-dithiole-2-thiones *via* sulphur bridge.

toluene, CH_3CN, and 1,4-dioxane. Thus, the optimized reaction conditions are Cu_2O(20%)/L2(40%)/DMF/120 $^\circ\text{C}/10$ h.

To study the scope of this methodology and its application in the synthesis of aryl substituted 1,3-dithiole-2-thiones, the reaction

Table 1 Optimization	of the reaction	conditions be	etween iodoben	zene and
(TBA) ₂ [Zn(DMIT) ₂] ^a				

ד)	$(\text{TBA})_2 \left[S \xrightarrow{S} \sum_{s} z_n^{S} \right]_{s} \left[S \xrightarrow{S} z_n^{S} \right]_{s} \left[(\text{TBA})_2 (\text{Zn}(\text{DMIT})_2 \right]_{s} \right]_{s} \left[S \xrightarrow{S} z_n^{S} \right]_{s} \left[S \xrightarrow$	s s] +]			s s 1a
		Et J	Å (,		но он
	L1 L2		L3	L4	L5
Entr	y Cu source (%)	Ligand	(%) $T(^{\circ}C)$	Time (h)	Yield of $1a (\%)^b$
1	Cu ₂ O (20)	L1 (40)	120	10	72
2	$Cu_2O(20)$	L2 (40)	120	10	77
3	$Cu_2O(20)$	L3 (40)	120	10	69
4	$Cu_2O(20)$	L4 (40)	120	10	56
5	$Cu_2O(20)$	L5 (40)	120	10	57
6	$Cu_2O(20)$	_ ` ´	120	10	50
7	CuCl (20)	L2 (40)	120	10	60
8	CuBr (20)	L2 (40)	120	10	55
9	CuI (20)	L2 (40)	120	10	58
10	$CuBr_2$ (20)	L2 (40)	120	10	45
11	$CuSO_4(20)$	L2 (40)	120	10	38
12	$Cu(OAc)_2 \cdot H_2O(20)$	L2 (40)	120	10	60
13	$CuSO_4 \cdot 5H_2O(20)$	L2 (40)	120	10	48
14	$CuCl_2 \cdot 2H_2O(20)$	L2 (40)	120	10	40
15	$Cu_2O(0)$	L2 (40)	120	10	0
16	$Cu_2O(5)$	L2 (10)	120	10	43
17	$Cu_2O(10)$	L2 (20)	120	10	59
18	$Cu_2O(15)$	L2 (30)	120	10	65
19	$Cu_2O(25)$	L2(50)	120	10	64
20	$Cu_2O(20)$	L2(40)	60	10	0
21	$Cu_2O(20)$	L2(40)	80	10	Trace
22	$Cu_2O(20)$	L2(40)	100	10	53
23	$Cu_2O(20)$	L2 (40)	150	10	69
24	$Cu_2O(20)$	L2(40)	120	2.5	16
25	$Cu_2O(20)$	L2 (40)	120	5.0	31
26	$Cu_2O(20)$	L2 (40)	120	7.5	50
27	$Cu_2O(20)$	L2 (40)	120	12.5	73

^{*a*} Reagents: (TBA)₂[Zn[DMIT)₂] (1.69 mmol), iodobenzene (7.44 mmol), DMF (3 mL). ^{*b*} Isolated yield.

 $\label{eq:constraint} \textbf{Table 2} \ \text{Synthesis of the aryl-substituted 1,3-dithiole-2-thiones} \ via \ \text{sulphur} \ bridge^a$

(TBA) ₂ [Zn(DMIT) ₂] + I-	Cu ₂ O (20 mol%) <u>L2 (40 mol%)</u> DMF, 120 °C, 10 h	∑SSS S 1a - 29a
Ar	1,3-Dithiole-2-thione	Yield $(\%)^b$
C ₆ H ₅	1a	77
C_6H_4 -2-Me	2a	66
C_6H_4 -4-Me	3a	70
C ₆ H ₄ -3-Me	4a	67
C ₆ H ₄ -2-OMe	5a	56
C ₆ H ₄ -4-OMe	6a	75
C ₆ H ₄ -3-OMe	7a	58
C_6H_4 -4-NM e_2	8a	64
C_6H_4 -2-NHC(O)CH ₃	9a	70
C_6H_4 -2-Cl	10a	75
C_6H_4 -4-Cl	11a	60
C ₆ H ₄ -3-Cl	12a	70
C ₆ H ₄ -2-Br	13a ^c	60^d
C ₆ H ₄ -4-Br	14a	55
C ₆ H ₄ -3-Br	15a	65
C_6H_4 -4-I	16a ^c	53
C ₆ H ₄ -2-CO ₂ Me	17a ^e	85
C_6H_4 -4- CO_2Me	18a	50
C_6H_4 -3- CO_2Me	19a	50
C_6H_4 -4- CO_2Et	20a	70
C ₆ H ₄ -2-COMe	21a ^e	76
C ₆ H ₄ -4-COMe	22a	50
C_6H_4 -2-CN	23a	78
C_6H_4 -2-NO ₂	$24a^e$	91
C ₆ H ₄ -3-NO ₂	25a	50
4-Biphenyl	26a	56
2-Thienyl	27a	70
2-Pyridyl	$28a^e$	90
3-Pyridyl	29a	60
· · · ·		

 a Reaction conditions: (TBA)₂[Zn(DMIT)₂] (1.69 mmol), Ar-I (7.44 mmol), Cu₂O (0.34 mmol), L2 (ethyl acetoacetate, 0.68 mmol), DMF (3 mL), 120 °C, 10 h. b Isolated yield. c Aryl iodide was set as 6 eq. d 23% of **30a** was also isolated. e Reaction temperature was 80 °C.

Table 3 Synthesis of the aryl-fused 1,3-dithiole-2-thiones via sulphur bridge^a



 a Reaction conditions: (TBA)₂[Zn(DMIT)₂] (1.69 mmol), aryl orthodiiodide (3.5 mmol), Cu₂O (0.34 mmol), L2 (0.68 mmol), DMF (3 mL), 80 $^\circ$ C, 10 h.

of (TBA)₂[Zn(DMIT)₂] with a number of aryl iodides (orthodiiodides) was carried out as summarized in Tables 2 and 3. In this synthetic approach, all types of aryl iodides, including the electron-donating, electron-withdrawing, and sterically hindered ortho-substituted aryl iodides, are well tolerated. Most of the aryl iodides can be transformed to the corresponding aryl substituted 1,3-dithiole-2-thiones in \geq 60%. Remarkably, the reaction can be run at lower temperature (80 °C) with better yield when the orthosubstituent is electron-withdrawing group (17a, 21a, 24a), and the highest yield is 91% for 24a. Heteroaryl iodides also provided good results for the synthesis of 1,3-dithiole-2-thiones (27a-29a). In particular, 2-iodopyridine was transformed to the desired product 28a at 80 °C with 90% yield. In the case of ortho-diiodoaryls, the corresponding aryl-fused 1,3-dithiole-2-thiones can be obtained in \geq 65% (30a-37a). It should be noted that 1-bromo-2-iodobenzene can simultaneously afford 30a with 23% yield during the preparation of 13a. Meanwhile, the reaction of (TBA)₂[Zn(DMIT)₂] with 1-chloro-2-iodobenzene under the same conditions exclusively provided 10a, and ortho-dibromobenzene



Fig. 1 Crystal structure of **34a**. Half of the molecule is crystallographically unique, and C1 and S1 atoms are located on the mirror plane (blue dashed line). The terminal ethylenedioxy group is disordered with two positions for the carbon atom, C61 and C62 (*s.o.f* = 0.5). The cyan circles represent the hydrogen atoms.

Table 4 Synthesis of the aryl substituted TTFs via sulphur bridge^a

Ar ¹ S S 0	$+ X = \sqrt{\frac{S}{\frac{S}{Ar^2}}} + X = 0, S$	P(OEt) ₃ Ar ¹⁻ 80 °C, 6 h Ar ¹	S = S = S = S = S = S = S = S = S = S =
Ar ¹	Ar ²	TTFs	Yield $(\%)^b$
Phenyl 2-Pyridyl 2-Thienyl 2-Pyridyl 2-Pyridyl	Phenyl 2-Pyridyl 2-Thienyl Phenyl 2-Thienyl	TTF-1 TTF-2 TTF-3 TTF-4 TTF-5	92 80 93 80 75

^{*a*} Experimental details are supplied in ESI.^{† *b*} Isolated yield.

did not react with $(TBA)_2[Zn(DMIT)_2]$ even at higher temperature. We also carried out the synthesis of asymmetric 1,3-dithiole-2thiones (**38a–40a**) *via* the three-component tandem procedure, the yield of the desired product is about 40% (see ESI[†] for the experimental and structural details).

The resulting aryl-substituted/fused 1,3-dithiole-2-thiones were converted into the corresponding 1,3-dithiole-2-ones (**1b–37b**) by reaction with $Hg(OAc)_2$,⁴ and most of the transformations were almost quantitative. The single crystals of **17b**, **24b**, **34a** and **35a** were obtained by slowly evaporating the solvent. Fig. 1 depicts the crystal structure of **34a**, and those of **17b**, **24b**, and **35a** are shown in ESI† (Fig. S1–S3). On the basis of the resulting 1,3-dithiole-2-chalcogenones, we have prepared a variety of aryl substituted/fused TTFs through the typical approach of phosphate-mediated coupling reaction, and the selected results are summarized in Table 4 (see ESI† for further details). The isolated yields for all these TTFs were over 75%.

In conclusion, we have developed a straightforward synthetic method for the aryl substituted/fused 1,3-dithiole-2-thiones *via* sulphur bridge by using Cu-catalyzed C–S coupling between the aryl iodides and zinc–thiolate complex (TBA)₂[Zn(DMIT)₂]. This protocol enables us to create a library of TTFs incorporating aryls *via* sulphur bridge in low cost and large substituent scope. The present work also suggests that the zinc–thiolate complex, which is ambient stable and without foul smell, would be a promising sulphur source in Cu-catalyzed S-arylation. The investigation of the optical and electrochemical properties, as well as the solid state structures of the aryl substituted/fused TTFs are in progress and will be reported in due course.

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Notes and references

 For the comprehensive reviews, see: (a) M. R. Bryce, Chem. Soc. Rev., 1991, 20, 355; (b) M. Adam and K. Müllen, Adv. Mater., 1994, 6, 439; (c) T. Jørgensen, T. K. Hansen and J. Becher, Chem. Soc. Rev., 1994, 41; (d) M. R. Bryce, J. Mater. Chem., 1995, 5, 1481; (e) J. Garín, Adv. Heterocycl. Chem., 1995, 62, 249; (f) T. Otsubo, Y. Aso and K. Takimiya, Adv. Mater., 1996, 8, 203; (g) E. Coronado and C. J. Gómez-García, *Chem. Rev.*, 1998, **98**, 273; (*h*) M. R. Bryce, *Adv. Mater.*, 1999, **11**, 11; (*i*) M. B. Nielsen, C. Lomholt and J. Becher, *Chem. Soc. Rev.*, 2000, **29**, 153; (*j*) J. L. Segura and N. Martín, *Angew. Chem., Int. Ed.*, 2001, **40**, 1372; (*k*) P. Frère and P. J. Skabara, *Chem. Soc. Rev.*, 2005, **34**, 69.

- 2 For selected aryl substituted/fused TTFs via C–C bond, see: (a) Y. Mitamura, H. Yorimitsu, K. Oshima and A. Osuka, Chem. Sci., 2011, 2, 2017; (b) K. Lincke, A. F. Frellsen, C. R. Parker, A. D. Bond, O. Hammerich and M. B. Nielsen, Angew. Chem., Int. Ed., 2012, 51, 6099; (c) M. Jaggi, C. Blum, B. S. Marti, S. Liu, S. Leutwyler and S. Decurtins, Org. Lett., 2010, 12, 1344; (d) Q. Zhu, L. Huo, Y. Qin, Y. Zhang, Z. Lu, J. Wang and J. Dai, J. Phys. Chem. B, 2010, 114, 361; (e) J. Wu, S. Liu, T. D. Keene, A. Neels, V. Mereacre, A. K. Powell and S. Decurtins, Inorg. Chem., 2008, 47, 3452; (f) Q. Zhu, Y. Liu, W. Lu, Y. Zhang, G. Bian, G. Niu and J. Dai, Inorg. Chem., 2007, 46, 10065; (g) C. Jia, S. Liu, C. Tanner, C. Leiggener, A. Neels, L. Sanguinet, E. Levillain, S. Leutwyler, A. Hauser and S. Decurtins, Chem.–Eur. J., 2007, 13, 3804.
- 3 (a) S.-Y. Hsu and L. Y. Chiang, J. Org. Chem., 1987, 52, 3444; (b)
 H. Müller, A. Lerf, H. P. Fritz and K. Andres, Synth. Met., 1991, 41–43, 2381; (c) J. P. Parakka, A. M. Kini and J. M. Williams, Tetrahedron Lett., 1996, 37, 8085; (d) R. A. Bissell, N. Boden, R. J. Bushby, C. W. G. Fishwick, E. Holland, B. Movaghar and G. Ungar, Chem. Commun., 1998, 113; (e) P. J. Skabara, I. M. Serebryakov, D. M. Roberts, I. F. Perepichka, S. J. Coles and M. B. Hursthouse, J. Org. Chem., 1999, 64, 6418; (f) P. J. Skabara,

D. M. Roberts, I. M. Serebryakov and C. Pozo-Gonzalo, *Chem. Commun.*, 2000, 1005; (g) A. L. Kanibolotsky, L. Kanibolotskaya, S. Gordeyev, P. J. Skabara, I. McCulloch, R. Berridge, J. E. Lohr, F. Marchioni and F. Wudl, *Org. Lett.*, 2007, **9**, 1601.

- 4 (*a*) M. Narita and C. U. Jr Pittman, *Synthesis*, 1976, 489; (*b*) A. Krief, *Tetrahedron*, 1986, 42, 1209; (*c*) J. M. Fabre, *Chem. Rev.*, 2004, **104**, 5133; (*d*) *TTF Chemistry: Fundamentals and Applications of Tetrathiafulvalenes*, ed. J. Yamada and T. Sugimoto, Kodansha, Tokyo, and Springer, Berlin, Heideberg, New York, 2004.
- 5 For selected Cu-catalyzed S-arylation, see: (a) F. Y. Kwong and S. L. Buchwald, Org. Lett., 2002, 4, 3517; (b) L. Rout, T. K. Sen and T. Punniyamurthy, Angew. Chem., Int. Ed., 2007, 46, 5583; (c) J. Mao, G. Xie, M. Wu, J. Guo and S. Ji, Adv. Synth. Catal., 2008, 350, 2477; (d) L. Rout, P. Saha, S. Jammi and T. Punniyamurthy, Eur. J. Org. Chem., 2008, 640; (e) H. Xu, X. Zhao, J. Deng, Y. Fu and Y. Feng, Tetrahedron Lett., 2009, 50, 434; (f) J. She, Z. Jiang and Y. Wang, Tetrahedron Lett., 2009, 50, 593; (g) C. Chen, Y. Chen, C. Lin, H. Lin and C. Lee, Chem. Commun., 2010, 46, 282; (h) Y. Yuan, I. Thomé, S. H. Kim, D. Chen, A. Beyer, J. Bonnamour, E. Zuidema, S. Chang and C. Bolm, Adv. Synth. Catal., 2010, 352, 2892; (i) S. Kovács and Z. Novák, Org. Biomol. Chem., 2011, 9, 711; (j) D. J. C. Prasad and G. Sekar, Org. Lett., 2011, 13, 1008; (k) C. Shen, H. Xia, H. Yan, X. Chen, S. Ranjit, X. Xie, D. Tan, R. Lee, Y. Yang, B. Xing, K. Huang, P. Zhang and X. Liu, Chem. Sci., 2012, 3, 2388.
- 6 T. K. Hansen, J. Becher, T. Jorgensen, K. S. Varma, R. Khedekar and M. P. Cava, *Org. Synth. Coll.*, 1998, 9, 203.