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A new route to extended tetrathiafulvalenes from α-acetyl ketene-*S*,*S*-acetals

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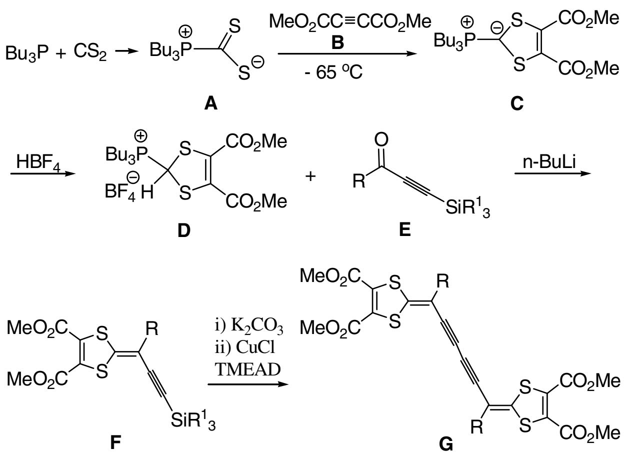
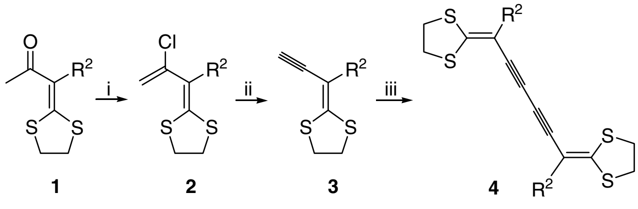
Abstract—A new route to extended tetrathiafulvalenes was described. The extended TTFs with hexa-2,4-diyne-1,6-diylidene spacer between the two 1,3-dithiole rings were prepared simply from the easily available α-acetyl ketene-(*S*,*S*)-acetals in good yields under mild conditions.

Since the first synthesis of tetrathiafulvalene (TTF) was reported by Wudl et al.,[1] TTF and its derivatives (TTFs) have been widely explored in both materials and supramolecular chemistry.[2] The extended TTFs, in which a π-conjugated spacer is incorporated between the two dithiole rings, exhibit enhanced π-donor properties and stabilization of the dication state[3] and thus represent a topic of great interest in the field of molecular conductors, small band gap molecular semi-conductors, and nonlinear optics.[4] To date, a considerable number of olefinic and aromatic spacers have been introduced with the aim to tune the redox properties of the π-electron system.[3,5] However, there are few reports of the alkyne-spaced TTFs.

In the context of alkyne-spaced TTFs, Gorgues and co-workers. reported the synthesis of substituted 1,4-bis(1,3-dithiol-2-ylidene)but-2-ynes.[6] The acetylenic TTF dications were isolated by Yoshida and co-workers.[7] Recently, some di- and poly-yne acetylenic TTFs and their derivatives were described by Diederich and co-workers[8] and Nielsen et al.,[9] respectively. In the research mentioned above, a synthetic route, as described in Scheme 1, is commonly used.[6–9] As part of our research on the synthetic applications of α-acetyl ketene-(*S*,*S*)-acetals,[10,11] recently, a series of α-ethynyl ketene-(*S*,*S*)-acetals **3** (Scheme 2) and analogues were prepared in high yields via a consecutive Vilsmeier–Haack and dehydrochlorination reaction starting from the corresponding α-acetyl ketene-(*S*,*S*)-acetals under



Scheme 1.



Scheme 2. Reagents and conditions: (i) $POCl_3$–DMF, 0 °C; (ii) NaOH (1.0 equiv), CH_3OH, 20 °C; (iii) $Ni(PPh_3)_2Cl_2$, $PdCl_2$, CuI, $N(CH_2CH_3)_3$, THF, 20 °C.

Keywords: α-Acetyl ketene-*S*,*S*-acetals; Acetylenic dithiafulvenes; Extended tetrathiafulvalene; Acetylenic tetrathiafulvalene; Coupling reaction.

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mild conditions.[12] Most recently, through sequential oxidative coupling of α,α-diethynyl ketene-(*S*,*S*)-acetal, we successfully prepared the first heteroatom-substituted expanded 1,3-dithiolan[5]radialene with the basic structural characters of the alkyne-extended tetrathiafulvalenes.[13] These experimental results prompted us to explore a direct synthetic route to acetylenic TTFs starting from the readily available α-acetyl ketene-(*S*,*S*)-acetals. In the letter, we wish to report our preliminary results of this research.

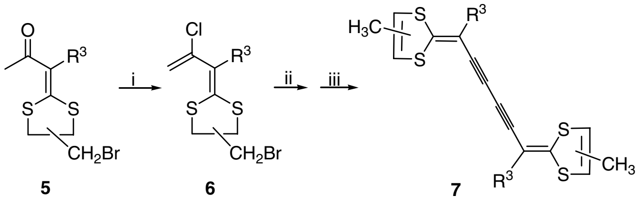
Although the route in Scheme 1 is efficient for the preparation of acetylenic TTFs, a five-step procedure and time consuming or expensive starting materials are normally required. With the consideration that α-ethynyl ketene-(*S*,*S*)-acetals **3** are a kind of acetylenic dihydrodithiafulvenes and could be served as the building blocks of alkyne-extended tetrahydro-TTFs, we first focused our attention on the self-coupling reaction of **3**. It was found that compounds **3** underwent the homo-coupling reaction very easily and the corresponding extended tetrahydro-TTFs **4** were formed in high to excellent yields when **3** (1.0 equiv) was added to the mixture of 2.0 mol % of $Ni(PPh_3)_2Cl_2$, 2.0 mol % of $PdCl_2$, 5.0 mol % of CuI, and 1.5 equiv of triethylamine in THF and stirred for 5–6 h at room temperature (Scheme 2 and Table 1).

With the successful synthesis of extended tetrahydro-TTFs **4**, we then focused on the preparation of acetylene-spaced TTFs based on the three-step procedure as described in Scheme 2. Starting from the activated methylene compounds and 1,2,3-tribromopropane, the corresponding α-acetyl ketene-(*S*,*S*)-acetals **5** (Scheme 3), which possessed the skeleton structure and unsaturated degree as required for acetylene-spaced TTFs, were synthesized region-specifically in 87–94% yields according to the known method.[10–13] Subsequently, the α-chlorovinyl ketene-(*S*,*S*)-acetals **6** were produced through the Vilsmeier–Haack reaction of compounds **5** in good yields (Table 2). Similarly, compounds **7**,[14] the extended TTFs with hexa-2,4-diyne-1,6-diylidene spacers between the two 1,3-dithiole rings, were finally synthesized in good yields under the similar conditions as the synthesis of **4** except the dehydrochlorination and the dehydrobromination of **6** and the followed oxidative coupling steps were combined (Scheme 3 and Table 2) to simplify the experimental procedures. Compared with the route of Scheme 1, this new route had following advantages: (1) the readily available starting materials and cheap reagents; (2) a procedure proceeded smoothly under mild conditions. Therefore, our preliminary results presented a simpler procedure for the synthesis of extended TTFs.

Table 1. Preparation of alkyne-extended tetrahydro-TTFs **4**

Entry	Substrate	R^2	Time (h)	Product	Yield[a] (%)
1	**3a**	$COOCH_3$	6	**4a**	97
2	**3b**	4-Cl–PhNHCO	6	**4b**	91
3	**3c**	H	5	**4c**	75

[a] Isolated yields.



Scheme 3. Reagents and conditions: (i) $POCl_3$–DMF, 0 °C, 8–10 h; (ii) NaOH (2.0 equiv), C_2H_5OH, 60–70 °C, 3–4 h; (iii) $Ni(PPh_3)_2Cl_2$, $PdCl_2$, CuI, THF, $N(CH_2CH_3)_3$, 20 °C, 15–20 min.

Table 2. Synthesis of compounds **6** and **7**

Entry	R^3	Product and yield[a] (%)			
		6	Yield	**7**	Yield
1	$COOC_2H_5$	**6a**	87	**7a**	52
2	4-Cl–PhNHCO	**6b**	76	**7b**	45
3	$COCH_3$	**6c**	55	**7c**	43
4	CN	**6d**	83	**7d**	40

[a] Isolated yields.

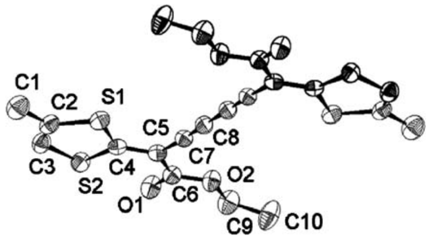


Figure 1. Crystal structure of the acetylenic TTFs **7a**. Hydrogen atoms are omitted for clarity.

According to the ^1H NMR spectra of compounds **6** and **7**, it was indicated that these compounds were produced as a mixture of isomers (with methyl substitute at the 4(4′)- or 5(5′)-position of the corresponding 1,3-dithiolane or 1,3-dithiole moiety). During the crystallization of **7a** from the mixed solvents of diethyl ether–hexane (1:1, v/v), one isomer of **7a** was isolated and the single crystal structure revealed that two fulvene double bonds in this isomer adopted the s-trans conformation with respect to the connecting buta-1,3-diynediyl moiety and the two dithiafulvene units lay on the same plane (Fig. 1).[15]

In conclusion, we have described a novel method for the synthesis of acetylene-spaced TTFs, by which a series of tetrahydro acetylenic TTFs and acetylene-spaced TTFs with laterally appended function groups were obtained with the readily available α-acetyl ketene-(*S*,*S*)-acetals involving only the Vilsmeier–Haack reaction, dehydrohalogenation and the oxidative coupling steps. Further research on expanding the application of this new route is in progress.

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Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2006.02.128.

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14. General procedure for **7a**: To a solution of compound **6a** (2.00 mmol, 687 mg) and NaOH (4.00 mmol, 160 mg) in EtOH–H_2O (4:1; v/v, 30 mL) was heated at 60–70 °C for 3–4 h. The reaction mixture was poured into cold water (50 mL), extracted with diethyl ether (3×10 mL), and dried over anhydrous $MgSO_4$. This extract combined was then directly added to a solution of $Ni(PPh_3)_2Cl_2$ (0.040 mmol, 26.16 mg), $PdCl_2$ (0.040 mmol, 7.08 mg), CuI (0.10 mmol, 19.00 mg), and triethylamine (3.00 mmol, 0.42 mL) in THF (30 mL). After the reaction solution was stirred for 15–20 min at room temperature, the solvent was removed under reduced pressure, and the residue was purified by silica gel chromatography (diethyl ether–hexane = 1/1, v/v) to give the pure **7a** (234 mg, 52% yield). Compound **7a**: red crystal; mp 192–194 °C; ^1H NMR ($CDCl_3$, 400 MHz) one isomer δ: 1.35 (t, $J = 8.0$ Hz, 6H), 2.29 (s, 6H), 4.31 (q, $J = 8.0$ Hz, 4H), 6.49 (s, 2H); the other δ: 1.35 (t, $J = 8.0$ Hz, 6H), 2.28 (s, 6H), 4.28 (q, $J = 8.0$ Hz, 4H), 6.43 (s, 2H); IR (KBr, cm^{-1}): 3445, 3065, 2982, 2121, 1668, 1473, 1373, 1285, 1235, 1172, 1029, 933, 761; MS (EI) m/z 451 $[(M+1)]^+$; calcd (found) for $C_{20}H_{18}O_4S_4$: C, 53.31 (53.52); H, 4.03 (4.10).
15. Crystal data for **7a**: $C_{20}H_{18}O_4S_4$, dark red crystal, $M = 450.58$, monoclinic, $P2(1)/n$, $a = 10.7902(8)$ Å, $b = 7.4372(10)$ Å, $c = 13.6358(14)$ Å, $\alpha = 90°$, $\beta = 102.762(2)°$, $\gamma = 90°$, $V = 1067.2(2)$ Å^3, $Z = 2$, $T = 293(2)$, $F_{000} = 468$, $R_1 = 0.0762$, $wR_2 = 0.2400$. The CCDC deposition number: 246076.