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ARTICLE TYPE

A convenient tandem one-pot synthesis of donor-acceptor-type triphenylene 2,3-dicarboxylic esters from diarylacetylene

Chun Feng,^{*a} Xian-Li Tian,^a Jing Zhou,^a Shi-Kai Xiang,^a Wen-Hao Yu,^a Bi-Qin Wang,^{*a} Ping Hu,^a Carl Redshaw^{a,b} and Ke-Qing Zhao^aReceived (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX
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A tandem one-pot method for the direct synthesis of polysubstituted triphenylene 2,3-dicarboxylic esters with different substitution patterns has been developed through enyne metathesis of diarylacetylene, followed by Diels-Alder, aromatization and a cyclization cascade.

Derivatives of triphenylene, which is comprised of a flat polyaromatic core surrounded by multiple flexible n-carbon side chains, are potential HIV inhibitors for use in AIDS therapy.¹

Furthermore, triphenylenes have been extensively explored as building blocks for the preparation of functional electronic and optoelectronic devices in material chemistry owing to their remarkable self-assembling and charge transporting properties.²

There are two exceptional examples of triphenylene structure in terms of the electronic properties of the peripheral substituents. Firstly, there is the most commonly studied electron-rich or donor-type hexaalkoxytriphenylene (Figure 1, A), which usually exhibit hexagonal columnar mesophases over relatively narrow temperature ranges above room temperature.³ Secondly, the electron-deficient or acceptor-type triphenylene functionalized with six polar ester groups (Figure 1, B), allows for an exceptionally wide-range of 2D lattices in its columnar assembly and it has been noted that such columns can align in homeotropic fashion on a variety of substrates.^{2c} Williams and co-workers have shown that the addition of electron-withdrawing substituents can lead to an increase in the molecular dipole moment, which help to minimize the repulsive interactions between adjacent aromatic π -systems and promotes the formation and stabilization of columnar phases.⁴ Therefore studies on triphenylene derivatives possessing electron-withdrawing substituents have attracted increased interest.^{2c,5} However, reports on monomeric triphenylenes derivatives possessing simultaneously both electron-donating and electron-withdrawing substituents are exceedingly rare, probably because of the lack of practical synthetic methods.

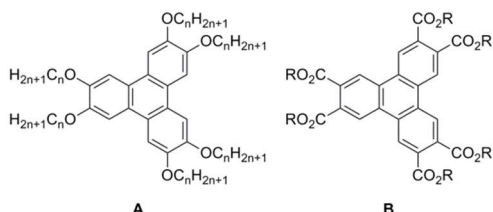
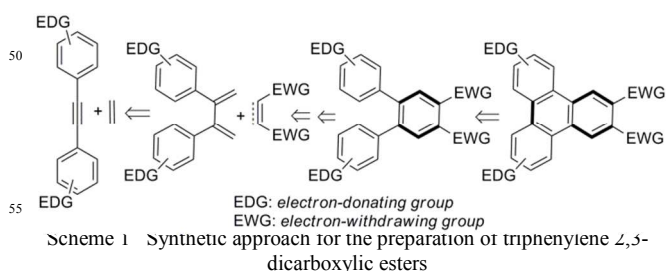
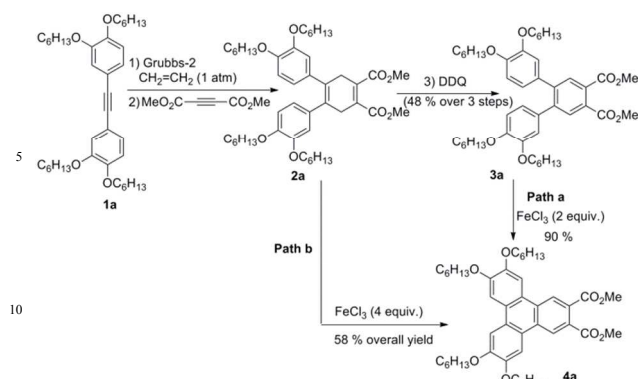


Figure 1 Two exceptional examples of triphenylene molecule



For the construction of the triphenylene framework, oxidative coupling between suitably substituted biphenyl and benzene derivatives,⁶ iodine promoted photocyclisation,⁷ Lewis acid promoted cyclization of *ortho*-terphenyl (prepared by Ullman coupling reaction or by Suzuki-type cross coupling reactions),⁸ and the oxidative trimerization of arenes,⁹ etc.,¹⁰ have been reported. However, the scope of the above strategies was limited to the preparation of triphenylenes containing electron-donating substituents (e.g., -OR, -SR etc.).^{2a,2g} By contrast, the introduction of electron-withdrawing group is restricted to classic electrophilic aromatic substitutions, which have severe electronic and regioselective constraints,¹¹ and the chemistry of [6]radialene,^{2c,5b} which involves the use of the expensive hexakis(bromomethyl) benzene. On the other hand, most of the syntheses of functionalized triphenylenes suffer from the lack of readily available precursors and require multiple steps with harsh conditions. Thus, the direct and convenient synthesis of triphenylene derivatives from easily available starting materials remains a challenge.

Recently, we developed a concise method to prepare a series of functionalized *ortho*-terphenyls via a CuI-promoted enyne metathesis–Diels-Alder annulation–oxidation strategy.¹² As an extension of our previous work, we envisioned that two vicinal aromatic rings could be fused to the central benzene ring through well-established oxidative coupling reactions to directly construct triphenylene skeletons. More importantly, electron-withdrawing substituents can be easily installed on to the skeleton via DA reactions as shown in Scheme 1. In this paper, we introduce a new strategy for the direct synthesis of donor-acceptor-type triphenylene 2,3-dicarboxylic esters in a one-pot manner through a cascade reaction involving enyne metathesis of diarylacetylene, cycloaddition with dienophile, and subsequent aromatization and oxidative cyclodehydrogenation.

Scheme 2 Two pathways for the synthesis of triphenylene **4a**

Considering that the final step of the synthesis involves an intramolecular oxidative aromatic coupling which works with highly electron-rich precursors,¹³ an electron-rich diarylacetylene is necessary to make the biaryl connection more likely to occur according to our design. The triphenylenes with alkoxy substituents have been most intensively studied due to their liquid crystal properties. Given this, we choose the tetraalkoxy-substituted diarylacetylene (**1a**) as a model substrate. Treatment of **1a** with the Grubbs-2 catalyst in the presence of CuI, followed by DA reaction with dimethylacetylenedicarboxylate (DMAD) and aromatization with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) gave the desired *ortho*-terphenyl (**3a**) in 48 % isolated yield. Subsequent oxidative cyclodehydrogenation of **3a** using 2 equivalents of FeCl₃ as an oxidant in a mixture of dichloromethane and nitromethane at 0 °C gave the final product **4a** in 90 % isolated yield, and 43 % overall yield (Scheme 2,

Table 1 Optimization of reaction conditions^a

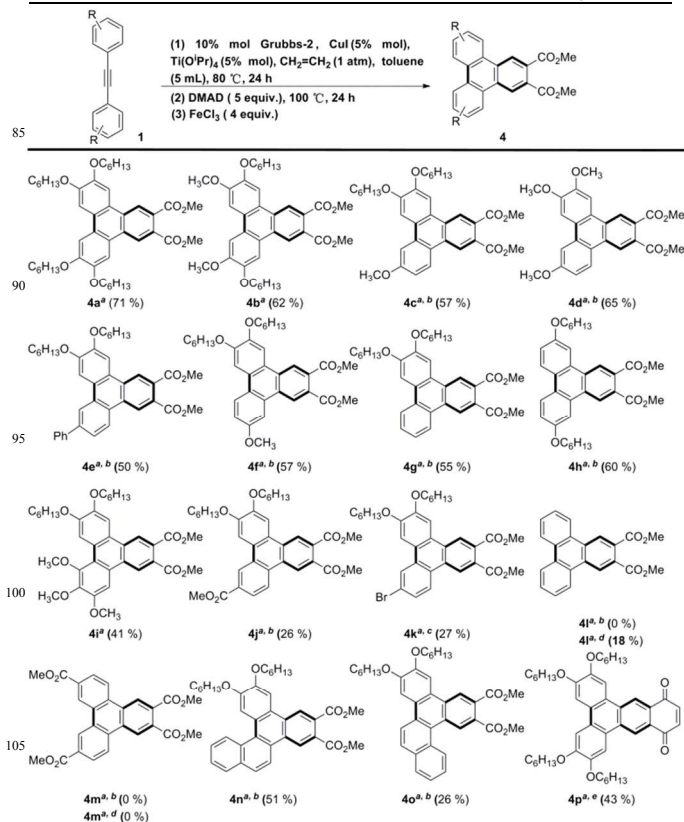
Entry	Grubbs-2 (mol %)	CuI (mol %)	Lewis Acid (mol %)	oxidant (equiv.)	Yield ^b (%)	
					3a	4a
1	10	5	–	FeCl ₃ (2.0)	9	26
2	10	5	–	FeCl ₃ (4.0)	–	58
3	10	5	–	FeCl ₃ (6.0)	–	51
4	10	5	–	FeCl ₃ (8.0)	–	56
5	15	7.5	–	FeCl ₃ (4.0)	–	46
6	20	10	–	FeCl ₃ (4.0)	–	39
7	10	5	AlCl ₃ 10%	FeCl ₃ (4.0)	–	37
8	10	5	TiCl ₄ 5%	FeCl ₃ (4.0)	–	53
9	10	5	Ti(O ⁱ Pr) ₄ 5%	FeCl ₃ (4.0)	–	71
10	10	5	Ti(O ⁱ Pr) ₄ 10%	FeCl ₃ (4.0)	–	66
11	10	5	Ti(O ⁱ Pr) ₄ 15%	FeCl ₃ (4.0)	–	68
12	10	5	Ti(O ⁱ Pr) ₄ 5%	FeCl ₃ (6.0)	–	66
13	10	5	Ti(O ⁱ Pr) ₄ 5%	MoCl ₅ (2.5)	–	55
14	10	5	–	DDQ (1.2)	48	–
15	10	5	Ti(O ⁱ Pr) ₄ 5%	DDQ/MeSO ₃ H (2.4)	–	20

^a Reactions were carried out in the scale of 0.125 mmol of **1a**. ^b Isolated yield.

path a). Since the aromatization of **2a** and the oxidative cyclodehydrogenation of **3a** involve the use of an oxidant, we postulated that the two steps can be processed as one step if the proper amount of oxidant was used. To our delight, treatment of the reaction mixture of **2a** with 4 equivalents of FeCl₃ in a mixture of dichloromethane and nitromethane at 0 °C indeed gave the final product **4a** in 58 % overall isolated yield (Scheme 2, path b). Notably, all steps can be carried out in a one-pot manner, and do not involve the isolation of intermediates.

A previous report has indicated that certain oxygen functionalities in the substrate can strongly coordinate with the ruthenium carbene complex, thereby decreasing its catalytic activity and impeding enyne metathesis.¹⁴ Thus Lewis acids were introduced into the reaction system to compete or prevent the coordination of the O-atom to the ruthenium carbene intermediate.¹⁵ The preliminary study indicates that Ti(OⁱPr)₄ is the best choice in this reaction. When the reaction was run with the addition of 5 % mol of Ti(OⁱPr)₄ using 4 equivalents of FeCl₃ as an oxidant, the reaction gave the expected product **4a** in 71 % overall isolated yield (Table 1, entry 9). Increasing the amount of Ti(OⁱPr)₄ did not affect the reaction. However, AlCl₃ and TiCl₄ were too strong to use in this reaction. Use of other oxidants such as MoCl₅ and DDQ/H⁺ did not afford a better performance than FeCl₃.

Table 2 Synthesis of polysubstituted triphenylene 2,3-dicarboxylic ester

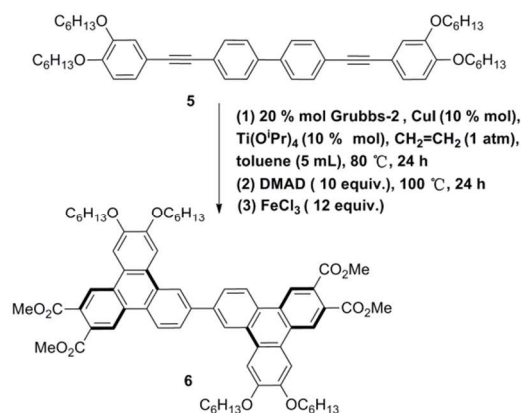


^a All the reactions were carried out in the scale of 0.125 mmol of **1**. Isolated yield. ^b 6.0 equiv. of FeCl₃ was used. ^c 2.5 equiv. of MoCl₅ as oxidant. ^d 5 equiv. of MoCl₅ as oxidant. ^e 2.0 equiv. of 1,4-quinone was used instead of DMAD.

Subsequently, we set out to test different substrates for the formation of polysubstituted triphenylene 2,3-dicarboxylic esters

(Table 1). Various alkoxy-substituted diarylacetylenes were tested and the desired products **4** with different substitution patterns (from tetra- to hepta-substituted) were produced in variable overall yields. The reaction takes place in moderate to good overall yield provided that at least two alkoxy groups are present in one of the rings (from **4a** to **4g**) or if the two alkoxy groups are respectively located at the *para* position of the newly formed bond (**4h**). While some substrates are suitable, the efficiency is decreased for certain electronic (**4j** and **4k**) and steric (**4i**) factors. However, the Br group can be incorporated into the triphenylene skeleton with this strategy (**4k**), which offers the potential for further functionalization. Diphenylacetylene was also used as a substrate but the desired product **4l** was produced in 18 % yield only when 5 equivalents of MoCl₅ were used as an oxidant. Unfortunately, triphenylenes with four electron-withdrawing substituents attached (**4m**) cannot be obtained using this strategy. Moreover, unsymmetrical peripheral substitution can easily be achieved by changing the length of some of the side chains in the substrate, which has a large effect on the thermal behaviour of liquid crystalline materials.¹⁶ Further, the presence of a methoxyl group at the peripheral position can be used to produce valuable hydroxyfunctionalized triphenylenes by demethylation, which can be further utilized to construct more complicated structures.¹⁷ Importantly, 1-((3,4-bis(hexyloxy)phenyl)ethynyl)naphthalene and 2-((3,4-bis(hexyloxy)phenyl)ethynyl)naphthalene were also suitable substrates for the synthesis of more complicated dimethyl-12,13-bis(hexyloxy)benzo[*f*]chrysene-2,3-dicarboxylate (**4n**) and dimethyl-12,13-bis(hexyloxy)benzo[*g*]chrysene-2,3-dicarboxylate (**4o**). Notably, 1,4-quinone is also suitable as a reaction partner, which lead to the formation of 2,3,6,7-tetrakis(hexyloxy)benzo[*f*]tetraphene-10,13-dione (**4p**) in 43 % isolated yield.

This strategy can also be applied to the syntheses of twinned and oligomeric triphenylene discotics. Starting from 4-ethynyl-reaction with commercial 4,4'-diiodo-1,1'-biphenyl furnished the corresponding 4,4'-bis((3,4-bis(hexyloxy)phenyl)ethynyl)-1,1'-biphenyl (**5**). Treatment of **5** with our developed strategy directly afforded the polysubstituted symmetrical triphenylene dimer **6** in 38 % isolated yield (Scheme 3).



Scheme 3 Synthesis of triphenylene dimer

The thermal properties of compound **4a** were examined using polarized optical microscopy and differential scanning calorimetry (DSC). This difunctionalized triphenylene was found

to exhibit columnar hexagonal mesophases over a much broader temperature range of 41-175 °C (Figure 2) *versus* 2,3,6,7,10,11-hexaalkoxytriphenylene, which forms a columnar hexagonal phase from only 67-98 °C (lit.^{3a}). This large difference likely reflects enhancement in the mesophase stability probably through polarisation of the ester carbonyl groups, which exert an

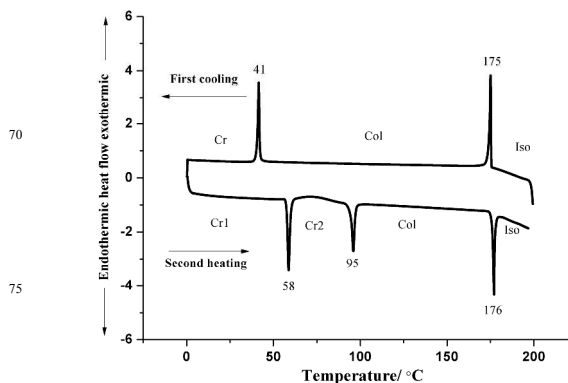


Figure 2 DSC traces of compound **4a** in heating and cooling run (Cr = crystal, Col = columnar, Iso = isotropic).

Conclusions

In conclusion, we have designed an efficient synthetic procedure for the preparation of polysubstituted triphenylene 2,3-dicarboxylic esters via a tandem addition process starting from the readily available diarylacetylene. It should be noted that although this method proceeds in moderate overall yield, it is complementary to other traditional strategies for preparing new types of triphenylene derivatives. This can be viewed as a simple alternative that may offer access to more complicated triphenylene-based molecules with different substitution patterns via a one-pot strategy by tuning the structure of the diarylacetylene and dienophile. Furthermore, the approach herein for covalently linking electron donor and electron acceptor components at the molecular level allows access to new materials which are expected to behave as intrinsic, non-composite p/n-type semiconductors.¹⁸ Our preliminary studies indicate that the compound **4a** exhibits a liquid crystal phase over a much broader temperature range compared to the hexaalkoxytriphenylene. The further research is ongoing in our laboratory.¹⁹

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Notes and references

¹¹⁰ ^a College of Chemistry and Material Sciences, Sichuan Normal University, Chengdu, 610068, P.R. China. E-mail: feng_chun@126.com; wangbiqin1964@126.com

^b Department of Chemistry, The University of Hull, Hull, HU6 7RX, UK

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structural modifications on the self-assembly as well as the mesomorphic properties of triphenylene 2,3-dicarboxylic esters.

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