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Nitric Acid Promoted Metal-Free Bromothiolation of Internal Alkynes with Hydrobromic Acid and Disulfides

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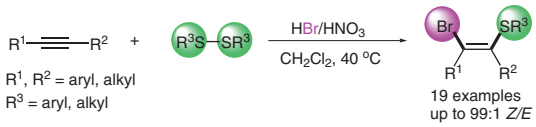

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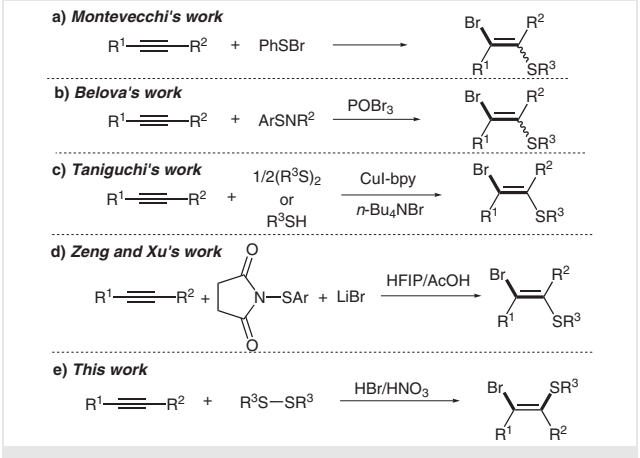
Abstract A novel, metal-free bromo-thiolation of internal alkynes with hydrobromic acid and disulfides has been developed. The reaction is promoted by commercial-grade nitric acid and is used to construct a series of unexplored β-bromoalkenyl sulfides in moderate to good yield. Most products were obtained with high stereoselectivity as *syn*-configured tetrasubstituted alkenes. Both sulfide groups of the disulfide reagent were used in this method.

Key words bromo-thiolation, internal alkynes, hydrobromic acid, disulfides, nitric acid, β-bromoalkenyl sulfides, *syn*-configuration

Alkenyl sulfides are widely utilized as versatile building blocks[1] and key components in the synthesis of many natural products and biologically active molecules.[2] Consequently, new effective synthetic methods for these convenient intermediates has attracted much attention,[3] especially for β-haloalkenyl sulfides, which are easily converted into various alkenes and alkynyl sulfides as coupling partners in nucleophilic substitutions and transition-metal-catalyzed cross-coupling reactions.[4] Since the original work reported by Modena's group,[5] numerous methods have been developed to prepare a variety of β-haloalkenyl sulfides, including chloro,[6] bromo,[7] and iodo[8] groups. However, approaches that can be used to access β-bromoalkenyl sulfides have been less extensively investigated.[9]

Typically, β-bromoalkenyl sulfides are synthesized by bromo-thiolation of alkynes using different sulfenylating agents (Scheme 1a–d). Montevecchi and co-workers realized the addition of sulfenyl bromine to alkynes in 1993.[7a] Belova's group developed the reactions of alkynes and sulfonamides activated by phosphorus oxohalides ($POCl_3$, $POBr_3$).[7b] Subsequently, Taniguchi reported copper-catalyzed addition of halides and sulfide groups to alkynes utilizing disulfides and thiols.[7c,d] Recently, Zeng and Xu's group developed a regio- and stereoselective halothiolation of alkynes using lithium halides (Br, Cl, I) and *N*-thiosuccinimides as starting materials.[7f] Nevertheless, the products of these strategies were *anti*-configured, while the other *syn*-additive isomers come out as byproducts. Moreover, terminal and dialkyl alkynes are more tolerant to these preparations, and diarly acetylenes are not so compatible. Furthermore, some of them suffer from the disadvantages of requiring metal catalysts and unstable sulfenylating agents, which are hard to transfer to an industrial scale. Therefore, the development of metal-free catalyzed, easy-to-handle, stereo- and regioselective synthetic methods for *syn*-configured bromoalkenyl sulfides remains a significant and challenging task.



Scheme 1 Bromothiolation of alkynes

Herein, we present a method for direct bromo-thiolation of internal alkynes using hydrobromic acid (40% aqueous solution) and disulfides, only promoted by commercial-

grade nitric acid (65% aqueous solution) (Scheme 1e). The reported reaction can selectively afford the corresponding *syn*-configured tetrasubstituted alkenes containing two good leaving groups, a thiolate and a bromide, and uses both sulfide groups of the disulfide reagent. Notably, the method can be scaled up to gram-scale with no loss in yield.

Initially, we chose the reaction of diphenylacetylene (**1a**) and *p*-toyl disulfide (**2a**) as the model, given that the *Z*/*E* ratio of the corresponding product can be determined by ^{1}H NMR analysis more clearly (Table 1). It should be noted that the reaction did not occur in the absence of HNO_3, which suggested that HNO_3 played an important role in this transformation (entry 1). Screening of solvents showed that the solvent was crucial to the transformation (entries 2–6). CH_2Cl_2 proved to be the best option and improved both the yield and *Z*/*E* selectivity significantly (entry 3), whereas the use of either THF or DMSO did not produce **3a** at all (entries 5 and 6). NaBr and NH_4Br could also be used as bromine sources with excellent selectivity, while TBAB did not work (entries 7–9). When HNO_3 was replaced with H_2SO_4 and $HClO_4$, only a trace amount of product could be detected by GC-MS (entries 10 and 11). Lower and higher temperature resulted in poor yield of the product (entries 12 and 13). In addition, when the amounts of HNO_3 and HBr were decreased to 0.25 equiv and 5.0 equiv, respectively, the prod-

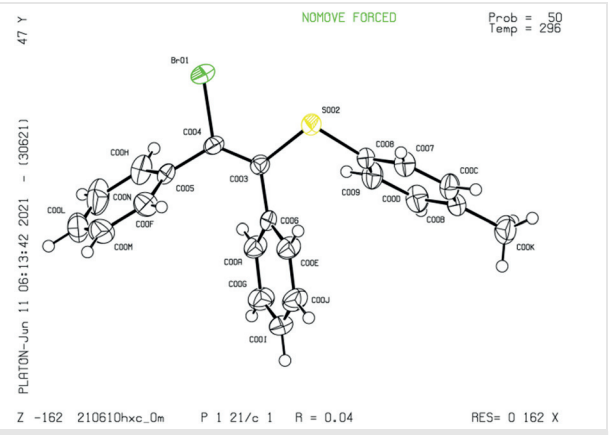
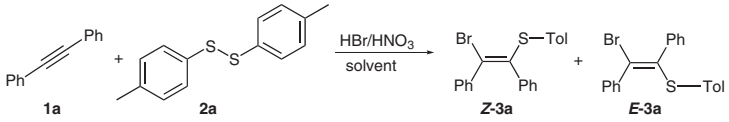


Figure 1 ORTEP drawing of compound **3a**with thermal ellipsoids set at 50% probability

Table 1 Optimization of reaction conditions[a]



Entry	[Br] (equiv)	Additive (equiv)	Solvent	Yield (%)[b]	*Z*/*E*[c]
1	HBr (10.0)	–	DCE	0	–
2	HBr (10.0)	HNO_3 (0.5)	DCE	50	40:60
3	HBr (10.0)	HNO_3 (0.5)	CH_2Cl_2	91	99:1
4	HBr (10.0)	HNO_3 (0.5)	$CHCl_3$	28	50:50
5	HBr (10.0)	HNO_3 (0.5)	THF	0	–
6	HBr (10.0)	HNO_3 (0.5)	DMSO	0	–
7	NaBr (10.0)	HNO_3 (0.5)	CH_2Cl_2	26	99:1
8	NH_4Br (10.0)	HNO_3 (0.5)	CH_2Cl_2	22	99:1
9	TBAB (10.0)	HNO_3 (0.5)	CH_2Cl_2	0	–
10	HBr (10.0)	H_2SO_4 (0.5)	CH_2Cl_2	trace	–
11	HBr (10.0)	$HClO_4$ (0.5)	CH_2Cl_2	trace	–
12[d]	HBr (10.0)	HNO_3 (0.5)	CH_2Cl_2	50	38:62
13[e]	HBr (10.0)	HNO_3 (0.5)	CH_2Cl_2	trace	–
14	HBr (10.0)	HNO_3 (0.25)	CH_2Cl_2	80	86:14
15	HBr (5.0)	HNO_3 (0.5)	CH_2Cl_2	67	72:28
16[f]	HBr (10.0)	HNO_3 (0.5)	CH_2Cl_2	88	91:9

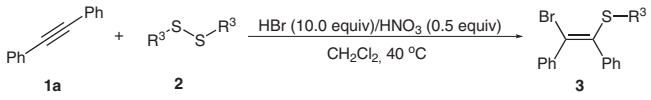
[a] Reaction conditions: **1a** (0.40 mmol), **2a** (0.22 mmol), mixture of HBr and HNO_3, solvent (4 mL), under air, 40 °C, 8 h.
[b] Isolated yield.
[c] *Z*/*E*ratio determined by ^{1}H NMR analysis.
[d] At 20 °C.
[e] At 60 °C for 1 h.
[f] **1a** (4.0 mmol), **2a** (2.2 mmol), solvent (30 mL), 6 h.

uct yield and selectivity decreased to 80% (*Z*/*E*: 86/14, entry 14) and 67% (*Z*/*E*: 72/28, entry 15). To our delight, the reaction could be scaled up to 4.0 mmol, and 1.3 g **3a** (88%) was isolated with only slightly loss in selectivity (*Z*/*E*, 91:9, entry 16 and the Supporting Information).

To confirm the configuration of (*Z*)-**3a** unambiguously, the product was purified by using column chromatography and analyzed by single-crystal X-ray crystallography (Figure 1).

With the optimized conditions in hand, various disulfides were applied in the reaction to establish the scope of this protocol (Table 2). The results disclosed that numerous combinations of diaryl or dialkyl disulfides and diphenylacetylene (**1a**) could produce the corresponding β-bromoalkenyl sulfides in moderate to excellent yields. In general, diaryl disulfides afforded a higher yield and had good *syn*-selectivity (entries 1–8); however, a strong electron-donating group (OMe) adversely affected the regioselectivity (entry 2). Lower yields were observed when *ortho*-substituted substrates were used as coupling partner, because of increased steric hindrance. For example, **2e**, **2g**, and **2i**, bearing an *o*-fluoro, *o*-bromo, and *o*-methy group, respectively, reacted with **1a** to give desired products in 78, 67, and 53% yield (entries 4, 6, and 8). Regrettably, dialkyl disulfides showed lower reactivity and selectivity. When dibenzyl and dicyclohexyl disulfides participated in the reaction, yields and *Z*/*E* ratio decreased to 77% (50:50) and 60% (33:67), while a substrate with a *n*-dibutyl substituent gave the product in 43% yield (entries 9–11).[10]

Table 2 Scope of Disulfides for the Synthesis of β-Bromoalkenyl Sulfides[a]



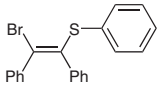
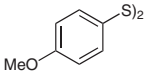
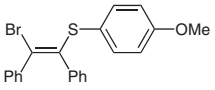
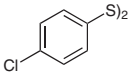
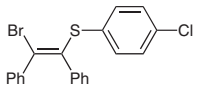
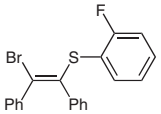
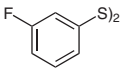
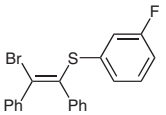
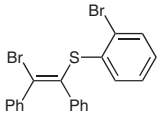
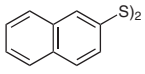
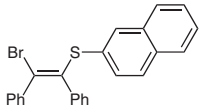
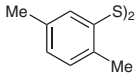
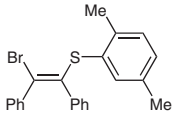
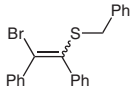
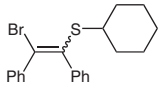
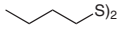
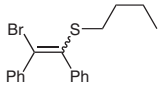
Entry	Disulfide **2**	Product **3**	Yield (%)[b] (*Z*/*E*)[c]
1	 **2b**	 **3b**	90 (99:1)
2	 **2c**	 **3c**	88 (83:17)
3	 **2d**	 **3d**	82 (99:1)
4	 **2e**	 **3e**	78 (99:1)
5	 **2f**	 **3f**	84 (99:1)
6	 **2g**	 **3g**	67 (99:1)

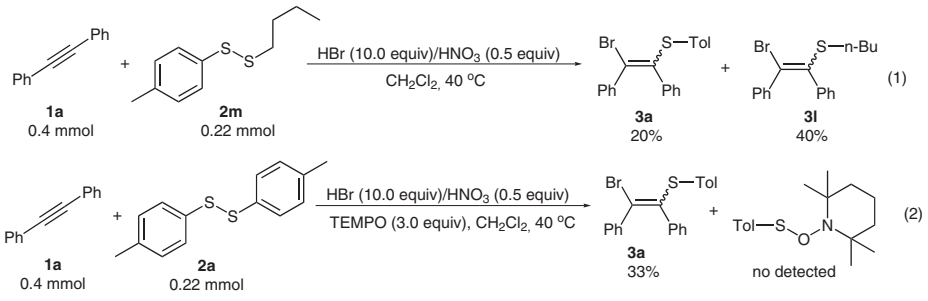
Table 2 (continued)

Entry	Disulfide **2**	Product **3**	Yield (%)[b] (*Z*/*E*)[c]
7	 **2h**	 **3h**	71 (99:1)
8	 **2i**	 **3i**	53 (99:1)
9	 **2j**	 **3j**	77 (50:50)
10	 **2k**	 **3k**	60 (33:67)
11	 **2l**	 **3l**	43 (61:39)

[a] Reaction conditions: **1a** (0.40 mmol), **2** (0.22 mmol), mixture of HBr (4.0 mmol) and HNO_3 (0.2 mmol), in CH_2Cl_2 (4 mL), under air, 40 °C, 8 h.
[b] Isolated yield.
[c] *Z*/*E* ratio determined by ^1H NMR analysis.

Subsequently, a series of alkynes were further examined for the bromothiolation of **2a**. As showed in Table 3, symmetrical arylacetylenes, substituted at the *para*-position including chloro and bromo groups, reacted smoothly, while fluoro and methyl substituents gave a mixture of the *Z*/*E* isomers (entries 1–4). To our delight, unsymmetrical alkynes **1f** and **1g** could be used to selectively produce the β-bromoalkenyl sulfides in 54 and 41% yields, respectively, although the configurations were not confirmed (entries 5 and 6). When dialkylacetylene **1h** was examined, the *anti*-configured product (*E*)-**3t**[7c,d] was afforded in 49% yield. Unfortunately, terminal alkynes, phenylacetylene and 1-heptyne, were not suitable for the reaction (entries 8 and 9).

To identify the possible reaction mechanism, control experiments were conducted (Scheme 2). Firstly, we introduced unsymmetrical disulfide[11] **2m** into the reaction with diphenylacetylene (**1a**). Both sulfide groups were added to alkyne, and afforded the corresponding products **3a** in 20% yield and **3l** in 40% yield (based on 0.4 mmol of **1a**; Eq. 1). Then, the radical scavenger 2,2,6,6-tetramethylpiperidinooxy (TEMPO) was added to the model reaction. The reaction was not inhibited in the presence of TMEPO (3 equiv), giv-

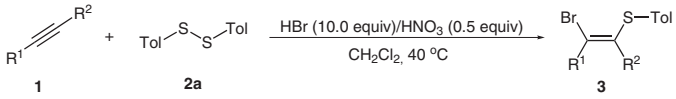


Scheme 2 Control experiments

ing **3a** in 33% yield.[10] Moreover, no adduct of radical quencher was detected, which indicated a radical pathway was unlikely (Eq. 2).[12]

Based on the above results, a proposed mechanism for bromothiolation of diphenylacetylene (**1a**) with diary disulfide **2a** is illustrated (Scheme 3). Initially, nitric acid mixes with excess hydrobromic acid to generate nitrosyl bromide,[13] which can react with **1a** to form *p*-toluensulfenyl bromide **A**.[14] Then, the addition of **A** to alkyne **2a** gives a thiirenium intermediate, which is represented as a covalent species **B** or a tight ion pair **C**.[5] Finally, the intermediate complex collapses to afford the product **3a**, yielding the *syn*-configured adduct. The high *Z*-selectivity of reaction can be rationalized by the tight ion pair **C**, which may dissociate into free thiirenium ion without the influence of good solvent for Br^- and the stabilizing effect of aryl groups.

Table 3 Scope of Diarylacetylenes for the Synthesis of β-Bromoalkenyl Sulfides[a]



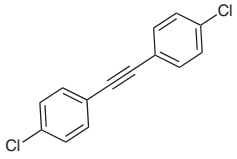
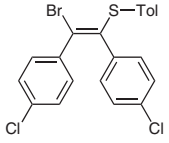
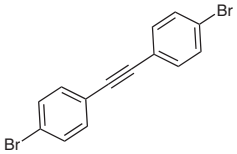
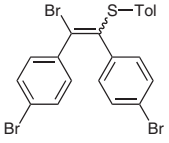
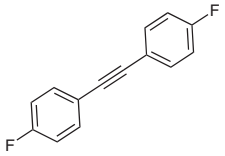
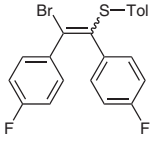
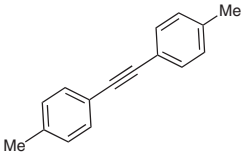
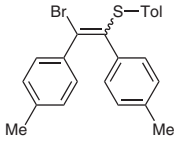
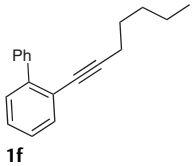
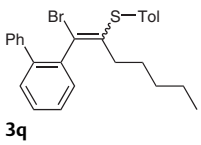
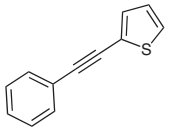
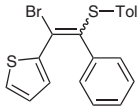
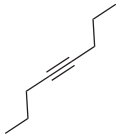
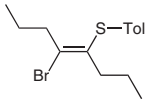
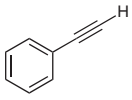
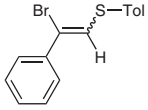
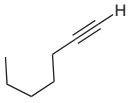
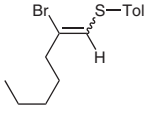
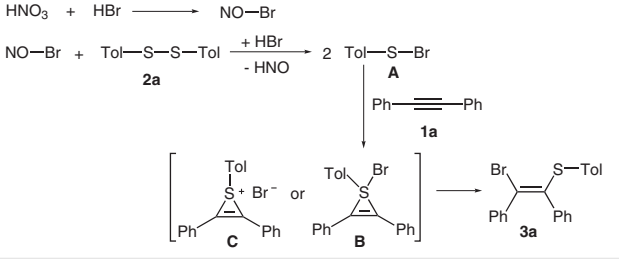
Entry	Diarylacetylene **1a**	Product **3**	Yield (%)[b] (*Z*/*E*)[c]
1	 **1b**	 **3m**	72 (99:1)
2	 **1c**	 **3n**	77 (95:5)
3	 **1d**	 **3o**	66 (61:39)
4	 **1e**	 **3p**	52 (68:32)
5	 **1f**	 **3q**	54 (99:1)

Table 3 (continued)

Entry	Diarylacetylene **1a**	Product **3**	Yield (%)[b] (*Z*/*E*)[c]
6	 **1g**	 **3r**	41 (89:11)
7	 **1h**	 **3s**	49 (1:99)
8	 **1i**	 **3t**	trace
9	 **1j**	 **3u**	trace

[a] Reaction conditions: **1a** (0.40 mmol), **2** (0.22 mmol), mixture of HBr (4.0 mmol) and HNO_3 (0.2 mmol), in CH_2Cl_2 (4 mL), under air, 40 °C, 8 h.
[b] Isolated yield.
[c] *Z*/*E* ratio determined by ^1H NMR analysis.



Scheme 3 Proposed reaction mechanism

In summary, we have developed a metal-free bromothiolation of internal alkynes with disulfides under simple and mild conditions. This unprecedented protocol offers β-bromoalkenyl sulfides with good functional tolerance and high *syn*-stereoselectivity, and showed great promise for the synthesis of bioactive complex alkenyl sulfides. In addition, a scale-up experiment revealed the potential application value of this protocol.

Conflict of Interest

The authors declare no conflict of interest.

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Supporting Information

Supporting information for this article is available online at https://doi.org/10.1055/s-0040-1719934.

References and Notes

(1) (a) Kondo, T.; Mitsudo, T.-A. *Chem. Rev.* **2000**, *100*, 3205. (b) Kuniyasu, H.; Kambe, N. *Chem. Lett.* **2006**, *35*, 1320. (c) Marcantoni, E.; Massaccesi, M.; Petrini, M.; Bartoli, G.; Bellucci, M. C.; Bosco, M.; Sambri, L. *J. Org. Chem.* **2000**, *65*, 4553. (d) Li, Q.; Dong, T.; Liu, X.; Lei, X. *J. Am. Chem. Soc.* **2013**, *135*, 4996. (e) Itami, K.; Higashi, S.; Mineno, M.; Yoshida, J.-I. *Org. Lett.* **2005**, *7*, 1219.

(2) (a) Nieves, I.; Garrido, M.; Abad, J. L.; Delgado, A. *Synlett* **2010**, 2950. (b) Allan, R. D.; Duke, R. K.; Hambley, T. W.; Johnston, G. A. R.; Mewett, K. N.; Quickert, N.; Tran, H. W. *Aust. J. Chem.* **1996**, *49*, 785.

(3) (a) Yu, G.; Ou, Y.; Chen, D.; Huang, Y.; Yan, Y.; Chen, Q. *Synlett* **2020**, *31*, 83. (b) Mulina, O. M.; Doronin, M. M.; Kostyagina, V. A.; Timofeev, G. P. *Russ. J. Org. Chem.* **2021**, *57*, 1302. (c) Lu, F.; Xu, J.; Li, H.; Wang, K.; Ouyang, D.; Sun, L.; Huang, M.; Jiang, J.;

Hu, J.; Alhumade, H.; Lu, L.; Lei, A. *Green Chem.* **2021**, *23*, 7982. (d) Li, X.; Zhang, B.; Yu, Z.; Zhang, D.; Shi, H.; Xu, L.; Du, Y. *Synthesis* **2022**, *54*, 1375. (e) Zhang, D.; Zhang, J.; Li, X.; Yu, Z.; Li, Y.; Sun, F.; Du, Y. *Synthesis* **2022**, *54*, 411.

(4) (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457. (b) Negishi, E.-I.; Anastasia, L. *Chem. Rev.* **2003**, *103*, 1979. (c) Nicolaou, K. C.; Bulger, P. G.; Sarlah, D. *Angew. Chem. Int. Ed.* **2005**, *44*, 4442. (d) Johansson Seechurn, C. C. C.; Kitching, M. O.; Colacot, T. J.; Snieckus, V. *Angew. Chem. Int. Ed.* **2012**, *51*, 5062. (e) Wu, W.; Jiang, H. *Acc. Chem. Res.* **2014**, *47*, 2483.

(5) Calo, V.; Scorrano, G.; Modena, G. *J. Org. Chem.* **1969**, *34*, 2020.

(6) (a) Lucchini, V.; Modena, G.; Valle, G.; Capozzi, G. *J. Org. Chem.* **1981**, *46*, 4720. (b) Capozzi, G.; Caristi, C.; Lucchini, V.; Modena, G. *J. Chem. Soc., Perkin Trans. 1* **1982**, 2197. (c) Capozzi, G.; Romeo, G.; Lucchini, V.; Modena, G. *J. Chem. Soc., Perkin Trans. 1* **1983**, 831. (d) Iwasaki, M.; Fujii, T.; Nakajima, K.; Nishihara, Y. *Angew. Chem. Int. Ed.* **2014**, *53*, 13880. (e) Iwasaki, M.; Fujii, T.; Yamamoto, A.; Nakajima, K.; Nishihara, Y. *Chem. Asian J.* **2014**, *9*, 58. (f) Surineni, N.; Buragohain, P.; Saikia, B.; Barua, N. C.; Baruah, R. K. *Tetrahedron Lett.* **2015**, *56*, 6965. (g) Liang, S.; Jiang, L.; Yi, W.-B.; Wei, J. *Org. Lett.* **2018**, *20*, 7024.

(7) (a) Benati, L.; Montevecchi, P. C.; Spagnolo, P. *Tetrahedron* **1993**, *49*, 5365. (b) Zyk, N. V.; Beloglazkina, E. K.; Belova, M. A.; Zefirov, N. S. *Russ. Chem. Bull.* **2000**, *49*, 1846. (c) Taniguchi, N. *Synlett* **2008**, 849. (d) Taniguchi, N. *Tetrahedron* **2009**, *65*, 2782. (e) Bao, Y.; Zhong, L.; Hou, Q.; Zhou, Q.; Yang, F. *Chin. J. Chem.* **2018**, *36*, 1063. (f) Liu, S.; Zheng, X.; Xu, B. *Org. Chem. Front.* **2020**, *7*, 1690.

(8) (a) Lin, Y.-M.; Lu, G.-P.; Cai, C.; Yi, W.-B. *Org. Lett.* **2015**, *17*, 3310. (b) Bao, Y.; Yang, X.; Zhou, Q.; Yang, F. *Org. Lett.* **2018**, *20*, 1966.

(9) For alkynes thiolation see: (a) Truce, W. E.; Tichenor, G. J. W. *J. Org. Chem.* **1972**, *37*, 2391. (b) Ogawa, A.; Ikeda, T.; Kimura, K.; Hirao, T. *J. Am. Chem. Soc.* **1999**, *121*, 5108. (c) Taniguchi, T.; Fujii, T.; Idota, A.; Ishibashi, H. *Org. Lett.* **2009**, *11*, 3298. (d) Shiu, H.-Y.; Chan, T.-C.; Ho, C.-M.; Liu, Y.; Wong, M.-K.; Che, C.-M. *Chem. Eur. J.* **2009**, *15*, 3839. (e) Jim, C. K. W.; Qin, A.; Lam, J. W. Y.; Mahtab, F.; Yu, Y.; Tang, B. Z. *Adv. Funct. Mater.* **2010**, *20*, 1319. (f) Banerjee, B.; Litvinov, D. N.; Kang, J.; Bettale, J. D.; Castle, S. L. *Org. Lett.* **2010**, *12*, 2650. (g) Jin, Z.; Xu, B.; Hammond, G. B. *Eur. J. Org. Chem.* **2010**, 168. (h) Minozzi, M.; Monesi, A.; Nanni, D.; Spagnolo, P.; Marchetti, N.; Massi, A. *J. Org. Chem.* **2011**, *76*, 450. (i) Nurhanna Riduan, S.; Ying, J. Y.; Zhang, Y. *Org. Lett.* **2012**, *14*, 1780. (j) Singh, R.; Raghuvanshi, D. S.; Singh, K. N. *Org. Lett.* **2013**, *15*, 4202. (k) Truong, V. X.; Dove, A. P. *Angew. Chem. Int. Ed.* **2013**, *52*, 4132. (l) Chen, J.; Chen, S.; Xu, X.; Tang, Z.; Au, C.-T.; Qiu, R. *J. Org. Chem.* **2016**, *81*, 3246. (m) Ye, Y.; Huang, C.; Zhao, C.; Ren, B.; Xiao, H.; Li, X. *Synth. Commun.* **2016**, *46*, 1634. (n) Pramanik, M.; Choudhuri, K.; Chakraborty, S.; Ghosh, A.; Mal, P. *Chem. Commun.* **2020**, *56*, 2991.

(10) **Synthesis of 3; General procedure**: Alkyne **1** (0.40 mmol) and disulfide **2** (0.22 mmol) were added into a 25 mL oven-dried flask and dissolved in dichloromethane (4 mL), then hydrobromic acid (40% aqueous, 10 equiv) mixed with nitric acid (65% aqueous, 0.5 equiv) was added dropwise. The solution was then stirred for 8 h at 40 °C. After the reaction was finished, the reaction mixture was cooled to room temperature, diluted in diethyl ether (15 mL), and washed with brine (2 × 15 mL). The aqueous phase was re-extracted with diethyl ether (15 mL). The combined organic extracts were dried over Na_2SO_4 and concentrated in vacuum and the resulting residue was purified by silica gel column chromatography (hexane/ethyl acetate) to afford product **3**.

Spectroscopic data of (*Z*)-(2-bromo-1,2-diphenylvinyl)(*p*-tolyl)-sulfane (**3a**): Yield: 136.7 mg (91%); white solid; mp 105.0–106.1 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.56 (d, *J* = 8.0 Hz, 2 H), 7.34–7.43 (m, 5 H), 7.17–7.27 (m, 3 H), 7.00 (d, *J* = 8.0 Hz, 2 H), 6.88 (d, *J* = 8.0 Hz, 2 H), 2.19 (s, 3 H). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 140.7, 139.7, 137.2, 136.4, 131.9, 130.1, 129.7, 129.3, 129.2, 128.6, 128.2, 127.8, 127.7, 121.5, 21.0. HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{21}H_{18}{}^{78.9183}BrS$: 381.0307; found: 381.0298. HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{21}H_{18}{}^{80.9163}BrS$: 383.0287; found: 383.0273.

See the Supporting Information for **3a–s**.

(11) Song, M.; Hu, Q.; Li, Z.-Y.; Sun, X.; Yang, K. *Chin. Chem. Lett.* **2022**, *33*, 4269.

(12) (a) Dénès, F.; Pichowicz, M.; Povie, G.; Renaud, P. *Chem. Rev.* **2014**, *114*, 2587. (b) Zhou, S.-F.; Pan, X.-Q.; Zhou, Z.-H.; Shoberu, A.; Zhang, P.-Z.; Zou, J.-P. *J. Org. Chem.* **2015**, *80*, 5348. (c) Lin, Y.-M.; Lu, G.-P.; Wang, G.-X.; Yi, W.-B. *J. Org. Chem.* **2017**, *82*, 382. (d) Fındık, V.; Varinca, B. T.; Degirmenci, I.; Sag Erdem, S. *J. Phys. Chem. A* **2021**, *125*, 3556.

(13) Ratcliffe, C. T.; Shreeve, J. N. M.; Wynne, K. J. *Nitrosyl Halides, inInorganic Syntheses, vol. 11*; Jolly, W. L., Ed.; Wiley: Weinheim, **1968**, 194.

(14) (a) Kroll, F. E. K.; Morphy, R.; Rees, D.; Gani, D. *Tetrahedron Lett.* **1997**, *38*, 8573. (b) Schlosser, K. M.; Krasutsky, A. P.; Hamilton, H. W.; Reed, J. E.; Sexton, K. *Org. Lett.* **2004**, *6*, 819. (c) Yadav, J. S.; Subba Reddy, B. V.; Jain, R.; Baishya, G. *Tetrahedron Lett.* **2008**, *49*, 3015.