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Visible Light Photocatalyzed Direct Conversion of Aryl-/Heteroarylamines to Selenides at Room Temperature

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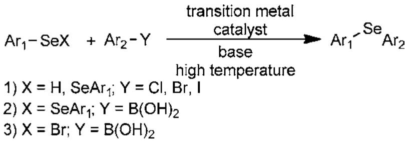
Ⓢ *Supporting Information*

ABSTRACT: A novel strategy for the direct conversion of aryl- and heteroarylamines to selenides has been developed via diazotization of amines with *tert*-butyl nitrite in neutral medium followed by reaction with diaryl/diheteroaryl/dialkyl diselenides in one pot under photocatalysis at room temperature in the absence of any metal. This reaction is also applied for the synthesis of tellurides. The selenylation of heteroarylamine by this protocol is of much significance because of the difficulty in diazotization of these molecules by a standard diazotization method in acid medium.

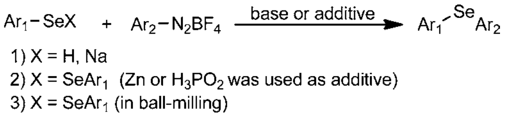
The applications of photoredox catalysis in organic synthesis has received considerable interest in recent years.[1] One of the important applications is toward the formation of aryl radicals which has made light-mediated aromatic substitution a powerful alternative to widely employed metal-catalyzed reactions.[2] These photocatalyzed reactions in the presence of suitable photosensitizers involve a single-electron-transfer process, and the primary merits of these reactions are a metal-free protocol and mild generation of aryl radicals at room temperature.

The organoselenides have received continued interest because of their presence as structural motifs in a variety of molecules of biological, pharmaceutical, and material interest.[3] They are also used as catalysts[4] and useful intermediates[5] in organic reactions. Thus, a number of methods have been developed for their synthesis.[6] One of the widely accepted and efficient practices is the transition-metal-catalyzed C–Se bond formation by the coupling of aryl hadies/boronic acids/triflates and selenol/PhSeNa/diphenyl diselenide (Scheme 1).[7] These reactions are usually performed at a higher temperature for a relatively long period. Recently, aryldiazonium salts have attracted much attention as an important source of aryl radicals, and they have been employed successfully for a variety of aryl substitution reactions.[8] In fact, aryl diazonium salts particularly fluoroborates become an attractive alternative to aryl halides and triflates because of their ease of preparation from readily available amines and better reactivity with high chemoselectivity. The aryl diazonium fluoroborates have also been employed for the synthesis of diaryl selenides by transition-metal-free coupling with diaryl diselenides under microwave irradiation,[9a] by ball-milling,[9b] and by conventional methods in the presence of hypophosphorus acid (Scheme 2).[9c] However, the major limitation of these processes using diazonium fluoroborates is toward the synthesis of heteroaryl selenides as heteroarylamines such as pyridinyl- and quinolinyl-amines are difficult to diazotize because of their tendency to form salt during diazotization in acidic medium.[10] A similar difficulty is also encountered in the reaction of 2-ethynylanilines which form cinnolones readily during diazotization.[11] Needless to say, conversion of these amines to selenides was not addressed in any of these procedures.[9]

Scheme 1. Transition-Metal-Catalyzed Cross-Coupling Reactions To Form a C–Se Bond



Scheme 2. Transition-Metal-Catalyst-Free Reaction To Form a C–Se Bond Using Diazonium Salts



To overcome these drawbacks, we report here a novel protocol for the synthesis of aryl/heteroaryl selenides from aryl/heteroarylamines using ^{t}BuONO and diaryl/diheteroaryl/dialkyl selenides in one pot at room temperature under photocatalysis in absence of any metal and base (Scheme 3). Although a couple of reports on visible light photocatalyzed C–S bond formation involving diazonium ion appeared recently (Scheme 4)[8f,h] there is no report on C–Se bond formation from anilines in one pot.

To standardize the reaction conditions, a series of experiments were performed under varying reaction parameters such

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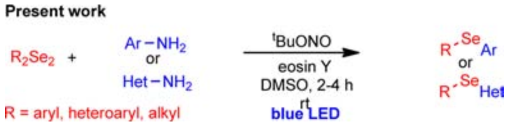
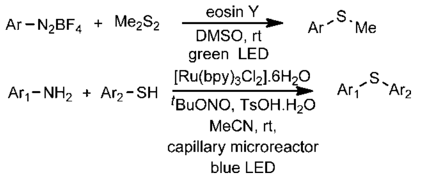
Scheme 3. Visible Light Photocatalyzed Direct One-Pot Synthesis of Organoselenides from Aryl- and Heteroarylamines

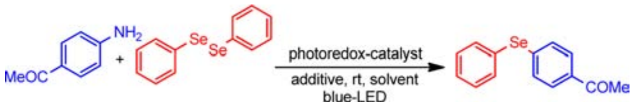


Scheme 4. Recent Developments on C−S Bond Formation under Visible Light Photocatalysis



as additive, organocatalyst, solvent, and time for a representative reaction of 4-aminoacetophenone and diphenyl diselenide. Among a variety of solvents and organocatalysts studied, eosin Y as a single-electron-transfer agent in DMSO produced the best result under the blue-LED light (Table 1, entry 2). The reaction did not proceed in the absence of either blue-LED or eosin Y (Table 1, entries 10 and 11). Although [Ru(bpy)$_3$]Cl$_2$ too serves as SET agent in this reaction (Table 1, entry 9) less expensive eosinY becomes obvious choice in place of highly expensive ruthenium catalyst. Other SET reagents such as Rose Bengal or fluoroscein (Table 1, entries 12 and 13) failed to produce satisfactory results. Although CH$_3$CN is considerably effective (Table 1, entry 4), in other polar solvents such as DMF, 1,4-dioxane, and THF much lower yields were obtained (Table 1, entries 3, 5, and 8). Nonpolar solvents like toluene and xylene did not initiate the reaction at all (Table 1, entries 6 and 7). The reaction did not proceed in the absence of ^{t}BuONO (Table 1, entry 1).

Table 1. Standardization of Reaction Conditions[a]

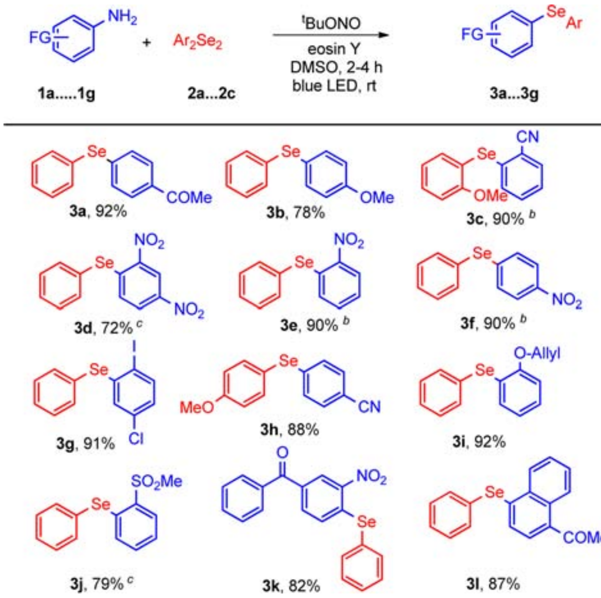


entry	photocatalyst	solvent	additive	time (h)	yield[b] (%)
1	eosin Y	DMSO		10	
2	eosin Y	DMSO	^{t}BuONO	2	90
3	eosin Y	DMF	^{t}BuONO	2	30
4	eosin Y	CH$_3$CN	^{t}BuONO	2	70
5	eosin Y	1,4-dioxane	^{t}BuONO	25	trace
6	eosin Y	toluene	^{t}BuONO	30	
7	eosin Y	Xylene	^{t}BuONO	16	
8	eosin Y	THF	^{t}BuONO	16	trace
9	[Ru(bpy)$_3$]Cl$_2$	DMSO	^{t}BuONO	16	80
10[b]	eosin Y	DMSO	^{t}BuONO	18	
11		DMSO	^{t}BuONO	18	
12	fluoroscene	DMSO	^{t}BuONO	6	22
13	rose bengal	DMSO	^{t}BuONO	6	trace

[a] Reaction conditions: amine (0.5 mmol), diselenide (0.5 mmol), additive (1.1 mmol), photocatalyst (0.01 mmol), blue LED. [b] Reaction was carried out in the absence of light.

Thus, in a general experimental procedure a mixture of amine (0.5 mmol), diaryl diselenide (0.5 mmol) ^{t}BuONO (0.6 mmol), and eosin Y (0.01 mmol) in DMSO (2 mL) was stirred under blue-LED light at room temperature for 2 h (TLC). After evaporation of DMSO, standard workup by extraction with ethyl acetate followed by column chromatography over silica gel provided the pure product. A wide range of diversely substituted aryl- and heteroarylamines underwent reactions with diaryl diselenides by this procedure to produce the corresponding selenides. The products obtained from arylamines are outlined in Scheme 5 and those with heteroarylamines in Scheme 6. Both electron donating (−OMe, −*O*-allyl) and electron withdrawing (−COMe, −CN, −CF$_3$, −NO$_2$) groups at all positions of the aromatic ring are compatible with these reactions. The dinitro-substituted phenyl phenyl selenide (Scheme 5, **3d**), which is of great potential for biological activity,[12] has been easily prepared by this procedure. A series of substituted aryl heteroaryl and diheteroaryl selenides have been efficiently obtained from the corresponding anilines (Scheme 6) by this protocol. This is of much interest to pharmaceutical industries as these compounds are of considerable importance for biological screening.[13] Several heterocyclic units such as pyridinyl, quinolinyl, and thiazolyl anilines, which do not provide selenides by the conventional procedures using diazonium fluoroborates,[8f,9] have been successfully employed in this selenylation reaction (Scheme 6). 2-Ethynylanilines that produce cinnolones via a diazotization reaction[11] are readily converted to the corresponding 2-alkynylaryl selenides by this protocol (Scheme 7).

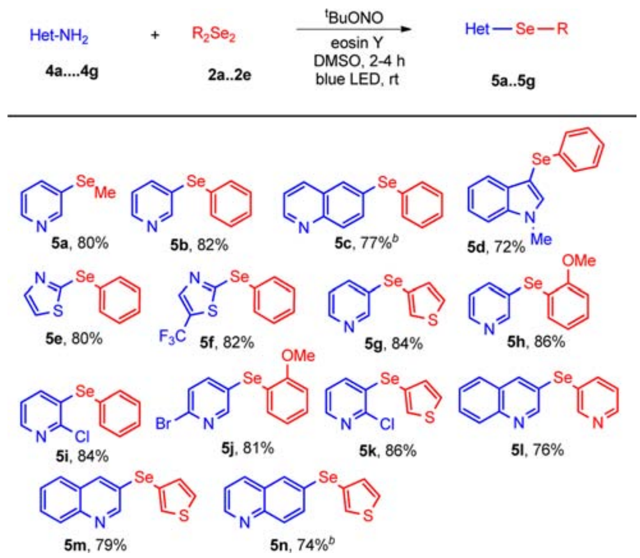
Scheme 5. Visible Light Photocatalyzed Synthesis of Diaryl Selenides[a]



[a] Reaction conditions: amine (1.0 mmol), diselenide (1.0 mmol), ^{t}BuONO (1.1 mmol), eosin Y (0.01 mmol), DMSO (2.0 mmol), blue LED, 2 h. [b] 3 h. [c] 4 h.

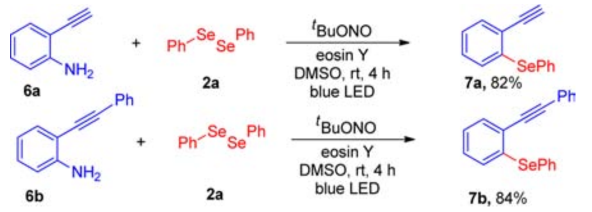
This strategy is also applied for the synthesis of unsymmetrical bis-selenides and selenosulfides starting from nitroanilines (Scheme 8) and diaryl and aryl heteroaryl tellurides from the corresponding anilines (Scheme 9).

Scheme 6. Visible Light Photocatalyzed Synthesis of Heteroaryl Selenides[a]

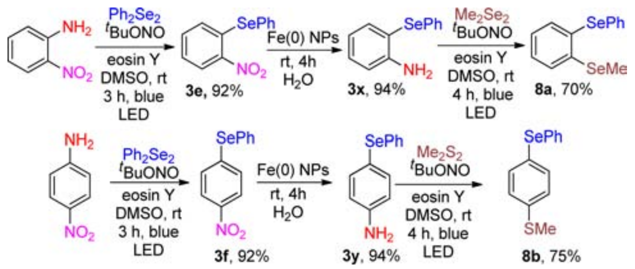


[a] Reaction conditions: heteroarylamine (1.0 mmol), diselenide (1.0 mmol), ^{t}BuONO (1.1 mmol), eosin Y (0.01 mmol), DMSO (2.0 mmol), blue LED, 2 h. [b] 3 h.

Scheme 7. Visible Light Photocatalyzed One-Pot Synthesis of 2-Ethynyl Aryl Selenides from 2-Ethynylamines



Scheme 8. Visible Light Photocatalyzed Synthesis of Bis-Selenide and Selenosulfide Starting from Nitroanilines

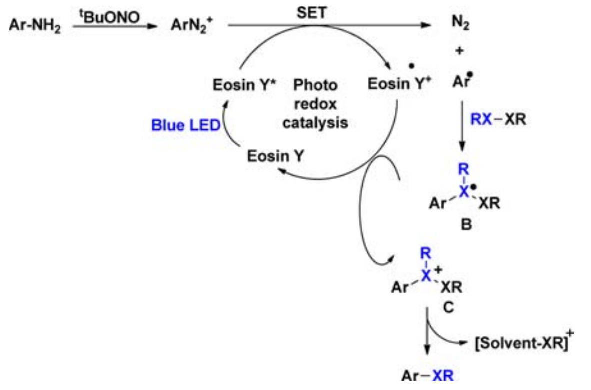


Scheme 9. Visible Light Photocatalyzed Synthesis of Tellurides

In general, the reactions are clean and high yielding. The reactions are performed at room temperature in neutral reaction medium, which makes the procedure compatible with a wide range of functionalities and heteroarylanilines. As mentioned earlier, very recently two similar procedures under photocatalysis have been reported for C−S bond formation.[8f,h] One of these[8f] involved a two-step procedure using preformed diazonium fluoroborate, although the other one[8h] presents a direct conversion of anilines to sulfides using thiols and Ru catalyst. However, they are primarily concerned with C−S bond formation, and only one reaction for the synthesis of aryl selenide was addressed in the two-step procedure.[8f] Thus, the present procedure of C−Se bond formation is quite different, presenting an efficient and general procedure for a one-pot conversion of anilines including heteroaryl- and 2-ethynylaryl-amines to selenides and tellurides.

Most likely, the reaction occurs by the interaction of the aryldiazonium ion, generated in situ, with the diphenyl diselenide under visible light. A reaction pathway is outlined in Scheme 10 in accordance with the previous reports.[8] Aryl diazonium ion undergoes reduction by photoactivated eosin Y, and the resulting aryl radical interacts with diaryl diselenide to produce a trivalent selenide radical **B** which is stabilized by aryl and selenium moiety. The radical **B** then leads to intermediate **C** via one-electron oxidation by eosin Y radical cation, which undergoes cleavage to provide the product. The involvement of radical pathway is confirmed by arrest of the reaction in presence of TEMPO (radical quencher) and THF (radical trapper).

Scheme 10. Possible Reaction Pathway for Visible Light Photocatalyzed Synthesis of Organochalcogenides from Anilines



To conclude, an efficient and general method for the one-pot conversion of aniline to selenide at ambient conditions under photocatalysis is developed. This procedure avoids isolation and handling of hazardous diazonium salt and use of any metal. The reaction tolerates a broad range of functionalities, and more significantly heteroaryl- and 2-ethynylanilines are successfully converted to the corresponding selenides in this procedure, which were not addressed in earlier reports.[8f,9] This protocol is also employed for the synthesis of tellurides. We are not aware of any procedure for direct conversion of anilines to selenides and tellurides in one-pot at room temperature under visible light, and thus, this is the first report of this reaction using a green protocol.

■ ASSOCIATED CONTENT

S Supporting Information

Typical experimental procedure and characterization data of all products and copies of their ^{1}H NMR and ^{13}C NMR spectra.

This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) (a) Reckenthaler, M.; Griesbeck, A. G. *Adv. Synth. Catal.* **2013**, *355*, 2727. (b) Hari, D. P.; Konig, B. *Angew. Chem., Int. Ed.* **2013**, *52*, 4734. (c) Prier, C. K.; Rankic, D. A.; MacMillan, D. W. C. *Chem. Rev.* **2013**, *113*, 5322.

(2) (a) Lerardini, R.; Peduli, G. F.; Tundo, A.; Zanardi, G. *J. Chem. Soc., Chem. Commun.* **1985**, 1390. (b) Lerardini, R.; Nanni, D.; Tundo, A.; Zanardi, G. *Synthesis* **1988**, 333. (C) Prantsch, G.; Heinrich, M. In *Radicals in Synthesis III*; Heinich, M., Ganasauer, A., Eds.; Springer: Berlin/Heidelberg, 2012; Vol. *320*, pp 33−59. (d) Wetzel, A.; Ehrhardt, V.; Heinrich, M. R. *Angew. Chem., Int. Ed.* **2008**, *47*, 9130. (e) Heinrich, M. R.; Wetzel, A.; Kirschstein, M. *Org. Lett.* **2007**, *9*, 3833. (f) Pratsch, G.; Anger, C. A.; Ritter, K.; Heinrich, M. R. *Chem.—Eur. J.* **2011**, *17*, 4104. (g) Staples, M. K.; Grange, R. L.; Angus, J. A.; Ziogas, J.; Tan, N. P. H.; Taylor, M. K.; Schiesser, C. H. *Org. Biomol.Chem.* **2011**, *9*, 473.

(3) (a) Mugesh, G.; duMont, W. W.; Sies, H. *Chem. Rev.* **2001**, *101*, 2125. (b) Nogueira, C. W.; Zeni, G.; Rocha, J. B. T. *Chem. Rev.* **2004**, *104*, 6255. (c) Woods, J. A.; Hadfield, J. A.; Mcgown, A. T.; Fox, B. W. *Bioorg. Med. Chem.* **1993**, *1*, 333. (d) Engman, L.; Stern, D.; Frisell, H.; Vessman, K.; Berglund, M.; Ek, B.; Anderson, C. M. *Bioorg. Med. Chem.* **1995**, *3*, 1255. (e) Bernardon, J.-M.; Diaz, P. *PCT Int. Appl.* WO 1999065872 A1, 1999. (f) Millois, C.; Diaz, P. *Org. Lett.* **2000**, *2*, 1705.

(4) Wirth, T. *Tetrahedron* **1999**, *55*, 1.

(5) (a) Okamoto, Y. In *The Chemistry of Organic Selenium and Tellurium Compounds*; Patai, S., Rappoport, Z., Eds.; Wiley: Chichester, U. K., 1986; Vol. *1*, p 10. (b) Hellberg, J.; Remonen, T.; Johansson, M.; Inganas, O.; Theander, M.; Engman, L.; Eriksson, P. *Synth. Met.* **1997**, *84*, 251.

(6) (a) Miyaura, N. In *Metal-Catalyzed Cross Coupling Reactions*; de Meijere, A., Diederich, F., Eds.; Wiley-VCH: Weinheim, 2004; Vol. *1*, pp 41−123. (b) Zeni, G.; Ludtke, D. S.; Panatieri, R. B.; Braga, A. L. *Chem. Rev.* **2006**, *106*, 1032. (c) Perin, G.; Lenardao, E. J.; Jacob, R. G.; Panatieri, R. B. *Chem. Rev.* **2009**, *109*, 1277.

(7) (a) Nishiyama, Y.; Tokunaga, K.; Sonada, N. *Org. Lett.* **1999**, *1*, 1725. (b) Itoh, T.; Mase, T. *Org. Lett.* **2004**, *6*, 4587. (c) Cristau, H. J.; Chaband, B.; Chene, A.; Christol, H. *Synthesis* **1981**, 892. (d) Takagi, K. *Chem. Lett.* **1987**, 2221. (e) Suzuki, H.; Abe, H.; Osuka, A. *Chem. Lett.* **1981**, 151. (f) Kwong, F. Y.; Buchwald, S. L. *Org. Lett.* **2002**, *4*, 3517. (g) Gujadhur, R. K.; Venkataraman, D. *Tetrahedron Lett.* **2003**, *44*, 81. (h) Wang, M.; Ren, K.; Wang, L. *Adv. Synth. Catal.* **2009**, *351*, 1586. (i) Correa, A.; Carril, M.; Bolm, C. *Angew. Chem., Int. Ed.* **2008**, *120*, 2922.

(8) (a) Kalyani, D.; McMurtrey, K. B.; Neufeldt, S. R.; Sanford, M. S. *J. Am. Chem. Soc.* **2011**, *133*, 18566. (b) Hari, D. P.; Schroll, P.; Konig, B. *J. Am. Chem. Soc.* **2012**, *134*, 2958. (c) Hari, D. P; Hering, T.; Konig, B. *Org. Lett.* **2012**, *14*, 5334. (d) Yu, J.; Zhang, L.; Yan, G. *Adv. Synth. Catal.* **2012**, *354*, 2625. (e) Schroll, P.; Hari, D. P.; Konig, B. *Chem. Open* **2012**, *1*, 130. (f) Majek, M.; Wanglein, A. J. V. *Chem. Commun.* **2013**, *49*, 5507. (g) Hering, T.; Hari, D. P.; Konig, B. *J. Org. Chem.* **2012**, *77*, 10347. (h) Wang, X.; Cuny, G. D.; Noel, T. *Angew Chem., Int. Ed.* **2013**, *52*, 7860. (i) Xiao, T.; Dong, X.; Tang, Y.; Zhou, L. *Adv. Synth. Catal.* **2012**, *354*, 3195.

(9) (a) Kundu, D.; Ahammed, S.; Ranu, B. C. *Green Chem.* **2012**, *14*, 2024. (b) Mukherjee, N.; Chatterjee, T.; Ranu, B. C. *J. Org. Chem.* **2013**, *8*, 11110. (c) Balaguez, R. A.; Ricordi, V. G.; Freitas, C. S.; Perin, G.; Schumacher, R. F.; Alves, D. *Tetrahedron Lett.* **2014**, *55*, 1057.

(10) Wang, X.; Xu, Y.; Mo, F.; Ji, G.; Qiu, D.; Feng, J.; Ye, Y.; Zhang, S.; Zhang, Y.; Wang, J. *J. Am. Chem. Soc.* **2013**, *135*, 10330.

(11) Dey, R.; Chatterjee, T.; Ranu, B. C. *Tetrahedron Lett.* **2011**, *52*, 461.

(12) Engman, L.; Cotgreave, I.; Angulo, M.; Taylor, C. W.; Paine-Murrieta, G. D.; Powis, G. *Anticancer Res.* **1997**, *17*, 4599.

(13) (a) Matsho, M.; Ogino, T.; Tsuri, K. *PCT Int. Appl.* WO 1996030370 A2, 1996. (b) Kundu, D.; Chatterjee, T.; Ranu, B. C. *Adv. Synth. Catal.* **2013**, *355*, 2285.