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Regioselective intramolecular cyclization of *o*-alkynyl arylamines with the *in situ* formation of ArXCl to construct poly-functionalized 3-selenylindoles†

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In this article, a practical and metal-free method for the synthesis of poly-functionalized 3-selenyl/sulfenyl/telluriumindoles from *o*-alkynyl arylamines has been achieved. In this protocol, the *in situ* formation of selenenyl chloride, sulfenyl chloride or tellurenyl chloride is considered as the key intermediate and the 3-selenyl/sulfenyl/telluriumindoles can be obtained in good to excellent yields. Furthermore, the product 2-phenyl-3-(phenylselanyl)-1-tosyl-1*H*-indole can be selectively oxidized to compounds 2-phenyl-3-(phenylseleninyl)-1-tosyl-1*H*-indole and 2-phenyl-3-(phenylselenonyl)-1-tosyl-1*H*-indole in good yields.

Introduction

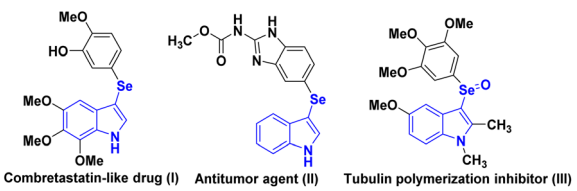
As an active nitrogen-containing heterocyclic skeleton, indole exists widely in biologically active natural products and synthetic bioactive products, and represents an important "privileged scaffold".[1] Among the numerous indoles, 3-arylselenoindoles are particularly attractive due to their potential use in therapeutics such as anti-oxidant, anti-tumor, and anti-cancer agents.[2] For example, as a novel combretastatin-like drug, 3-selenylindole compound (I) exhibits highly potent inhibitory activity against cancer cells[3] (Scheme 1). *In vitro* tubulin polymerization and immunostaining experiments showed that antineoplastic agent (II) significantly inhibits tubulin polymerization *in vitro*.[4]

Acting as a tubulin polymerization inhibitor, the corresponding selenoxide of 3-(3,4,5-trimethoxyphenyl)seleno-1*H*-indole inhibits tumor cells by interfering with the tubulin system of tumor cells.[4–6] Therefore in terms of the unique biological activity and the synthetic methodology, the building of selenium-containing compounds has become one of the most hotspot in the last decade.[7]

Direct selenylation based on the indole compounds is one of the most classical synthetic methods to construct 3-selenylindoles.[8] Undeniably, 2-alkynylanilines are also powerful synthons for the synthesis of 3-selenylindoles[9–13] (Scheme 2).

The metal-catalyzed (facilitated) selenoamination of 2-alkynylanilines with diorganyl diselenides had been achieved in the past decade[9,10] (Scheme 2a). In 2009, Larock and co-workers reported a two-step process of synthesis 3-selenylindoles with arylselenyl chlorides in the presence of a stoichiometric amount of *n*-Bu_4NI[11] (Scheme 2b). Most recently, visible light catalysis for the construction of bioactive molecules has received increasing attention.[14] In 2017, an efficient method for the preparation of 3-selenyl indoles through visible light-promoted tandem cyclization of 2-alkynylanilines with diaryl(alkyl)diselenides under transition metal-free and photocatalyst-free conditions was reported[12] (Scheme 2c). Therefore, the development of a practical protocol of construct of 3-selenylindoles under metal-free conditions is still desirable.

Because of the unstable properties of the sulfenyl chlorides or selenenyl chlorides, Du and co-works have developed a metal-free protocol about the *in situ* formation of PhXCl from PhXXPh and $PhICl_2$ to the synthesis of chalcogenides.[15] In recent years, one of the research focuses of our group is the construction of heterocyclic compounds based on the controllable functionalization of alkynes.[16] Inspired by the works



Scheme 1 Bioactive compounds of 3-selenylindoles.

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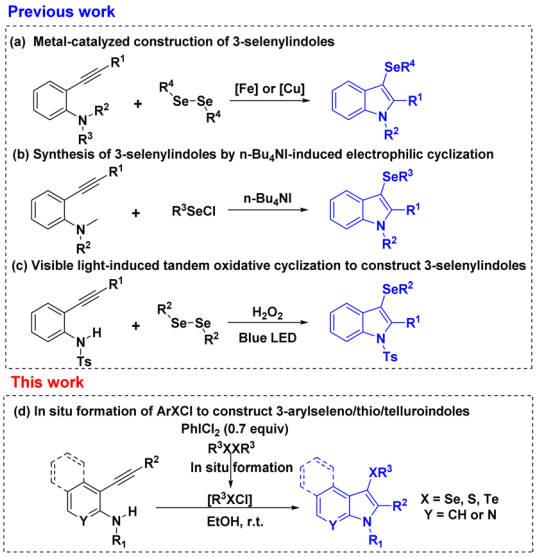


Scheme 2 Methods for the synthesis of 3-selenylindoles.

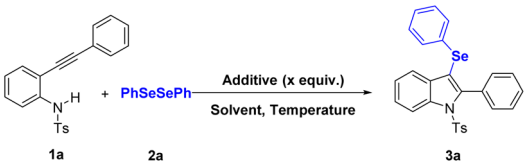
above, herein, we report a simple metal-free method to afford the 3-selenyl/sulfenyl/telluriumindoles in the presence of the *in situ* generated ArSeCl, ArSCl, or ArTeCl from the reaction between the diselenides, disulfides, or ditellurides and $PhICl_2$ (Scheme 2d).

Results and discussion

In order to verify the feasibility of this reaction, 4-methyl-*N*-(2-(phenylethynyl)phenyl)benzenesulfon-amide (**1a**) was initially employed to react with 1,2-diphenyldiselane (**2a**) under various conditions (Table 1). To our delight, after adding substrate **1a** (0.20 mmol) to the solution of the reaction of substrate **2a** (0.10 mmol) and $PhICl_2$ (0.14 mmol) in MeCN (2.0 mL) at room temperature then stirring the mixtures for 12 hours in the absence of light delivered the desired product 2-phenyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (**3a**) in a yield of 85% (Table 1, entry 1). Changing the hypervalent iodine(III) oxidants from $PhICl_2$ to PIDA or PIFA gave the poor conversion under otherwise identical conditions (Table 1, entries 2 and 3). When using *m*CPBA as the oxidant, the expected product **3a** was not detected (Table 1, entry 4). Hereafter, a series of solvents including DMF, DMAC, DCM, toluene, and EtOH were tested and the solvent screening revealed that DCM and EtOH provided superior results in yields of 88% and 97%, respectively (Table 1, entries 5–9). As we can see, increasing or decreasing the amount of the oxidant $PhICl_2$ resulted in reduced conversions (Table 1, entries 10 and 11). Increasing the amount of PhSeSePh **2a** to 0.15 mmol gave the similar result (Table 1, entry 12). Conducting the reaction under an ice-bath or 50 °C rather than at room temperature, lower yields were observed (Table 1, entries 13 and 14). Finally, the best conditions for the preparation of 3-selenylindoles were 0.5 equiv. of PhSeSePh and 0.7 equiv. of $PhICl_2$ in EtOH at room temperature.

With the optimized reaction conditions in hand, a variety of *o*-alkynyl arylamines were prepared and we investigated the

Table 1 Optimization of the reaction conditions[a,b]

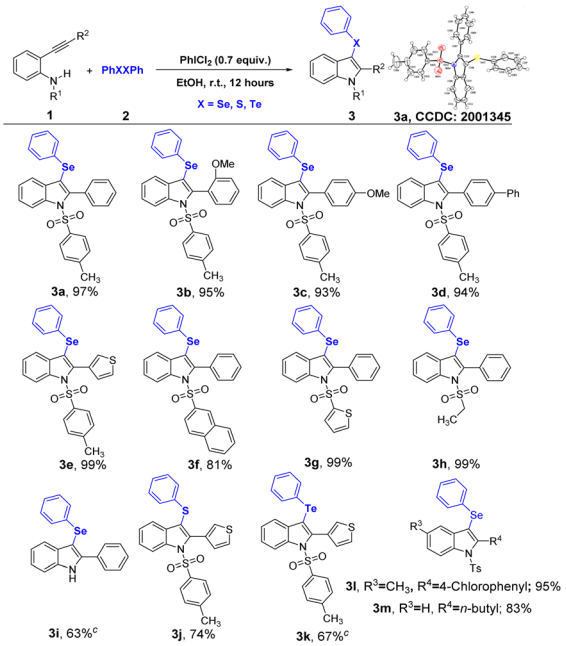


Entry	Additive (equiv.)	Solvent	*T* (°C)	Yield (%)
1	$PhICl_2$ (0.7)	MeCN	r.t.	85
2	PIDA (0.7)	MeCN	r.t.	10
3	PIFA (0.7)	MeCN	r.t.	13
4	*m*CPBA (0.7)	MeCN	r.t.	N.D.
5	$PhICl_2$ (0.7)	DMF	r.t.	42
6	$PhICl_2$ (0.7)	DMAC	r.t.	40
7	$PhICl_2$ (0.7)	DCM	r.t.	88
8	$PhICl_2$ (0.7)	Toluene	r.t.	61
9	**$PhICl_2$ (0.7)**	**EtOH**	**r.t.**	**97**
10	$PhICl_2$ (0.8)	EtOH	r.t.	91
11	$PhICl_2$ (0.6)	EtOH	r.t.	90
12[c]	$PhICl_2$ (0.7)	EtOH	r.t.	94
13	$PhICl_2$ (0.7)	EtOH	0	72
14	$PhICl_2$ (0.7)	EtOH	50	86

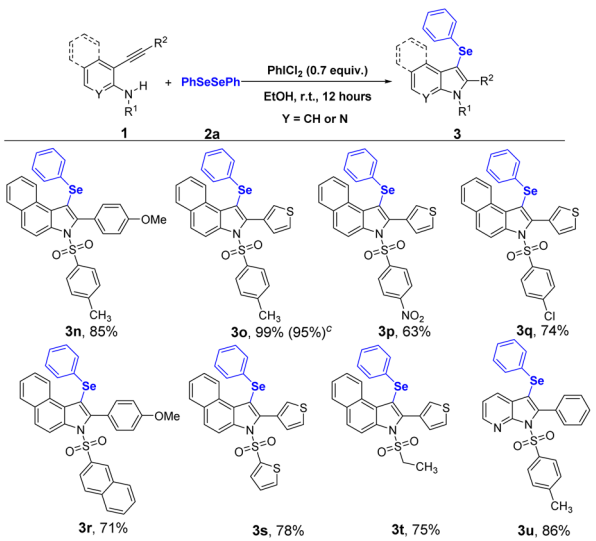
[a] Reaction conditions: **1a** (0.20 mmol) and **2a** (0.10 mmol) in solvent (2.0 mL) were stirred for 12 hours in the absence of light. [b] Isolated yields. [c] **2a** (0.15 mmol).

generality of these regioselective intramolecular cyclization under the *in situ* formation of ArXCl to construct polyfunctionalized 3-selenyl/sulfenyl/telluriumindoles (Schemes 3 and 4). 2-Phenyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (**3a**) was synthesized under the standard conditions which was identified by NMR, HRMS, IR, and the diffraction of X-ray (CCDC: 2001345†). Firstly, the reactions of various substituted *N*-(2-(argioethynyl)phenyl)-4-methylbenzenesulfonamides **1b–1e** with 1,2-diphenyldiselane (**2a**) were examined, which afforded the corresponding products with the different functional groups on the aromatic rings **3b–3e** in 93–99% yields. It is noteworthy that 3-(phenylselanyl)-2-(thiophen-3-yl)-1-tosyl-1*H*-indole **3e** exhibited the high yield in 99%. Regarding the scope of sulfonyl functionality, fortunately, besides *p*-tolylsulfonyl substrates, naphthylsulfonyl **1f**, 1-thiophen-2-sulfonyl **1g** and ethylsulfonyl **1h** could also successfully participated in the current selenium cyclization, leading to the desired products **3f**, **3g** and **3h** in 81%, 99% and 99% yield, respectively. To our delight, the reaction underwent smoothly when using the substrate with no protecting group substituted, and gave the product 2-phenyl-3-(phenylselanyl)-1*H*-indole (**3i**) in 63% yield by extending the reaction time to 24 hours. 1,2-Diphenyldisulfane (**2b**) and 1,2-diphenylditellane (**2c**) were also used as the reaction substrate under the standard conditions, the expected products 3-(phenylthio)-2-(thiophen-3-yl)-1-tosyl-1*H*-indole (**3j**) and 3-(phenyltellanyl)-2-(thiophen-3-yl)-1-tosyl-1*H*-indole (**3k**) were synthesized in 74% and 67% yield, respectively.

When there is a methyl substituent on the benzene ring, the reaction proceeded smoothly and **3l** was obtained in excellent



Scheme 3 Synthesis of 3-selenyl/sulfenyl/telluriumindoles. [a]Reaction conditions: **1** (0.20 mmol), **2** (0.10 mmol), and $PhICl_2$ (0.14 mmol) in EtOH (2.0 mL) were stirred at room temperature for 12 h in the absence of light. [b]Isolated yields. [c]Reaction for 24 hours.

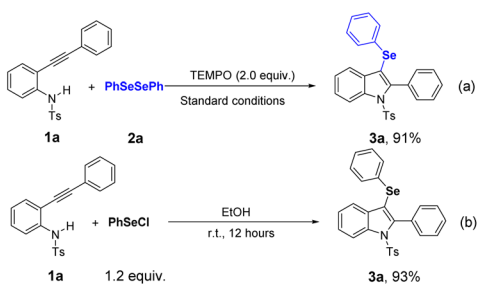


Scheme 4 Synthesis of 3-arylselenobenzo[*e*]indoles and 3-arylselenopyrrolo[2,3-*b*]pyridine. [a]Reaction conditions: **1** (0.20 mmol), **2** (0.10 mmol), and $PhICl_2$ (0.14 mmol) in EtOH (2.0 mL) were stirred at room temperature for 12 hours in the absence of light. [b]Isolated yields. [c]1.0 mmol scale experiment.

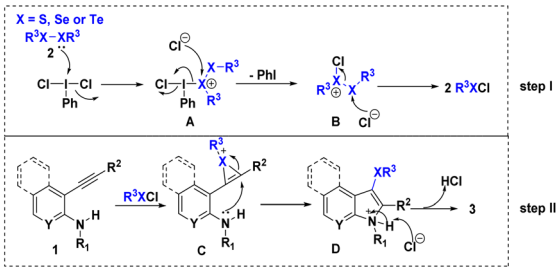
yield. Moreover, using the reaction substrate containing alkyl alkyne, the product **3m** was obtained in the yield of 83%. After the thorough exploration of the reaction scope of *o*-alkynylanilines, we came to investigate the reactivity of variously substituted 2-alkynyl-1-naphthylamines and the 3-alkynylpyridin-2-amine (Scheme 4). Changing the benzene ring to naphthalene ring did not have a great influence on the yields of the reaction. As expected, substrates bearing *p*-methoxyphenyl or 3-thienyl gave the corresponding products **3n** and **3o** in 85%, and 99% yield, respectively. Moreover, the reactivity of 1-(thiophen-3-ethynyl)naphthalen-2-amines which had various substituted groups on the nitrogen atom was also evaluated. It can be seen from the results that substrates bearing substituted benzenesulfonyl, 2-naphthalenesulfonyl and 2-thiophenesulfonyl were investigated, and the experimental results showed that these substrates also worked well. Especially when the starting material with a strong electron-withdrawing group of *p*-nitrobenzenesulfonyl (**1p**) was used as the substrate, the expected product **3p** was still obtained in a yield of 63%. In addition, by changing the arylsulfonyl to ethylsulfonyl, the selenylated product **3t** was isolated in 75% yield. The reaction worked well when using 4-methyl-*N*-(3-(phenylethynyl)pyridin-2-yl)benzenesulfonamide (**1u**) as the starting material, furnishing 2-phenyl-3-(phenylselanyl)-1-tosyl-1*H*-pyrrolo[2,3-*b*]pyridine (**3u**) in 86% yield. In the end, a 1.0 mmol scale experiment of **1o** had been carried out and the desired product **3o** was obtained in 95% yield.

In order to gain insights into the reaction mechanism, some control experiments were conducted. Firstly, 2.0 equiv. of TEMPO was added to the reaction of 4-methyl-*N*-(2-(phenylethynyl)phenyl)benzenesulfon-amide (**1a**) with 1,2-diphenyldiselane (**2a**) under the standard conditions. From the reaction results, it could be seen that the yield of the desired product 2-phenyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (**3a**) was 91%, which excluded a free-radical pathway for this reaction (Scheme 5a). Next, considering the previous work about the *in situ* formation of RSCl/ArSeCl and their application to the synthesis of chalcogenides, we wondered if the ArXCl was the key intermediate. Subsequently, the reaction of 4-methyl-*N*-(2-(phenylethynyl)phenyl)benzenesulfon-amide (**1a**) with 1.2 equiv. PhSeCl in EtOH at room temperature for 12 hours afforded the corresponding selenylated product **3a** in 93% yield (Scheme 5b).

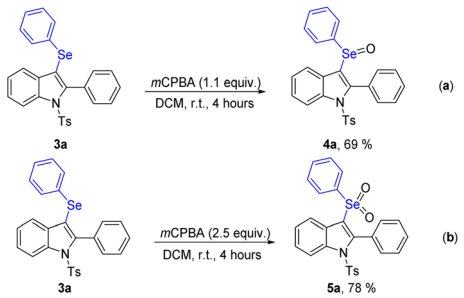
Based on the experimental results described above as well as previous literature reports,[11,15] a plausible mechanism for this reaction is shown in Scheme 6 which involves R^3XCl formation (step I) followed by a R^3XCl-mediated electrophilic cyclization (step II). The intermediate **A** was formed through the attack of X (sulfur/selenium/tellurium) on the iodine center in $PhICl_2$. Subsequently, the intermediate **A** is converted to intermediate **B** after elimination of PhI. Next, two molecules of PhXCl are



Scheme 5 Control experiments.



Scheme 6 Plausible mechanism.



Scheme 7 Preparation of **4a** and **5a**.

produced through the chloride anion nucleophilically attacking the X atom of the intermediate **B** (step I). Subsequently, substrate **1** reacts with R^3XCl to form the intermediate **C**. Then, the nitrogen atom acts as a nucleophile and attacks the X-onium center to afford the intermediate **D**. Finally, the removal of hydrogen proton from intermediate **D** assisted by the attack of chloride ion leads to the formation of the final product **3** (step II).

In order to expand the application of the synthesized 3-selenoindoles, we performed the selective oxidative reactions (Scheme 7). The product 2-phenyl-3-(phenylseleninyl)-1-tosyl-1*H*-indole (**4a**) was synthesized using **3a** as the starting material and 1.1 equiv. *m*CPBA as the oxidant (Scheme 7a). When the oxidant of *m*CPBA was increased to 2.5 equiv., the product 2-phenyl-3-(phenylselenonyl)-1-tosyl-1*H*-indole (**5a**) was obtained in 78% yield (Scheme 7b).

Conclusions

In summary, we have developed a simple, practical, metal-free protocol for the synthesis of various functionalized 3-selenyl/sulfenyl/telluriumindoles from the reactions of *in situ* generated RXCl with *o*-alkynyl arylamines. Under the optimized reaction conditions, the reactions generated the corresponding products in good to excellent yields based on the high atom economy with excellent functional group tolerance. Through the experimental results and the related literature, a plausible reaction mechanism was proposed and ArXCl is proved to be the key intermediate. Furthermore, the product 2-phenyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (**3a**) can be selectively oxidized to compounds **4a** and **5a** in good yields. Further studies on the synthetic application are currently under way.

Experimental

General methods and materials

Unless stated otherwise, reactions were conducted in dried glassware. Commercially available reagents and solvents were used as received. 300–400 mesh silica gel was used for flash column chromatography. Visualization on TLC was achieved by the use of UV light (254 nm). 400 MHz and 100 MHz were used for the record of ^{1}H NMR and ^{13}C NMR spectra. Chemical shifts (δ ppm) were reported in parts per million referring to either the internal standard of TMS or the residue of the deuterated solvents. Splitting pattern was described as follows: s for singlet, d for doublet, t for triplet, q for quartet, and m for multiplet. Coupling constants were reported in Hz. The high-resolution mass spectrum (HRMS) was performed on Waters Xevo G2-S QTof mass spectrometer. All the substrates were synthesized with references to published literature.[17] Deposition number 2001345 (for **3a**) contain the ESI crystallographic data for this paper.†

Typical procedure for the synthesis of 3a

Substrate **2a** (0.10 mmol) and $PhICl_2$ (0.14 mmol) were stirred in EtOH (2.0 mL) at room temperature for 15 minutes in the absence of light, then substrate **1a** (0.20 mmol) was added. After the substrate **1a** was completely consumed (monitored by TLC), the mixture was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (PE : EA = 20 : 1) to afford the desired product **3a** as white solid (97.6 mg, 97%).

Characterization data

2-Phenyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (3a). White solid, 97.6 mg, 97%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 6.94 (d, J = 6.9 Hz, 2H), 7.02–7.10 (m, 5H), 7.26 (d, J = 4.0 Hz, 1H), 7.31 (d, J = 8.4 Hz, 4H), 7.39 (t, J = 7.6 Hz, 3H), 7.45 (d, J = 8.4 Hz, 2H), 8.37 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 110.5, 116.3, 121.2, 124.6, 125.7, 126.0, 126.9, 127.1, 129.0, 129.2, 129.3, 129.4, 130.9, 131.6, 131.8, 132.1, 135.0, 137.5, 144.9; IR (neat) 3329, 1655, 1574, 1451, 1239, 824, 730 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{27}H_{22}NO_2SSe$: 504.0536, found 504.0531.

2-(2-Methoxyphenyl)-3-(phenylselanyl)-1-tosyl-1*H*-indole (3b). White solid, 101.3 mg, 95%, eluent (PE : EA = 15 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 3.60 (s, 3H), 6.90 (d, J = 8.3 Hz, 1H), 6.98 (t, J = 7.4 Hz, 1H), 7.06–7.13 (m, 8H), 7.23–7.25 (m, 1H), 7.37 (t, J = 7.8 Hz, 1H), 7.42–7.46 (m, 4H), 8.30 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 55.1, 109.8, 110.3, 115.3, 119.4, 120.3, 121.0, 124.0, 125.2, 125.9, 127.0, 128.8, 129.3, 129.6, 131.1, 131.6, 131.7, 132.9, 135.7, 137.1, 141.4, 144.6, 158.5; IR (neat) 3415, 3038, 1635, 1569, 1451, 1241, 823, 735 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{28}H_{24}NO_3SSe$: 534.0642, found 534.0634.

2-(4-Methoxyphenyl)-3-(phenylselanyl)-1-tosyl-1*H*-indole (3c). White solid, 99.1 mg, 93%, eluent (PE : EA = 15 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 3.86 (s, 3H), 6.91–6.94 (m, 4H), 7.04 (t, J = 7.2 Hz, 2H), 7.09 (d, J = 8.1 Hz, 3H), 7.24–7.32

(m, 5H), 7.41 (t, J = 7.9 Hz, 1H), 7.45 (d, J = 7.8 Hz, 1H), 8.39 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 55.2, 110.1, 112.6, 116.4, 121.1, 123.0, 124.7, 125.6, 126.0, 126.9, 129.0, 129.4, 132.0, 132.3, 133.0, 134.9, 137.6, 144.9, 145.0, 160.3; IR (neat) 3238, 3101, 1638, 1571, 1455, 1231, 826, 738 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{28}H_{24}NO_3SSe$: 534.0642, found 534.0638.

2-([1,1′-Biphenyl]-4-yl)-3-(phenylselanyl)-1-tosyl-1*H*-indole (3d). White solid, 108.9 mg, 94%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.35 (s, 3H), 6.96 (d, J = 6.6 Hz, 2H), 7.05–7.11 (m, 5H), 7.28–7.47 (m, 10H), 7.63 (d, J = 7.8 Hz, 2H), 7.69 (d, J = 6.3 Hz, 2H), 8.40 (d, J = 8.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 110.8, 116.1, 116.4, 121.2, 124.7, 125.8, 126.1, 126.9, 127.2, 127.6, 127.7, 128.8, 128.9, 129.0, 129.2, 129.4, 129.5, 129.8, 131.8, 132.1, 132.2, 132.3, 134.9, 137.7, 140.4, 141.7, 144.7, 144.9; IR (neat) 3329, 3035, 1662, 1568, 1451, 1234, 821, 736 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{33}H_{26}NO_2SSe$: 580.0849, found 580.0853.

3-(Phenylselanyl)-2-(thiophen-3-yl)-1-tosyl-1*H*-indole (3e). White solid, 100.8 mg, 99%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.32 (s, 3H), 6.92 (d, J = 7.4 Hz, 2H), 7.02 (t, J = 7.2 Hz, 2H), 7.07 (d, J = 8.2 Hz, 3H), 7.15 (d, J = 4.8 Hz, 1H), 7.18 (s, 1H), 7.23 (s, 1H), 7.28 (d, J = 8.5 Hz, 3H), 7.39 (t, J = 7.8 Hz, 1H), 7.45 (d, J = 7.7 Hz, 1H), 8.36 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 110.8, 116.2, 121.1, 123.7, 124.6, 125.7, 126.0, 126.8, 128.2, 129.0, 129.1, 129.4, 130.5, 130.9, 132.0, 132.1, 134.9, 137.5, 140.0, 144.9; IR (neat) 3332, 3041, 1648, 1572, 1451, 1235, 819, 728 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{25}H_{20}NO_2S_2Se$: 510.0101, found 510.0105.

1-(Naphthalen-2-ylsulfonyl)-2-phenyl-3-(phenylselanyl)-1*H*-indole (3f). White solid, 87.3 mg, 81%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.85–6.90 (m, 4H), 7.01 (t, J = 6.6 Hz, 1H), 7.28–7.31 (m, 3H), 7.36–7.42 (m, 3H), 7.44–7.49 (m, 3H), 7.57 (t, J = 7.2 Hz, 1H), 7.64 (t, J = 7.0 Hz, 1H), 7.75 (t, J = 7.4 Hz, 2H), 7.83 (d, J = 8.2 Hz, 1H), 7.94 (s, 1H), 8.49 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 110.6, 116.4, 121.3, 121.4, 124.8, 125.9, 126.0, 127.2, 127.7, 127.9, 128.97, 129.01, 129.1, 129.3, 129.4, 129.5, 130.8, 131.5, 131.7, 132.1, 134.7, 135.2, 137.7, 144.9; IR (neat) 3358, 3021, 1644, 1569, 1455, 1231, 829, 731 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{30}H_{22}NO_2SSe$: 540.0536, found 540.0551.

2-Phenyl-3-(phenylselanyl)-1-(thiophen-2-ylsulfonyl)-1*H*-indole (3g). White solid, 98.0 mg, 99%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.91 (t, J = 4.3 Hz, 1H), 6.98–7.00 (m, 2H), 7.06–7.09 (m, 3H), 7.28–7.32 (m, 2H), 7.41–7.49 (m, 8H), 8.33 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 111.5, 116.5, 121.4, 125.1, 125.9, 126.2, 127.1, 127.3, 129.1, 129.3, 129.4, 130.9, 131.4, 131.6, 132.5, 133.3, 133.4, 137.3, 137.5, 144.8; IR (neat) 3312, 3032, 1651, 1576, 1451, 1227, 821, 731 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{24}H_{18}NO_2S_2Se$: 495.9944, found 495.9939.

1-(Ethylsulfonyl)-2-phenyl-3-(phenylselanyl)-1*H*-indole (3h). White solid, 87.3 mg, 99%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (t, J = 7.4 Hz, 3H), 3.07–3.13 (m, 2H), 7.13 (s, 5H), 7.32 (t, J = 7.5 Hz, 1H), 7.41–7.42 (m, 6H), 7.60 (d, J = 7.7 Hz, 1H), 8.16 (d, J = 8.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 7.7, 49.0, 109.3, 115.0, 121.5, 124.5, 125.8, 126.3, 127.4, 127.8, 129.1, 129.3, 129.8, 130.8, 131.5, 131.6, 137.2, 144.8; IR (neat) 3419, 3033, 1649, 1578, 1445, 1241, 826, 732 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{22}H_{20}NO_2SSe$: 442.0380, found 442.0387.

2-Phenyl-3-(phenylselanyl)-1*H*-indole (3i). White solid, 44.0 mg, 63%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.11–7.16 (m, 3H), 7.19–7.24 (m, 3H), 7.29 (t, J = 7.6 Hz, 1H), 7.40–7.46 (m, 4H), 7.68 (d, J = 7.9 Hz, 1H), 7.73 (d, J = 7.2 Hz, 2H), 8.56 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 95.7, 111.1, 120.9, 121.1, 123.3, 125.4, 128.2, 128.5, 128.7, 129.1, 132.0, 132.1, 134.1, 136.2, 142.1; IR (neat) 3409, 3042, 1647, 1572, 1452, 1237, 823, 732 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{20}H_{16}NSe$: 350.0448, found 350.0447.

3-(Phenylthio)-2-(thiophen-3-yl)-1-tosyl-1*H*-indole (3j). White solid, 68.2 mg, 74%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.36 (s, 3H), 6.78 (d, J = 8.6 Hz, 2H), 7.04 (d, J = 8.6 Hz, 2H), 7.12 (d, J = 8.4 Hz, 4H), 7.25–7.29 (m, 2H), 7.36–7.45 (m, 4H), 7.49–7.51 (m, 1H), 8.38 (d, J = 8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 115.1, 116.5, 120.1, 124.8, 126.3, 126.5, 127.0, 128.0, 128.9, 129.3, 129.5, 130.5, 131.4, 132.4, 134.8, 135.1, 137.6, 137.8, 145.1; IR (neat) 3402, 3037, 1649, 1567, 1451, 1239, 822, 731 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{25}H_{20}NO_2S_3$: 462.0656, found 462.0661.

3-(Phenyltellanyl)-2-(thiophen-3-yl)-1-tosyl-1*H*-indole (3k). White solid, 74.9 mg, 67%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 7.02–7.16 (m, 7H), 7.25–7.29 (m, 3H), 7.41–7.43 (m, 3H), 7.49–7.50 (m, 2H), 8.33 (d, J = 8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 100.0, 114.8, 115.9, 123.5, 124.4, 126.0, 126.2, 126.9, 127.2, 128.5, 129.2, 129.5, 132.2, 132.3, 133.8, 135.3, 135.7, 138.0, 139.1, 144.9; IR (neat) 3410, 3101, 1644, 1569, 1451, 1235, 828, 728 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{25}H_{20}NO_2S_2Te$: 559.9998, found 559.9992.

2-(4-Chlorophenyl)-5-methyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (3l). White solid, 104.7 mg, 95%, eluent (PE : EA = 20 : 1). ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.38 (s, 3H), 2.41 (s, 3H), 6.95–6.89 (m, 2H), 7.07 (t, J = 7.5 Hz, 2H), 7.15–7.10 (m, 3H), 7.29–7.24 (m, 4H), 7.32 (d, J = 8.3 Hz, 2H), 7.41–7.35 (m, 2H), 8.26 (d, J = 8.4 Hz, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 21.4, 21.7, 110.9, 116.1, 121.1, 126.1, 126.8, 127.5, 128.9, 129.1, 129.4, 129.5, 131.9, 132.5, 132.8, 134.8, 134.8, 135.3, 135.8, 143.8, 145.0; IR (neat) 3319, 3023, 1658, 1571, 1448, 1233, 822, 732 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{28}H_{23}ClNO_2SSe$: 552.0303, found 552.0309.

2-Butyl-3-(phenylselanyl)-1-tosyl-1*H*-indole (3m). White solid, 80.2 mg, 83%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.95 (t, J = 7.3 Hz, 3H), 1.44 (dd, J = 14.9, 7.4 Hz, 2H), 1.76–1.65 (m, 2H), 2.41 (s, 3H), 3.36–3.24 (m, 2H), 7.07 (dd, J = 8.0, 1.6 Hz, 2H), 7.19–7.10 (m, 3H), 7.30–7.20 (m, 3H), 7.40–7.33 (m, 1H), 7.48 (d, J = 7.7 Hz, 1H), 7.67 (d, J = 8.3 Hz, 2H), 8.27 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.8, 21.7, 22.8, 28.4, 33.3, 108.0, 115.3, 120.6, 124.2, 124.9, 126.0, 126.4, 128.8, 129.1, 129.9, 131.9, 132.0, 135.9, 137.1, 144.9, 147.2; IR (neat) 3329, 3044, 1651, 1571, 1455, 1237, 821, 727 cm^{-1}; HRMS (ESI-TOF) m/z: $[M + H]^+$ calcd for $C_{25}H_{26}NO_2SSe$: 484.0849, found 484.0861.

2-(4-Methoxyphenyl)-1-(phenylselanyl)-3-tosyl-3*H*-benzo[*e*]indole (3n). White solid, 99.1 mg, 85%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 3.89 (s, 3H), 6.94 (d, J = 8.4 Hz, 2H), 7.00–7.12 (m, 6H), 7.25–7.27 (m, 3H), 7.38 (d, J = 8.1 Hz, 2H), 7.46 (s, 2H), 7.88 (d, J = 9.1 Hz, 1H), 7.94 (d, J = 6.4 Hz, 1H), 8.65 (d, J = 9.2 Hz, 1H), 9.44 (d, J = 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 55.3, 108.6, 112.6, 115.6, 123.4, 123.6, 124.9, 125.2, 125.8, 126.2, 126.5, 126.8, 127.9, 128.2, 128.4, 129.2, 129.5, 131.4, 133.3, 133.6, 134.9, 135.3, 145.0, 145.2, 160.2; IR (neat) 3338, 3035, 1661, 1568, 1445, 1241, 822, 731 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{32}H_{26}NO_3SSe$: 584.0799, found 584.0781.

1-(Phenylselanyl)-2-(thiophen-3-yl)-3-tosyl-3*H*-benzo[*e*]indole (3o). White solid, 110.7 mg, 99%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.33 (s, 3H), 6.96–7.10 (m, 8H), 7.16 (s, 1H), 7.32 (t, J = 3.9 Hz, 1H), 7.35 (d, J = 8.1 Hz, 2H), 7.43–7.48 (m, 2H), 7.86 (d, J = 9.2 Hz, 1H), 7.92 (d, J = 6.8 Hz, 1H), 8.62 (d, J = 8.4 Hz, 1H), 9.45 (d, J = 8.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 109.2, 115.4, 123.6, 124.7, 125.2, 125.8, 126.3, 126.7, 127.9, 128.3, 128.4, 128.4, 129.2, 129.5, 130.7, 131.2, 131.3, 133.5, 135.0, 135.2, 140.2, 145.1; IR (neat) 3404, 3044, 1641, 1576, 1451, 1235, 824, 731 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{29}H_{22}NO_2S_2Se$: 560.0257, found 560.0259.

3-((4-Nitrophenyl)sulfonyl)-1-(phenylselanyl)-2-(thiophen-3-yl)-3*H*-benzo[*e*]indole (3p). White solid, 74.3 mg, 63%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.96–6.98 (m, 2H), 7.01–7.09 (m, 4H), 7.20 (s, 1H), 7.35 (s, 1H), 7.49–7.50 (m, 2H), 7.60 (d, J = 8.3 Hz, 2H), 7.91 (d, J = 9.2 Hz, 1H), 7.95 (d, J = 7.5 Hz, 1H), 8.11 (d, J = 8.6 Hz, 2H), 8.57 (d, J = 9.2 Hz, 1H), 9.47 (d, J = 7.1 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 110.9, 115.0, 123.6, 124.1, 124.2, 125.1, 125.7, 126.3, 126.7, 127.4, 127.8, 128.0, 128.5, 128.9, 129.3, 130.2, 131.1, 131.6, 133.1, 134.8, 139.7, 143.0, 150.5; IR (neat) 3403, 3041, 1646, 1572, 1453, 1243, 821, 737 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{28}H_{19}N_2O_4S_2Se$: 590.9951, found 590.9956.

3-((4-Chlorophenyl)sulfonyl)-1-(phenylselanyl)-2-(thiophen-3-yl)-3*H*-benzo[*e*]indole (3q). White solid, 85.7 mg, 74%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.94 (d, J = 7.4 Hz, 2H), 7.05–7.10 (m, 4H), 7.17 (s, 1H), 7.25 (d, J = 5.7 Hz, 2H), 7.31–7.36 (m, 3H), 7.46–7.48 (m, 2H), 7.88 (d, J = 9.2 Hz, 1H), 7.92–7.94 (m, 1H), 8.59 (d, J = 9.2 Hz, 1H), 9.46 (d, J = 8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 110.0, 115.3, 123.6, 123.8, 125.0, 125.5, 126.0, 126.5, 127.0, 128.1, 128.3, 128.5, 128.6, 129.2, 129.3, 130.5, 131.1, 131.4, 133.4, 135.0, 136.3, 140.0, 140.6; IR (neat) 3389, 3045, 1651, 1577, 1455, 1231, 821, 733 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{28}H_{19}ClNO_2S_2Se$: 579.9711, found 579.9706.

3-(Naphthalen-2-ylsulfonyl)-1-(phenylselanyl)-2-(thiophen-3-yl)-3*H*-benzo[*e*]indole (3r). White solid, 84.5 mg, 71%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.83–6.89 (m, 4H), 6.95–6.96 (m, 1H), 7.04–7.05 (m, 1H), 7.11 (s, 1H), 7.28 (s, 1H), 7.38–7.47 (m, 3H), 7.53–7.57 (m, 1H), 7.62 (t, J = 7.2 Hz, 1H), 7.70 (d, J = 8.8 Hz, 1H), 780 (t, J = 10.0 Hz, 2H), 7.88–7.93 (m, 2H), 7.98 (s, 1H), 8.71 (d, J = 9.2 Hz, 1H), 9.42 (d, J = 7.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 109.2, 115.4, 121.1, 123.6, 124.6, 125.2, 125.8, 126.3, 126.8, 127.8, 127.9, 128.1, 128.4, 128.6, 128.9, 129.2, 129.3, 129.5, 129.6, 130.6, 131.2, 131.3, 131.5, 133.4, 134.9, 135.2, 135.2, 140.1; IR (neat) 3411, 3028, 1651, 1568, 1451, 1233, 825, 729 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{32}H_{22}NO_2S_2Se$: 596.0257, found 596.0261.

1-(Phenylselanyl)-3-(thiophen-2-ylsulfonyl)-2-(thiophen-3-yl)-3*H*-benzo[*e*]indole (3s). White solid, 85.9 mg, 78%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.88 (t, J = 4.3 Hz, 1H) 6.99–7.04 (m, 5H), 7.14 (d, J = 4.92 Hz, 1H), 7.24 (s, 1H), 7.31–7.32 (m, 2H), 7.45–7.46 (m, 3H), 7.87 (d, J = 9.2 Hz, 1H), 7.92 (d, J = 7.8 Hz, 1H), 8.53 (d, J = 9.2 Hz, 1H), 9.45 (d, J = 7.7 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 110.0, 115.4, 123.6, 123.8, 125.1, 125.4, 125.9, 126.4, 126.9, 127.1, 127.9, 128.2, 128.3, 128.4, 129.3, 130.7, 130.9, 131.5, 133.4, 133.7, 134.6, 137.9, 140.2; IR (neat) 3401, 3043, 1642, 1563, 1451, 1241, 829, 726 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{26}H_{18}NO_2S_3Se$: 551.9665, found 551.9667.

3-(Ethylsulfonyl)-1-(phenylselanyl)-2-(thiophen-3-yl)-3*H*-benzo[*e*]indole (3t). White solid, 74.6 mg, 75%, eluent (PE : EA = 20 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.10 (t, J = 7.4 Hz, 3H), 3.18 (q, J = 7.4 Hz, 2H), 7.09–7.17 (m, 6H), 7.34–7.35 (m, 2H), 7.49–7.51 (m, 2H), 7.84 (d, J = 9.2 Hz, 1H), 7.92–7.94 (m, 1H), 8.38 (d, J = 9.2 Hz, 1H), 9.53 (d, J = 9.0 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 7.7, 49.7, 108.3, 114.3, 123.6, 123.8, 124.1, 125.3, 126.1, 126.5, 126.9, 127.9, 128.3, 128.5, 128.7, 129.3, 130.6, 130.9, 131.1, 133.4, 134.7, 139.8; IR (neat) 3398, 3029, 1639, 1551, 1450, 1238, 831, 731 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{24}H_{20}NO_2S_2Se$: 498.0101, found 498.0111.

2-Phenyl-3-(phenylselanyl)-1-tosyl-1*H*-pyrrolo[2,3-*b*]pyridine (3u). White solid, 86.7 mg, 86%, eluent (PE : EA = 15 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.36 (s, 3H), 7.07–7.11 (m, 5H), 7.16–7.22 (m, 3H), 7.38–7.40 (m, 2H), 7.43–7.49 (m, 3H), 7.70 (d, J = 7.8 Hz, 1H), 7.84 (d, J = 8.3 Hz, 2H), 8.52 (d, J = 3.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 106.4, 119.9, 124.3, 126.5, 127.4, 128.0, 129.1, 129.3, 129.4, 129.4, 129.9, 130.9, 131.1, 131.2, 135.7, 144.7, 145.1, 145.5, 149.2; IR (neat) 3411, 3040, 1637, 1566, 1451, 1239, 822, 731 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{26}H_{21}N_2O_2SSe$: 505.0489, found 505.0488.

2-Phenyl-3-(phenylseleninyl)-1-tosyl-1*H*-indole (4a). White solid, 71.6 mg, 69%, eluent (PE : EA = 10 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.34 (s, 3H), 7.11–7.17 (m, 3H), 7.32–7.56 (s, 13H), 7.71 (d, J = 7.8 Hz, 1H), 8.30 (d, J = 8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 115.6, 120.7, 124.7, 126.0, 126.3, 126.7, 126.9, 127.9, 128.2, 128.9, 129.5, 129.7, 130.3, 130.9, 131.0, 132.3, 135.0, 137.2, 145.6; IR (neat) 3329, 1641, 1568, 1442, 1251, 856, 741 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{27}H_{22}NO_3SSe$: 520.0486, found 520.0482.

2-Phenyl-3-(phenylselenonyl)-1-tosyl-1*H*-indole (5a). White solid, 83.5 mg, 78%, eluent (PE : EA = 10 : 1). ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.36 (s, 3H), 7.11–7.18 (m, 3H), 7.32–7.57 (m, 13H), 7.71 (d, J = 7.9 Hz, 1H), 8.30 (d, J = 8.5 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.6, 105.0, 115.6, 120.7, 124.7, 126.0, 126.3, 126.9, 127.9, 128.1, 128.9, 129.5, 129.7, 130.3, 130.9, 132.3, 135.0, 137.2, 140.3, 143.3, 145.6; IR (neat) 3256, 1652, 1588, 1465, 1241, 851, 733 cm^{-1}; HRMS (ESI-TOF) m/z: [M + H]$^+$ calcd for $C_{27}H_{22}NO_4SSe$: 536.0435, found 536.0441.

Conflicts of interest

There are no conflicts to declare.

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