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A $SeCl_2$-Mediated Approach Toward Indole-Containing Polysubstituted Selenophenes

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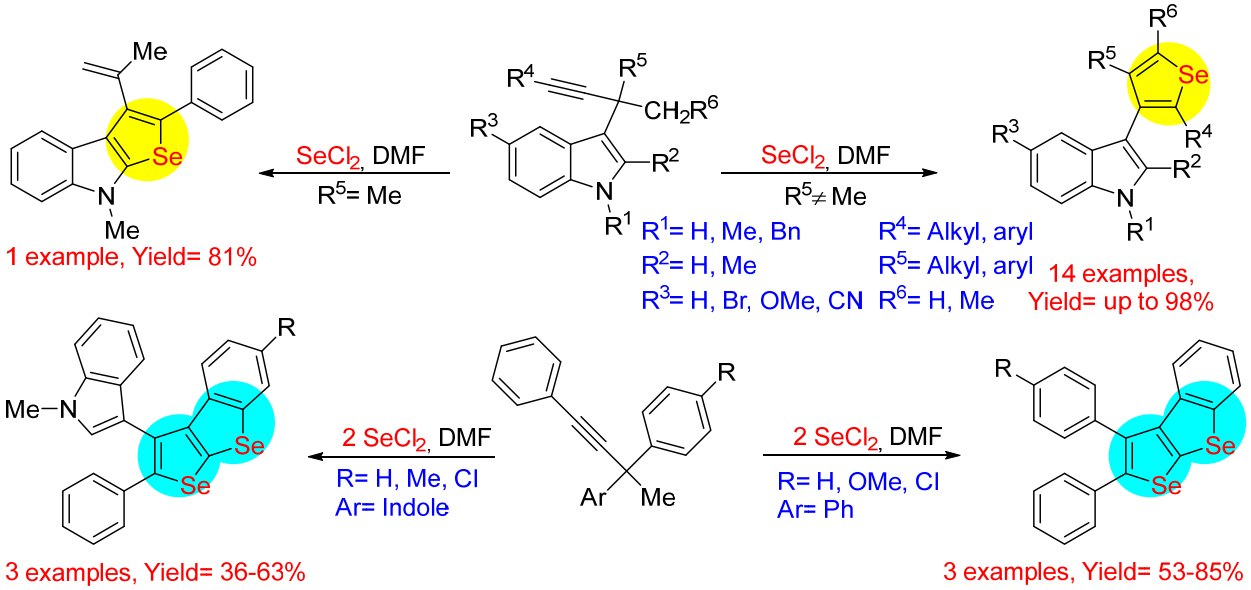


ABSTRACT: A novel and efficient $SeCl_2$-mediated chalcogenative cyclization strategy toward 3-selenophen-3-yl-1*H*-indoles from readily available and conveniently substituted propargyl indoles, is described. It entails an unprecedented selenirenium-induced 1,2-indolyl shift prompted by the

electrophilic addition of $SeCl_2$ to the triple bond of the propargyl indole, followed by cyclization through the intermediacy of a 1-seleno-1,3-diene. The reaction takes place at room temperature, shows excellent selectivity, broad substrate scope and wide functional group tolerance.

KEYWORDS: $SeCl_2$, heterocycles, cyclization, arylacetylenes, indolo[2,3-*b*]selenophenes, substituted selenophenes

INTRODUCTION

The selenophene motif is found in a wide array of compounds, many of which are of pharmacological interest due to their important biological activities. These include antioxidant,[1] anti-inflammatory,[2] antitumor and cytostatic,[3] as well as antibacterial,[4a] antinocioceptive,[4b] antihypertensive,[4c] enzyme inhibition,[5] photobiological,[6] and anticonvulsant,[7] among others. The heterocycle has been embedded into certain natural products and selenophene-containing drug analogs have also been prepared.[8]

In addition, selenophenes have been eliciting increasing interest as building blocks in organic synthesis and materials science, for their potential technological applications in organic light emitting diodes (OLEDs),[9a] organic field effect transistors (OFETs),[9b] organic solar cells,[9c] and other electronic components.[9d] Figure 1 depicts the structures of selected bioactive and technologically interesting selenophenes.

The synthetic approaches to polysubstituted selenophenes and their condensed congeners have been repeatedly reviewed.[10] An analysis of them revealed that suitable substrates for their access include alkynes and alkenes, but β-diketo compounds, imines and amides have also been used. On the other hand, the sources of the selenium atom have included mainly inorganic chemicals such

as selenium itself, Na_2Se, NaHSe, SeO_2, $SeOCl_2$, P_2Se_5, KSeCN, $SeCl_4$, $SeBr_4$, and selenium dihalides, among others, but also alkyl and arylselenium derivatives (ArSeCl/Br, PhSeSePh), as well as selenoesters and other derivatives.

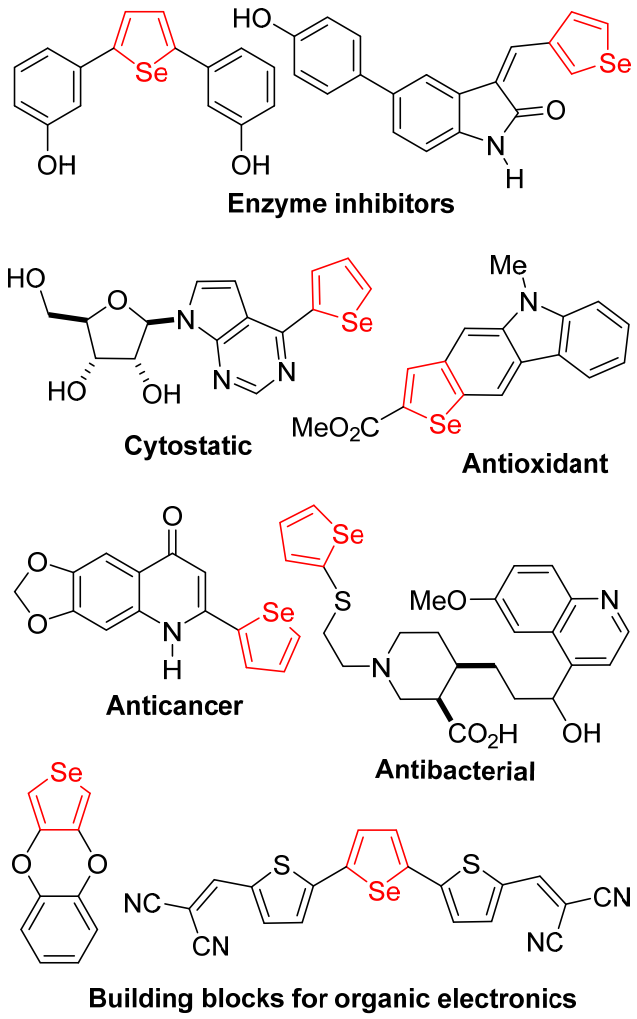


Figure 1. Selected examples of bioactive and technologically interesting selenophene derivatives.

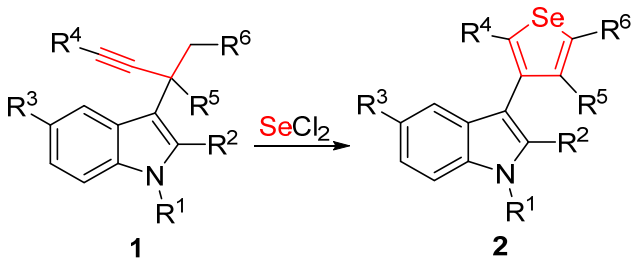
However, the known routes are not exempt from some disadvantages, including harsh conditions, low product yields or the requirement of time-consuming multistep preparations of rather complex or expensive starting materials. Further, some approaches suffer from severe

limitations in terms of compatible substituents, which limit their substrate scope.

Therefore, despite the huge progress in this area, the need of efficient syntheses of functionalized selenophenes still stimulates the development of new, milder and more selective methods to complement and advance existing technologies.

The electrophilic cyclization of unsaturated compounds, which is believed to proceed through an intramolecular, stepwise mechanism involving cationic intermediates, has been confirmed as an efficient approach for the one-pot construction of heterocycles, offering exciting opportunities for innovation. On the other hand, the indole nucleus is a privileged structure found in many biologically or technologically relevant compounds.[11]

In view of our interest in developing new methods for the elaboration of organochalcogen compounds,[12] and considering our latest results on the synthesis of propargyl indoles,[13] we decided to continue this study.



Scheme 1. Proposed strategy for the $SeCl_2$-mediated synthesis of indole-containing poly-substituted selenophenes.

Accordingly, herein we report the use of our recently reported approach toward substituted alkynes in combination with $SeCl_2$ as a suitable selenium source, for the development of an efficient and operationally straightforward strategy toward indole-containing selenophenes (Scheme 1).

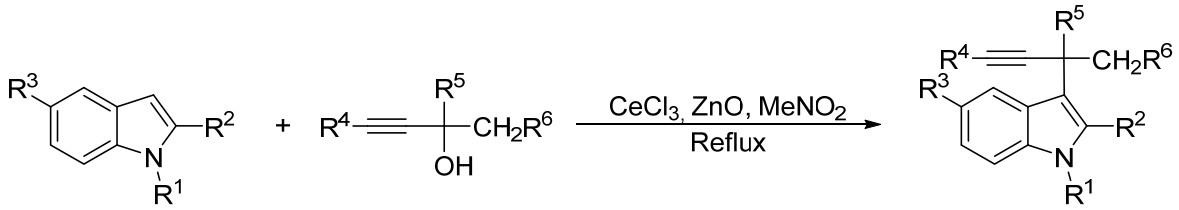
The new protocol employs readily available and rather inexpensive starting materials and is applicable to a wide variety of substrates. To the best of our knowledge, except for an isolated report on the synthesis of 2-substituted indoles carrying a selenophene moiety,[14] the direct attachment of the indole nucleus to the selenophene motif has not been performed to date.

RESULTS AND DISCUSSION

The best approach toward 3(3-alkynyl)1*H*-indoles **1** is the catalytic electrophilic aromatic substitution of propargylic alcohols.[15a-e] Hence, the target compounds **1a-i** and **1k-q** were prepared in 52-89% yield by reaction of the indole derivatives **3a-f** and **3h** with propargylic alcohols **4a-i** in refluxing $MeNO_2$ (Table 1), under promotion by $CeCl_3.7H_2O$ (30 mol%), to which ZnO was added.[13a,b] The indole derivative **1j** was conveniently prepared by conventional protection of **1k** with $(Boc)_2O$.[15f]

On the other hand, selenium dihalides are unstable, readily undergoing disproportionation; therefore, their preparation has traditionally been considered difficult,[16] and their use in the synthesis of organoselenium compounds has been rather limited. Fortunately, a modern alternative gives ready access to useful, clear brownish red solutions of pure $SeCl_2$. The reagent can be prepared *in situ* by resorting to the reaction between SO_2Cl_2 and selenium.[17] Recently, this approach has been employed in reactions involving addition to alkenes[18] and alkynes,[19] as well as in aromatic substitutions, as exemplified by the synthesis of diaryl selenides,[17b,20] and ring-forming processes.[21]

Table 1. Synthesis of the starting propargyl indoles.

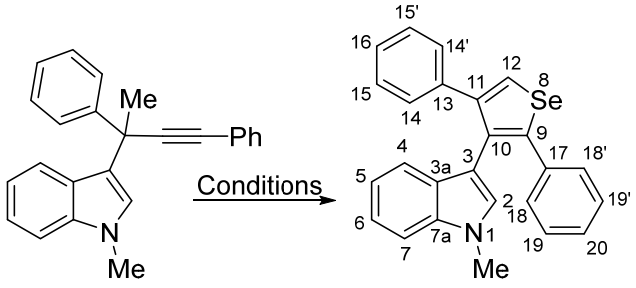


entry	indole	R^1	R^2	R^3	propargyl alcohol	R^4	R^5	R^6	product	time (h)	yield (%)[a]
1	**3a**	Me	H	H	**4a**	Ph	Ph	H	**1a**	3	72
2	**3a**	Me	H	H	**4b**	4Cl-C_6H_4	Ph	H	**1b**	4	71
3	**3a**	Me	H	H	**4c**	4Me-C_6H_4	Ph	H	**1c**	3	79
4	**3a**	Me	H	H	**4d**	*n*-Bu	Ph	H	**1d**	5	52
5	**3b**	Me	H	Br	**4a**	Ph	Ph	H	**1e**	4	78
6	**3c**	Me	H	CN	**4a**	Ph	Ph	H	**1f**	5	65
7	**3d**	Me	H	MeO	**4a**	Ph	Ph	H	**1g**	3	70
8	**3e**	Me	Me	H	**4a**	Ph	Ph	H	**1h**	3	85
9	**3f**	Bn	H	H	**4a**	Ph	Ph	H	**1i**	2	65
10	**-**	Boc	H	H	**-**	Ph	Ph	H	**1j**[b]	24	90
11	**3h**	H	H	H	**4a**	Ph	Ph	H	**1k**	3.5	84
12	**3a**	Me	H	H	**4e**	Ph	4Cl-C_6H_4	H	**1l**	4	70
13	**3a**	Me	H	H	**4f**	Ph	4MeO-C_6H_4	H	**1m**	3	75
14	**3a**	Me	H	H	**4a**	Ph	Ph	Me	**1n**	3	75
15	**3b**	Me	H	Br	**4h**	4Br-C_6H_4	H	H	**1o**	4	70
16	**3a**	Me	H	H	**4g**	Ph	Me	H	**1p**	4	89
17	**3a**	Me	H	H	**4i**	Ph	4Me-C_6H_4	H	**1q**	3	85

[a] Yields of pure products isolated by column chromatography (hexane/EtOAc), identified by GC-MS, ^1H and ^{13}C NMR. [b] Prepared in 90% yield by reaction of **1k** with $(Boc)_2O$.

Therefore, in order to test the feasibility of our strategy, suitable solvent and conditions for the *in situ* formation of $SeCl_2$ and the concomitant formation of **2a** from **1a** were initially sought (Table 2), observing that the process could be accomplished in short time in solvents such as MeCN, THF, $CDCl_3$ and DMF (entries 1-4).

Table 2. Optimization of the $SeCl_2$-mediated synthesis of indole-substituted selenophenes.[a]



entry	reactants ratio (Se^0:SO_2Cl_2:**1a**)	solvent	reaction time after addition of **1a** (h)	yield of **2a**(%)[b]
1	1.0:2.0:1.0	MeCN	0.5	-[c]
2	1.0:2.0:1.0	THF	0.5	54
3	1.0:2.0:1.0	$CHCl_3$	overnight	38
4	1.0:2.0:1.0	DMF	0.5	90
5	1.0:1.0:1.0	DMF	1.0	46
6	1.0:1.5:1.0	DMF	0.5	83

[a]The reactions were run at room temperature, under an inert atmosphere. [b]Reaction time for $SeCl_2$ generation: 1.5 h. Reaction time after $SeCl_2$ generation: 0.5 h. [c]No reaction.

In this way, the performance of the model reaction between propargyl indole **1a** and the *in-situ*-prepared $SeCl_2$ was examined, changing the reaction solvent and the reagent ratios. It was observed that no reaction took place in MeCN after 0.5 h (entry 1), moderate yields (54%) were

obtained in THF (entry 2), whereas the use of $CHCl_3$ afforded only 38% of **2a** after an overnight reaction period (entry 3).

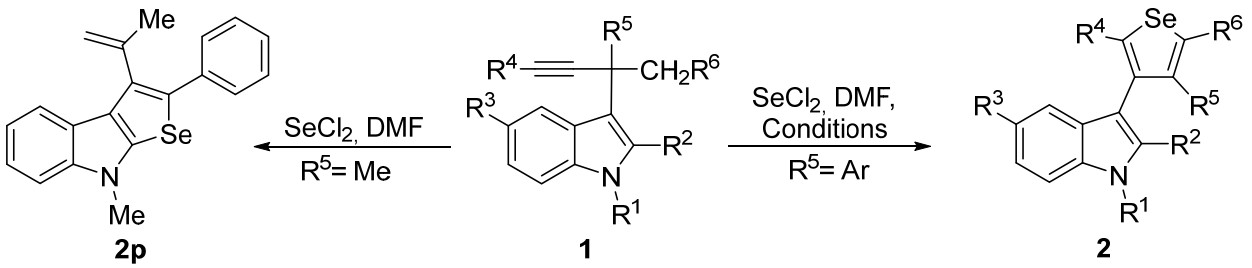
Gratifyingly, however, excellent results (90%) were attained when the transformation was carried out for 0.5 h in DMF (entry 4). The latter condition also provided the best performance. In fact, it was observed that equimolar amounts of the reactants gave low (46%) product yield (entry 5), and that the yield improved to 83% in the presence of a 1.5 molar excess of SO_2Cl_2 (entry 6).

With a view to explore the scope and limitations of this new selenophene-forming reaction, and in order to obtain complex polysubstituted heterocycles, to evaluate its scope and limitations, once the optimum conditions were established, the protocol was extended to other propargyl indoles (**1a-p**). Changing one variable at a time, six points of diversification were examined. These included the substituent attached to the terminal position of the alkyne moiety, C-2, C-5 and the *N*-substituent of the indole nucleus, as well as the nature of the other two substituents of the propargylic position.

Regarding the group directly bonded to the alkyne (Table 3), it was found that, among phenyl derivatives, the substituent attached to the *para* position of the ring did not affect the performance of the transformation (entries 1-3 and 15). However, replacing the aromatic ring with a less reactive aliphatic group resulted in a substrate that proved unsuitable for this transformation (entry 4).

When modifications were made on the indole nucleus, it was observed that the electronic characteristics (electron donor or acceptor) of the C-5 substituent did not affect the performance of the transformation, and the corresponding selenophenes were obtained in very high yields (entries 5-7 and 15). It was also concluded that the transformation accepts 2-substituted indoles, as demonstrated with **1h**, which afforded the corresponding product (**2h**) in excellent yield (entry 8).

Table3. Scope of the $SeCl_2$-mediated synthesis of polysubstituted selenophenes.



2p **1** **2**

entry	propargyl indole	R^1	R^2	R^3	R^4	R^5	R^6	product	time (min)	yield (%)[a]
1	**1a**	Me	H	H	Ph	Ph	H	**2a**	5	90
2	**1b**	Me	H	H	4Cl-C_6H_4	Ph	H	**2b**	30	88
3	**1c**	Me	H	H	4Me-C_6H_4	Ph	H	**2c**	5	91
4	**1d**	Me	H	H	*n*-Bu	Ph	H	**2d**	30	22
5	**1e**	Me	H	Br	Ph	Ph	H	**2e**	5	92
6	**1f**	Me	H	CN	Ph	Ph	H	**2f**	30	88
7	**1g**	Me	H	MeO	Ph	Ph	H	**2g**	30	90
8	**1h**	Me	Me	H	Ph	Ph	H	**2h**	30	89
9	**1i**	Bn	H	H	Ph	Ph	H	**2i**	30	93
10	**1j**	Boc	H	H	Ph	Ph	H	**2j**	24[b]	0
11	**1k**	H	H	H	Ph	Ph	H	**2k**	15	84[c]
12	**1l**	Me	H	H	Ph	4Cl-C_6H_4	H	**2l**	30	94
13	**1m**	Me	H	H	Ph	4MeO-C_6H_4	H	**2m**	60	75
14	**1n**	Me	H	H	Ph	Ph	Me	**2n**	10	98
15	**1o**	Me	H	Br	4Br-C_6H_4	Ph	H	**2o**	30	92
16	**1p**	Me	H	H	Ph	Me	H	**2p**	45	81

[a]Yields of pure products isolated by column chromatography (hexane/EtOAc) and identified by GC-MS, ^1H and ^{13}C NMR. [b]Time in hours. [c]The reaction was carried out at 0 ºC.

On the other hand, it was observed that the nature of the substituent of the indole nitrogen was relevant to the reaction performance. *N*-methyl and *N*-benzyl (entry 9) substituted indoles were suitable substrates, whereas no reaction product was obtained when their *N*-Boc congener was used as the starting indole (entry 10), even after 24 h of reaction.

Notably, employing the unsubstituted indole (*N*-H) was also fruitful; the reaction of **1k** afforded a very good yield (84%) of the expected product **2k**, in short time (entry 11); however, it was found that the transformation should be carried out at 0 ºC for the best results, since at room temperature it resulted in a mixture of inseparable products.

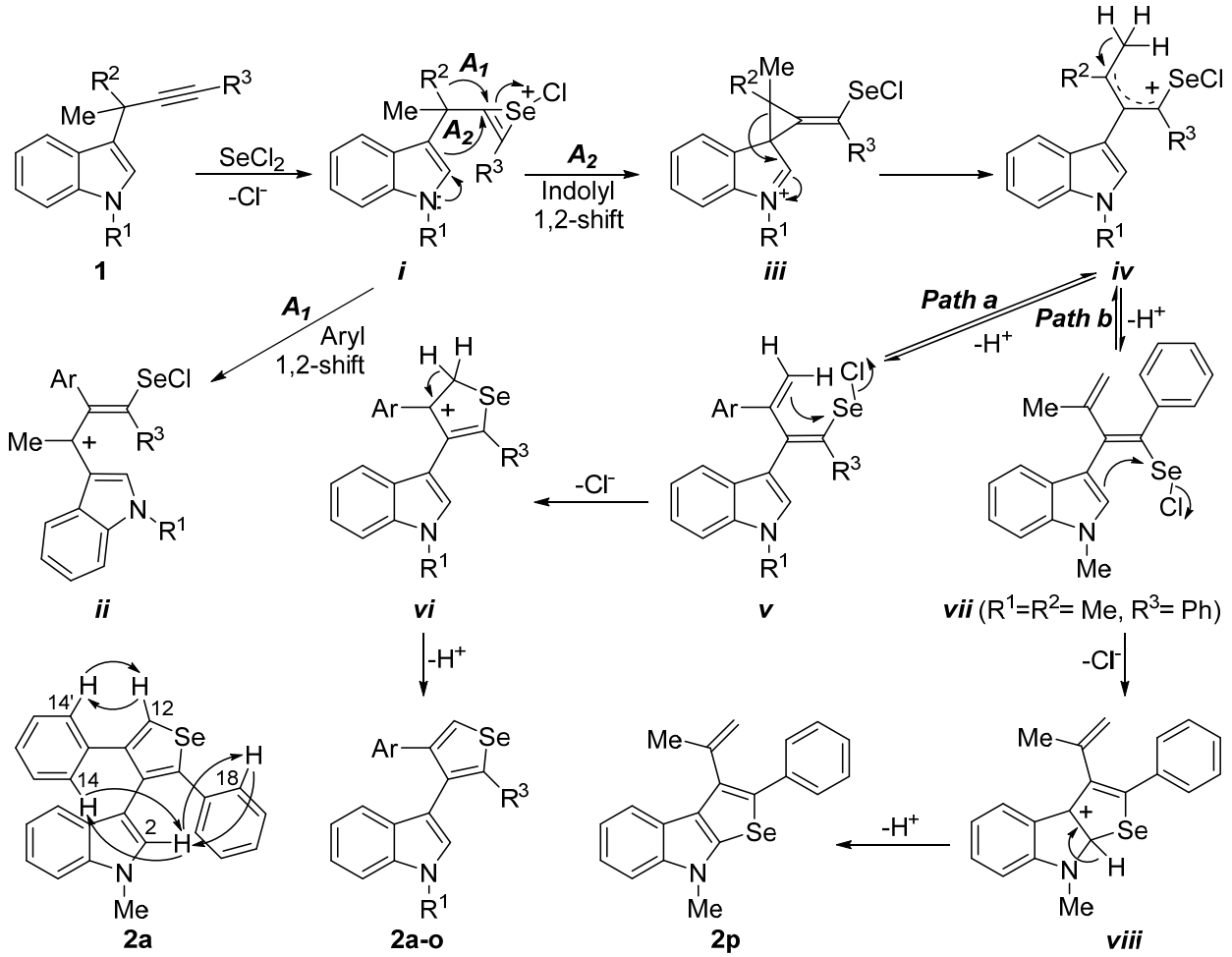
It was also detected that in case of compounds displaying a phenyl ring as the other propargyl substituent, the presence of an electron donating group (OMe) on the *para* position of the aromatic ring, adversely affected the reaction performance when compared with a less electron contributing counterpart, such as a chloride (entries 12 and 13).

In the presence of a phenyl moiety, the propargylic methyl group could be homologated, without the performance of the reaction being affected (entry 14). Interestingly, the resulting product was a tetra-substituted selenophene. However, switching to a couple of methyl groups at the propargylic position (**1p**) resulted in good yield of the indolo[2,3-*b*]selenophene derivative **2p** (81%) which was probably obtained through a different cyclization mechanism (entry 16).

The structures of the products were elucidated by means of an exhaustive analysis of their ^{1}H and ^{13}C NMR spectra and the interpretation of additional NMR experiments, such as NOESY, which helped the unambiguous establishment of the corresponding structures. For example, cross-peaks were found in the NOESY spectrum of **2a** between H-2 and H-18, between H-2 and H-14 and between H-12 and H-14 (Scheme 2).

Although the fine details of the reaction mechanism remain unknown, several clues collected during the experiments suggested that the reactions leading to **2a-o** and **2p** probably proceeded

through the formation of a common intermediate, resulting from an initial 1,2-migration of the 3-indolyl moiety. This enabled the formulation of a multi-pathway mechanism (for **2a-o** and **2p**) consistent with all the results, as depicted in Scheme 2.



Scheme 2. Proposed mechanism for the synthesis of compounds **2a-o** and **2p**, and key NOE cross-peaks of **2a**.

The proposed sequence begins with the electrophilic addition of $SeCl_2$ to the triple bond of **1**, which should result in the generation of the selenirenium intermediate ***i***. In turn, this would trigger a cationic cascade that could undego at least three different evolutions, including a chloride-

mediated nucleophilic ring opening of the selenirenium, and two intramolecular alternatives (***A₁*** and ***A₂***). The latter resemble the course of the rearrangements that take place during substitution at a neopentyl centre. The lack of reactivity of the Boc derivative **1j** (Table 3, entry 10) may be explained by the need of intermediate ***i*** to trigger the cyclization process.

In the route ***A₁***, a 1,2-sigmatropic rearrangement of the aryl group (R^2) would result in the tertiary allyl carbocationic intermediate ***ii***, which could gain additional stabilization from the pendant 3-indolyl moiety. Alternatively, according to route ***A₂***, the intermediate ***i*** could engage in a 1,2-indolyl shift with the aid of the lone pair of electrons of the indolic nitrogen, to afford the polysubstituted spirocycle ***iii***, which in turn would undergo ring opening of the strained cyclopropane motif, to give the carbocationic common intermediate ***iv***.

The mechanism of the 1,2-migrations varies from stepwise to concerted. However, in this case it should be assumed that ring opening of the selenirenium and C-C bond formation through S_N2' attack of the indole C-3 position to the electron defficient centre, leading to the spirocyclic intermediate ***iii*** is somehow a concerted process, which would avoid passing through a highly reactive vinyl cation species.[22]

The migratory aptitudes of the migrating moieties are typically correlated with their electron-richness and ability to stabilize a positive charge in the transition state/intermediate.[23] The observed results suggest that, as expected, the indolyl motif exhibits a better migratory aptitude than the differently substituted benzenoids tested; even in the case of **1m**, which carries a 4-methoxy substituent, the 1,2-migration of the indolyl moiety prevails.

In addition, literature reports indicate that methyl groups have low migratory aptitude and that the relative aptitudes of phenyl and methyl groups for migration during cationic rearrangements is > 100:1.[24] Therefore, a Nametkin-type rearrangement should not be considered in this scenario.

In case R^2 is an aromatic substituent, the reaction mechanism would take ***path a***, where loss

of a proton from the common intermediate ***iv*** would afford the selenodiene ***v***, suitable for cyclization to the cationic intermediate ***vi***. Finally, the latter would deliver the contiguously trisubstituted selenophene products **2a-o**, after loss of the elements of HCl in the last two steps. Thus, the overall process is an extremely atom economic transformation. It is plausible that the presence of an alkyl R^3 substituent may fail to provide satisfactory stabilization to the carbocationic intermediate ***vi***, resulting in lower product yields (Table 3, entry 4).

On the other side, the intriguing formation of compound **2p** suggested the involvement of a slightly different route. The process could take ***path b*** where the common carbocationic intermediate ***iv*** would loss a proton and afford selenodiene ***vii***, a geometric isomer of ***v***. In turn, and resembling ***path a***, the selenodiene ***vii*** would undergo an intramolecular nuclephilic attack by the indole ring, finally affording the fused selenophene **2p** by way of the intermediate ***viii***.

Since no 3-(selenophen-3-yl)-1*H*-indole like **2a-o** accompanied the isolation of **2p**, it can be conjectured that the transformation of ***iv*** into ***v*** or ***vii*** should be reversible, enabling the process to opt between both structure-dependent cyclization paths. The observed products suggest that ***path a*** would not be favored with **1p**, probably because of the relative stability of the intermediates ***v*** and ***vii***, and owing to the fact that the more reactive indolyl moiety would compete successfully with the isopropenyl residue in completing the reaction sequence toward **2p**.

It is worth noting that the 1,2-indolyl shift has very few precedents; it has been reported in the context of some pinacol-type rearrangements,[25] gold-mediated reactions of 3-allenyl and 3-alkynyl derivatives of indoles, extensively studied by the group of Sanz,[26] and in the biosynthesis of violacein, an antibacterial and anticancer purple pigment, produced by *Chromobacterium violaceum*.[27]

Summing up, the accumulated evidence indicates that the reaction proceeds through the electrophilic addition of $SeCl_2$ to the triple bond and always involves an initial 1,2-indolyl shift

(***A₂***), instead of the alternate aryl migration (***A₁***) to afford the common intermediate ***iv***; then, substrates carrying an extra aromatic ring on the propargylic position (**1a-o**) would take ***path a***, whereas ***path b*** would be operating in case of the dialkyl substituted propargyl indoles (**1p**). Since no mixtures of products have been obtained, it seems that the paths would be mutually exclusive.

On the other hand, despite some seleno[3,4-*b*]indoles are known,[28a] the seleno[2,3-*b*]indole skeleton of **2p** is unprecedented and the analogous thieno[2,3-*b*]indoles are rare.[28b-e] However, the latter acquired importance because thienodolin, a natural product from *Streptomyces albogriseolus* MJ286-76F7 (Figure 2), is a nitric oxide synthase inhibitor, with potent plant-growth regulatory properties on rice seedlings.[29]

Other thieno[2,3-*b*]indoles have shown to display antifungal activity, and are potentially useful in the treatment of central nervous system diseases (Parkinson's, senile dementia, brain ischemia, epilepsy), or for the preparation of conducting polymers,[30] suggesting that compounds like **2p** may also exhibit relevant bioactivity.

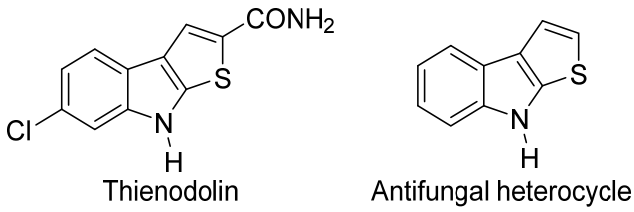
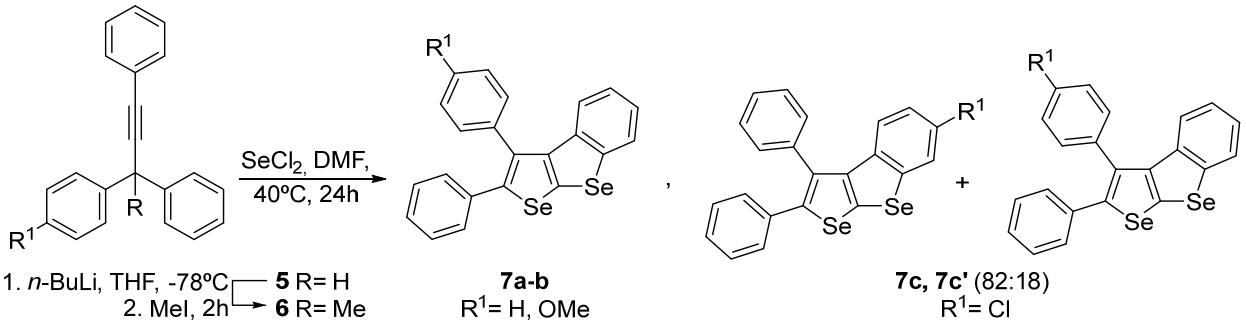


Figure 2. Thienodolin and an antifungal heterocycle as selected bioactive thieno[2,3-*b*]indoles.

The observation of the unusual 1,2-indole migration among propargyl indoles **1a-o** and the odd outcome of their congener **1p** prompted us to evaluate whether other aromatic substituents would be able to undergo the 1,2-migration and initiate the cascade toward substituted selenophenes.

Hence, the model 3-methyl-substituted 1,3,3-triphenyl-1-butyne derivatives **6a-c** were prepared (Table 4) through the MeI-mediated alkylation of the propargyl carbanions, formed by exposure of the corresponding 1,3,3-triphenyl-1-propynes (**5a-c**)[31] to *n*-BuLi in THF. The reaction performance was rather low, possibly as a result of the concomitant formation of allenes as side products.[32] Gratifyingly, however, when the models **6a-c** were subjected to reaction with $SeCl_2$ under the previously optimized conditions, the cyclized products **7a-c** were obtained in moderate to very good yields.

Table 4. $SeCl_2$-mediated synthesis of 2,3-diaryl benzo[*b*]selenopheno[3,2-*d*]selenophenes.



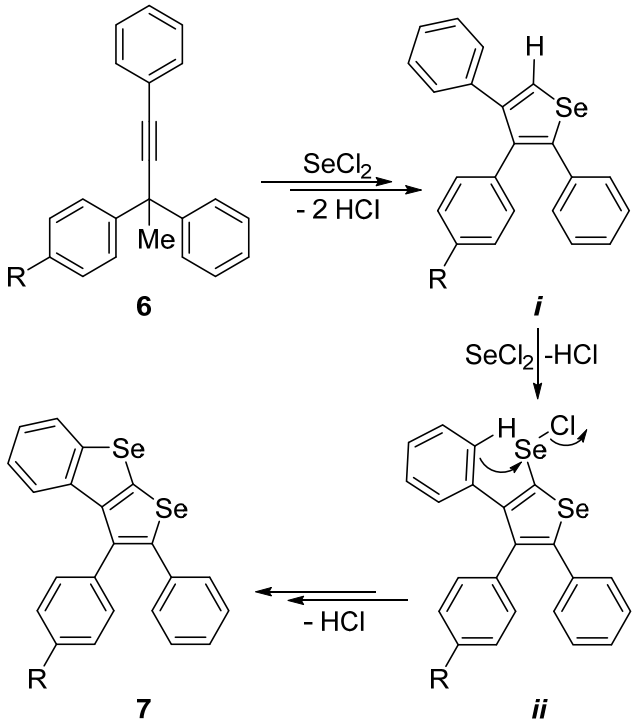
entry	starting material	R^1	substituted butyne	yield (%)[a]	cyclized product	yield (%)[a]
1	**5a**	H	**6a**	42	**7a**	85
2	**5b**	OMe	**6b**	17	**7b**	83
3	**5c**	Cl	**6c**	40	**7c**+**7c'**	53[b]

[a]Yield after column chromatography. [b]Mixture of isomers (82:18 by CG-MS analysis).

Despite being quite unexpected, the isolation of **7a-c** confirmed that aromatic rings other than substituted indoles are also capable of undergoing the required initial 1,2-migration, and suggested that the reaction has a much wider scope. Further, isolation of **7c** as a mixture of products resulting from migration of the phenyl and 4-chlorophenyl moieties reinforces the conjecture that the

migration aptitude is related to the electronic richness of the potentially migrating groups.

A plausible mechanism for the formation of the benzo[*b*]selenopheno[3,2-*d*]selenophene ring system is depicted in Scheme 3. It is proposed that the initial steps, affording intermediate ***i***, are analogous to those yielding the contiguously trisubstituted selenophenes **2a-o** (Scheme 2).



Scheme 3. Formation of benzo[*b*]selenopheno[3,2-*d*]selenophenes **7a-c**. Proposed mechanism.

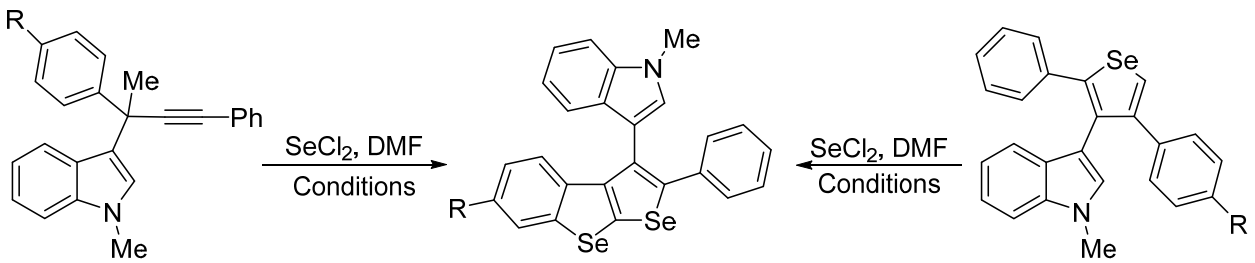
In turn, in the presence of another equivalent of $SeCl_2$, ***i*** could undergo the electrophilic additions of the reagent, resulting in **7** through the intermediacy of the chloroseleno intermediate ***ii***. However, the final causes behind the different behavior of compounds **1a-o** and their congeners **6a-c** remain unknown.

Considering that exposure of **6a-c** to $SeCl_2$ resulted in the formation of products **7a-c**, containing two selenium atoms and that the reaction could not be stopped at the first stage, it was

explored if, starting from **1** or **2** it would be also possible to obtain products carrying two selenium atoms in their structure. In this way, propargyl indoles **1a**, **1l** and **1q** were made to react with two successive portions of 1.0 equivalents each of $SeCl_2$.

Not unexpectedly, it was observed the formation of the corresponding selenopheno[3,2-*d*]selenophenenes **8a-c**, respectively, in moderate yields (Table 5).

Table 5. $SeCl_2$-mediated synthesis of 1-methyl-3-(2-phenylbenzo[*b*]selenopheno[3,2-*d*]selenophen-3-yl)-1*H*-indoles.



1a, 1l, 1q **8a-c** **2a**

entry	propargyl indole	R	$SeCl_2$ (equiv.)	reaction time (min.)	cyclized product	yield (%)[a]
1	**1a**	H	1.0 + 1.0	5 + 10	**8a**	38
2	**2a**	H	1.0	10	**8a**	64
3	**1l**	Cl	1.0 + 1.0	5 + 10	**8b**	36
4	**1q**	Me	1.0 + 1.0	5 + 10	**8c**	44

[a]Yield after column chromatography.

Furthermore, it was observed that the reaction can also accept **2a** as substrate. In this case, it gave **8a** in 64% yield (entry 2) after reacting with 1.0 equivalent of $SeCl_2$ during 10 min. These reactions with $SeCl_2$ proved to be very selective, since no formation of **8** could be observed when compounds **1a** and **1l** were employed as starting materials and made to react with only 1.0 equivalent of $SeCl_2$ (Table 3, entries 1 and 12).

The structures of compounds **7b** and **8a** were also assessed by single crystal X-ray diffraction analysis (Figure 3).[33] This revealed that the tricyclic core is essentially planar in both compounds. In the case of **7b**, the observed dihedral angles C6–C7–C8–C9, C10–Se2–C1–Se1 and C3–C2–Se1–C1 are –0.2º, +179.7º and +179.9º, respectively. On the other hand, it was found that both aromatic substituents are contorted away from each other, with observed dihedral angles C10–C9–C17–C22 and C9–C10–C11–C16 of –102.6º and +113.2º, respectively. In addition, with a dihedral angle C21–C20–O–C23 of +4.9º, the methoxy substituent is almost coplanar with the aromatic ring.

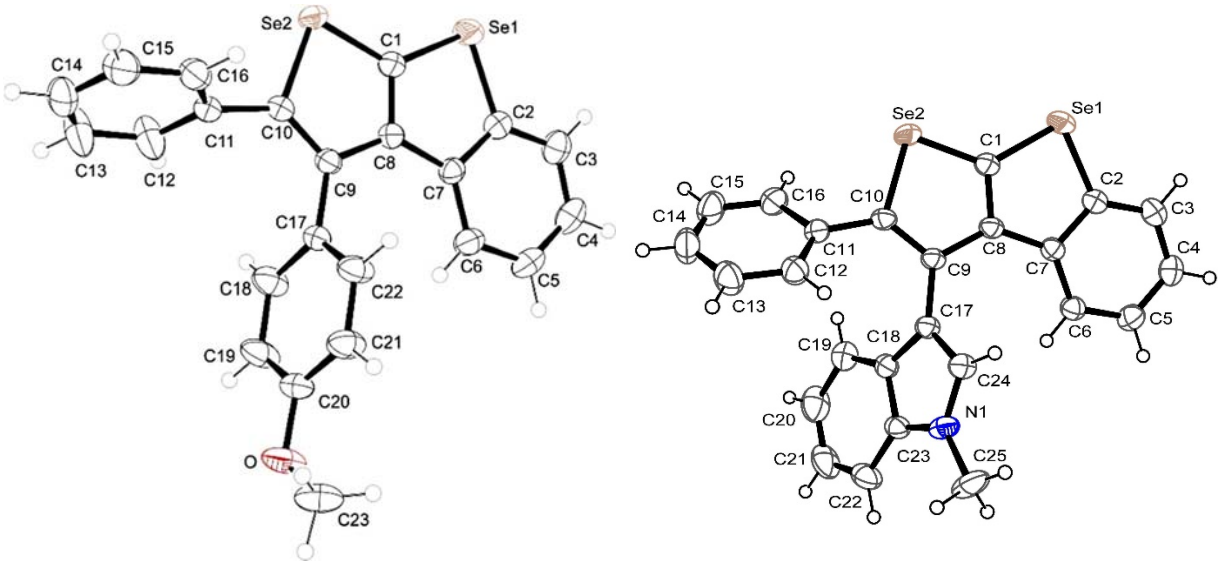


Figure 3. ORTEP representations of X-ray crystal structures of compounds **7b** (left) and **8a** (right), with ellipsoids drawn at the 50% probability level.

In line with previous observations, it was also found that the tricyclic core is still essentially planar in **8a**; the observed dihedral angles C6–C7–C8–C9, C10–Se2–C1–Se1 and C3–C2–Se1–C1 are +3.3º, +179.5º and +176.0º, respectively. Opposite to the previous finding, it was observed that both aromatic substituents are contained in planes rotated in the same direction with regards to the

tricyclic skeleton, and slightly tilted away from each other. The observed dihedral angles C10–C9–C17–C24 and C9–C10–C11–C12 are –125.5º and +136.2º, respectively.

CONCLUSIONS

We have demonstrated that conveniently substituted propargyl indoles can afford contiguously functionalized trisubstituted selenophenes, through a $SeCl_2$-mediated tandem 1,2-indole migration/cyclization. The reaction is general for a wide variety of compounds simultaneously possessing alkyl and aryl substituents at the propargylic position. It provided a number of new heterocycles potentially useful in medicinal chemistry. However, under the same conditions, propargyl indoles carrying two pendant alkyl substituents at the propargylic position yielded a seleno[2,3-*b*]indole derivative.

The broad scope of the reaction was demonstrated by exploring the chemical space at different points of diversification; it was also shown that some of the resulting products can be further transformed, rapidly providing access to polycyclic compounds with increased structural complexity. Some limitations were also found.

$SeCl_2$ acted as a suitable electrophilic agent for the introduction of selenium, and the transformation, which entailed the migration of the indole as the most electron-rich propargyl substituent, proceeded in short times, high yields and under mild experimental conditions. The scope of the reaction was also demonstrated with 1,3,3-triphenyl-1-butynes, which afforded 2,3-diaryl benzo[*b*]selenopheno[3,2-*d*]selenophenes. The observed migratory aptitudes strongly support an electrophilic mechanism for this transformation, with involvement of a selenirenium-type intermediate. Additional efforts to explore synthetic applications of this novel reaction are currently underway and their results will be reported in due time.

EXPERIMENTAL SECTION

General considerations. The melting points were taken on a MQAPF-301 melting point apparatus and are reported uncorrected. ^{1}H and ^{13}C NMR spectra were recorded on Bruker 400 and 600 NMR spectrometers, with the samples dissolved in $CDCl_3$and DMSO-d_6. Chemical shifts are informed in ppm downfield from the signal of TMS, used as internal standard, and the coupling constants (*J*) are expressed in Hertz (Hz). Low resolution mass spectra were obtained from a Shimadzu QP2010 gas-chromatograph coupled to a mass spectrometer. High-resolution mass spectral data were obtained on a Bruker microTOF-Q IIT instrument, employing sodium formate as reference. X-Ray diffraction data were acquired with a Bruker Kappa APEX II CCD diffractometer, fit with a graphite monochromator and a Mo-Kα radiation source (λ = 0.71073 Å). Elemental analyses of the products were obtained in a Perkin-Elmer CHN 2400 elemental analyzer.

The reagents for synthesis were obtained commercially. The solvents were purified and dried according to usual procedures.[34] All the other reagents were used as received, without further purification. Chromatographic purifications were conducted by column chromatography using silica gel (230–400 mesh, 40-63 μm), eluting with hexane or hexane-EtOAc mixtures of increasing polarity. Progress of the reactions was monitored by thin layer chromatography, using UV light (254 and 365 nm), I_2 or H_2SO_4/vanillin solution for detection of the spots.

General Procedure for the Preparation of the Propargylic Alcohols.[15g] A mixture of the corresponding ketone (5 mmol) and the alkyne (7.5 mmol), were transferred to a 25 mL flask and mixed with stirring until a homogeneous solution was obtained. The mixture was treated with *t*-BuOK (842 mg, 7.5 mmol) and stirred at room temperature until complete consumption of starting materials was verified by TLC. The reaction mixture was diluted with water (100 mL) and the

products were extracted with EtOAc (3 × 100 mL). The combined organic extracts were washed with water (100 mL) and brine (10 mL), dried over $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography, eluting with hexane:EtOAc (95:5, *v/v*).

General Procedure for the Preparation of the Propargyl Indoles.[13b] The indole (1.0 mmol) was added to a stirred solution of the propargyl alcohol (1.1 mmol) in anhydrous $MeNO_2$ (2 mL) and the mixture was treated with anhydrous $CeCl_3$ (73.5 mg, 0.3 mmol) and ZnO (81 mg, 1.0 mmol). The mixture was heated under reflux until consumption of starting materials was completed (TLC). The reaction mixture was partitioned between brine (10 mL) and EtOAc and the products were extracted with EtOAc (3 × 50 mL). The combined organic extracts were washed with water (50 mL) and brine (10 mL), dried over $MgSO_4$, filtered through a cotton plug and concentrated under reduced pressure. The residue was purified by silica gel column chromatography eluting with hexane:EtOAc (98:2, *v/v*).

*3-(2,4-Diphenylbut-3-yn-2-yl)-1-methyl-1H-indole (**1a**).* White solid (241 mg, 72% yield): mp 113 ºC; Lit.:[15b] 110–112 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61–7.59 (m, 2H), 7.50 (d, 1H, J = 8.0), 7.44–7.41 (m, 2H), 7.29–7.32 (m, 6H), 7.21–7.17 (m, 1H), 7.16–7.14 (m, 1H), 6.99 (s, 1H), 6.96 (ddd, J = 8.0, 6.9, 1.0, 1H), 3.74 (s, 3H), 2.10 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 146.2, 137.8, 131.6, 128.1 (×2), 127.6, 126.6, 126.3, 126.2, 126.1, 123.9, 121.5, 121.2, 120.2, 118.8, 109.1, 95.2, 82.9, 39.8, 32.7, 31.0. EIMS (*m/z*, rel. int., %) 335 (M^+, 63), 320 ([M-Me]$^+$, 100).

*3-(4-(4-Clorophenyl)-2-phenylbut-3-yn-2-yl)-1-methyl-1H-indole (**1b**).* White solid (263 mg, 71% yield): mp 124–126 ºC; Lit.:[15e] 122–126 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.58–7.55 (m, 2H),

7.46 (d, *J* = 8.0, 1H), 7.35–7.32 (m, 2H), 7.29–7.14 (m, 7H), 6.98–6.94 (m, 2H), 3.74 (s, 3H), 2.08 (s, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 146.0, 137.8, 133.6, 132.8, 128.4, 128.1, 126.5, 126.4, 126.1, 126.0, 122.3, 121.6, 121.1, 119.9, 118.8, 109.2, 96.2, 81.9, 39.9, 32.7, 30.9. EIMS (*m/z*, rel. int., %) 371 ($[M+2]^+$, 21), 370 ($[M+1]^+$, 18), 369 (M^+, 58), 356 ($[M+2\text{-}Me]^+$, 36), 354 ($[M\text{-}Me]^+$, 100).

*1-Methyl-3-(2-phenyl-4-(p-tolyl)but-3-yn-2-yl)-1H-indole (***1c***).* White solid (275 mg, 79% yield) mp 119–120 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61–7.58 (m, 2H), 7.51–7.48 (m, 1H), 7.33–7.30 (m, 2H), 7.29–7.23 (m, 3H), 7.21–7.13 (m, 2H), 7.07–7.04 (m, 2H), 6.98 (s, 1H), 6.95 (ddd, *J* = 8.1, 7.0, 1.1, 1H), 3.73 (s, 3H), 2.30 (s, 3H), 2.09 (s, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 146.4, 137.8, 137.6, 131.5, 128.8, 128.0, 126.6, 126.3, 126.2, 121.5, 121.3, 120.9, 120.4, 118.7, 109.1, 94.4, 83.0, 39.8, 32.6, 31.0, 21.3. EIMS (*m/z*, rel. int., %) 349 (M^+, 60), 334 ($[M\text{-}Me]^+$, 100). HRMS (ESI) *m/z*: $[M+Na]^+$ calcd. for $C_{26}H_{23}NNa$ 372.1723; found: 372.1727.

*1-Methyl-3-(2-phenyl-oct-3-yn-2-yl)-1H-indole (***1d***).* Yellow oil (186 mg, 59% yield): ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.54–7.53 (m, 2H), 7.42 (d, *J* = 8.0, 1H), 7.25–7.22 (m, 3H), 7.18–7.12 (m, 2H), 6.94–6.92 (m, 2H), 3.70 (s, 3H), 2.24 (t, *J* = 7.1, 2H), 1.97 (s, 3H), 1.52 (quintet, *J* = 7.7, 2H), 1.42 (septet, *J* = 7.4, 2H), 3.70 (s, 3H). $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ 146.9, 137.7, 127.9, 126.5, 126.2, 126.1, 126.0, 121.4, 121.3, 120.9, 118.5, 109.0, 85.4, 82.9, 39.2, 32.6, 31.4, 31.1, 22.0, 18.6, 13.6. EIMS (*m/z*, rel. int., %) 315 (M^+, 39), 300 ($[M\text{-}Me]^+$, 100). HRMS (ESI) *m/z*: $[M+Na]^+$ calcd. for $C_{23}H_{25}NNa$ 338.1879; found: 338.1876.

*5-Bromo-3-(2,4-diphenylbut-3-yn-2-yl)-1-methyl-1H-indole (***1e***).* White solid (323 mg, 78% yield): mp 107–108 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.68 (s, 1H), 7.56 (d, *J* = 8.0, 2H), 7.45 (m, 2H), 7.31–7.26 (m, 5H), 7.24–7.20 (m, 2H), 7.10 (d, *J* = 8.6, 1H), 6.97 (s, 1H), 3.70 (s, 3H), 2.06 (3H). $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ 145.7, 136.4, 131.6, 128.2, 128.1, 127.7, 127.6, 127.2, 126.6, 126.4, 124.4, 123.6, 119.8, 112.2, 110.7, 94.6, 83.2, 39.7, 32.8, 31.0. EIMS (*m/z*, rel. int.,

%) 415 ([M+2]$^+$, 58), 413 (M$^+$, 54), 400 ([M+2-Me]$^+$, 94), 398 ([M-Me]$^+$, 100). HRMS (ESI) *m/z*: [M+Na]$^+$ calcd. for $C_{25}H_{20}BrNNa$ 436.0671; found: 436.0671.

*3-(2,4-Diphenylbut-3-yn-2-yl)-1-methyl-1H-indole-5-carbonitrile (***1f***).* White solid (234 mg, 65% yield): mp 143–145 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.82 (s, 1H), 7.55 (d, *J* = 7.4, 2H), 7.44–7.42 (m, 2H), 7.36 (dd, *J* = 8.5, 1.1, 1H), 7.31–7.27 (m, 6H), 7.23 (t, *J* = 6.9, 1H), 7.14 (s, 1H), 3.78 (s, 3H), 2.08 (s, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 145.3, 139.2, 131.5, 128.3, 128.3, 128.2, 127.9, 126.8, 126.6, 126.3, 125.8, 124.5, 123.2, 121.6, 120.8, 110.1, 101.8, 93.9, 83.6, 39.6, 32.9, 31.0. EIMS (*m/z*, rel. int., %) 360 (M$^+$, 14), 345 ([M-Me]$^+$, 29). HRMS (ESI) *m/z*: [M+Na]$^+$ calcd. for $C_{26}H_{20}N_2Na$ 383.1519; found: 383.1520.

*3-(2,4-Diphenylbut-3-yn-2-yl)-5-methoxy-1-methyl-1H-indole (***1g***).* White solid (255 mg, 70% yield): mp 95–96 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.60 (d, *J* = 7.8, 2H), 7.44–7.46 (m, 2H), 7.30–7.25 (m, 5H), 7.22–7.19 (m, 1H), 7.14 (d, *J* = 8.8, 1H), 6.96–6.94 (m, 2H), 6.83 (dd, *J* = 8.8, 2.1, 1H), 3.71 (s, 3H), 3.64 (s, 3H), 2.08 (s, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 153.2, 146.1, 133.1, 131.6, 128.2, 128.1 (×2), 127.6, 126.7, 126.6, 126.3, 123.8, 119.5, 111.7, 109.8, 103.0, 95.0, 82.9, 55.7, 39.7, 32.8, 30.9. EIMS (*m/z*, rel. int., %) 365 (M$^+$, 63), 350 ([M-Me]$^+$, 100). HRMS (ESI) *m/z*: [M+Na]$^+$ calcd. for $C_{26}H_{23}NNaO$ 388.1672; found: 388.1672.

*3-(2,4-Diphenylbut-3-yn-2-yl)-1,2-dimethyl-1H-indole (***1h***).* White solid (296 mg, 85% yield): mp 153–155 ºC; Lit.:[15b] 157–159 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65 (d, *J* = 8.1, 1H), 7.58–7.55 (m, 2H), 7.44–7.41 (m, 2H), 7.28–7.16 (m, 7H), 7.11 (ddd, *J* = 8.1, 7.0, 1.1, 1H), 6.97 (ddd, *J* = 8.1, 7.0, 1.1,1H), 3.60 (s, 3H), 2.28 (s, 3H), 2.27 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 148.3, 136.5, 134.35, 131.5, 128.1, 128.0, 127.5, 126.7, 126.6, 126.2, 124.1, 120.5, 120.1, 118.9, 114.7, 108.7, 96.3, 83.2, 41.6, 32.4, 29.3, 11.8. EIMS (*m/z*, rel. int., %) 349 (M$^+$, 57), 334 ([M-Me]$^+$, 100).

*1-Benzyl-3-(2,4-diphenylbut-3-yn-2-yl)-1H-indole (***1i***).* White solid (267 mg, 65% yield): mp 128–

129 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.61–7.58 (m, 2H), 7.51 (d, *J* = 8.0, 1H), 7.44–7.40 (m, 2H), 7.32–7.16 (m, 10H), 7.14–7.07 (m, 4H), 6.95 (ddd, *J* = 8.0, 7.0, 1.0, 1H), 5.28 (s, 2H), 2.09 (m, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ146.3, 137.6, 131.6, 128.7, 128.2, 128.1, 127.6, 127.5, 126.7, 126.6, 126.5, 126.4, 125.6, 123.9, 121.7, 121.4, 120.9, 119.1, 109.6, 95.2, 83.1, 50.0, 39.9, 31.0. EIMS (*m/z*, rel. int., %) 411 (M^+, 38), 396 ([M-Me]$^+$, 39). HRMS (ESI) *m/z*: [M+Na]$^+$ calcd. for $C_{31}H_{25}NNa$ 434.1879; found: 434.1877.

*3-(2,4-Diphenylbut-3-yn-2-yl)-1H-indole (***1k***).* White solid (269 mg, 84% yield): mp 75–76 ºC; Lit.:[15b] 73–75 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 (s, 1H), 7.59–7.57 (m, 2H), 7.50–7.48 (m, 1H), 7.43–7.40 (m, 2H), 7.29–7.16 (m, 7H), 7.14–7.12 (m, 1H), 7.10 (d, *J*= 2.5, 1H), 6.96 (ddd, *J* = 8.1, 7.0, 1.0, 1H), 2.09 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 146.1, 137.0, 131.6, 128.1 (2C), 127.6, 126.6, 126.4, 125.7, 123.8, 122.0, 121.7, 121.4, 121.1, 119.3, 111.0, 95.0, 83.0, 39.8, 30.9. EIMS (*m/z*, rel. int., %) 321 (M^+, 21), 306 ([M-Me]$^+$, 100).

*3-(2-(4-Chlorophenyl)-4-diphenylbut-3-yn-2-yl)-1-methyl-1H-indole (***1l***).* Yellow solid (258 mg, 70% yield): mp 130 ºC; Lit.:[15b] 128–130 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.53–7.50 (m, 2H), 7.44 (d, *J* = 8.0, 1H), 7.43–7.41 (m, 2H), 7.28–7.22 (m, 6H), 7.19–7.16 (m, 1H), 7.02 (s, 1H), 6.99–6.96 (m, 1H), 3.76 (s, 3H), 2.06 (s, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 144.9, 137.9, 132.1, 131.6, 128.2, 128.1, 128.1, 127.8, 126.1, 125.8, 123.5, 121.6, 121.0, 119.5, 118.9, 109.2, 94.5, 83.2, 39.4, 32.7, 30.9. EIMS (*m/z*, rel. int., %) 371 ([M+2]$^+$, 21), 369 (M^+, 61), 354 ([M-Me]$^+$, 100).

*3-(2-(4-Methoxyphenyl)-4-phenylbut-3-yn-2-yl)-1-methyl-1H-indole (***1m***).* White solid (274 mg, 75% yield): mp 116–117 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.52–7.49 (m, 3H), 7.43–7.42 (m, 2H), 7.26–7.24 (m, 4H), 7.16 (t, *J* = 7.5, 1H), 6.98–6.96 (m, 2H), 6.81 (d, *J* = 8.7, 2H), 3.76 (s, 3H), 3.73 (s, 3H), 2.07 (s, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 158.0, 138.4, 137.8, 131.3, 128.0, 127.7, 127.7, 126.1, 126.0, 123.9, 121.5, 121.2, 120.4, 118.7, 113.4, 109.1, 95.4, 82.7, 55.1, 39.1, 32.6, 31.0. EIMS (*m/z*, rel. int., %) 365 (M^+, 66), 350 ([M-Me]$^+$, 100). HRMS (ESI) *m/z*: [M+Na]$^+$

calcd. for $C_{26}H_{23}NNaO$ 388.1672; found: 388.1670.

*3-(1,3-Diphenylpent-1-yn-3-yl)-1-methyl-1H-indole (***1n***).* White solid (261 mg, 75% yield): mp 123–125 ºC; Lit.:[15b] 124–126 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60–7.57 (m, 2H), 7.53–7.50 (m, 1H), 2.47–7.44 (m, 2H), 7.29–7.22 (m, 6H), 7.20–7.12 (m, 2H), 7.01 (s, 1H), 6.94 (ddd, *J* = 8.1, 7.0, 1.1, 1H), 3.73 (s, 3H), 2.57 (dq, *J* = 13.0, 7.2, 1H), 2.32 (dq, *J* = 13.0, 7.2, 1H), 1.04 (t, *J* = 7.2, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 144.6, 137.7, 131.6, 128.1, 127.9, 127.6, 127.3, 126.4, 126.3, 126.2, 124.0, 121.4, 121.2, 119.5, 118.7, 109.1, 93.7, 84.7, 45.3, 34.7, 32.6, 9.9. EIMS (*m/z*, rel. int., %) 349 (M^+, 16), 321 ([M-C_2H_4]$^+$, 28), 320 ([M-Et]$^+$, 100).

*5-Bromo-3-(4-(p-bromophenyl)-2-phenylbut-3-yn-2-yl)-1-methyl-1H-indole (***1o***).* Yellow solid (343 mg, 70% yield): mp 119–120 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.65–7.64 (m, 1H), 7.55–7.52 (m, 2H), 7.41–7.38 (m, 2H), 7.31–7.27 (m, 4H), 7.25–7.19 (m, 2H), 7.11 (d, *J* = 8.7, 1H), 6.93 (s, 1H), 3.70 (s, 3H), 2.05 (3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 145.5, 136.5, 133.0, 131.4, 128.3, 127.7, 127.3, 126.7, 126.4, 124.6, 123.6, 122.6, 121.9, 119.7, 112.4, 110.7, 96.0, 82.3, 39.8, 32.8, 30.9. EIMS (*m/z*, rel. int., %) 492 ([M+2]$^+$, 64), 490 (M^+, 33), 479 ([M+2-Me]$^+$, 53), 477 ([M-Me]$^+$, 100). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{25}H_{20}Br_2N$ 493.9937; found: 493.9956.

*1-Methyl-3-(2-methyl-4-phenylbut-3-yn-2-yl)-1H-indole (***1p***).*[15b] Yellow oil (243 mg, 89% yield): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00–7.97 (m, 1H), 7.43–7.39 (m, 2H), 7.28–7.20 (m, 5H), 7.11 (ddd, *J* = 8.1, 6.9, 1.2, 1H), 6.96 (s, 1H), 3.70 (s, 3H), 1.79 (s, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 137.8, 131.6, 128.0, 127.4, 125.9, 124.7, 124.1, 121.4, 121.1, 121.0, 118.6, 109.0, 97.1, 80.4, 32.5, 31.2, 30.7. EIMS (*m/z*, rel. int., %) 273 (M^+, 32), 258 ([M-Me]$^+$, 100).

*3-(2-(4-Tolyl)-4-phenylbut-3-yn-2-yl)-1-methyl-1H-indole (***1q***).* White solid (258 mg, 74% yield): mp 111–112 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53–7.51 (m, 1H), 7.49–7.47 (m, 2H), 7.44–7.41 (m, 2H), 7.27–7.21 (m, 4H), 7.18–7.14 (m, 1H), 7.10–7.07 (m, 2H), 6.99–6.95 (m, 2H), 3.74 (s,

3H), 2.30 (s, 3H), 2.08 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 143.3, 137.8, 135.8, 131.6, 128.8, 128.0, 127.5, 126.5, 126.1, 126.0, 124.0, 121.5, 121.3, 120.3, 118.7, 109.1, 95.4, 82.7, 39.5, 32.6, 31.0, 20.9. EIMS (*m/z*, rel. int., %) 349 (M^+, 60), 334 ($[M-Me]^+$, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{26}H_{24}N$ 350.1903; found: 350.1916.

*tert-Butyl 3-(2,4-diphenylbut-3-yn-2-yl)-1H-indole-1-carboxylate (***1j***).* A solution of propargyl indole **1k** (1.60 g, 5 mmol) in CH_2Cl_2 (10 mL) was treated successively with pyridine (0.52 mL, 6.4 mmol), Boc_2O (1.19 g, 6.4 mmol) and DMAP (0.061 g, 0.5 mmol). The reaction mixture was stirred for 24 h at room temperature, then $NH_4Cl_{(sat)}$ (125 mL) was added and the products were extracted with EtOAc (2 × 150 mL). The solvent was removed under vacuo and the residue purified by column chromatography, eluting with hexanes, to afford **1j** (1.90 g, 90% yield), as a white solid: mp 48–50 °C. ^1H NMR (600 MHz, $CDCl_3$) δ 8.19 (s, 1H), 7.68 (s, 1H), 7.58 (d, *J* = 7.7, 2H), 7.43–7.42 (m, 2H), 7.36 (d, *J* = 7.7, 1H), 7.30–7.20 (m, 7H), 7.05 (t, *J* = 7.5, 1H), 2.08 (s, 3H), 1.69 (s, 9H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 149.9, 144. 9, 136.0, 131.6, 128.7, 128.2, 128.1, 127.8, 126.7, 126.4, 125.7, 124.1, 123.4, 122.5, 122.2, 121.4, 115.0, 93.5, 83.7, 39.7, 30.8, 28.1. HRMS (ESI) *m/z*: $[M+Na]^+$ calcd. for $C_{29}H_{27}NNaO_2$ 444.1934; found: 444.1936.

General Procedure for the Preparation of the Indole-substituted Selenophenes (2a-p). A mixture of Se^0 (0.5 mmol) and SO_2Cl_2 (1.0 mmol), was stirred under argon for 1.0 hour at room temperature. A brown solution was formed. Then DMF (1.5 mL) was added and the system was stirred for 0.5 hour, when it was treated dropwise with a DMF (1.5 mL) solution of the aryl propargyl indole (0.5 mmol). The system was stirred for the prescribed time under the chosen temperature. The reaction was quenched with brine (10 mL) and extracted with EtOAc (3 × 50 mL). The combined organic extracts were washed with water (50 mL) and brine (10 mL), dried

over $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography, eluting with hexane.

*3-(4,5-Diphenylselenophen-3-yl)-1-methyl-1H-indole (**2a**).* White solid (186 mg, 90% yield): mp 164–165 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.24–7.23 (m, 2H), 7.18 (d, *J* = 8.2, 1H), 7.13–7.0 (m, 9H), 7.02 (d, *J* = 7.9, 1H), 6.81–6.78 (m, 1H), 6.52 (s, 1H), 3.59 (s, 3H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 147.4, 146.2, 139.3, 137.3, 136.5, 132.1, 128.9. 128.8, 128.7, 128.0, 127.6, 127.5, 126.8, 126.5, 126.4, 121.1, 120.5, 118.9, 111.2, 108.6, 32.6. EIMS (*m/z*, rel. int., %) 413 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{25}H_{20}NSe$ 414.0761; found: 414.0757.

*3-(5-(4-Chlorophenyl)-4-phenylselenophen-3-yl)-1-methyl-1H-indole (**2b**).* White solid (197 mg, 88% yield): mp 179–180 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.92 (s, 1H), 7.21–7.19 (m, 1H), 7.18–7.14 (m, 2H), 7.11–7.04 (m, 8H), 7.02 (dt, *J* = 8.0, 1.0, 1H), 6.83 (ddd, *J* = 8.0, 7.0, 1.0, 1H), 6.52 (s, 1H), 3.62 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 147.6, 144.7, 139.2, 136.6, 135.9, 132.7, 130.0, 128.8, 128.7, 128.3 (x2), 127.6, 127.5, 126.7, 126.5, 121.3, 120.4, 119.1, 111.0, 108.8, 32.7. EIMS (*m/z*, rel. int., %) 449 ($[M+2]^+$, 12), 448 ($[M+1]^+$, 45), 447 (M^+, 31), 446 ($[M-1]^+$, 100). Anal. Calcd. for $C_{25}H_{18}ClNSe$: C, 67.20; H, 4.06; N, 3.13. Found: C, 66.97; H, 4.27; N, 3.11.

*1-Methyl-3-(4-phenyl-5-(p-toluyl)selenophen-3-yl)-1H-indole (**2c**).* White solid (194 mg, 91% yield): mp 193–195 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 (s, 1H), 7.21–7.04 (m, 10H), 6.89 (d, *J* = 7.7, 2H), 6.83–6.79 (m, 1H), 6.53 (s, 1H), 3.60 (s, 3H), 2.21 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 147.5, 146.6, 139.5, 136.6, 136.5, 134.5, 131.7, 128.9, 128.8, 128.7 (2C), 127.8, 127.5, 126.4, 126.0, 121.1, 120.6, 118.9, 111.5, 108.6, 32.6, 21.0. EIMS (*m/z*, rel. int., %) 427 (M^+, 100). HRMS (ESI) *m/z*: $[M+Na]^+$ calcd. for $C_{26}H_{21}NNaSe$ 450.0731; found: 450.0732.

*3-(2-Butyl-4-phenylselenophen-3-yl)-1-methyl-1H-indole (**2d**).* Yellow oil (43 mg, 22% yield): ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.76 (s, 1H), 7.30 (t, *J* = 8.0, 1H), 7.26 (t, *J* = 8.1, 1H), 7.18–7.16 (m,

1H), 7.09–7.04 (m, 5H), 7.02–6.99 (m, 1H), 6.62 (s, 1H), 3.66 (s, 3H), 2.84–2.70 (m, 2H), 1.66–1.59 (m, 2H), 1.29 (sextet, J = 7.4, 2H), 0.81 (t, J = 7.4, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ151.0, 146.3, 139.3, 136.4, 132.0, 128.4 (x2), 128.2, 127.5, 126.1, 123.4, 121.2, 120.2, 119.0, 111.5, 108.9, 35.3, 32.6, 31.2, 22.3, 13.8. EIMS (*m/z*, rel. int., %) 393 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{23}H_{24}NSe$ 394.1068; found: 394.1061.

*5-Bromo-3-(4,5-diphenylselenophen-3-yl)-1-methyl-1H-indole (***2e***).* White solid (225 mg, 92% yield): mp 170–171 ºC. ^1H NMR (600 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.24–7.21 (m, 2H), 7.14–7.10 (m, 10H), 7.04–7.02 (m, 1H), 6.52 (s, 1H), 3.58 (s, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 147.2, 146.7, 139.2, 137.1, 135.1, 131.4, 130.0, 129.1, 128.9, 128.7, 128.1, 127.7, 127.1, 126.7, 126.6, 124.0, 123.1, 112.5, 111.0, 110.3, 32.9. EIMS (*m/z*, rel. int., %) 492 ($[M+2]^+$, 77), 490 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{25}H_{19}BrNSe$ 491.9866; found: 491.9852.

*3-(4,5-Diphenylselenophen-3-yl)-1-methyl-1H-indole-5-carbonitrile (***2f***).* White solid (193 mg, 88% yield): mp 198–199 ºC. ^1H NMR (600 MHz, $CDCl_3$) δ 7.95 (s, 1H), 7.33 (s, 1H), 7.26–7.24 (m, 1H), 7.21–7.19 (m, 3H), 7.14–7.10 (m, 6H), 7.09–7.07 (m, 2H), 6.65 (s, 1H), 3.64 (s, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ147.2, 146.8, 138.9, 137.8, 136.7, 130.9, 130.5, 128.8, 128.6, 128.2, 127.7, 127.2, 127.1, 127.0, 126.7, 126.1, 124.2, 120.5, 112.6, 109.7, 102.0, 32.9. EIMS (*m/z*, rel. int., %) 439 ($[M+1]^+$, 21), 438 (M^+, 100). Anal.Calcd. for $C_{26}H_{18}N_2Se$: C, 71.40; H, 4.15; N, 6.40. Found: C, 71.20; H, 4.21; N, 6.24.

*3-(4,5-Diphenylselenophen-3-yl)-5-methoxy-1-methyl-1H-indole (***2g***).* White solid (199 mg, 90% yield): mp 158–160 ºC. ^1H NMR (600 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.28–7.25 (m, 2H), 7.15–7.10 (m, 8H), 7.05 (d, J = 8.7, 1H), 6.7 (dd, J = 8.7, 2.2, 1H), 6.45 (s, 1H), 6.39 (d, J = 2.2, 1H), 3.56 (s, 3H), 3.47 (s, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 153.5, 147.2, 145.6, 139.4, 137.5, 132.2, 131.7, 129.5, 128.8, 128.7, 128.1, 127.6, 127.4, 126.8, 126.6, 126.5, 111.9, 110.6, 109.4, 101.6, 55.4, 32.8. EIMS (*m/z*, rel. int., %) 443 (M^+, 100). Anal. Calcd. for $C_{26}H_{21}NOSe$: C, 70.59; H, 4.78;

N, 3.17. Found: C, 69.91; H, 4.93; N, 3.09.

*3-(2,4-Diphenylselenophen-3-yl)-1,2-dimethyl-1H-indole (**2h**).* White solid (190 mg, 89% yield): mp 163–165 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (s, 1H), 7.21–7.17 (m, 2H), 7.16–7.14 (m, 1H), 7.08–6.99 (m, 10H), 6.82–6.78 (m, 1H), 3.51 (s, 3H), 1.80 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 147.7, 147.1, 139.3, 137.5, 136.7, 134.7, 132.4, 128.4, 128.2, 128.0, 127.7, 127.5, 126.7, 126.3, 126.1, 120.2, 119.4, 118.9, 109.0, 108.1, 29.5, 10.7. EIMS (*m/z*, rel. int., %) 427 (M^+, 100). HRMS (ESI) *m/z*: $[M+Na]^+$ calcd. for $C_{26}H_{21}NNaSe$ 450.0731; found: 450.0735.

*1-Benzyl-3-(4,5-diphenylselenophen-3-yl)-1H-indole (**2i**).* White solid (227 mg, 93% yield): mp 164–165 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.27–7.25 (m, 2H), 7.21–7.19 (m, 3H), 7.16–7.14 (m, 2H), 7.12–7.09 (m, 7H), 7.06 (d, *J* = 8.1, 1H), 7.02–6.99 (m, 1H), 6.85–6.84 (m, 2H), 6.82–6.79 (m, 1H), 6.68 (s, 1H), 5.16 (s, 2H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 147.4, 146.6, 139.3, 137.3, 137.2, 135.9, 132.1, 128.9, 128.7, 128.5, 128.4, 128.0, 127.9, 127.6, 127.3, 126.8, 126.6, 126.5, 126.4, 121.4, 120.5, 119.2, 112.0, 109.3, 49.8. EIMS (*m/z*, rel. int., %) 489 (M^+, 66). Anal. Calcd. for $C_{31}H_{23}NSe$: C, 76.22; H, 4.75; N, 2.87. Found: C, 76.71; H, 4.93; N, 2.85.

*3-(4,5-Diphenylselenophen-3-yl)-1H-indole (**2k**).* White solid (167 mg, 84% yield): mp 202–204 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.89 (s, 1H), 7.24–7.20 (m, 3H), 7.13–7.02 (m, 10H), 6.82–6.80 (m, 1H), 6.65 (d, *J* = 2.4, 1H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 147.4, 146.7, 139.3, 137.3, 135.6, 132.1, 128.9, 128.7, 128.0, 127.6, 127.1, 126.8, 126.5, 126.4, 124.4, 121.7, 120.4, 119.4, 113.0, 110.6. EIMS (*m/z*, rel. int., %) 399 (M^+, 100). Anal. Calcd. for $C_{24}H_{17}NSe$: C, 72.36; H, 4.30; N, 3.52. Found: C, 71.94; H, 4.47; N, 3.45.

*3-(4-(4-Chlorophenyl)-5-phenylselenophen-3-yl)-1-methyl-1H-indole (**2l**).* White solid (210 mg, 94% yield): mp 179–181 ºC. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.91 (s, 1H), 7.22–7.20 (m, 3H), 7.10–7.08 (m, 4H), 7.05 (m, 4H), 7.02 (d, 7.9, 1H), 6.84–6.81 (m, 1H), 6.54 (s, 1H), 3.63 (s, 3H). ^{13}C{^{1}H}

NMR (150 MHz, $CDCl_3$) δ 146.8, 146.0, 137.8, 137.1, 136.5, 132.3, 131.8, 129.8, 128.8 (×2), 128.1, 127.8, 127.4, 126.9, 126.8, 121.3, 120.3, 119.1, 110.9, 108.8, 32.7. EIMS (*m/z*, rel. int., %) 448 ($[M+2]^+$, 47), 447 ($[M+1]^+$, 45), 446 (M^+, 100). Anal. Calcd. for $C_{25}H_{18}ClNSe$: C, 67.20; H, 4.06; N, 3.13. Found: C, 66.71; H, 4.05; N, 3.04.

*3-(4-(4-Methoxyphenyl)-5-phenylselenophen-3-yl)-1-methyl-1H-indole (***2m***).* White solid (166 mg, 75% yield): mp 133–135 ºC. ^1H NMR (600 MHz, $CDCl_3$) δ 7.85 (s, 1H), 7.24–7.22 (m, 2H), 7.21 (d, *J* = 8.1, 1H), 7.08–7.03 (m, 7H), 6.82–6.80 (m, 1H), 6.63 (d, *J* = 8.1, 2H), 6.53 (s, 1H), 3.69 (s, 3H), 3.61 (s, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 158.3, 147.0, 146.2, 137.4, 136.5, 132.1, 121.0, 129.7, 128.9, 128.8, 128.0, 127.6, 126.7, 125.6, 121.1, 120.6, 118.9, 113.0, 111.4, 108.6, 55.1, 32.7. EIMS (*m/z*, rel. int., %) 443 (M^+, 100). Anal. Calcd. for $C_{26}H_{21}NOSe$: C, 70.59; H, 4.78; N, 3.17. Found: C, 70.41; H, 4.77; N, 3.17.

*1-Methyl-3-(2-methyl-3,5-diphenylselenophen-3-yl)-1H-indole (***2n***).* White solid (209 mg, 98% yield): mp 177–178 ºC. ^1H NMR (600 MHz, $CDCl_3$) δ 7.23–7.20 (m, 2H), 7.12–7.08 (m, 4H), 7.06–7.00 (m, 7H), 6.79–6.75 (m, 1H), 6.38 (s, 1H), 3.52 (s, 3H), 2.47 (s, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 144.1, 141.6, 139.7, 138.5, 137.4, 136.4, 133.2, 130.1, 128.8, 128.7, 128.0, 127.5, 127.4, 126.4, 126.2, 121.0, 120.6, 118.7, 112.4, 108.5, 32.5, 16.8. EIMS (*m/z*, rel. int., %) 427 (M^+, 100). HRMS (ESI) *m/z*: $[M+Na]^+$ calcd. for $C_{26}H_{21}NNaSe$ 450.0731; found: 450.0732. Anal. Calcd. for $C_{26}H_{22}NSe$: C, 73.23; H, 4.96; N, 3.28. Found: C, 73.25; H, 4.91; N, 3.31.

*5-Bromo-3-(2-(4-bromophenyl)-4-phenylselenophen-3-yl)-1-methyl-1H-indole (***2o***).* White solid (261 mg, 92% yield): mp 194–196 ºC. ^1H NMR (600 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.26–7.22 (m, 2H), 7.16–7.11 (m, 3H), 7.10–7.08 (m, 5H), 7.07–7.06 (m, 1H), 7.05–7.03 (m, 1H), 6.52 (s, 1H), 3.60 (s, 3H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 147.5, 145.4, 139.1, 136.3, 135.4, 132.2, 131.5, 130.6, 130.0, 129.2, 128.8, 127.8, 127.1, 126.9, 124.5, 123.0, 121.3, 112.9, 111.0, 110.5, 33.0.

EIMS (*m/z*, rel. int., %) 572 ([M+4]$^+$, 50), 571 ([M+3]$^+$, 26), 570 ([M+2]$^+$, 100), 569 ([M+1]$^+$, 29), 568 (M$^+$, 82). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{25}H_{18}Br_2NSe$ 569.8966; found: 569.8968.

*8-Methyl-2-phenyl-3-(prop-1-en-2-yl)-8H-selenopheno[2,3-b]indole (***2p***).* Yellow solid (142 mg, 81% yield): mp 122–123 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89–7.87 (m, 1H), 7.57–7.54 (m, 2H), 7.35–7.30 (m, 3H), 7.26–7.22 (m, 2H), 7.13 (ddd, *J* = 8.1, 7.1, 1.1, 1H), 5.42–5.41 (m, 1H), 5.29–5.28 (m, 1H), 3.82 (s, 3H), 2.09 (dd, *J* = 1.4, 0.9, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 142.6, 141.7, 141.6, 137.2, 135.2, 133.6, 128.6, 128.4, 126.7, 124.1, 123.9, 121.5, 119.2, 118.8, 117.2, 108.7, 33.2, 23.4. EIMS (*m/z*, rel. int., %) 351 (M$^+$, 100). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{20}H_{18}NSe$ 352.0599; found: 352.0592.

General Procedure for the Preparation of the 1,3,3-Triphenyl-1-propynes (5a-c).[31c] Diphenyl methanol (2.0 mmol) and phenylacetylene (2.2 mmol) were successively added to a round bottom flask, containing $BrCH_2CH_2Br$ (2.0 mL) and the stirred solution was treated with $Cu(OTf)_2$ (0.01 mmol). After heated the mixture at 120 ºC for 12 hours, the reaction was left to attain room temperature and quenched with brine (10 mL). The organic products were extracted with CH_2Cl_2 (3 × 50 mL) and the combined organic layers were washed with water (50 mL) and brine (5 mL), dried over $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography, eluting with hexane.

*Prop-2-yne-1,1,3-triyltribenzene (***5a***).*[31c] White solid (493 mg, 92% yield): mp 72–73 °C; Lit.: 77–79 °C.[31b] ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.48–7.46 (m, 2H), 7.44–7.43 (m, 4H), 7.33–7.28 (m, 7H), 7.24–7.21 (m, 2H), 5.21 (s, 1H). ^{13}C{^{1}H} NMR (150 MHz, $CDCl_3$) δ 141.7, 131.6, 128.6, 128.2, 127.9, 127.8, 126.8, 123.4, 90.1, 84.8, 43.7. EIMS (*m/z*, rel. int., %) 268 (M$^+$, 100), 267 ([M-1]$^+$, 54).

*(3-(4-Methoxyphenyl)prop-1-yne-1,3-diyl)dibenzene (**5b**).*[31e] Yellow oil (500 mg, 84% yield): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76–7.44 (m, 2H), 7.72–7.40 (m, 2H), 7.34–7.28 (m, 4H), 7.27–7.24 (m, 4H), 6.85–6.82 (m, 2H), 5.14 (s, 1H), 3.72 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 158.5, 142.0, 133.9, 131.6, 128.8, 128.5, 128.1, 127.8, 127.7, 126.7, 123.5, 113.9, 90.5, 84.7, 55.1, 42.8. EIMS (*m/z*, rel. int., %) 298 (M^+, 100), 283 ($[M\text{-}Me]^+$, 30), 267 ($[M\text{-}OMe]^+$, 18).

*(3-(4-Chlorophenyl)prop-1-yne-1,3-diyl)dibenzene (**5c**).*[31c-e] Yellow oil (568 mg, 94% yield): ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45–7.43 (m, 2H), 7.38–7.37 (m, 2H), 7.32–7.31 (m, 2H), 7.28 (t, J = 7.6, 2H), 7.23–7.22 (m, 5H), 7.19 (t, J = 7.3, 1H), 5.12 (s, 1H). $^{13}C\{^1H\}$ NMR (150 MHz, $CDCl_3$) δ 141.1, 140.2, 132.6, 131.5, 129.1, 128.6, 128.1, 128.0, 127.7, 127.0, 123.1, 89.5, 85.1, 43.0. EIMS (*m/z*, rel. int., %) 303 ($[M+2]^+$, 20), 301 (M^+, 56), 268 ($[M\text{-}Cl]^+$, 24).

General Procedure for the Preparation of the 1,3,3-Triphenyl-1-butynes (6a-c).[31a,32c] A solution of the 1,3,3-triphenyl-1-propyne (**5**, 1.0 mmol) in THF (3.0 mL) was cooled to -78 ºC and treated dropwise with a solution of *n*-BuLi in hexanes (1.2 equiv.) during 30 min. Then, a 1M THF solution of MeI (1.2 mmol) was added dropwise during 30 min. and the reaction temperature was raised to -10 ºC, while stirring for an additional period of 1 h. The reaction was quenched with brine (10 mL) and the products were extracted with EtOAc (3 × 50 mL). The combined extracts were washed with water (50 mL) and brine (10 mL), dried over $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography, eluting with hexane, to separate the alkyne from the corresponding allene, which has virtually the same R_f.

*1,3,3-Triphenylbut-1-yne (**6a**).*[31a,32c] White solid (118 mg, 42% yield): mp 58–59 °C. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50–7.45 (m, 6H), 7.31–7.25 (m, 7H), 7.21–7.17 (m, 2H), 2.03 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 146.5, 131.6, 128.2, 128.1, 127.8, 127.0, 126.4, 123.6, 95.3, 84.2, 45.1,

30.5. EIMS (*m/z*, rel. int., %) 282 (M^+, 70), 267 ([M-Me]$^+$, 100). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{22}H_{19}$ 283.1481; found: 283.1476

*(3-(4-Methoxyphenyl)but-1-yne-1,3-diyl)dibenzene (***6b***).* Colorless oil (53 mg, 17% yield): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.50–7.43 (m, 4H), 7.41–7.38 (m, 2H), 7.31–7.24 (m, 5H), 7.21–7.18 (m, 1H), 6.84–6.81 (m, 2H), 3.74 (s, 3H), 2.01 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 158.1, 146.8, 138.7, 131.5, 128.1 (2C), 128.0, 127.8, 126.8, 126.4, 123.6, 113.5, 95.5, 84.0, 55.1, 44.4, 30.7. EIMS (*m/z*, rel. int., %) 312 (M^+, 80), 297 ([M-Me]$^+$, 100). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{23}H_{21}O$ 313.1587; found: 313.1584.

*(3-(4-Chlorophenyl)but-1-yne-1,3-diyl)dibenzene (***6c***).* Colorless oil (126 mg, 40% yield): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47–7.39 (m, 6H), 7.30–7.23 (m, 7H), 7.22–7.16 (m, 1H), 2.00 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 146.0, 145.2, 132.4, 131.6, 128.5, 128.4, 128.3, 128.2, 128.0, 126.9, 126.7, 123.4, 94.7, 84.6, 44.8, 30.5.EIMS (*m/z*, rel. int., %) 318 ([M+2]$^+$, 25), 316 (M^+, 70), 301 ([M-Me]$^+$, 100), 281 ([M-Cl]$^+$, 88). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{22}H_{18}Cl$ 317.1092; found: 317.1065.

General Procedure for the Preparation of the Benzo[*b*]selenopheno[3,2-*d*]selenophenes (7a-c). A mixture of Se^0 (1.0 mmol) and SO_2Cl_2 (1.2 mmol), was stirred under argon for 1.0 hour at room temperature. A brown solution was formed. Then, DMF (1.5 mL) was added, and the system was stirred for 0.5 hour until a clear red solution result, when it was treated dropwise with a DMF (1.5 mL) solution of the aryl propargyl indole (0.5 mmol). The system was stirred for 24 hours at 40 °C. The reaction was quenched with brine (10 mL) and extracted with EtOAc (3 × 50 mL). The combined organic extracts were washed with water (50 mL) and brine (10 mL), dried over $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography, eluting with hexane.

*2,3-Diphenylbenzo[b]selenopheno[3,2-d]selenophene (**7a**).* White solid (186 mg, 85% yield): mp 180–182 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82–7.80 (m, 1H), 7.41–7.34 (m, 5H), 7.22–7.11 (m, 6H), 7.04–7.00 (m, 1H), 6.93–6.91 (m 1H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 147.7, 144.9, 144.8, 137.3, 136.9, 136.3, 136.2, 134.0, 130.5, 129.3, 128.6, 128.2, 127.7, 127.2, 125.8, 124.3, 123.8, 123.3. EIMS (*m/z*, rel. int., %) 437 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{22}H_{15}Se_2$ 438.9499; found: 438.9424.

*3-(4-Methoxyphenyl)-2-phenylbenzo[b]selenopheno[3,2-d]selenophene (**7b**).* White solid (194 mg, 83% yield): mp 193–195 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82–7.80 (m, 1H), 7.28–7.24 (m, 2H), 7.20–7.12 (m, 6H), 7.07–7.00 (m, 2H), 6.96–6.92 (m, 2H), 3.85 (s, 3H). $^{13}C\{^{1}H\}$ NMR (100 MHz, $CDCl_3$) δ 159.25, 147.6, 145.2, 144.9, 137.4, 136.3, 136.0, 133.8, 131.6, 129.3, 128.9, 128.2, 127.1, 125.8, 124.3, 123.8, 123.3, 114.1, 55.2. EIMS (*m/z*, rel. int., %) 467 (M^+, 100), 452 ([M-Me]$^+$, 29). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{23}H_{17}OSe_2$ 468.9604; found: 468.9636.

*3-(4-Chlorophenyl)-2-phenylbenzo[b]selenopheno[3,2-d]selenophene (**7c**).* White solid (101 mg, 43% yield): mp 187–189 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.79 (d, *J* = 2.1, 1H), 7.42–7.33 (m, 5H), 7.24–7.16 (m, 5H), 7.01 (dd, *J* = 8.7, 2.1, 1H), 6.79 (d, *J* = 8.7, 1H). $^{13}C\{^{1}H\}$ NMR (150 MHz, $CDCl_3$) δ 148.1, 145.6, 144.0, 136.4, 135.9, 135.8, 135.6, 134.1, 130.4, 129.8, 129.2, 128.7, 128.2, 127.9, 127.3, 125.3, 124.9, 123.6. EIMS (*m/z*, rel. int., %) 473 ($[M+2]^+$, 52), 471 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{22}H_{14}ClSe_2$ 472.9109; found: 472.9101.

General Procedure for the Preparation of the phenylbenzo[*b*]selenopheno[3,2-*d*]selenophenes (8a-c). Two flasks, each containing a mixture of Se^0 (0.5 mmol) and SO_2Cl_2 (1.0 mmol), were stirred under argon for 1.0 hour at room temperature, when brown solutions were formed. Then, DMF (1.5 mL) was added, and the systems were further stirred for 0.5 hour. The

resulting clear red solution in one of the flasks was treated dropwise with a DMF (1.5 mL) solution of the aryl propargyl indole (**1**, 0.5 mmol), and the system was stirred for 5 minutes; then, it was treated with the DMF solution of $SeCl_2$ contained in the second flask, and the reaction was stirred for another 10 minutes. The reaction was quenched with brine (10 mL) and extracted with EtOAc (3 × 50 mL). The combined organic extracts were washed with water (50 mL) and brine (10 mL), dried over $MgSO_4$, filtered and concentrated under reduced pressure. The residue was purified by silica gel column chromatography, eluting with hexane. The same procedure was employed when starting from **2a**, except that 1.0 equiv. $SeCl_2$ was used and the reaction was stirred for 10 minutes.

*1-Methyl-3-(2-phenylbenzo[b]selenopheno[3,2-d]selenophen-3-yl)-1H-indole (**8a**).* White solid (93 mg, 38% yield from **1a**; 154 mg, 64% yield from **2a**): mp 230–233 ºC. ^{1}H NMR (400 MHz, DMSO-d_6) δ 8.03–8.00 (m, 1H), 7.56–7.53 (m, 1H), 7.33 (s, 1H), 7.23–7.08 (m, 8H), 6.95 (ddd, J =7.9, 7.0, 1.0, 1H), 6.88 (ddd, J = 8.2, 7.1, 1.2, 1H), 6.79–6.76 (m, 1H), 3.84 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, DMSO-d_6) δ 148.5, 144.8, 144.5, 137.0, 136.6, 136.4, 135.6, 129.0, 128.4, 128.3, 128.2, 128.0, 127.1, 126.1, 123.9, 123.6, 122.3, 121.6, 119.5, 119.2, 110.2, 109.0, 32.6. EIMS (*m/z*, rel. int., %) 490 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{25}H_{18}NSe_2$ 491.9764; found: 491.9754.

*3-(6-Chloro-2-phenylbenzo[b]selenopheno[3,2-d]selenophen-3-yl)-1-methyl-1H-indole (**8b**).* White solid (85 mg, 36% yield): mp 180–183 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.78–7.76 (m, 1H), 7.40 (t, J = 8.3, 1H), 7.34 (t, J = 8.0, 1H), 7.28 (ddd, J = 8.3, 7.1, 1.2, 1H), 7.20–7.18 (m 2H), 7.14–7.10 (m, 3H), 7.05 (ddd, J = 8.0, 7.0, 1.0, 1H), 6.86 (d, J = 1.3, 1H), 6.85 (s, 1H), 3.78 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 149.5, 145.5, 144.9, 136.7, 136.6, 135.8, 133.7, 129.7, 128.9, 128.7, 128.3, 128.2, 127.1, 125.0, 124.8, 124.0, 122.0, 120.4, 119.8, 109.5, 109.4, 32.9. EIMS (*m/z*, rel. int., %) 524 (M^+, 100). HRMS (ESI) *m/z*: $[M+H]^+$ calcd. for $C_{25}H_{17}ClNSe_2$

525.9380; found: 525.9394.

1-Methyl-3-(6-methyl-2-phenylbenzo[b]selenopheno[3,2-d]selenophen-3-yl)-1H-indole ***(8c)***. White solid (187 mg, 74% yield): mp 197–199 ºC. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.60–7.59 (m, 1H), 7.39–7.36 (m, 2H), 7.27–7.23 (m, 1H), 7.21–7.18 (m, 2H), 7.12–7.09 (m, 3H), 7.03 (ddd, *J* = 8.0, 7.0, 0.9, 1H), 6.85–6.83 (m, 2H), 6.71–6.69 (m, 1H), 3.76 (s, 3H), 2.30 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 148.9, 145.7, 145.0, 136.9, 136.8, 135.0, 133.6, 132.3, 129.0, 128.9, 128.4, 128.2, 128.1, 126.9, 125.7, 125.6, 123.1, 121.8, 120.6, 119.7, 110.0, 109.2, 32.8, 21.1. EIMS (*m/z*, rel. int., %) 473 ([M+2]$^+$, 52), 471 (M$^+$, 100). HRMS (ESI) *m/z*: [M+H]$^+$ calcd. for $C_{26}H_{20}NSe_2$ 505.9921; found: 505.9940.

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Notes

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■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.xxxxxxx.

NMR spectra for relevant compounds (PDF)

Crystallographic data for compounds **7b** and **8a** (CIF)

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