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SYNTHESIS OF 3,1-BENZOTHIAZINES FROM 2-ALKENYL- AND 2-ALKYNYLANILIDES AND LAWESSON REAGENT

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Abstract – Reaction of 2-vinylacetanilide with P_4S_{10} gave 2-vinylthioacetanilide, whereas reaction of 2-vinylacetanilide with Lawesson reagent (LR) afforded 2,4-dimethyl-4*H*-3,1-benzothiazine in 62% yield. Reaction of 2-alkynylanilides with LR gave 4-exomethylene-4*H*-3,1-benzothiazines in good yields.

INTRODUCTION

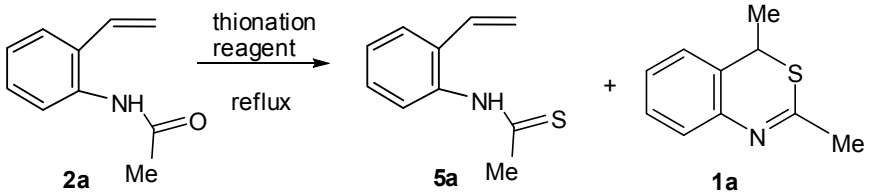
4*H*-3,1-Benzothiazines (**1**) are important compounds because of their biological and structural appeal. 4*H*-3,1-Benzothiazine derivatives with aromatic substituents at positions 2 and/or 4 exhibit many kinds of biological activities[1] and are of interest for the production of recording materials and use in photographic and laser techniques.[2] Moreover, they are valuable building blocks and can be used for the synthesis of indole derivatives in particular.[3] Recent methods include the reaction of 2-alkenylanilides (**2**) having electron-withdrawing groups with LR,[4] the reaction of 2-hydroxyalkylanilides with LR,[5] the reaction of 2-alkynylthioformanilides with DBU,[6] the reaction of 2-alkynylaniline with isothiocyanate,[7] and the Friedel-Crafts reaction of isothiocyanate.[8] However, there is no report on the direct synthesis of benzothiazines from 2-alkynylanilides (**3**). These results prompted us to investigate the reaction of 2-alkenylanilides **2** having electron-donating groups and 2-alkynylanilides **3** with LR, to find out whether the corresponding intramolecular cyclization would proceed or not. Herein, we describe a new approach to the synthesis of 4*H*-3,1-benzothiazines 1 and 4-exomethylene-4*H*-3,1-benzothiazines (**4**) based on a thionation process followed by a cyclization process from 2-alkenyl- and 2-alkynylanilides.

RESULTS AND DISCUSSION

2-Alkenylanilides **2** with electron-withdrawing groups (CO_2Me and CN) underwent thionation and intramolecular cyclization to give 3,1-benzothiazines.[4] As the intramolecular cyclization did not proceed by using 2-alkenylformanilide and P_4S_{10} as the thionation reagent,[6] we first attempted to react 2-alkenylanilide **2** with P_4S_{10} or LR to investigate the possibility of tandem thionation and intramolecular cyclization.

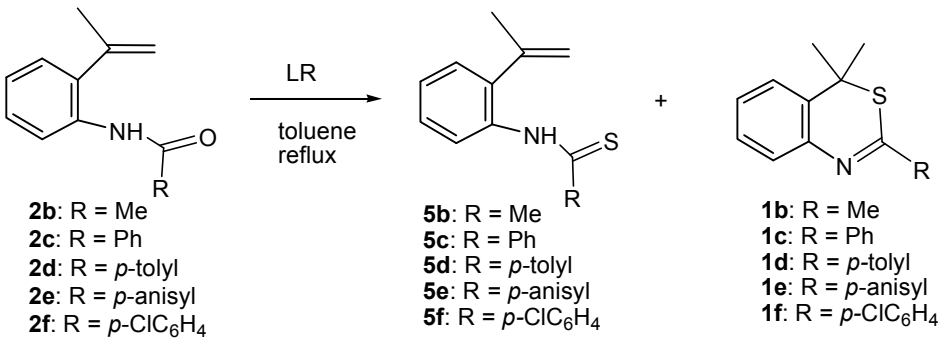
Treatment of 2-vinylacetanilide (**2a**) with P_4S_{10} in refluxing pyridine (6 h) resulted in the formation of 2-vinylthioacetanilide (**5a**) in 66% yield (Table 1, Entry 1). When the reaction was carried out by using LR as the thionation reagent, starting **2a** was recovered almost quantitatively (Entry 2). The reaction of **2a** with LR in refluxing chloroform also recovered starting **2a** (Entry 3). However, when toluene was used as the solvent (refluxing for 12 h), 2,4-dimethyl-3,1-benzothiazine (**1a**) was obtained in 62% yield.

Table 1. Reaction of **2a** with thionation reagent



Entry	Thionation Reagent	Solvent	Time / h	**5a** (yield /%)	**1a** (yield /%)
1	P_4S_{10} (0.5 eq)	pyridine	6	66	0
2	LR (0.5 eq)	pyridine	6	0	0
3	LR (0.5 eq)	$CHCl_3$	8	0	0
4	LR (0.5 eq)	THF	12	0	0
5	LR (0.5 eq)	toluene	12	0	62

From these results, the optimum conditions for tandem thionation and intramolecular cyclization of **2** were judged to be LR (0.5 eq) in refluxing toluene. We then tried the reaction by using anilide (**2b-2f**) prepared from commercially available isopropenylaniline as substrates under these reaction conditions (Scheme 1). The reaction of 2-isopropenylacetanilide (**2b**) with LR gave 2-isopropenylthioacetanilide (**5b**) and 2,4,4-trimethyl-4*H*-3,1-benzothiazine (**1b**) in 19% and 68% yields, respectively (Table 2, Entry 1). When the reaction was carried out in refluxing toluene for 12 h, **1b** was isolated in 89% yield (Entry 2). Other isopropenylanilides **2c-2f** also afforded benzothiazines **1c-1f** in good yields (Entries 3-6).



2b: R = Me
2c: R = Ph
2d: R = *p*-tolyl
2e: R = *p*-anisyl
2f: R = *p*-ClC_6H_4

5b: R = Me
5c: R = Ph
5d: R = *p*-tolyl
5e: R = *p*-anisyl
5f: R = *p*-ClC_6H_4

1b: R = Me
1c: R = Ph
1d: R = *p*-tolyl
1e: R = *p*-anisyl
1f: R = *p*-ClC_6H_4

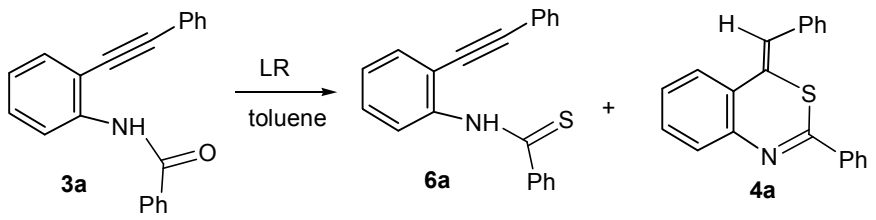
Scheme 1

Table 2. Reaction of 2-alkenylanilide **2** with LR

Entry	Anilide **2**	Time/h	Thioanilide **5**	Thiazine **1**
1	**2b**	4	**5b** 19	**1b** 68
2	**2b**	12	**5b** 0	**1b** 89
3	**2c**	12	**5c** 0	**1c** 89
4	**2d**	12	**5d** 0	**1d** 53
5	**2e**	15	**5e** 0	**1e** 84
6	**2f**	18	**5f** 0	**1f** 91

Thus, the thionation and intramolecular cyclization of anilides **2** with LR afforded 3,1-benzothiazines **1** in moderate to good yields.

Previously, we have reported the synthesis of 3,1-benzoxazines by active halogen mediated intramolecular cyclization of 2-alkenylanilides.[9] As thioanilides are more nucleophilic than the corresponding anilides, the formation of 3,1-benzothiazines by intramolecular cyclization would proceed without any activating reagents. Although the two-step synthesis of 4-alkenyl-3,1-benzothiazine was accomplished by the reaction of 2-alkynylformanilides with P_4S_{10} followed by the addition of DBU,[6] the sequential thionation and cyclization of 2-alkynylanilides **3** was not reported. The only reported example was the reaction of anilides **3** with phenylisothiocyanates, which afforded 2-imino-3,1-benzothiazines, and 2-imino substituents were required.[7] Thus, we then tried to react anilide **3** with LR to find out whether tandem thionation and cyclization would proceed. Starting 2-alkynylanilides **3** were synthesized by the acylation of 2-alkynylanilines, which were easily synthesized by the Sonogashira coupling reaction.[10] Treatment of [2-(2-phenylethynyl)phenyl]benzanilide (**3a**) with LR (0.5 eq) at rt for 36 h resulted in the almost recovery of **3a** (Scheme 2, Table 3, Entry 1). When 1 eq of LR was used, small amount of 2-(phenylethynyl)thiobenzanilide (**6a**) was formed (Entry 2). When the reaction was carried out in refluxing toluene for 5 h, (*Z*)-4-benzylidene-2-phenyl-4*H*-3,1-benzothiazine (**4a**) were obtained in 82% yield (Entry 3). When P_4S_{10} was used as the thionation reagent, thioanilide **6a** was obtained in 42% yield and further cyclization did not proceed (Entry 4). It is noteworthy that isolated **6a** was allowed to react with 0.1 eq of LR in refluxing toluene to afford **4a** in 85% yield.

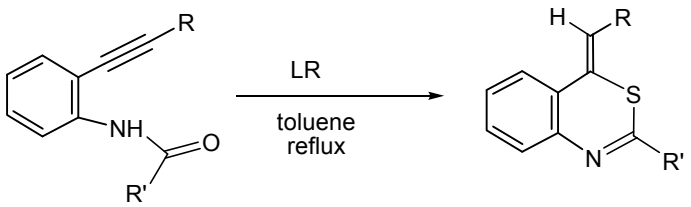


Scheme 2

Table 3. Reaction of anilide **3a** with thionation reagent

Entry	Thionation Reagent	eq	Temp /°C	Time/h	**6a** Yield/%	**4a** Yield/%
1	LR	0.5	rt	36	0	0
2	LR	1.0	rt	36	10	0
3	LR	0.5	reflux	5	0	82
4	P_4S_{10}	0.5	reflux	8	42	0

As the optimum conditions for tandem thionation and intramolecular cyclization would be LR (0.5 eq) in refluxing toluene, we then applied these conditions to a variety of 2-alkynylanilides (**3b-3i**) (Scheme 3). The results are shown in Table 4. The reaction of **3b** with LR in refluxing toluene for 12 h gave 3,1-benzothiazine **4b** in 57% yield (Entry 2).



3a: R = Ph, R' = Ph
3b: R = *n*-Bu, R' = Ph
3c: R = *t*-Bu, R' = Ph
3d: R = Ph, R' = Me
3e: R = Ph, R' = Et
3f: R = Ph, R' = *p*-Tol
3g: R = Ph, R' = *p*-Anis
3h: R = Ph, R' = *p*-ClC_6H_4
3i: R = Ph, R' = *p*-$CF_3C_6H_4$

4a: R = Ph, R' = Ph
4b: R = *n*-Bu, R' = Ph
4c: R = *t*-Bu, R' = Ph
4d: R = Ph, R' = Me
4e: R = Ph, R' = Et
4f: R = Ph, R' = *p*-Tol
4g: R = Ph, R' = *p*-Anis
4h: R = Ph, R' = *p*-ClC_6H_4
4i: R = Ph, R' = *p*-$CF_3C_6H_4$

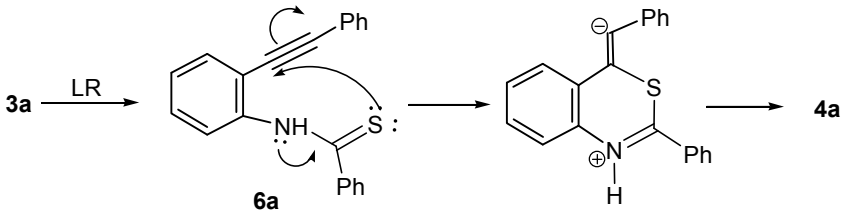
Scheme 3

Table 4. Reaction of anilide **3** with LR

Entry	Alkynylanilide **3**	Tim /h	**4**	Yield / %
1	**3a**	5	**4a**	82
2	**3b**	12	**4b**	57
3	**3c**	48	**4c**	68
4	**3d**	23	**4d**	72
5	**3e**	18	**4e**	77
6	**3f**	7	**4f**	80
7	**3g**	5	**4g**	87
8	**3h**	24	**4h**	71
9	**3i**	48	**4i**	68

When a sterically hindered anilide, such as 2-(3,3-dimethyl-1-butynyl)phenylacetanilide **3c**, was used as substrate, prolonged reaction time is required (48 h) (Entry 3). Electron-donating groups, such as a methoxy or a methyl group, at para position gave relatively high yields of benzothiazines **4f** and **4g** (Entries 6 and 7). Electron-withdrawing groups at para position **3h-3i** gave moderate yields of products **4h** and **4i** (Entries 8 and 9).

The reaction would proceed as follows: LR reacted with anilide **3a** to afford to give the corresponding thioanilide **6a**. Thiocarbonyl sulfur of **6a** intramolecularly attacked triple bond to afford cyclized prodict, which finally produced **4a** (Scheme 4).



Scheme 4

The stereochemistry of **4** was determined from proton NMR spectra. The exo-alkene signal of **4c** appeared at 6.14 ppm. The reported example of (*Z*)-benzylideneisochromene showed a signal at 6.32 ppm assignable to the exo-alkene proton, which is similar to **4c**.[11] NOESY spectrum of **4c** shows the correlation between exomethylene proton and 5-H proton (Figure 1). Fortunately, as single crystals of **4c** were obtained, the X-ray crystallographic analysis of **4c** could be performed. As shown in Figure 2, stereochemistry of **4c** has *Z*-form.

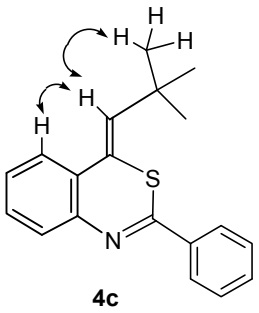


Figure 1

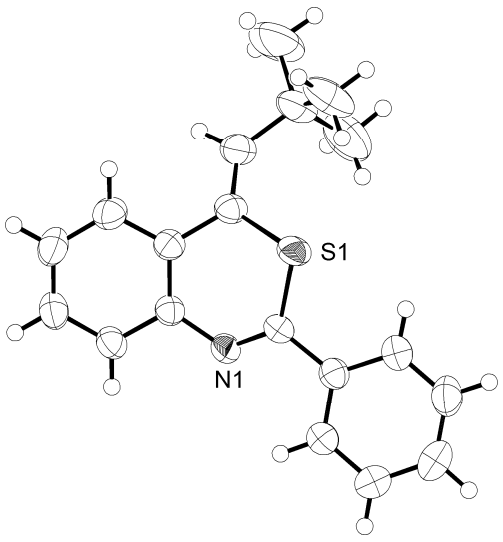


Figure 2. ORTEP Drawing of 4c

In summary, 2-vinylacetanilide **2a** reacted with P_4S_{10} to afford thioacetanilide **5a**, whereas the reaction of anilides **2** with LR gave 3,1-benzothiazines **1** in good yields. The reaction of 2-alkynylanilides **3** with LR in refluxing toluene gave 4-methylene-3,1-benzothiazines **4** in good yields. We have successfully synthesized 3,1-benzothiazines from 2-alkenylanilides and 2-alkynylanilides by thionation and intramolecular cyclization in one-pot operation.

EXPERIMENTAL

General

All chemicals were obtained from commercial suppliers and were used without further purification. NMR spectra (^{1}H at 400 MHz; ^{13}C at 100 MHz) were recorded in $CDCl_3$, and chemical shifts are expressed in ppm relative to internal TMS for ^{1}H- and ^{13}C-NMR. Melting points were uncorrected.

Marterial

All reagents (2-isopropenylaniline, LR, and P_4S_{10}) were purchased from TCI or Aldrich. 2-Vinylaniline was synthesized by reduction of 2-nitrostyrene[12] with Sn/HCl.

2-Alkynylanilines were synthesized by Sonogashira coupling reaction.[10] 2-Vinylanilides were synthesized by the method reported in the literature.[9,13] 2-Alkynylanilides were synthesized by the reaction of 2-alkynylanilines with acyl chlorides.[14] Followings are new compounds. Compound **3c**: colorless needles; ^{1}H NMR ($CDCl_3$) δ = 1.38 (s, 9H, *t*-Bu), 7.03 (dd, 1H, *J* = 7.6 Hz and 7.6 Hz, Ar), 7.32 (dd, 1H, *J* = 7.6 Hz and 7.6 Hz, Ar), 7.40 (d, 1H, *J* = 7.6 Hz, Ar), 7.48-7.57 (m, 3H, Ar), 7.94 (d, 2H, *J* = 6.8 Hz, Ar), 8.58 (d, 1H, *J* = 8.4 Hz, Ar), 8.86 (br, 1H, NH). MS (GC): Calcd for $C_{19}H_{19}NO$: 277.15. Found; 277.87 (M^+). Compound **3e**: colorless needles. ^{1}H NMR ($CDCl_3$) δ = 1.28 (dd, 3H, *J* = 7.4 Hz and 7.6 Hz, CH_3), 2.46 (dt, 2H, *J* = 7.6 Hz and 7.6 Hz, CH_2), 7.05 (dd, 1H, *J* = 7.6 Hz and 7.6 Hz, Ar), 7.34-7.40 (m, 4H, Ar), 7.49-7.55 (m, 3H, Ar), 8.04 (br, 1H, NH), 8.44 (d, 1H, *J* = 8.0 Hz, Ar). MS (GC): Calcd for $C_{17}H_{15}NO$: 249.12. Found; 248.97 (M^+). Compound **3f**: colorless needles. ^{1}H NMR ($CDCl_3$) δ = 2.43 (s, 3H, CH_3), 7.09 (dd, 1H, *J* = 7.6 Hz and 7.6 Hz, Ar), 7.27 (d, 2H, *J* = 8.0 Hz, Ar), 7.40-7.44 (m, 3H, Ar), 7.85 (d, 2H, *J* = 8.0 Hz, Ar), 8.62 (d, 1H, *J* = 8.8 Hz, Ar), 8.93 (br, 1H, NH). MS (GC): Calcd for $C_{22}H_{17}NO$: 311.13. Found; 310.97 (M^+). Compound **3g**: colorless needles. ^{1}H NMR ($CDCl_3$) δ = 3.88 (s, 3H, OCH_3), 6.96 (d, 2H, *J* = 8.8 Hz, Ar), 7.09 (dd, 1H, *J* = 7.4 Hz and 7.6 Hz, Ar), 7.39-7.41 (m, 3H, Ar), 7.53-7.57 (m, 3H, Ar), 7.92 (d, 2H, *J* = 8.8 Hz, Ar), 8.09 (d, 1H, *J* = 8.8 Hz, Ar), 8.60 (d, 1H, *J* = 8.4 Hz, Ar), 8.88 (br, 1H, NH). MS (ESI): Calcd for $C_{22}H_{17}NO_2$: 327.13. Found; 352.64 (M +2+ Na^+). Compound **3h**: colorless needles. ^{1}H NMR ($CDCl_3$) δ = 7.12 (dd, 1H, *J* = 7.6 Hz and 7.6 Hz, Ar), 7.41-7.43 (m, 3H, Ar), 7.45 (d, 2H, *J* = 8.4 Hz, Ar), 7.52-7.56 (m, 3H, Ar), 7.74 (d, 1H, *J* = 8.8 Hz, Ar), 7.89 (d, 1H, *J* = 8.4 Hz, Ar), 8.58 (d, 1H, *J* = 8.4 Hz, Ar), 8.88 (br, 1H, NH). MS (ESI): Calcd for

$C_{21}H_{14}ClNO$: 331.08. Found; 356.53 (M +2+ Na^+). Compound **3i**: colorless needles. ^1H NMR ($CDCl_3$) δ = 7.14 (dd, 1H, *J* = 7.6 Hz and 7.6 Hz, Ar), 7.41-7.46 (m, 4H, Ar), 7.52-7.58 (m, 3H, Ar), 7.74 (d, 2H, *J* = 8.0 Hz, Ar), 8.06 (d, 2H, *J* = 8.0 Hz, Ar), 8.60 (d, 1H, *J* = 8.4 Hz, Ar), 8.93 (br, 1H, NH). MS (GC): Calcd for $C_{22}H_{14}F_3NO$; 365.10. Found; 364.85(M^+).

Reaction of 2-vinylacetanilide 2a with P_4S_{10} in refluxing pyridine

To a solution of 2-vinylacetanilide **2a** (0.081 g, 0.50 mmol) in pyridine (5 mL) was added P_4S_{10} (0.056 g, 0.25 mmol) in one portion. After refluxing for 6 h, the reaction mixture was washed with water and extracted with EtOAc (7 mL x 3). The combined extract was washed with water, dried over sodium sulfate, filtered, and evaporated to give pale brown oil, which was chromatographed over alumina by elution with hexane:EtOAc (1:1) to afford pale yellow oil of 2-vinylthioacetanilide **5a** (0.056 g, 0.32 mmol, 64%). **5a**: yellow oil; (lit.,[15] yellow oil) (rotational isomeric mixture) ^1H NMR ($CDCl_3$) δ = 2.39 (s, 3H, CH_3), 2.76 (s, 3H), 5.39 (d, 1H, *Jcis* =11.2 Hz, =C<u>H</u>H) 5.44 (d, 1H, *Jcis* = 11.2 Hz, =C<u>H</u>H), 5.74 (d, 1H, J_{trans} = 17.6 Hz, =CH<u>H</u>), 5.80 (d, J_{trans} =17.6 Hz, =CH<u>H</u>), 6.74 (dd, 1H, *J* = 11.2 and 17.6 Hz, =CH), 6.82 (dd, 1H, *J* = 11.2 and 17.6 Hz, =CH), 7.16-7.62 (m, 4H, Ar). 8.52 (br, 1H, NH), 9.22 (br, 1H, NH). ^{13}C NMR ($CDCl_3$) 5a': δ = 30.33 (CH_3), 118.32 (=CH_2), 126.92, 127.47, 128.66, 129.26 (Ar), 131.47 (=CH), 134.77, 135.75, (Ar), 205.85 (C=S). **5a**": δ = 34.83 (CH_3), 117.47 (=CH_2), 128.56, 127.86, 128.50, 129.08, 132.06 (=CH), 134.31, 136.42 (Ar), 202.61 (C=S).

Reaction of 2a with LR in toluene

To a solution of 2-vinylacetanilide **2a** (0.081 g, 0.50 mmol) in toluene (5 mL) was added LR (0.10 g, 0.25 mmol) in one portion. After refluxing for 12 h, the reaction mixture was filtered through short silica gel column, and evaporated to give brown oil, which was chromatographed over silica gel by elution with hexane:EtOAc (1:1) to afford pale yellow oil of 2,4-dimethyl-4*H*-3,1-benzothiazine **1a** (0.053 g, 0.30 mmol, 60%). **1a**: yellow oil, ^1H NMR ($CDCl_3$) δ = 1.44(d, 3H, *J* = 7.2 Hz, CH_3), 2.42 (s, 3H, CH_3), 4.04 (dt, 1H, *J* = 7.0 Hz and 7.2 Hz, CH), 7.10 (d, 1H, *J* = 7.2 Hz, Ar), 7.22-7.26 (m, 1H, Ar), 7.31-7.33 (m, 2H, Ar). ^{13}C NMR ($CDCl_3$) δ = 24.46 (CH_3), 29.07 (CH), 37.50 (CH_3), 124.82, 126.13, 127.29, 127.82, 128.42, 142.67 (Ar), 160.26 (C=N). HRMS: Calcd for $C_{10}H_{11}NS$; 177.0612. Found; 177.0605 (M^+).

Other reactions were carried out in a similar manner.

2-Isopropenylthioacetanilide (**5b**): colorless needles: mp 84-86 ^oC (rotational isomeric mixture); ^1H NMR ($CDCl_3$) δ = 2.04 (s, 3H, =CCH_3), 2.06 (s, 3H, =CCH_3), 2.47 (s, 3H, CH_3), 2.66 (s, 3H, CH_3), 5.00 (s, 1H, =CH), 5.02 (s, 1H, =CH), 5.32 (s, 1H, =CH), 5.33 (s, 1H, =CH), 7.10-7.37 (m, 5H + 4H, Ar), 8.21 (d, 1H, *J* = 8.0 Hz, Ar), 8.68 (br, 1H, NH), 8.80 (br, 1H, NH). ^{13}C NMR ($CDCl_3$) **5b'**: δ = 23.58 (CH_3), 30.08(CH_3), 116.99 (=CH_2), 126.91, 127.55, 128.54, 129.65, 135.24 (=CH), 140.02, 142.68 (Ar), 200.65

(C=S). **5b"**: δ = 24.09 (CH_3), 35.92 (CH_3), 118.08 (=CH_2), 126.01, 127.22, 128.40, 128.57 (Ar), 135.07 (=CH), 138.25, 142.46, (Ar), 204.69 (C=S). Anal. Calcd for $C_{11}H_{13}NS$: C, 69.07; H, 6.85; N, 7.32. Found: C, 68.99; H, 6.77; N, 7.70.

2,4,4-Trimethyl-4*H*-3,1-benzothiazine (**1b**). yellow oil: ^{1}H NMR ($CDCl_3$) δ = 1.59 (s, 6H, CH_3), 2.41 (s, 3H, CH_3), 7.26-7.37 (m, 4H, Ar). ^{13}C NMR ($CDCl_3$) δ = 28.37 (CH_3), 29.46 (2CH_3), 43.44 ($\underline{C}(CH_3)_2$), 121.16, 127.44, 127.91, 128.00, 130.13, 143.13 (Ar), 161.18 (C=N). HRMS: Calcd for $C_{11}H_{13}NS$; 191.0769. Found; (M^+) 191.0772.

4,4-Dimethyl-2-phenyl-4*H*-3,1-benzothiazine (**1c**) (0.11 g, 0.44 mmol, 89%).

1c: yellow oil, ^{1}H NMR ($CDCl_3$) δ = 1.68 (s, 6H, 2CH_3), 7.34-7.41 (m, 3H, Ar), 7.48-7.51 (m, 3H, Ar), 7.55 (d, 1H, *J* = 8.0 Hz, Ar), 8.15 (d, 2H, *J* = 7.6 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 29.11 (2CH_3), 43.54 ($\underline{C}(CH_3)_2$), 121.49, 127.89, 128.13, 128.28, 128.33, 128.70, 131.15, 131.59, 138.61, 143.93 (Ar), 161.09 (C=N). HRMS: Calcd for $C_{16}H_{15}NS$; 253.0925. Found; 253.0934 (M^+).

4,4-Dimethyl-2-(*p*-tolyl)-4*H*-3,1-benzothiazine (**1d**). yellow oil, ^{1}H NMR ($CDCl_3$) δ = 1.66 (s, 6H, CH_3), 2.41 (s, 3H, CH_3), 7.25-7.39 (m, 5H, Ar), 7.52 (d, 1H, J = 7.8 Hz, Ar), 8.04 (d, 2H, J = 6.4 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 21.75 (CH_3), 29.09 (2CH_3), 43.49 ($\underline{C}(CH_3)_2$), 121.47, 127.85, 128.03, 128.06, 128.32, 129.44, 131.24, 135.99, 142.07, 144.05 (Ar), 161.00(C=N). HRMS: Calcd for $C_{17}H_{17}NS$; 267.1082. Found; (M^+) 267.1083.

4,4-Dimethyl-2-(*p*-anisyl)-4*H*-3,1-benzothiazine (**1e**). yellow oil, ^{1}H NMR ($CDCl_3$) δ = 1.67 (s, 6H, CH_3), 3.88 (s, 3H, OCH_3), 6.98 (d, 2H, *J* = 8.8 Hz, Ar), 7.17 (d, 1H, *J* = 7.6 Hz, Ar), 7.26-7.40 (m, 2H, Ar), 7.52 (d, 1H, J = 7.6 Hz, Ar), 8.12 (d, 2H, J = 8.8 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 27.75 (2CH_3), 42.38 ($\underline{C}(CH_3)_2$), 54.40 (OCH_3), 112.83, 120.21, 126.41, 126.63, 126.68, 128.90, 129.64, 129.86, 142.41, 159.80 (Ar), 161.55(C=N). HRMS: Calcd for $C_{17}H_{17}NOS$; 283.1031. Found; 283.1027 (M^+).

4,4-Dimethyl-2-(*p*-chlorophenyl)-4*H*-3,1-benzothiazine (**1f**). yellow oil, ^{1}H NMR ($CDCl_3$) δ = 1.66 (s, 6H, CH_3), 7.37-7.40 (m, 3H, Ar), 7.44 (d, 2H, *J* = 8.4 Hz, Ar), 7.52 (d, 1H, J = 7.6 Hz, Ar), 8.09 (d, 2H, J = 8.4 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 27.80 (2CH_3), 42.40 ($\underline{C}(CH_3)_2$), 120.23, 126.69, 126.81, 127.24, 127.60, 128.23, 129.65, 135.61, 136.44, 142.36 (Ar), 158.47 (C=N). HRMS: Calcd for $C_{16}H_{14}ClNS$; 287.0535. Found; 287.0530 (M^+).

Reaction of *N*-[2-(2-phenylethynyl)phenyl]benzanilide 3a with P_4S_{10}

To a solution of benzanilide **3a** (0.15 g, 0.50 mmol) in toluene (5 mL) was added P_4S_{10} (0.055 g, 0.25 mmol) in one portion. After refluxing for 15 h, the reaction mixture was washed with water and extracted with EtOAc (7 mL x 3). The combined extract was washed with water, dried over sodium sulfate, filtered, and evaporated to give pal brown oil, which was chromatographed over alumina gel by elution with hexane:EtOAc (10:1) to afford yellow crystals of *N*-[2-(2-phenylethynyl)phenyl]-

thiobenzanilide **6a** (0.12 g, 0.38 mmol, 76%). **6a**: yellow needles, mp 90-92°C. ^{1}H NMR ($CDCl_3$) δ = 7.22-7.55 (m, 11H, Ar), 7.62 (d, 1H, *J* = 7.6 Hz, Ar), 7.96 (br, 2H, Ar), 10.03 (br, 1H, NH). ^{13}C NMR ($CDCl_3$) δ = 84.48 (q-C), 98.24 (q-C), 115.75 (q-C), 119.35 (q-C), 121.18 q-C), 122.23 (q-C), 126.06, 127.02, 128.95, 129.35, 129.37, 131.54, 131.65, 132.12, 140.25, 144.05 (Ar), 196.75 (C=S). Anal. Calcd for $C_{21}H_{15}NS$: C, 80.48; H, 4.82; N, 4.47. Found: C, 81.10; H, 4.87; N, 5.10. Analytical data of **7a** was little bit off, however, spectral data of which clearly support the structure.

Reaction of *N*-[2-(2-phenylethynyl)phenyl]propionamide 3e with LR

To a solution of propionamide **3e** (0.12 g, 0.50 mmol) in toluene (5 mL) was added LR (0.10 g, 0.25 mmol). After refluxing for 18 h, the reaction mixture was filtered through short silica gel column, and evaporated to give a pale brown oil, which was chromatographed over silica gel by elution with hexane:EtOAc (5:1) to give yellow oil of (*Z*)-4-benzylidene-2-ethyl-4*H*-3,1-benzothiazine (**4e**) (0.10 g, 0.38 mmol). **4e**: yellow oil, ^{1}H NMR ($CDCl_3$) δ = 1.28 (t, 3H, *J* = 7.6 Hz, CH_3), 2.57 (q, 2H, *J* = 7.6 Hz, CH_2), 7.03 (s, 1H, =CH), 7.30-7.35 (m, 2H, Ar), 7.40-7.47 (m, 6H, Ar), 7.61 (d, 1H, *J* = 7.6 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 12.10 (CH_3), 34.77 (CH_2), 121.83 (=CH), 124.38, 124.87, 126.64, 127.66, 128.45, 128.52, 129.09, 129.41, 129.91, 136.06, 142.43 (Ar), 164.02 (C=N). HRMS: Calcd for $C_{17}H_{15}NS$; 265.0925. Found; 265.0924 (M^+).

Other reactions were carried out in a similar manner.

(*Z*)-4-Benzylidene-2-phenyl-4*H*-3,1-benzothiazine (**4a**): yellow oil, ^{1}H NMR ($CDCl_3$) δ = 7.13 (s, 1H, =CH), 7.32-7.57 (m, 11H, Ar), 7.66 (d, 1H, *J* = 8.0 Hz, Ar), 8.05 (d, 2H, *J* = 8.2 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 122.45 (CH), 124.54, 126.11, 126.22, 127.77, 127.81, 128.60, 128.72, 128.83, 129.64, 129.68, 129.97, 131.77, 136.03, 137.69, 143.13 (Ar), 158.10 (C=N). HRMS: Calcd for $C_{21}H_{15}NS$; 313.0925. Found; 313.0921 (M^+).

(*Z*)-4-Pentylidene-2-phenyl-4*H*-3,1-benzothiazine (**4b**): yellow oil, ^{1}H NMR ($CDCl_3$) δ = 0.94 (t, 3H, *J* = 7.2 Hz, CH_3), 1.40-1.54 (m, 4H, $2CH_2$), 2.30 (dd, 2H, *J* = 7.2 Hz and 7.6 Hz, CH_2), 6.09 (dd, 1H, *J* = 7.2 Hz and 7.2 Hz, =CH), 7.27 (dd, 1H, *J* = 7.6 Hz and 8.2 Hz, Ar), 7.36 (dd, 1H, *J* = 7.6 Hz and 8.2 Hz, Ar), 7.45-7.51 (m, 5H, Ar), 8.08 (d, 2H, *J* = 8.2 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 12.95 (CH_3), 21.38, 27.55, 30.06 (CH_2), 120.99 (=CH), 122.48, 123.30, 125.99, 126.33, 127.23, 127.48, 127.99, 128.25, 130.32, 136.73, 141.77 (Ar), 157.57(C=N). HRMS: Calcd for $C_{19}H_{19}NS$; 293.1238. Found; 293.0236 (M^+).

(*Z*)-4-*t*-Butylmethylene-2-phenyl-4*H*-3,1-benzothiazine (**4c**): yellow needles: mp:84-85 °C, ^{1}H NMR ($CDCl_3$) δ = 1.35 (s, 9H, $3CH_3$), 6.14 (s, 1H, =CH), 7.30 (dd, 1H, *J* = 6.4 Hz and 7.6 Hz, Ar), 7.36 (dd, 1H, *J* = 6.4 Hz and 7.6 Hz, Ar), 7.45-7.52 (m, 5H, Ar), 8.08 (d, 2H, *J* = 7.6 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 30.15 ($3CH_3$), 33.75 ($\underline{C}(CH_3)_3$), 122.84, 123.48 (Ar), 124.32 (=CH), 127.91, 128.58, 128.84, 129.05, 129.18, 131.70, 138.01, 139.45, 143.25 (Ar), 158.81(C=N). EI-MS: Calcd for $C_{19}H_{19}NS$; 293. Found;

(M^+) 293. Anal. Calcd for $C_{19}H_{19}NS$: C, 77.77; H, 6.53; N, 4.77. Found: C, 77.59; H, 6.53; N, 4.94. X-Ray crystallographic data for **4c**: Mr = 293.41, a = 11.512(8) Å, b = 12.053(8) Å, c = 24.029(16) Å, V = 3218(4) $Å^3$, T = 293 K, monoclinic, space group $P2_1/a$, Z = 8, 6342 dependent reflections, R1 = 0.0575, wR2 = 0.1278. Crystallographic data have been deposited with Cambridge Crystallographic Data Centre. Deposition number CCDC-815982.

(*Z*)-4-Benzylidene-2-methyl-4*H*-3,1-benzothiazine (**4d**): yellow oil, ^{1}H NMR ($CDCl_3$) δ = 2.36 (s, 3H, CH_3), 7.02 (s, 1H, =CH), 7.30-7.46 (m, 8H, Ar), 7.61 (d, 1H, *J* = 7.8 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 27.90 (CH_3), 121.51 (=CH), 124.39, 124.88, 126.56, 127.74, 128.52, 128.78, 128.91, 129.40, 129.96, 135.95, 142.40 (Ar), 158.91(C=N). HRMS: Calcd for $C_{16}H_{13}NS$; 251.0769. Found; 251.0776 (M^+).

(*Z*)-4-Benzylidene-2-(*p*-tolyl)-4*H*-3,1-benzothiazine (**4f**): yellow needles: mp146-148 °C, ^{1}H NMR ($CDCl_3$) δ = 2.41 (s, 3H, CH_3), 7.12 (s, 1H, =CH), 7.24-7.26 (m, 2H, Ar), 7.31-7.39 (m, 2H, Ar), 7.43-7.47 (m, 3H, Ar), 7.53-7.57 (m, 3H, Ar), 7.64 (d, 1H, *J*= 8.0 Hz, Ar), 7.94 (d, 2H, *J*= 8.0 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 21.83 (CH_3), 122.52 (=CH), 124.53, 126.06, 126.29, 127.74, 128.56, 128.57, 128.58, 129.53, 129.56, 129.65, 129.91, 135.00, 136.08, 142.28, 143.23 (Ar), 158.01 (C=N). EI-MS: Calcd for $C_{22}H_{17}NS$; 327. Found; (M^+) 327. Anal. Calcd for $C_{22}H_{17}NS$: C, 80.47; H, 5.42; N, 4.21. Found: C, 80.70; H, 5.23; N, 4.28.

(*Z*)-4-Benzylidene-2-(*p*-methoxyphenyl)-4*H*-3,1-benzothiazine (**4g**): yellow needles: mp124-126 °C, ^{1}H NMR ($CDCl_3$) δ = 3.86 (s, 3H, OCH_3), 6.94 (d, 2H, *J* = 6.8 Hz, Ar), 7.12 (s, 1H, =CH), 7.34-7.38 (m, 2H, Ar), 7.43 (dd, 3H, *J* = 7.6 Hz and 8.0 Hz, Ar), 7.52 (dd, 3H, *J* = 7.6 Hz and 8.0 Hz, Ar), 7.63 (d, 1H, *J* = 7.6 Hz, Ar), 8.02 (d, 2H, *J* = 6.8 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 55.68 (OCH_3), 114.14 (Ar), 122.48 (=CH), 124.55, 126.05, 126.37, 127.74, 128.56, 128.35, 128.56, 129.39, 129.51, 129.68, 129.90, 130.32, 136.13, 143.36, 157.38 (Ar), 162.71 (C=N). EI-MS: Calcd for $C_{22}H_{17}NOS$; 343. Found; 343 (M^+). Anal. Calcd for $C_{22}H_{17}NOS$: C, 76.94; H, 4.99; N, 4.08. Found: C, 76.85; H, 5.05; N, 4.28.

(*Z*)-4-Benzylidene-2-(*p*-chlorophenyl)-4*H*-3,1-benzothiazine (**4h**): yellow needles, mp 153-155 °C, ^{1}H NMR ($CDCl_3$) δ = 7.13 (s, 1H, =CH), 7.33-7.48 (m, 7H, Ar), 7.51-7.53 (m, 3H, Ar), 7.65 (d, 1H, *J* = 7.6 Hz, Ar), 7.99 (d, 2H, *J* = 8.4 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 121.14 (=CH), 123.29, 124.34, 125.31, 126.61, 127.31, 127.38, 127.70, 127.73, 128.14, 128.31, 128.72, 134.57, 134.71, 136.60, 141.64 (Ar), 155.45 (C=N). EI-MS: Calcd for $C_{21}H_{14}ClNS$; 347. Found; 347 (M^+). Anal. Calcd for $C_{21}H_{14}ClNS$: C, 72.51; H, 4.06; N, 4.03. Found: C, 72.53; H, 4.10; N, 4.23.

(*Z*)-4-Benzylidene-2-(*p*-trifluoromethylphenyl)-4*H*-3,1-benzothiazine (**4i**): yellow oi1, ^{1}H NMR ($CDCl_3$) δ = 7.14 (s, 1H, =CH), 7.34-7.57 (m, 8H, Ar), 7.66-7.71 (m, 3H, Ar), 8.16 (d, 2H, *J* = 8.4 Hz, Ar). ^{13}C NMR ($CDCl_3$) δ = 122.38 (=CH), 124.55, 125.31 (Ar), 125.64 (q, *J* = 15.0 Hz, CF_3), 126.74, 127.95, 127.97, 128.61, 129.37, 129.55, 129.85, 130.07, 132.96, 133.28, 135.77, 140.69, 142.74 (Ar), 156.49

(C=N). HRMS: Calcd for $C_{22}H_{14}F_3NS$; 381.0799. Found; 381.0791 (M^+).

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