JOC The Journal of Organic Chemistry

Article

pubs.acs.org/joc

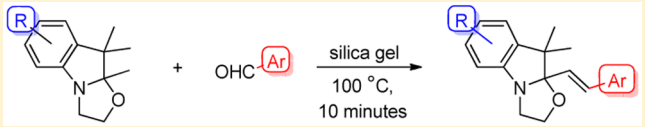
Silica-Mediated Synthesis of Indolinooxazolidine-Based Molecular Switches

György Szalóki* and Lionel Sanguinet*

Laboratoire MOLTECH-Anjou, Université d'Angers, CNRS-UMR 6200, 2 boulevard Lavoisier, 49045 Angers Cedex, France

Supporting Information

ABSTRACT: A novel and convenient method for the synthesis of photochromic compounds is reported here. It is based on the use of commercially available untreated silica, as an efficient catalyst to perform the condensation between indolinooxazolidine derivatives and aromatic aldehydes under solvent-free conditions. The scope and limitations of this transformation were investigated and several novel photochromic indolinooxazolidines were synthesized. This methodology can also be applied to the synthesis of other photoactive compounds such as spiropyrans or spirooxazines. According to our working protocol the reaction did not require any solvent or additional reagents and gave the products within 10 min in isolated yields of up to 90%.



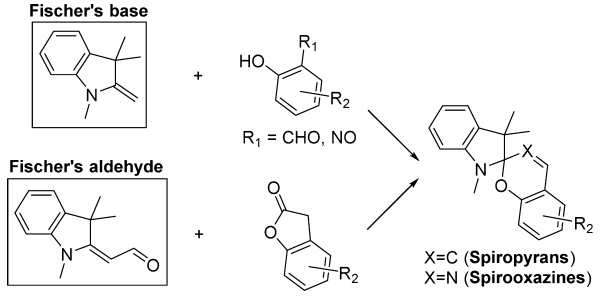
INTRODUCTION

Photochromism of spiropyrans was first reported in the early 1950s.[1,2] Shortly thereafter, the concept of a binary element acting as a computer memory emerged, which was clearly revolutionary.[3] This triggered intense research in the field of information storage, fluid flow visualization, ophthalmic lenses, and cosmetics, just to name a few.[4−9] Today, spiropyrans continue to attract attention and they have found widespread application in biomolecular sensing,[10,11] cell imaging,[12] drug delivery,[13] and photomechanical[14−16] and hybrid materials.[17] Among the large library of reported photochromic molecules, spiropyrans (SP) and closely related spirooxazines (SPO) continue to be one of the most extensively studied families of photochromic compounds due to their favorable photo-, electro-, and solvatochromic properties and simple synthetic accessibility.[18] On the other hand, the indolinooxazolidines, which are one of their subfamilies, are much less studied even though they exhibit some interesting features such as multimode switching abilities (photo-, electro-, acidochromism) and promising nonlinear optical properties.[19−25] Their association with some other molecular switches has been reported and offers a higher degree of complexity in optoelectronic devices especially in terms of data storage and signal processing.[26−28]

There are two main strategies toward the preparation of these spiro-systems (Scheme 1).[29] The most common method is based on the reaction between aromatic aldehydes and Fischer's base. The second approach is used when the corresponding hydroxyaldehyde is not accessible and it is realized by reacting α-carbonyl compounds and Fischer's aldehyde.[30]

The reactive intermediate in the most common synthetic strategy is the corresponding enamine, formed in situ from the Fischer's base or its salt under the reaction conditions. The product is formed through a series of reversible steps involving several proton transfers;[31] therefore, it is often acid

Scheme 1. Two Main Synthetic Strategies towards Spiropyrans and Spirooxazines

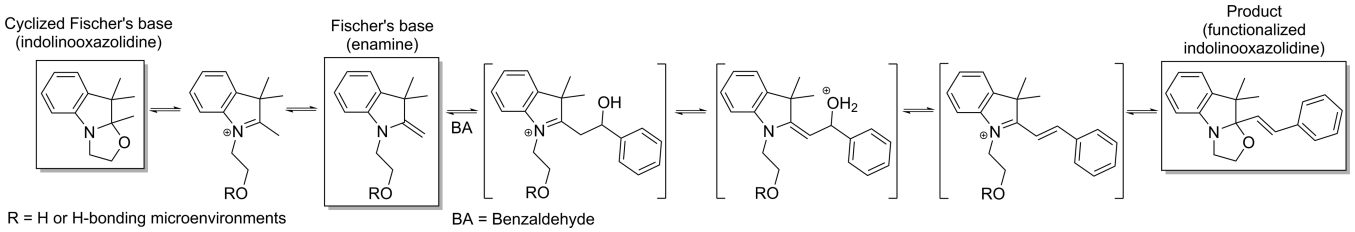


catalyzed.[32−35] However, the majority of reported examples are carried out in boiling ethanol or acetonitrile without any additives, with reaction time varying from a few hours up to several days.[36−44] Indolinooxazolidines can be considered as cyclized Fischer's bases; therefore, they react in a similar manner (Scheme 2). In this context, reactions are performed under acidic[45] or basic conditions,[21,23] although consistently high yields can be achieved in boiling ethanol without additional reagents.[46] In our laboratory we are not only focusing on the design of novel indolinooxazolidine based molecular switches but are also interested in tuning the photochromic properties of known compounds. In order to obtain a diverse library of analogues we needed a fast and efficient synthetic method. The classical conditions for the synthesis of indolinooxazolidine derivatives often proved to be harsh. In some cases, acetal formation was observed which hindered the desired reaction; however, this could be circumvented by using a more hindered solvent (*t*-BuOH). Nevertheless, some analogues remain unattainable even under these forcing conditions (vide infra).

Received: February 6, 2015

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

Scheme 2. Synthetic Pathway of the Title Reaction



The development of a new synthetic methodology under milder conditions would highly increase the utility of this condensation as it is the primary approach not only for the preparation of new indolinooxazolidines, but also for the synthesis of related spiropyrans and spirooxazines.[47]

It has been shown that hydrogen-bonding microenvironments cause ring opening in spiro-systems (Scheme 2).[24] Providing such an environment could facilitate the overall reaction by locking the spiro-compounds in their enamine forms. Therefore, we decided to investigate the possibility of using silica as a mediator for the preparation of a large variety of indolinooxazolidines. Indeed, silica and alumina surfaces have already proved to be excellent mediators for a great variety of reactions, such as addition onto alkenes[48] and alkynes,[49] selective oxidations of S/N functionalities,[50,51] isomerizations and rearrangements,[52] cross-coupling reactions,[53] and Michael additions.[54] The solid surface mediated approach continues to attract wider interest as it offers an environmentally benign way to synthesize certain compounds. Not only are these supports nontoxic, commercially available, and cheap, but they also can be recycled (in some cases up to 5−10 times) without any noticeable decrease of reactivity.[55] Furthermore, it has been shown that certain transformations proceed faster under solvent-free conditions. Herein we wish to present our preliminary optimization studies, which led to a fast and efficient protocol for the synthesis of indolinooxazolidines.

RESULTS AND DISCUSSION

This protocol was realized by an impregnation of commercial silica powder with indolino[2,1-*b*]oxazolidines and aromatic aldehydes. In certain cases the product was formed upon room temperature homogenization (vide infra). If the reaction did not occur at room temperature it was conducted at higher temperatures (for detailed protocol, see Experimental Section). Our first concern was the optimization of the temperature and the reaction time as they had a strong influence on the conversions. Anisaldehyde and trimethylindolino[2,1-*b*]-oxazolidine were used as starting materials for optimization (Figure 1). A short period of heating (15 min) allowed quick formation of the desired product with good conversions (65% and 78% at 100 and 200 °C, respectively). These results represent a great improvement of the classical method (in boiling ethanol without any additives) which required 9 days to reach a conversion of 67% (see SI). Interestingly, the evolution of the conversion as a function of the reaction time could be best fitted by a simple third-order reaction model (eq 1) at both temperatures (R^2 = 0.992 and 0.958 at 100 and 200 °C, respectively).

$$\text{conversion}\ (\%) = 100 - \frac{100}{\sqrt{(2kC_0^2t + 1)}} \qquad (1)$$

Conversions are based on NMR-data of the crude material.

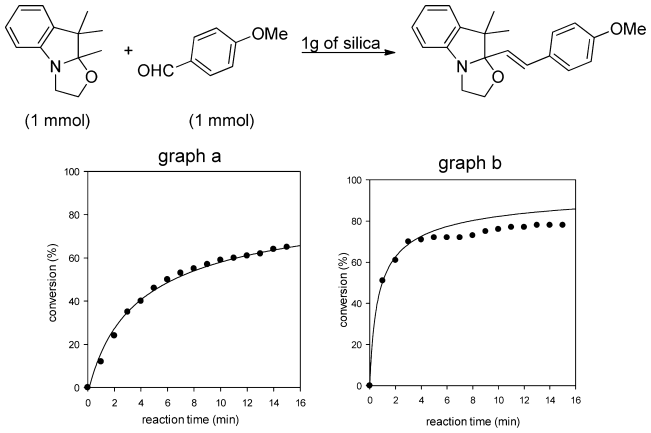
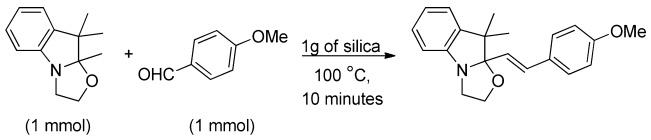


Figure 1. Evolution of the conversion at 100 °C (graph a) and 200 °C (graph b).

At 100 °C, the conversion progressed gradually with increasing reaction time as expected (graph a). The reaction rate increased at 200 °C; however, the same kind of fitting showed a breakdown after 3 min possibly due to a thermal decomposition of the reactants (graph b). In order to limit this last, further optimizations were carried out at 100 °C and the reaction time was arbitrarily fixed to 10 min. Although the reaction took place under neat conditions, the catalytic effect of silica was clearly shown (entries 1 and 5, Table 1). Moreover,

Table 1. Optimization of the Amount of Silica



entry	amount of silica (g)	conversion (%)[a]
1	0	9
2	2	43
3	1.5	38
4	1	64
5	0.5	72

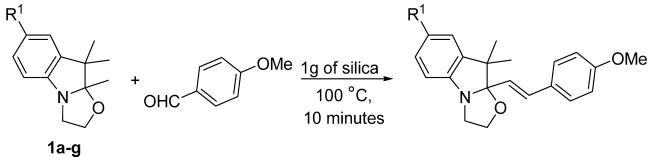
[a]Conversions are based on NMR-data of the crude material.

the reactant/silica ratio had a strong impact on the reaction efficiency. Decreasing the ratio by a factor of 4 resulted in almost a 2-fold increase in the conversion (entries 2 and 5). This improvement could be explained by the increasing surface concentrations of the reactants. It should be noted that using a ratio lower than 1 g/mmol was difficult to handle from a practical point of view; therefore, this ratio was kept during all optimization experiments.

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

With a suitable working protocol in hand, the substrate scope of both reactants was investigated. We synthesized a small library of compounds with a diverse substitution pattern either on the indolino[2,1-*b*]oxazolidine or the styrilic moiety. Electron donating groups gave good conversions (entry 5, Table 2), while weakly deactivating groups decreased the rate of the reaction (entries 2−4). Moreover, the strongly electron withdrawing nitro group gave only 6% conversion under similar conditions (entry 1). These results could be interpreted as decreasing electron density on the nitrogen atom hindered the in situ formation of the enamine.

Table 2. Substituent Effect on Indolinooxazolidines



1a-g

entry	compound	R^1	conversion (%) before heating	conversion (%) after heating
1	**1a**	NO_2	0	6
2	**1b**	Br	0	49
3	**1c**	Cl	0	51
4	**1d**	F	0	57
5	**1e**	OMe	0	64
6	**1f**	Me	0	64
7	**1g**	H	0	64

[a]Conversions are based on NMR-data of the crude material.

The nature of the aldehyde had a profound effect on the conversions (Table 3). Within the *para*-substituted series electron donating substituents hampered the reactivity of the aldehyde probably by making it less electrophilic (entries 2−4). On the other hand, electron withdrawing groups facilitated the reaction (entries 5−8). Interestingly, yields were higher for *ortho*-substituted aldehydes compared to *para*-substitution (entries 2, 5, and 9−12). At this point of our research, we do not have an explanation for this, however, reactivity is thought to be regulated by the combined inductive and mesomeric influence of the substituents. Nevertheless, the efficiency of this method was clearly demonstrated by certain cases where the product was formed in good conversions (54−78%) at ambient temperature immediately after homogenization (entries 7, 8, 11, and 12).

The informative nature of conversions was supported by the fact that isolated yields of certain analogues corresponded nicely to the conversions determined by NMR analysis. It is also worth noting that from a synthetic point of view aromatic halogenides, nitriles, or hydroxyls offer a good handle for further functionalization.

Similarly to aromatic aldehydes, heteroaromatic aldehydes gave high conversions (Table 4, entries 1−3). Electroactive units such as ferrocene or bithiophene could also be introduced, which could lead to interesting multimode switching properties as has previously been demonstrated (entries 3 and 4).[25] It is also important to note that the ferrocenyl product could not be formed under conventional conditions in refluxing ethanol or *t*-BuOH. Unfortunately, the reaction is restricted to aromatic aldehydes as reactions with benzophenone or acetophenone did not give the desired product even after prolonged heating of the reaction.

Our synthetic protocol showed good selectivity when several aldehyde functions are present on the aromatic partner, which represent a good starting point toward symmetrical and dissymmetrical multistate systems. As an example, the ratio of the mono- (**4a**) versus the bis-condensation (**4b**) product (Scheme 3) on the terephthalic aldehyde are simply shifted from 8/2 to 3/7 by changing the number of equivalents of trimethylindolino[2,1-*b*]oxazolidine from 1 to 2, respectively.

Finally, the synthetic utility of our methodology was also demonstrated by the synthesis of the parent SP and SPO analogues (Scheme 4). Spiropyran analogue (**5**) was formed in excellent yield (90% isolated yield) in 10 min, compared to 3 h under conventional conditions.[36−38] Using our protocol the naphthospirooxazine (**6**) was obtained with 57% conversion. Although, recent developments show comparable yields after 15 min, under classical conditions the reaction is generally low yielding.[56] The formation of spirooxazine (**7**) required more forcing conditions (30 min of heating), which is in agreement with previous reports on lower reaction rates requiring 6−7 days of reflux.[32,33,35] Nevertheless, these last examples also support the viability of our methodology providing an improved protocol for the synthesis of spiro-systems.

In summary, a fast and efficient silica mediated methodology was developed which does not require any solvent or additional reagents. The catalytic effect of silica was clearly demonstrated and parameters such as time, temperature, and silica amount were investigated. By applying this methodology to a small library of aromatic aldehydes we highlight the compatibility of our work protocol with most of the common functional groups, which offers a possibility to fine-tune the photochromic properties of indolinooxazolidines. Furthermore, its use for the synthesis of parent spiropyrans and spirooxazines presents our silica-mediated protocol as a powerful synthetic strategy toward many photochromic spiro-systems.

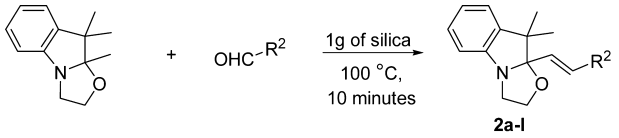
EXPERIMENTAL SECTION

General Experimental Conditions. For purifications technical grade silica gel (Aldrich, pore size 60 Å, 230−400 mesh, 40−63 μm) was used, which was stored in the oven at 120 °C.[48] For flash column chromatography, crystallizations, and additional manipulations, technical grade, nondry solvents were used. Characterization of the isolated products was carried out in $CDCl_3$ or $(CD_3)_2SO$ at 25 °C. Chemical shifts are reported in ppm relative to the solvent residual value: δ = 7.26 ($CDCl_3$), 2.50 ($(CD_3)_2SO$) for ^1H NMR and δ = 77.16 ($CDCl_3$), 39.52 ($(CD_3)_2SO$) for ^{13}C NMR. Coupling constants are reported in Hz and rounded to the nearest 0.1 Hz. Where necessary, DEPT, HMQC, COSY, and HMBC experiments were carried out to aid assignments. The corresponding indolinooxazolidines were synthesized according to the 3 step procedure described below. The synthesis of indolinooxazolidines **1a**,[33] **1b**,[57] **1e**,[24] **1f**,[58] and **1g**[26] has already been described, and therefore will not be discussed here.

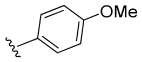
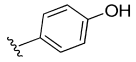
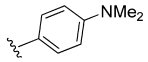
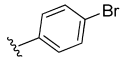
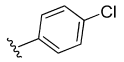
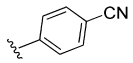
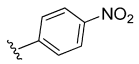
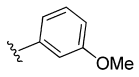
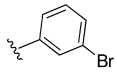
*5-Chloro-2,3,3-trimethylindolino[1,2-b]oxazoline (**1c**).* A solution of 4-chlorophenylhydrazine (15 g, 83.8 mmol) and 3-methyl-2-butanone (13.5 mL, 125.7 mmol, 1.5 equiv) in acetic acid (180 mL) was refluxed overnight. The solution was allowed to cool to room temperature and filtered. Then the solvent was removed under reduced pressure and dark-brown residue was taken up in DCM. This solution was washed cautiously with $NaHCO_3$ (2 times), water, and brine, dried ($MgSO_4$), and concentrated to afford the 5-chloro-2,3,3-trimethylindolenine (12.7 g, 78%) as a brown oil. R_f = 0.36 (PE/EtOAc, 1/1); ^1H NMR (300 MHz) δ 1.21 (6H, s, CH_3), 2.19 (3H, s, CH_3), 7.15−7.24 (2H, m, CH), 7.34−7.39 (1H, m, CH); ^{13}C NMR (75 MHz) δ 15.3 (CH_3), 22.8 (2 × CH_3), 54.0 (C), 120.7 (CH), 121.9 (CH), 127.7 (CH), 130.8 (C), 147.4 (C), 152.2 (C), 188.3 (C); IR $\bar{U}$ = 2965, 2928, 2869 cm^{-1}; MS (ESI): *m*/*z* (%): 196 (30) $[M(Cl^{37})+H]^+$, 194 (100) $[M(Cl^{35})+H]^+$; HRMS (ESI): *m*/*z* calcd.

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

Table 3. Substituent Effect on the Aromatic Aldehydes



2a-l

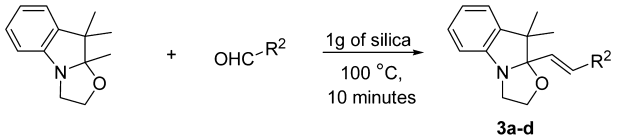
entry	product	R^2	Conversion (%) before heating	Conversion[a] (%) after heating.
1	**2a**		21	87(76)
2	**2b**		0	64(60)
3	**2c**		-[b]	-(70)[b]
4	**2d**		0	28(28)[c]
5	**2e**		33	80(72)
6	**2f**		29	89
7	**2g**		67	80(75)
8	**2h**		67	90(82)
9	**2i**		25	79(69)
10	**2j**		35	89(77)
11	**2k**		54	90(88)
12	**2l**		78	98(83)

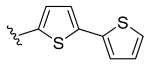
[a]Isolated yields are in parentheses. [b]Conversion could not be determined due to polarity issues. [c]30 min, 100 °C.

for $C_{11}H_{13}ClN$: 194.0731 $[M(Cl^{35})+H]^+$; found: 194.0735. The crude material was used in the following step without further purification. A solution of 5-chloro-2,3,3-trimethylindolenine (11.9 g, 61.8 mmol) and 2-iodoethanol (7.2 mL, 92.7 mmol, 1.5 equiv) in toluene (96 mL) was refluxed overnight. The solution was allowed to cool to room temperature and filtered. The product was washed with cold Et_2O (3

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

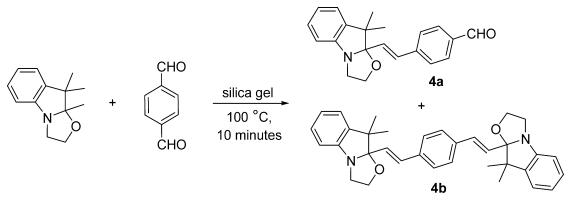
Table 4. Effect of the Nature of the Aromatic System



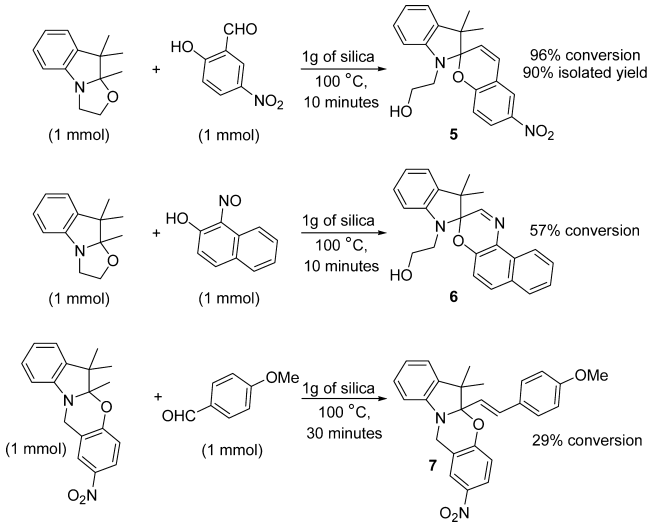
entry	product	R^2	Conversion (%) before heating	Conversion[a] (%) after heating.
1	**3a**		11	92
2	**3b**		55	92
3	**3c**		9	77(69)
4	**3d**		0	59(57)

[a]Isolated yields are in parentheses.

Scheme 3. Mono- and Bis-Condensation between Trimethylindolino[2,1-*b*]oxazolidine and Terephthalic Aldehyde



Scheme 4. Synthesis of SPs and SPOs



times) and acetone (3 times) consecutively, and dried (under reduced pressure) to afford the 1-(2-hydroxyethyl)-5-chloro-2,3,3-trimethylindoleninium iodide (17.5 g, 77%) as a pink solid. m.p.: 190−191 °C; ^{1}H NMR (300 MHz, $(CD_3)_2SO$) δ 1.57 (6H, s, CH_3), 2.84 (3H, s, CH_3), 3.86 (2H, t, J = 5.0, CH_2), 4.60 (2H, t, J = 4.8, CH_2), 7.71 (1H, dd, J = 8.6, 2.0, CH), 8.01 (1H, d, J = 8.6, CH), 8.08 (1H, d, J = 1.9, CH); ^{13}C NMR (75 MHz, $(CD_3)_2SO$) δ 14.7 (CH_3), 21.8 (2 × CH_3), 50.6 (CH_2), 54.5 (C), 57.7 (CH_2), 117.3 (CH), 124.0 (CH), 128.8 (CH), 134.2 (C), 140.0 (C), 143.8 (C), 198.3 (C); IR $\bar{U}$ = 3276, 3011, 2925 cm^{-1}; MS (FAB+): m/z (%): 240 (38) [M(Cl^{37})-I]$^+$, 238 (100) [M(Cl^{35})-I]$^+$, HRMS (FAB+): m/z calcd. for $C_{13}H_{17}ClNO$: 238.0993 [M(Cl^{35})-I]$^+$; found: 238.0994. The crude material was used in the following step without further purification. To a suspension of 1-(2-hydroxyethyl)-5-chloro-2,3,3-trimethylindoleninium iodide (17 g, 46.5 mmol) in water (450 mL) a solution of NaOH (2.8 g, 69.8 mmol, 1.5 equiv) in water (220 mL) was added and the resulting solution was stirred at room temperature for 30 min. The reaction mixture was extracted with Et_2O (3 times), washed with water (2 times), brine (1 time), dried ($MgSO_4$), and concentrated under reduced pressure to afford the 5-chloro-2,3,3-trimethylindolino[1,2-*b*]oxazoline (10.9 g, 99%) as a light-brown solid. m.p.: 56−57 °C; ^{1}H NMR (300 MHz) δ 1.17 (3H, s, CH_3), 1.36 (3H, s, CH_3), 1.40 (3H, s, CH_3), 3.45−3.70 (3H, m, CH_2), 3.79−3.88 (1H, m, CH_2), 6.66 (1H, d, J = 8.3, CH), 7.02 (1H, d, J = 2.0, CH), 7.08 (1H, dd, J = 8.3, 2.2, CH); ^{13}C NMR (75 MHz) δ 17.6 (CH_3), 20.8 (CH_3), 28.0 (CH_3), 47.2 (C), 50.2 (CH_2), 63.1 (CH_2), 109.3 (C), 113.0 (CH), 123.0 (CH), 126.6 (C), 127.5 (CH), 142.1 (C), 149.4 (C); IR $\bar{U}$ = 3060, 2971, 2932 cm^{-1}; MS (FAB+): m/z (%): 239 (40) [M(Cl^{37})]$^+$, 237 (100) [M(Cl^{35})]$^+$; HRMS (FAB+): m/z calcd. for $C_{13}H_{16}ClNO$: 237.0920 [M(Cl^{35})]$^+$; found: 237.0925.

*5-Fluoro-2,3,3-trimethylindolino[1,2-b]oxazoline (**1d**).* A solution of 4-fluorophenylhydrazine 15 g (92.3 mmol) and 3-methyl-2-butanone (14.8 mL, 138.4 mmol, 1.5 equiv) in acetic acid (200 mL) was refluxed overnight. The solution was allowed to cool to room temperature and filtered. Then the solvent was removed under reduced pressure and dark-brown residue was taken up in DCM. This solution was washed cautiously with $NaHCO_3$ (2 times), water, and brine, dried ($MgSO_4$). and concentrated to afford the 5-fluoro-2,3,3-trimethylindolenine (15.6 g, 96%) as an orange-brown solid. R_f = 0.36 (PE/EtOAc, 1/1); m.p.: 58−60 °C; ^{1}H NMR (300 MHz) δ 1.28 (6H, s, CH_3), 2.24 (3H, s, CH_3), 6.92−7.00 (2H, m, CH), 7.43 (1H, dd, J = 9.1, 4.7, CH); ^{13}C NMR (75 MHz) δ 15.5 (CH_3), 23.1 (2 × CH_3), 54.3 (d, J = 2.2, C), 109.2 (d, J = 24.3, CH), 114.2 (d, J = 23.6, CH),

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

120.6 (d, J = 8.9, CH), 147.7 (d, J = 8.5, C), 149.8 (d, J = 2.1, C), 161.3 (d, J = 243.6, C), 187.8 (d, J = 3.6, C); IR $\bar{U}$ = 3289, 2966, 2931, 2865 cm^{-1}; MS (ESI): m/z (%): 178 (100) $[M + H]^+$; HRMS (ESI): m/z calcd. for $C_{11}H_{13}FN$: 178.1027 $[M + H]^+$; found: 178.1029. The crude material was used in the following step without further purification. A solution of 5-fluoro-2,3,3-trimethylindolenine (15.4 g, 86.9 mmol) and 2-iodoethanol (10.2 mL, 130.4 mmol, 1.5 equiv) in toluene (135 mL) was refluxed overnight. The solution was allowed to cool to room temperature and filtered. The product was washed with cold Et_2O (3 times) and acetone (3 times) consecutively, and dried (under reduced pressure) to afford the 1-(2-hydroxyethyl)-5-fluoro-2,3,3-trimethylindoleninium iodide (25.1 g, 83%) as a pink solid. m.p.: 162−164 °C; ^1H NMR (300 MHz, $(CD_3)_2SO$) δ 1.57 (6H, s, CH_3), 2.82 (3H, s, CH_3), 3.87 (2H, t, J = 5.1, CH_2), 4.60 (2H, t, J = 4.9, CH_2), 7.49 (1H, td, J = 9.1, 2.5, CH), 7.87 (1H, dd, J = 8.2, 2.5, CH), 8.03 (1H, dd, J = 8.9, 4.2, CH); ^{13}C NMR (75 MHz, $(CD_3)_2SO$) δ 14.7 (CH_3), 21.9 (2 × CH_3), 50.6 (CH_2), 54.4 (C), 57.7 (CH_2), 111.5 (d, J = 26.0, CH), 115.9 (d, J = 25.0, CH), 117.6 (d, J = 9.6, CH), 137.4 (d, J = 1.6, C), 144.4 (d, J = 9.9, C), 162.5 (d, J = 247.2, C), 197.8 (d, J = 2.9, C); IR $\bar{U}$ = 3297, 3266, 3022 cm^{-1}; MS (ESI): m/z (%): 222 (100) $[M-I]^+$; HRMS (ESI): m/z calcd. for $C_{13}H_{17}FNO$: 222.1289 $[M-I]^+$; found: 222.1292. The crude material was used in the following step without further purification. To a suspension of 1-(2-hydroxyethyl)-5-fluoro-2,3,3-trimethylindoleninium iodide (24.6 g, 70.5 mmol) in water (500 mL) a solution of NaOH (4.2 g, 105.7 mmol, 1.5 equiv) in water (250 mL) was added and the resulting solution was stirred at room temperature for 30 min. The reaction mixture was extracted with Et_2O (3 times), washed with water (2 times) and brine (1 time), dried ($MgSO_4$), and concentrated under reduced pressure to afford the 5-fluoro-2,3,3-trimethylindolino[1,2-*b*]oxazoline (14.8 g, 95%) as a brown oil. ^1H NMR (300 MHz) δ 1.17 (3H, s, CH_3), 1.37 (3H, s, CH_3), 1.40 (3H, s, CH_3), 3.45−3.70 (3H, m, CH_2), 3.79−3.88 (1H, m, CH_2), 6.66 (1H, dd, J = 8.4, 4.3, CH), 6.77 (1H, dd, J = 8.2, 2.5, CH), 6.81 (1H, td, J = 8.8, 2.6, CH); ^{13}C NMR (75 MHz) δ 17.8 (CH_3), 20.8 (CH_3), 28.0 (CH_3), 47.3 (C), 50.5 (CH_2), 63.1 (CH_2), 109.6 (C), 110.0 (d, J = 23.6, CH), 112.5 (d, J = 8.4, CH), 113.8 (d, J = 23.4, CH), 141.9 (d, J = 7.3, C), 146.5 (d, J = 1.7, C), 159.0 (d, J = 238.1, C); IR $\bar{U}$ = 2967, 2935, 2883 cm^{-1}; MS (ESI): m/z (%): 222 (100) $[M + H]^+$; HRMS (ESI): m/z calcd. for $C_{13}H_{17}FNO$: 222.1289 $[M + H]^+$; found: 222.1289.

For all the functionalized indolinooxazolidines the following optimized protocol was used: To 1 g of silica the corresponding indolinooxazolidine (1.0 mmol) and aromatic aldehyde (1.0 mmol) was added and the heterogeneous mixture was homogenized by the addition of minimal amount (1−2 mL) of DCM. The solvent was removed under reduced pressure at ambient temperature and the powder was heated to 100 °C during 10 min under normal atmosphere in a 20 mL sealed tube (to avoid the evaporation of the more volatile aromatic aldehydes). Due to the solvent free conditions, the lack of vapor pressure makes the general procedure perfectly safe. For better homogenization of the solid reaction mixtures, continuous stirring was applied. Although it has been shown that evaporative deposition is not always necessary, we decided to homogenize our reactions to avoid the error of NMR conversions resulting from local concentration differences.[51] The corresponding products were purified either by flash column chromatography (using pentane/DCM, DCM, or DCM/MeOH systems) or by crystallization from pentane. Determination of the conversions was carried out by NMR spectroscopy: A 100 mg sample of the reaction was washed using $CDCl_3$ (0.7 mL) directly into an NMR tube. The conversions were calculated simply by comparing aromatic proton signals of the aldehydes and the characteristic olefinic proton peaks of the corresponding products (see SI, S34).

10-[2-(Phenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]oxazolidine ***(2a)***. Product was isolated as a light-brown solid (222 mg, 76%). m.p.: 105−107 °C; ^1H NMR (300 MHz) δ 1.21 (3H, s, CH_3), 1.49 (3H, s, CH_3), 3.43−3.56 (1H, m, CH_2), 3.62−3.88 (3H, m, CH_2), 6.33 (1H, d, J = 15.9, CH), 6.84 (1H, d, J = 7.8, CH), 6.92 (1H, d, J = 16.0, CH), 6.99 (1H, t, J = 7.3, CH), 7.12 (1H, d, J = 7.1, CH), 7.21 (1H, t, J = 7.1, CH), 7.31 (1H, d, J = 7.0, CH), 7.38 (2H, t, J = 7.3, CH), 7.49 (2H, d, J = 7.3, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 48.1 (C), 50.2 (CH_2), 63.7 (CH_2), 110.0 (C), 112.1 (CH), 121.8 (CH), 122.5 (CH), 126.0 (CH), 126.9 (2 × CH), 127.7 (CH), 128.0 (CH), 128.8 (2 × CH), 132.4 (CH), 136.5 (C), 139.8 (C), 150.7 (C); IR $\bar{U}$ = 2961, 2924, 2888, cm^{-1}; MS (FAB+): m/z (%): 292 (100) $[M + H]^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{22}NO$: 292.1701 $[M + H]^+$; found: 292.1701 ^1H and ^{13}C NMR were consistent with literature data.[24]

10-[2-(4-Methoxyphenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine ***(2b)***. Product was isolated as a light-brown solid (192 mg, 60%). m.p.: 91−93 °C; ^1H NMR (300 MHz) δ 1.20 (3H, s, CH_3), 1.47 (3H, s, CH_3), 3.42−3.57 (1H, m, CH_2), 3.61−3.74 (2H, m, CH_2), 3.77−3.86 (1H, m, CH_2), 3.84 (3H, s, CH_3), 6.18 (1H, d, J = 15.9, CH), 6.83 (1H, d, J = 7.6, CH), 6.85 (1H, d, J = 16.0, CH), 6.91 (2H, d, J = 8.7, CH), 6.97 (1H, t, J = 7.4, CH), 7.11 (1H, d, J = 7.3, CH), 7.19 (1H, td, J = 7.8, 1.0, CH), 7.43 (2H, d, J = 8.6, CH); ^{13}C NMR (75 MHz) δ 20.4 (CH_3), 28.5 (CH_3), 48.0 (C), 50.2 (CH_2), 55.4 (CH_3), 63.6 (CH_2), 110.1 (C), 112.1 (CH), 114.2 (2 × CH), 121.8 (CH), 122.5 (CH), 123.6 (CH), 127.7 (CH), 128.1 (2 × CH), 129.3 (C), 131.8 (CH), 139.9 (C), 150.7 (C), 159.5 (C); IR $\bar{U}$ = 2987, 2963, 2931 cm^{-1}; MS (FAB+): m/z (%): 322 (100) $[M + H]^+$; HRMS (FAB+): m/z calcd. for $C_{21}H_{24}NO_2$: 322.1807 $[M + H]^+$; found: 322.1801. The ^1H and ^{13}C NMR were consistent with literature data.[24]

10-[2-(4-Hydroxyphenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine ***(2c)***. Product was isolated as a red solid (215 mg, 70%). m.p.: 80−82 °C; ^1H NMR (300 MHz) δ 1.16 (3H, s, CH_3), 1.44 (3H, s, CH_3), 3.41−3.54 (1H, m, CH_2), 3.58−3.73 (2H, m, CH_2), 3.74−3.85 (1H, m, CH_2), 6.10 (1H, d, J = 15.9, CH), 6.79 (1H, d, J = 15.6, CH), 6.81 (1H, d, J = 8.0, CH), 6.82 (2H, d, J = 8.5, CH), 6.96 (1H, t, J = 7.3, CH), 7.09 (1H, d, J = 7.3, CH), 7.18 (1H, t, J = 7.2, CH), 7.29 (2H, d, J = 8.3, CH); ^{13}C NMR (75 MHz) δ 20.4 (CH_3), 28.5 (CH_3), 48.0 (C), 50.1 (CH_2), 63.6 (CH_2), 110.2 (C), 112.2 (CH), 115.8 (2 × CH), 121.8 (CH), 122.5 (CH), 122.7 (CH), 127.7 (CH), 128.2 (2 × CH), 128.6 (C), 132.1 (CH), 140.0 (C), 150.6 (C), 156.6 (C); IR $\bar{U}$ = 3050 (bs), 2958, 2956, 2869 cm^{-1}; MS (FAB+): m/z (%): 308 (100) $[M + H]^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{22}NO_2$: 308.1651 $[M + H]^+$; found: 308.1657.

10-[2-(4-Dimethylaminophenyl)ethylene]-9,9-trimethyl-indolino-[2,1-b]oxazolidine ***(2d)***. Product was isolated as a purple solid (95 mg, 28%). m.p.: 123−125 °C; ^1H NMR (300 MHz) δ 1.17 (3H, s, CH_3), 1.45 (3H, s, CH_3), 2.98 (6H, s, CH_3), 3.41−3.54 (1H, m, CH_2), 3.58−3.72 (2H, m, CH_2), 3.75−3.84 (1H, m, CH_2), 6.08 (1H, d, J = 15.9, CH), 6.72 (2H, d, J = 8.7, CH), 6.79 (1H, d, J = 16.0, CH), 6.81 (1H, d, J = 7.5, CH), 6.95 (1H, t, J = 7.3, CH), 7.09 (1H, d, J = 7.0, CH), 7.17 (1H, t, J = 7.5, CH), 7.37 (2H, d, J = 8.6, CH); ^{13}C NMR (75 MHz) δ 20.4 (CH_3), 28.5 (CH_3), 40.6 (2 × CH_3), 48.0 (C), 50.1 (CH_2), 63.5 (CH_2), 110.3 (C), 112.1 (CH), 112.5 (2 × CH), 121.0 (CH), 121.7 (CH), 122.5 (CH), 125.0 (C), 127.6 (CH), 127.8 (2 × CH), 132.2 (CH), 140.0 (C), 150.4 (C), 150.8 (C); IR $\bar{U}$ = 2958, 2925, 2886 cm^{-1}; MS (FAB+): m/z (%): 335 (100) $[M + H]^+$; HRMS (FAB+): m/z calcd. for $C_{22}H_{27}N_2O$: 335.2123 $[M + H]^+$; found: 335.2117. ^1H and ^{13}C NMR were consistent with literature data.[24]

10-[2-(4-Bromophenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine ***(2e)***. Product was isolated as a pale yellow solid (267 mg, 72%). m.p.: 118−120 °C; ^1H NMR (300 MHz) δ 1.17 (3H, s, CH_3), 1.46 (3H, s, CH_3), 3.40−3.52 (1H, m, CH_2), 3.59−3.84 (3H, m, CH_2), 6.30 (1H, d, J = 15.9, CH), 6.82 (1H, d, J = 8.0, CH), 6.83 (1H, d, J = 15.8, CH), 6.97 (1H, td, J = 7.5, 1.0, CH), 7.10 (1H, d, J = 7.8, CH), 7.19 (1H, td, J = 7.7, 1.2, CH), 7.33 (2H, d, J = 8.5, CH), 7.48 (2H, d, J = 8.4, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 48.1 (C), 50.2 (CH_2), 63.7 (CH_2), 109.9 (C), 112.2 (CH), 121.8 (C), 121.9 (CH), 122.5 (CH), 127.0 (CH), 127.8 (CH), 128.4 (2 × CH), 131.2 (CH), 131.9 (2 × CH), 135.5 (C), 139.7 (C), 150.6 (C); IR $\bar{U}$ = 2961, 2936, 2887 cm^{-1}; MS (FAB+): m/z (%): 372 (90) $[M(Br^{81})+H]^+$, 370 (100) $[M(Br^{79})+H]^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{21}BrNO$: 370.0807 $[M(Br^{79}) + H]^+$; found: 370.0799.

10-[2-(4-Cyanophenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine ***(2g)***. Product was isolated as a brown solid (236 mg, 75%). m.p.: 94−96 °C; ^1H NMR (300 MHz) δ 1.17 (3H, s, CH_3),

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

1.46 (3H, s, CH_3), 3.37−3.49 (1H, m, CH_2), 3.59−3.84 (3H, m, CH_2), 6.45 (1H, d, J = 15.9, CH), 6.82 (1H, d, J = 7.8, CH), 6.90 (1H, d, J = 15.9, CH), 6.97 (1H, td, J = 7.4, 0.7, CH), 7.10 (1H, dd, J = 7.3, 0.7 CH), 7.19 (1H, td, J = 7.7, 1.2, CH), 7.53 (2H, d, J = 8.3, CH), 7.64 (2H, d, J = 8.3, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 48.2 (C), 50.3 (CH_2), 63.8 (CH_2), 109.7 (C), 111.2 (C), 112.2 (CH), 119.0 (C), 122.0 (CH), 122.5 (CH), 127.3 (2 × CH), 127.9 (CH), 130.6 (CH), 130.7 (CH), 132.6 (2 × CH), 139.6 (C), 141.0 (C), 150.4 (C); IR $\bar{U}$ = 2964, 2926, 2867, 2226 cm^{-1}; MS (FAB+): m/z (%): 317 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{21}H_{21}N_2O$: 317.1654 [M + H]$^+$; found: 317.1650.

*10-[2-(4-Nitrophenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**2h**).* Product was isolated as a brown-red solid (274 mg, 82%). m.p.: 145−147 °C; ^{1}H NMR (300 MHz) δ 1.18 (3H, s, CH_3), 1.47 (3H, s, CH_3), 3.40−3.51 (1H, m, CH_2), 3.60−3.82 (3H, m, CH_2), 6.50 (1H, d, J = 15.9, CH), 6.83 (1H, d, J = 7.8, CH), 6.96 (1H, d, J = 15.9, CH), 6.97 (1H, td, J = 7.4, 0.7, CH), 7.10 (1H, dd, J = 7.3, 0.7, CH), 7.20 (1H, td, J = 7.7, 1.2, CH), 7.58 (2H, d, J = 8.8, CH), 8.21 (2H, d, J = 8.8, CH); ^{13}C NMR (75 MHz) δ 20.6 (CH_3), 28.5 (CH_3), 48.3 (C), 50.3 (CH_2), 63.9 (CH_2), 109.7 (C), 112.2 (CH), 122.1 (CH), 122.5 (CH), 124.2 (2 × CH), 127.4 (2 × CH), 127.9 (CH), 130.3 (CH), 131.6 (CH), 139.5 (C), 143.0 (C), 147.2 (C), 150.3 (C); IR $\bar{U}$ = 2967, 2931, 2890 cm^{-1}; MS (FAB+): m/z (%): 337 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{21}N_2O_3$: 337.1552 [M + H]$^+$; found: 337.1551.

*10-[2-(3-Methoxyphenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**2i**).* Product was isolated as a light-brown solid (220 mg, 69%). m.p.: 98−100 °C; ^{1}H NMR (300 MHz) δ 1.20 (3H, s, CH_3), 1.48 (3H, s, CH_3), 3.44−3.54 (1H, m, CH_2), 3.61−3.75 (2H, m, CH_2), 3.78−3.87 (1H, m, CH_2), 3.84 (3H, s, CH_3), 6.32 (1H, d, J = 15.9, CH), 6.84 (1H, d, J = 7.6, CH), 6.85 (1H, d, J = 7.9, CH), 6.88 (1H, d, J = 15.9, CH), 6.98 (1H, t, J = 7.3, CH), 7.03 (1H, s, CH), 7.09 (1H, d, J = 8.3, CH), 7.11 (1H, d, J = 8.0, CH), 7.20 (1H, td, J = 7.8, 1.0, CH), 7.29 (1H, t, J = 7.9, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 48.1 (C), 50.2 (CH_2), 55.4 (CH_3), 63.7 (CH_2), 109.9 (C), 112.0 (CH), 112.1 (CH), 113.7 (CH), 119.5 (CH), 121.8 (CH), 122.5 (CH), 126.3 (CH), 127.7 (CH), 129.8 (CH), 132.3 (CH), 138.0 (C), 139.8 (C), 150.6 (C), 160.0 (C); IR $\bar{U}$ = 2992, 2964, 2937, cm^{-1}; MS (FAB+): m/z (%): 322 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{21}H_{24}NO_2$: 322.1807 [M + H]$^+$; found: 322.1800.

*10-[2-(2-Methoxyphenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**2j**).* Product was isolated as a light-yellow solid (246 mg, 77%). m.p.: 74−76 °C; ^{1}H NMR (300 MHz) δ 1.19 (3H, s, CH_3), 1.46 (3H, s, CH_3), 3.45−3.55 (1H, m, CH_2), 3.60−3.74 (2H, m, CH_2), 3.78−3.86 (1H, m, CH_2), 3.86 (3H, s, CH_3), 6.33 (1H, d, J = 16.1, CH), 6.82 (1H, d, J = 7.8, CH), 6.91 (1H, d, J = 8.5, CH), 6.95 (2H, t, J = 7.4, CH), 7.10 (1H, d, J = 6.8, CH), 7.18 (1H, td, J = 7.6, 1.4, CH), 7.19 (1H, d, J = 16.1, CH), 7.26 (1H, td, J = 7.4, 1.5 CH), 7.52 (1H, dd, J = 7.6, 1.3, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 47.9 (C), 50.2 (CH_2), 55.5 (CH_3), 63.6 (CH_2), 110.2 (C), 111.1 (CH), 112.1 (CH), 120.7 (CH), 121.7 (CH), 122.5 (CH), 125.6 (C), 126.3 (CH), 127.3 (2 × CH), 127.6 (CH), 129.0 (CH), 139.9 (C), 150.9 (C), 157.1 (C); IR $\bar{U}$ = 3024, 2992, 2887, cm^{-1}; MS (FAB+): m/z (%): 322 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{21}H_{24}NO_2$: 322.1807 [M + H]$^+$; found: 322.1811.

*10-[2-(3-Bromophenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**2k**).* Product was isolated as a pale yellow solid (325 mg, 88%). m.p.: 112−114 °C; ^{1}H NMR (300 MHz) δ 1.17 (3H, s, CH_3), 1.45 (3H, s, CH_3), 3.39−3.50 (1H, m, CH_2), 3.59−3.82 (3H, m, CH_2), 6.30 (1H, d, J = 15.9, CH), 6.81 (1H, d, J = 7.8, CH), 6.82 (1H, d, J = 15.6, CH), 6.95 (1H, t, J = 7.4, CH), 7.09 (1H, d, J = 7.4, CH), 7.18 (1H, td, J = 7.6, 1.1, CH), 7.21 (1H, t, J = 7.8, CH), 7.36 (1H, d, J = 8.8, CH), 7.40 (1H, d, J = 8.2, CH), 7.60 (1H, t, J = 1.7, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 48.1 (C), 50.3 (CH_2), 63.7 (CH_2), 109.8 (C), 112.2 (CH), 121.9 (CH), 122.5 (CH), 123.0 (C), 125.5 (CH), 127.8 (CH), 127.9 (CH), 129.7 (CH), 130.3 (CH), 130.8 (CH), 131.0 (CH), 138.8 (C), 139.7 (C), 150.6 (C); IR $\bar{U}$ = 2959, 2925, 2886 cm^{-1}; MS (FAB+): m/z (%): 372 (70) [M(Br^{81}) + H]$^+$, 370 (100) [M(Br^{79}) + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{21}BrNO$: 370.0807 [M(Br^{79}) + H]$^+$; found: 370.0802.

*10-[2-(2-Bromophenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**2l**).* Product was isolated as a pale yellow solid (307 mg, 83%). m.p.: 96−98 °C; ^{1}H NMR (300 MHz) δ 1.21 (3H, s, CH_3), 1.49 (3H, s, CH_3), 3.49−3.60 (1H, m, CH_2), 3.63−3.76 (2H, m, CH_2), 3.82−3.90 (1H, m, CH_2), 6.21 (1H, d, J = 15.8, CH), 6.83 (1H, d, J = 8.0, CH), 6.97 (1H, t, J = 7.0, CH), 7.11 (1H, d, J = 6.6, CH), 7.13 (1H, d, J = 7.4, CH), 7.18 (1H, d, J = 7.8, CH), 7.25 (1H, d, J = 16.1, CH), 7.31 (1H, t, J = 7.2, CH), 7.58 (2H, m, CH); ^{13}C NMR (75 MHz) δ 20.5 (CH_3), 28.5 (CH_3), 47.9 (C), 50.3 (CH_2), 63.7 (CH_2), 109.8 (C), 112.2 (CH), 121.8 (CH), 122.5 (CH), 124.0 (C), 127.5 (CH), 127.7 (2 × CH), 129.2 (CH), 129.3 (CH), 131.8 (CH), 133.1 (CH), 137.0 (C), 139.7 (C), 150.8 (C); IR $\bar{U}$ = 2963, 2924, 2877 cm^{-1}; MS (FAB+): m/z (%): 372 (80) [M(Br^{81}) + H]$^+$, 370 (90) [M(Br^{79}) + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{21}BrNO$: 370.0807 [M(Br^{79}) + H]$^+$; found: 370.0792.

*10-[2-(Bithiophenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**3c**).* Product was isolated as a pink solid (260 mg, 69%). m.p.: 122−124 °C; ^{1}H NMR (300 MHz) δ 1.18 (3H, s, CH_3), 1.45 (3H, s, CH_3), 3.41−3.53 (1H, m, CH_2), 3.58−3.86 (3H, m, CH_2), 6.11 (1H, d, J = 15.6, CH), 6.81 (1H, d, J = 7.8, CH), 6.90−7.12 (6H, m, CH), 7.14−7.21 (2H, m, CH), 7.22 (1H, dd, J = 5.1, 1.0, CH); ^{13}C NMR (75 MHz) δ 20.4 (CH_3), 28.5 (CH_3), 48.2 (C), 50.2 (CH_2), 63.7 (CH_2), 109.7 (C), 112.1 (CH), 121.9 (CH), 122.5 (CH), 123.9 (CH), 124.0 (CH), 124.7 (CH), 125.6 (CH), 125.9 (CH), 127.5 (CH), 127.7 (CH), 128.0 (CH), 136.7 (C), 137.4 (C), 139.8 (C), 140.7 (C), 150.5 (C); IR $\bar{U}$ = 2998, 2952, 2886 cm^{-1}; MS (FAB+): m/z (%): 380 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{22}H_{22}NOS_2$: 380.1143 [M + H]$^+$; found: 380.1144.

*10-[2-(Ferrocenyl)ethylene]-9,9-trimethyl-indolino[2,1-b]-oxazolidine (**3d**).* Product was isolated as a green solid (228 mg, 57%). m.p.: 129−131 °C; ^{1}H NMR (300 MHz) δ 1.20 (3H, s, CH_3), 1.47 (3H, s, CH_3), 3.45−3.55 (1H, m, CH_2), 3.62−3.84 (3H, m, CH_2), 4.13 (5H, s, Fc-H), 4.26 (2H, t, J = 1.8, Fc-H), 4.43 (2H, m, Fc-H), 5.87 (1H, d, J = 15.6, CH), 6.66 (1H, d, J = 15.8, CH), 6.81 (1H, d, J = 7.8, CH), 6.96 (1H, td, J = 7.4, 0.6, CH), 7.11 (1H, dd, J = 7.3, 0.8, CH), 7.19 (1H, td, J = 7.7, 1.2, CH); ^{13}C NMR (75 MHz) δ 20.4 (CH_3), 28.6 (CH_3), 47.6 (C), 50.3 (CH_2), 63.5 (CH_2), 67.2 (2 × Fc-H), 69.1 (2 × Fc-H), 69.2 (5 × Fc-H), 82.3 (C), 110.1 (C), 112.1 (CH), 121.8 (CH), 122.3 (CH), 122.5 (CH), 127.7 (CH), 130.5 (CH), 139.8 (C), 150.7 (C); IR $\bar{U}$ = 3104, 2990, 2956, 2887 cm^{-1}; MS (FAB+): m/z (%): 400 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{24}H_{26}FeNO$: 400.1364 [M + H]$^+$; found: 400.1362.

*2-(3′,3′-Dimethyl-6-nitro-3′H-spiro[chromene-2,2′-indol]-1′-yl)-ethanol (**5**).* Product was isolated as a purple solid (317 mg, 90%). m.p.: 152−154 °C; ^{1}H NMR (300 MHz) δ 1.19 (3H, s, CH_3), 1.29 (3H, s, CH_3), 3.27−3.52 (2H, m, CH_2), 3.67−3.89 (2H, m, CH_2), 5.88 (1H, d, J = 10.4, CH), 6.67 (1H, d, J = 7.78, CH), 6.76 (1H, d, J = 8.7, CH), 6.91 (1H, td, J = 7.3, 0.7, CH), 6.91 (1H, d, J = 10.8, CH), 7.10 (1H, dd, J = 7.3, 0.8, CH), 7.20 (1H, td, J = 7.7, 1.2, CH), 8.00 (1H, d, J = 2.5, CH), 8.02 (1H, dd, J = 8.7, 2.7, CH); ^{13}C NMR (75 MHz) δ 20.1 (CH_3), 26.0 (CH_3), 46.2 (C), 52.9 (CH_2), 60.9 (CH_2), 106.8 (C), 107.0 (CH), 115.6 (CH), 118.6 (C), 120.0 (CH), 122.0 (2 × CH), 122.9 (CH), 126.1 (CH), 127.9 (CH), 128.3 (CH), 135.9 (C), 141.2 (C), 147.1 (C), 159.4 (C); IR $\bar{U}$ = 3364 (bs), 2961, 2926, 2867 cm^{-1}; MS (FAB+): m/z (%): 353 (100) [M + H]$^+$; HRMS (FAB+): m/z calcd. for $C_{20}H_{21}N_2O_4$: 353.1501 [M + H]$^+$; found: 353.1498. ^{1}H and ^{13}C NMR were consistent with literature data.[36]

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Additional data and the copies of ^{1}H and ^{13}C NMR. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: gyorgy.szaloki@univ-angers.fr.

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX

*E-mail: lionel.sanguinet@univ-angers.fr.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

This work was supported by grants from the ANR (PHOEBUS). The authors thank B. Siegler and Dr I. Freuze for their assistance in NMR spectroscopy and MS, respectively. We are also grateful to Dr. Helen Grounds for her useful comments.

■ REFERENCES

(1) Fischer, E.; Hirshberg, Y. *J. Chem. Soc.* **1952**, 4518−4548.
(2) Chaudé, O.; Rumpf, P. *C. R. Acad. Sci.* **1953**, *236*, 697.
(3) Hirshberg, Y. *J. Am. Chem. Soc.* **1956**, *78*, 2304−2312.
(4) Crano, J. C.; Flood, T.; Knowles, D.; Kumar, A.; VanGemert, B. *Pure Appl. Chem.* **1996**, *68*, 1395−1398.
(5) Crano, J. C.; Guglielmetti, R. J. *Organic Photochromic and Thermochromic Compounds: Vol. 1: Main Photochromic Families*; Kluwer Academic Publishers: New York, 1999.
(6) Berkovic, G.; Krongauz, V.; Weiss, V. *Chem. Rev.* **2000**, *100*, 1741−1753.
(7) Kawata, S.; Kawata, Y. *Chem. Rev.* **2000**, *100*, 1777−1788.
(8) Guglielmetti, R.; Chu, N. Y. C. Spiropyrans and Related Compounds, Spirooxazines. In *Photochromism*; Bouas-Laurent, H., Dürr, H., Eds.; Elsevier: Amsterdam, 2003; pp 855−882.
(9) Shallcross, R. C.; Zacharias, P.; Koehnen, A.; Koerner, P. O.; Maibach, E.; Meerholz, K. *Adv. Mater.* **2013**, *25*, 469−476.
(10) Natali, M.; Giordani, S. *Chem. Soc. Rev.* **2012**, *41*, 4010−4029.
(11) Qin, M.; Li, F.; Huang, Y.; Ran, W.; Han, D.; Song, Y. *Anal. Chem.* **2015**, *87*, 837−842.
(12) Zhang, J.; Wang, J.; Tian, H. *Mater. Horiz.* **2014**, *1*, 169−184.
(13) Tong, R.; Hemmati, H. D.; Langer, R.; Kohane, D. S. *J. Am. Chem. Soc.* **2012**, *134*, 8848−8855.
(14) Irie, M.; Yokoyama, Y.; Takahiro, S. *New Frontiers in Photochromism*; Springer: Japan, 2013.
(15) Kim, T.; Zhu, L.; Al-Kaysi, R. O.; Bardeen, C. J. *ChemPhysChem* **2014**, *15*, 400−414.
(16) Peterson, G. I.; Larsen, M. B.; Ganter, M. A.; Storti, D. W.; Boydston, A. J. *ACS Appl. Mater. Interfaces* **2015**, *7*, 577−583.
(17) Pardo, R.; Zayat, M.; Levy, D. *Chem. Soc. Rev.* **2011**, *40*, 672−687.
(18) Minkin, V. I. Photoswitchable Molecular Systems Based on Spiropyrans and Spirooxazines. In *Molecular Switches*, 2nd ed.; Feringa, B. L., Browne, W. R., Eds.; WILEY-VCH Verlag & Co. KGaA: Weinheim, 2011; pp 37−80.
(19) Kawami, S.; Yoshioka, H.; Nakatsu, K.; Okazaki, T.; Hayami, M. *Chem. Lett.* **1987**, *16*, 711−714.
(20) Petkov, I.; Charra, F.; Nunzi, J. M.; Deligeorgiev, T. *J. Photochem. Photobiol., A* **1999**, *128*, 93−96.
(21) Sanguinet, L.; Pozzo, J.-L.; Rodriguez, V.; Adamietz, F.; Castet, F.; Ducasse, L.; Champagne, B. *J. Phys. Chem. B* **2005**, *109*, 11139−11150.
(22) Mançois, F.; Sanguinet, L.; Pozzo, J.-L.; Guillaume, M.; Champagne, B.; Rodriguez, V.; Adamietz, F.; Ducasse, L.; Castet, F. *J. Phys. Chem. B* **2007**, *111*, 9795−9802.
(23) Mançois, F.; Pozzo, J.-L.; Pan, J.; Adamietz, F.; Rodriguez, V.; Ducasse, L.; Castet, F.; Plaquet, A.; Champagne, B. *Chem.—Eur. J.* **2009**, *15*, 2560−2571.
(24) Sheng, L.; Li, M.; Zhu, S.; Li, H.; Xi, G.; Li, Y.-G.; Wang, Y.; Li, Q.; Liang, S.; Zhong, K.; Zhang, S. X.-A. *Nature Commun.* **2014**, *5*.
(25) Szalóki, G.; Alévêque, O.; Pozzo, J.-L.; Hadji, R.; Levillain, E.; Sanguinet, L. *J. Phys. Chem. B* **2015**, *119*, 307−315.
(26) Sevez, G.; Gan, J.; Delbaere, S.; Vermeersch, G.; Sanguinet, L.; Levillain, E.; Pozzo, J.-L. *Photochem. Photobiol. Sci.* **2010**, *9*, 131−135.
(27) Andréasson, J.; Pischel, U. *Isr. J. Chem.* **2013**, *53*, 236−246.
(28) Szalóki, G.; Sevez, G.; Berthet, J.; Pozzo, J.-L.; Delbaere, S. *J. Am. Chem. Soc.* **2014**, *136*, 13510−13513.
(29) Bertelson, R. C.; Maeda, S. In *Organic Photochromic and Thermochromic Compounds: Vol. 1: Main Photochromic Families*; Crano, J. C., Guglielmetti, R. J., Eds.; Kluwer Academic Publishers: New York, 1999; pp 13 and 86.
(30) Bertelson, R. C. Photochromic processes involving heterocyclic cleavage. In *Photochromism*; Brown, H. G., Ed.; Wiley-Interscience: New York, 1971; pp 242−243.
(31) Guglielmetti, R. 4n+2 Systems: Spiropyrans. In *Photochromism*; Bouas-Laurent, H., Dürr, H., Eds.; Elsevier: Amsterdam, 2003; p 420.
(32) Tomasulo, M.; Sortino, S.; Raymo, F. M. *J. Org. Chem.* **2008**, *73*, 118−126.
(33) Deniz, E.; Tomasulo, M.; Sortino, S.; Raymo, F. M. *J. Phys. Chem. C* **2009**, *113*, 8491−8497.
(34) Deniz, E.; Impellizzeri, S.; Sortino, S.; Raymo, F. M. *Can. J. Chem.* **2011**, *89*, 110−116.
(35) Prostota, Y.; Berthet, J.; Delbaere, S.; Coelho, P. J. *Dyes Pigm.* **2013**, *96*, 569−573.
(36) Raymo, F. M.; Giordani, S. *J. Am. Chem. Soc.* **2001**, *123*, 4651−4652.
(37) Raymo, F. M.; Giordani, S.; White, A. J. P.; Williams, D. J. *J. Org. Chem.* **2003**, *68*, 4158−4169.
(38) Zhou, W.; Chen, D.; Li, J.; Xu, J.; Lv, J.; Liu, H.; Li, Y. *Org. Lett.* **2007**, *9*, 3929−3932.
(39) Beyer, C.; Wagenknecht, H.-A. *J. Org. Chem.* **2010**, *75*, 2752−2755.
(40) Shiraishi, Y.; Itoh, M.; Hirai, T. *Phys. Chem. Chem. Phys.* **2010**, *12*, 13737−13745.
(41) Deniz, E.; Cusido, J.; Swaminathan, S.; Battal, M.; Impellizzeri, S.; Sortino, S.; Raymo, F. M. *J. Photochem. Photobiol., A* **2012**, *229*, 20−28.
(42) Deniz, E.; Tomasulo, M.; Cusido, J.; Yildiz, I.; Petriella, M.; Bossi, M. L.; Sortino, S.; Raymo, F. M. *J. Phys. Chem. C* **2012**, *116*, 6058−6068.
(43) Zhu, S.; Li, M.; Sheng, L.; Chen, P.; Zhang, Y.; Zhang, S. X.-A. *Analyst* **2012**, *137*, 5581−5585.
(44) Shankar, B. H.; Jayaram, D. T.; Ramaiah, D. *Chem.—Asian J.* **2014**, *9*, 1636−1642.
(45) Bartnik, R.; Lesniak, S.; Mloston, G.; Zielinski, T.; Gebicki, K. *Chem. Stosow.* **1990**, *34*, 325−334.
(46) Sevez, G. Conception, synthèse et étude de nouveaux switches multimodulables; Thesis; Université Bordeaux 1; December 2009.
(47) Lukyanov, B. S.; Lukyanova, M. B. *Chem. Heterocycl. Compd.* **2005**, *41*, 281−311.
(48) Kropp, P. J.; Daus, K. A.; Tubergen, M. W.; Kepler, K. D.; Wilson, V. P.; Craig, S. L.; Baillargeon, M. M.; Breton, G. W. *J. Am. Chem. Soc.* **1993**, *115*, 3071−3079.
(49) Kropp, P. J.; Crawford, S. D. *J. Org. Chem.* **1994**, *59*, 3102−3112.
(50) Fields, J. D.; Kropp, P. J. *J. Org. Chem.* **2000**, *65*, 5937−5941.
(51) Kropp, P. J.; Breton, G. W.; Fields, J. D.; Tung, J. C.; Loomis, B. R. *J. Am. Chem. Soc.* **2000**, *122*, 4280−4285.
(52) Kropp, P. J.; Breton, G. W.; Craig, S. L.; Crawford, S. D.; Durland, W. F.; Jones, J. E.; Raleigh, J. S. *J. Org. Chem.* **1995**, *60*, 4146−4152.
(53) Basu, B.; Paul, S. *J. Catalysts* **2013**, *2013*, 20.
(54) Barange, D. K.; Raju, B. R.; Kavala, V.; Kuo, C.-W.; Tu, Y.-C.; Yao, C.-F. *Tetrahedron* **2010**, *66*, 3754−3760.
(55) Basu, B.; Paul, S.; Nanda, A. K. *Green Chem.* **2009**, *11*, 1115−1120.
(56) Koshkin, A. V.; Fedorova, O. A.; Lokshin, V.; Guglielmetti, R.; Hamelin, J.; Texier-Boullet, F.; Gromov, S. P. *Synth. Commun.* **2004**, *34*, 315−322.
(57) Niu, C.; Song, Y.; Yang, L. *Chin. J. Chem.* **2009**, *27*, 2001−2006.
(58) Ivashenko, O.; van Herpt, J. T.; Rudolf, P.; Feringa, B. L.; Browne, W. R. *Chem. Commun.* **2013**, *49*, 6737−6739.

DOI: 10.1021/acs.joc.5b00282
J. Org. Chem. XXXX, XXX, XXX−XXX