Tetrahedron Letters 57 (2016) 905–909

Contents lists available at ScienceDirect

Tetrahedron Letters

journal homepage: www.elsevier.com/locate/tetlet

Ion complexation-controlled columnar mesophase of calix[4]arene–cholesterol derivatives with Schiff-base bridges

Xiaoyi Zhang[a], Hongyu Guo[a], Fafu Yang[a,b,*], Jin Yuan[a]

[a] College of Chemistry and Chemical Engineering, Fujian Normal University, Fuzhou 350007, PR China
[b] Fujian Key Laboratory of Polymer Materials, Fuzhou 350007, PR China

ARTICLE INFO

Article history:
Received 18 November 2015
Revised 9 January 2016
Accepted 13 January 2016
Available online 14 January 2016

Keywords:
Calixarene
Cholesterol
Synthesis
Mesophase
Complexation

ABSTRACT

Two novel calix[4]arene–cholesterol derivatives **7a** and **7b** with Schiff-base bridges were synthesized in yields of 70–80%. Their structural and conformational characterization had been achieved by NMR, MS, and elemental analysis. Their mesomorphic behaviors were studied by polarizing optical microscopy, differential scanning calorimetry, and X-ray diffraction. They possess mesomorphic properties with the molecular arrangement of the calixarene bowlic column and Schiff-based cholesterol unit as ancillary lateral column. The complexes of **7a** and **7b** with $AgClO_4$ showed no mesophase. These results suggested that the mesophase of compounds **7a** and **7b** could be tuned by the ion-complexation behavior.

Liquid crystal (LC) materials have gained broad researchers' interests due to the diverse physical properties for both basic research and applied sciences, such as organic photovoltaic cells, organic light-emitting diodes, organic field-effect transistors, gas sensors.[1–4] Recently, the macrocycle-based liquid crystals have attracted much attention because the mesomorphic property could be tuned by the complexation behavior of macrocycle unit. For examples, Cammidge and his co-workers reported the triphenylene dimers containing crown ether macrocycle with interesting mesomorphic properties.[5,6] Laschat's group and Peng's group synthesized a series of crown ether–triphenylene liquid crystals and studied the relationship of mesomorphic properties and complexation abilities, respectively.[7–13] A cyclodextrin–triphenylene derivative was also prepared lately and it showed interesting mesomorphic properties.[14]

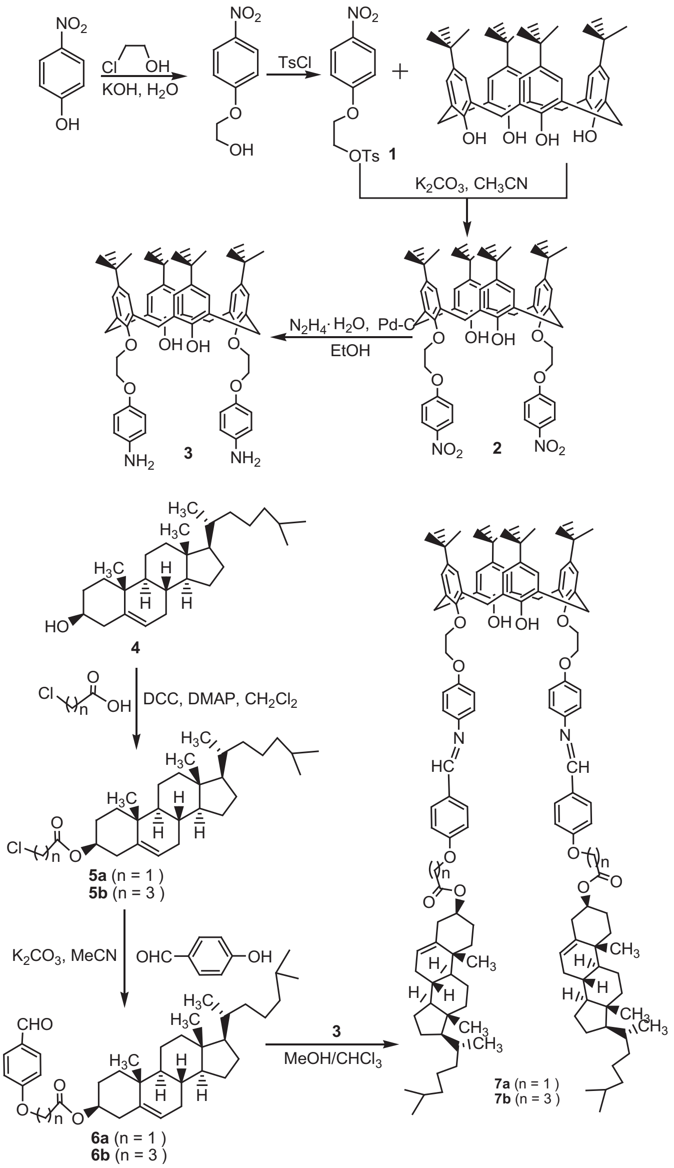
It was well known that, after crown ether and cyclodextrin, calixarenes were seen as the important supramolecular platforms to construct all kinds of calixarene derivatives with unique properties.[15–18] Two kinds of calixarene liquid crystals were also reported up to now.[18] One type of calixarene liquid crystal with bowl mesophase was synthesized by introducing long alkyl chains on calixarene skeleton.[19–25] Another type of calixarene liquid crystal was obtained by grafting the triphenylene units onto calixarene skeleton,[26–29] and they were columnar liquid crystals in most cases. These researches suggested that the complexation behavior of calixarene liquid crystals influenced greatly on the mesomorphic properties, such as the transformation or the disappearance of mesomorphic behavior after complexation. Lately, we synthesized the novel cholesterol–calixarene liquid crystal and found that their mesomorphic properties were influenced by the number of substituents and the structure of bridging chains, but no complexation behavior was concerned.[30] In the present study, two novel calix[4]arene–cholesterol derivatives with Schiff-base bridges were designed and synthesized. Moreover, the influences of complexation behaviors on the mesomorphic properties were investigated for the first time. The results implied that the liquid crystalline behaviors could be tuned by the ion complexation.

As the Schiff-base bond possesses good complexation abilities for soft metal cations, the calix[4]arene–cholesterol derivatives with Schiff-base bridges were designed as target molecules. The synthetic routes were illustrated in Scheme 1. According to the literature method,[31] compound **1** was synthesized by the etherification of paranitrophenol with chlorohydrins and following esterification with TsCl. Further, calix[4]arene-1,3-bis-nitro derivative **2** was prepared by treating compound **1** with calix[4]arene. Subsequently, compound **2** was deoxidized by hydrazine hydrate with Pd/C as catalyst and calix[4]arene-1,3-bis-amino derivative **3** was obtained in a yield of 72% after purification with column chromatography. On the other hand, by reacting cholesterol with 2-chloroacetic acid or 4-chlorobutanoic acid in CH_2Cl_2 using *N*,*N*′-dicyclohexylcarbodiimide (DCC) and 4-dimethylaminopyridine

---

[*] Corresponding author. Tel./fax: +86 591 83465225.
E-mail address: yangfafu@fjnu.edu.cn (F. Yang).

http://dx.doi.org/10.1016/j.tetlet.2016.01.047
0040-4039/



Scheme 1. synthetic routes of compounds **7a** and **7b**.

(DMAP) as catalysts, the cholesterol chlorinated derivatives **5a** and **5b** were synthesized in yields of 90% and 88%, respectively. By treating compounds **5a** or **5b** with *p*-hydroxybenzaldehyde in K_2CO_3/MeCN system, cholesterol derivatives **6a** and **6b** were prepared after recrystallization in $CHCl_3$/MeOH in yields of 80% and 75%, respectively. Finally, target compounds **7a** and **7b** were prepared by refluxing compound **3** and compound **6a** or **6b** in MeOH/$CHCl_3$ in '1 + 2' Schiff-base condensation mode. The yields of compounds **7a** and **7b** were as high as 74% and 77% after flash column chromatography, respectively.

The structures of all new compounds were confirmed by element analyses, ESI-MS spectra and NMR spectra. In the ESI-MS spectra, corresponding molecular ion peaks at 1980.6 and 2036.3 were observed for **7a** and **7b**, indicating the accomplishment of Schiff-base condensation. In their ^{1}H NMR spectra, two singlets (1:1) for the *tert*-butyl groups, one pair of doublets (1:1) for the methylene bridges and two singlets (1:1) for ArH suggested the cone conformation for calix[4]arene units. Only one peak for CH=N groups implied that they might be *trans*-structures based on the stabilities of molecules. Moreover, their ^{13}C NMR spectra exhibited corresponding signals for compounds **7a** and **7b**. For example, the peaks at 160–170 ppm and 60–77 ppm were assigned for C=O, C=N, OCH, and OCH_2, respectively. These data also supported the structures and conformations of compounds **7a** and **7b** again.

The liquid crystalline properties of compounds **7a** and **7b** were firstly studied by differential scanning calorimetry (DSC). The results were listed in Figure 1 and Table 1. Both compounds **7a** and **7b** exhibited two thermic peaks on second heating and cooling. For compound **7a**, two endothermic peaks at 77.4 °C and 117.7 °C were observed on second heating. Also, two exothermic peaks at 76.2 °C and 105.7 °C appeared on cooling. As for compound **7b**, the corresponding endothermic (or exothermic) peaks were at 75.6 (or 71.7) °C and 118.3 (or 102.9) °C upon heating (or cooling), respectively. Judging from the heats of fusion between corresponding crystallization and melting peaks, two phase transitions of solid state–mesophase and mesophase–isotropic phase could be deduced for the processes of cooling and heating of compounds **7a** and **7b**. These deductions were also further confirmed by polarizing optical microscopy (POM). The hysteresis behaviors observed for compounds **7a** and **7b** could be attributed to supercooling, which was a common phenomenon for such viscous materials. Comparing with the previous calix[4]arene–cholesterol liquid crystals with soft alkyl bridging chains,[30] compounds **7a** and **7b** showed higher phase transfer temperatures and smaller temperature scopes of mesophase. These phenomena could be ascribed to the influences of the rigid Schiff-base bridging chains on mesomorphic properties.

Furthermore, POM was used to investigate the mesophase textures of compounds **7a** and **7b** based on the DSC results. The two phase transitions of solid state–mesophase and mesophase–isotropic phases were clearly observed on heating and cooling. The phase transition temperatures were approximately in agreement with the temperatures of thermic peaks in DSC curves. The mesomorphic textures of compounds **7a** and **7b** at 90 °C are exhibited in Figure 2. It could be seen that the clear special textures were observed upon cooling for compounds **7a** and **7b**, respectively. These textures were the typical focal-conic columnar liquid crystals, which were further confirmed by X-ray diffraction (XRD) analysis.

Figure 3 showed the XRD traces of the mesomorphic states of compounds **7a** and **7b** at 90 °C. They exhibited similar peaks with a long range orientation ($2\theta = 2.7–3.0°$, sharp), and two short disordered orientations ($2\theta = 13–20°$, broad and $2\theta = 23°$, sharp). These XRD traces indicated the bowlic columnar liquid crystalline behaviors. The peaks at $2\theta = 2.83°$ and 2.93° suggested the distances of 31.19 Å and 30.13 Å, respectively. They were in accordance with

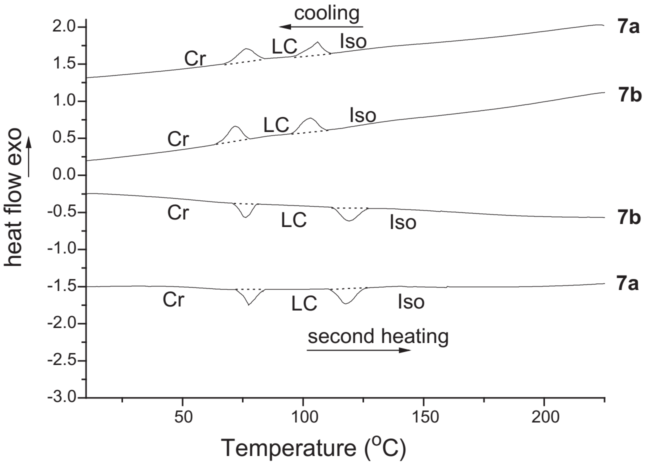


Figure 1. The DSC traces of compounds **7a** and **7b** on second heating and cooling (scan rate 8 °C min^{-1}).

Table 1
Transition temperatures (°C) and enthalpies (kJ mol^{-1}) of compounds **7a** and **7b**

Compd	Phase transition[a]	$T(\Delta H)$ heating scan	$T(\Delta H)$ cooling scan
7a	Cr–Col(Col–Cr)	77.4(12.23)	76.2(13.98)
	Col–Iso(Iso–Col)	117.7(13.89)	105.7(13.14)
7b	Cr–Col(Col–Cr)	75.6(11.45)	71.7(12.87)
	Col–Iso(Iso–Col)	118.3(14.07)	102.9(13.66)

[a] Cr = crystalline, Col = columnar phase, Iso = isotropic.

the diameters of compounds **7a** and **7b** approximately, implying the lattice constant arising from the columnar structures. The broad halos at 13–20° (4.4–6.8 Å) agreed to the average distances of columnar structures of the molten cholesterol units. The peaks at 23.4° (3.8 Å) and 24.3° (3.7 Å) were assigned to the intracolumnar order of calixarene units and Schiff-base structures, respectively. These XRD traces and analyses were in accordance with the previous calix[4]arene bowlic columnar liquid crystals with aliphatic chains.[26–30,32–36] Thus, the proposed columnar layered molecular arrangements were illustrated in Figure 4 (from a to b). However, the specific columnar structure (such as hexagonal or tetragonal columnar) was difficult to be deduced due to the absence of other distinct XRD peaks, which might suggest the mixed columnar phases with a low order among the liquid crystal columns.

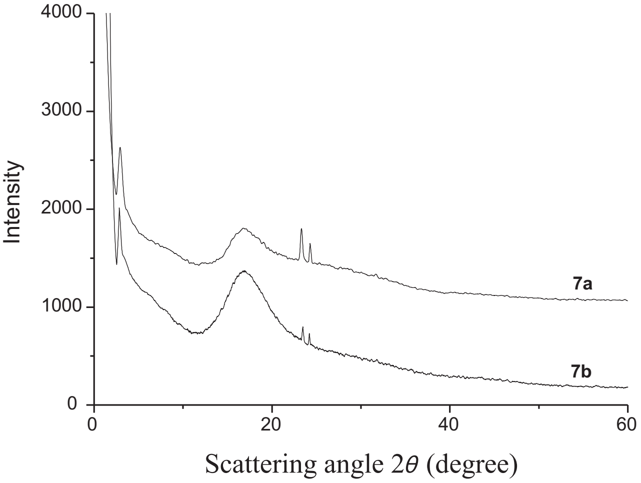


Figure 3. XRD traces of compounds **7a** and **7b** measured at 90 °C.

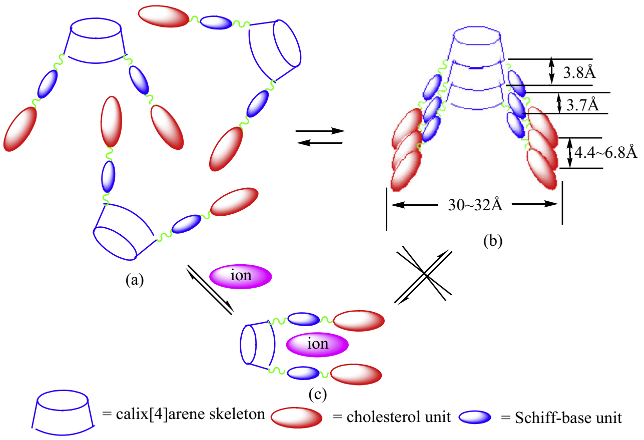


Figure 4. Schematic representation of the columnar layered molecular arrangements and the complexation models.

In order to investigate the influence of the complexation behaviors on the mesomorphic properties, the ionic complexes of **7a** and **7b** were prepared and their mesomorphic properties were studied. Considering the effective binding abilities of Schiff-base groups for soft metallic cations and the hydrogen-bonding action of OH groups for oxoanions, the complexes of **7a** and **7b** with $AgClO_4$ were prepared according to the procedure reported by Pedersen and modified by Laschat.[37,38] Typically, the $AgClO_4$ (2 equiv) in MeCN was added to the solution of compound **7a** or **7b** (1 equiv) in CH_2Cl_2. The resulting slurry was vigorously stirred overnight. Then the solvent was evaporated. The residue was taken up in boiling CH_2Cl_2 and the solution was filtered. The filtrate was concentrated and dried under vacuum to afford the respective complex in almost quantitative yields. The elemental analysis of complexes confirmed the 1:1 molar ratios of hosts/guests. The partial ^{1}H NMR spectrum of complex of **7a** with $AgClO_4$ was illustrated in Figure 5. The obvious shift was observed for OH, ArH, and CH=N groups, indicating that the weak interactions between Ag^+ and C=N groups, and the hydrogen bond between ClO_4^- and OH groups were responsible for the formation of the complex. The possible complex mode was proposed in Figure 5. After the two complexes were prepared, the mesomorphic properties of complexes were investigated by DSC and POM. The DSC results upon the second heating of the two complexes are exhibited in Figure 6. Only one peak of phase transition was observed in DSC curves. Due to the influence of the bulky organic groups, different orientation of cholesterol units (two cholesterol units in complexes were closer than that in neat compounds), and the weak interactions between hosts

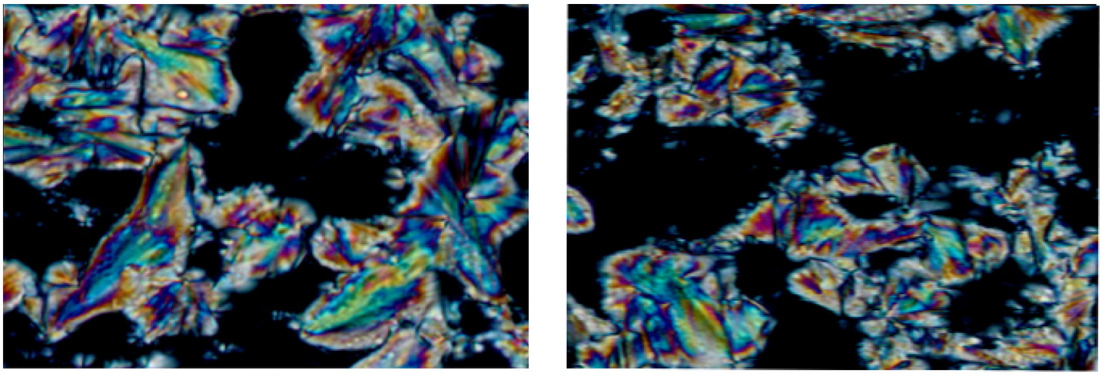

7a
7b

Figure 2. Mesomorphic textures of compounds **7a** and **7b** obtained under POM on cooling at 90 °C (×400).

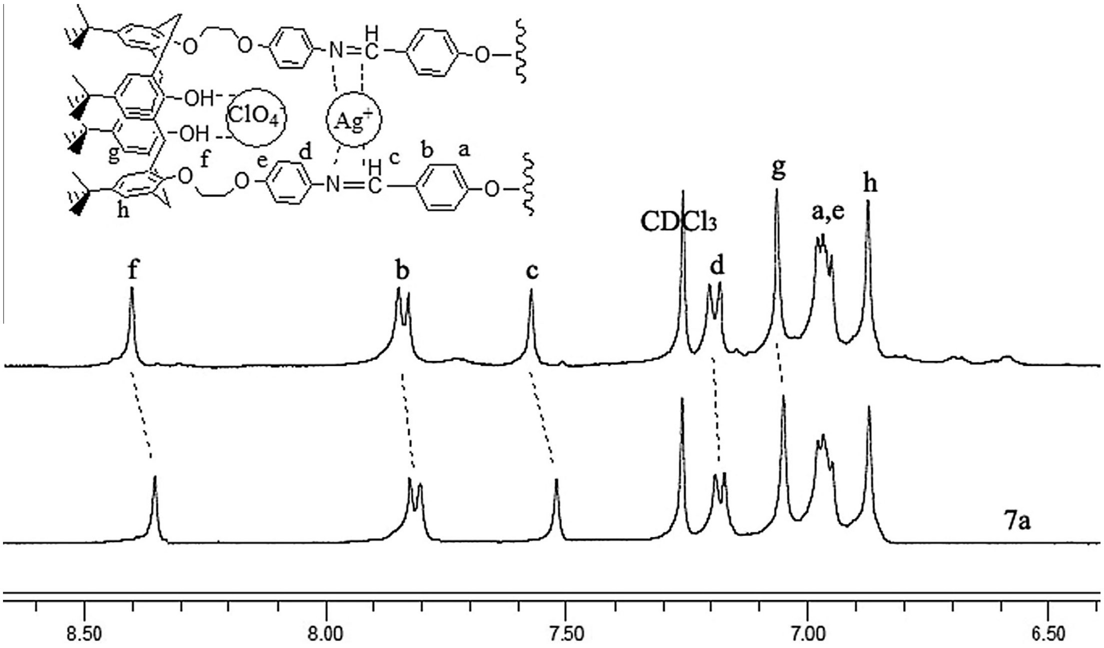


Figure 5. ^1H NMR spectra of triads **7a** and its 1:1 complex with $AgClO_4$.

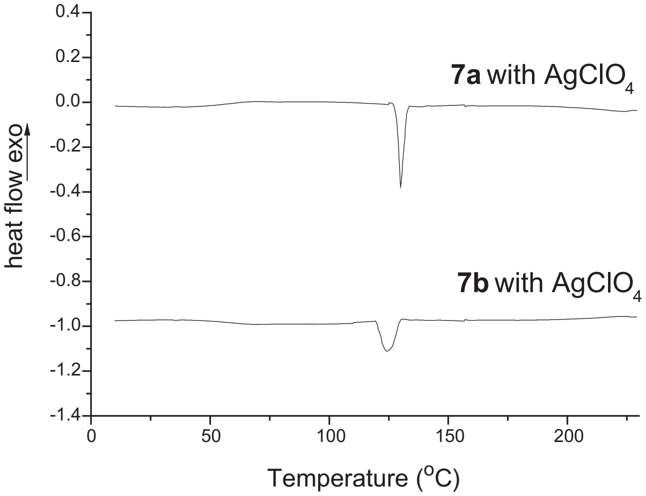


Figure 6. DSC traces of complexes **7a**(**7b**) with $AgClO_4$ on second heating (scan rate 10 °C min^{-1}).

and guests (the small shifts in ^1H NMR suggest the weak interaction), the melting points of complexes were only slight higher than that of neat compounds **7a** and **7b**. Moreover, under the POM observation, no mesophase was seen upon heating and cooling, although solid phase–isotropic phase transition could be observed. These results indicated that these complexes had no mesophase. The disappearance of the mesomorphic property after complexation might be explained by the fact that the binding of $AgClO_4$ not only enhanced the rigid structures based on the action between hosts and guests, but also produced the obstacle for columnar stacking of Schiff-base groups and cholesterol units as shown in Figure 4c. On the other hand, after the inorganic ions in complex **7a** were removed adequately by extraction with water, the neat compound **7a** could be obtained again. The ^1H NMR spectrum and phase transition temperatures in DSC curves were the same as that of initial compound **7a**. These results suggested the liquid crystal behavior could be reinstated after the removal of inorganic ions. We had tried to investigate more complexes with the other metal ions (K^+ and Hg^{2+}) or anion (NO_3^-), but no 1:1 complex was obtained and the structure of complex was difficult to be elucidated.

In conclusion, two calix[4]arene–cholesterol derivatives **7a** and **7b** with Schiff-base bridges were synthesized in yields of 70–80%. Their structures and conformation were characterized by NMR, MS, and elemental analysis. Their mesomorphic behaviors were studied by DSC, POM, and XRD. They possess mesomorphic properties with the molecular arrangement of the calixarene bowlic column and Schiff-based cholesterol units as ancillary lateral columns. The complexes of **7a** and **7b** with $AgClO_4$ were prepared and exhibit no mesophase. These results implied that the mesomorphic properties of compounds **7a** and **7b** could be tuned by the complexation behaviors of compounds **7a** and **7b**. The studies on the complexation properties for other organic guests and their influences on mesomorphic properties will be investigated in the following work.

Acknowledgments

Financial support from the National Natural Science Foundation of China (No: 21406036), Fujian Natural Science Foundation of China (No. 2014J01034), Fujian Province Science and Technology Key Project (2014N0025) and the Program for Innovative Research Team in Science and Technology in Fujian Province University were greatly acknowledged.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tetlet.2016.01.047.

References and notes

1. Sergeyev, S.; Pisula, W.; Geerts, Y. H. *Chem. Soc. Rev.* **2007**, *36*, 1902–1929.
2. Laschat, S.; Baro, A.; Steinke, N.; Giesselmann, F.; Hagele, C.; Scalia, G.; Judele, R.; Kapatsina, E.; Sauer, S.; Schreivogel, A.; Tosoni, M. *Angew. Chem., Int. Ed.* **2007**, *46*, 4832–4887.

3. Kato, T.; Mizoshita, N.; Kishimoto, K. *Angew. Chem., Int. Ed.* **2006**, *45*, 38–68; Kumar, S. *Chem. Soc. Rev.* **2006**, *35*, 83–109.
4. Yelamaggad, C. V.; Shanker, G.; Hiremath, U. S.; Prasad, S. K. *J. Mater. Chem.* **2008**, *18*, 2927–2949.
5. Li, J.; He, Z.; Gopee, H.; Cammidge, A. N. *Org. Lett.* **2010**, *12*, 472–475.
6. Zhang, L.; Gopee, H.; Hughes, D.; Cammidge, A. N. *Chem. Commun.* **2010**, 4255–4257.
7. Kaller, M.; Deck, C.; Meister, A.; Hause, G.; Baro, A.; Laschat, S. *Chem. Eur. J.* **2010**, *16*, 6326–6337.
8. Steinke, N.; Frey, W.; Baro, A.; Laschat, S.; Drees, C.; Nimtz, M.; Hägele, C.; Giesselmann, F. *Chem. Eur. J.* **2006**, *12*, 1026–1035.
9. Kaller, M.; Staffeld, P.; Haug, R.; Frey, W.; Giesselmann, F.; Laschat, S. *Liq. Cryst.* **2011**, *38*, 531–553.
10. Kaller, M.; Tussetschläger, S.; Fischer, P.; Deck, C.; Baro, A.; Giesselmann, F.; Laschat, S. *Chem. Eur. J.* **2009**, *15*, 9530–9542.
11. Steinke, N.; Jahr, M.; Lehmann, M.; Baro, A.; Frey, W.; Tussetschläger, S.; Sauer, S.; Laschat, S. *J. Mater. Chem.* **2009**, *19*, 645–654.
12. Steinke, N.; Kaller, M.; Nimtz, M.; Baro, A.; Laschat, S. *Liq. Cryst.* **2010**, *37*, 1139–1149.
13. Wang, D.; Hsu, J. F.; Bagui, M.; Dusevich, V.; Wang, Y.; liu, Y.; Holder, A.; Peng, Z. *Tetrahedron Lett.* **2009**, *50*, 2147–2149.
14. Yang, F. F.; Zhang, Y. M.; Guo, H. Y.; Bai, X. Y. *New J. Chem.* **2013**, *37*, 2275–2279.
15. Casnati, A.; Sansone, F.; Ungaro, R. *Calixarene Receptors in Ion Recognition and Sensing, in Advances in Supramolecular Chemistry*; Cerberus Press: South Miami, FL, 2004.
16. Lhoták, P. *Anion Receptors Based on Calixarenes, in Anion Sensing in Topics in Current Chemistry*; Springer: Berlin, 2005.
17. Yakovenko, A. V.; Boyko, V. I.; Kalchenko, V. I.; Baldini, L.; Casnati, A.; Sansone, F.; Ungaro, R. *J. Org. Chem.* **2007**, *72*, 3223–3231.
18. Yang, F. F.; Guo, H. Y.; Vicens, J. *J. Incl. Phenom. Macrocycl. Chem.* **2014**, *80*, 177–186.
19. Kohmoto, S.; Someya, Y.; Masu, H.; Yamaguchi, K.; Kishikawa, K. *J. Org. Chem.* **2006**, *71*, 4509–4515.
20. Cometti, G.; Dalcanale, E.; Vosel, A. D.; Levelut, A. M. *J. Chem. Soc., Chem. Commun.* **1990**, 163–165.
21. Bonsignore, S.; Cometti, G.; Dalcanale, E.; Vosel, A. D. *Liq. Cryst.* **1990**, *8*, 639–649.
22. Lo, P. K.; Chen, D.; Meng, Q.; Wong, M. S. *Chem. Mater.* **2006**, *18*, 3924–3930.
23. Budig, H.; Diele, S.; Paschke, R.; Ströhl, D.; Tschierske, C. *J. Chem. Soc., Perkin Trans. 2* **1996**, 1901–1906.
24. Koh, K. N.; Araki, K.; Komori, T.; Shinkai, S. *Tetrahedron Lett.* **1995**, *36*, 5191–5194.
25. Fang, X. T.; Guo, H. Y.; Yang, F. F.; Wu, Y. M. *Tetrahedron Lett.* **2015**, *56*, 6128–6131.
26. Yang, F. F.; Guo, H. Y.; Xie, J. W.; Lin, J. R. *Eur. J. Org. Chem.* **2011**, *26*, 5141–5145.
27. Yang, F. F.; Xu, B. T.; Guo, H. Y.; Xie, J. W. *Tetrahedron Lett.* **2012**, *53*, 1598–1602.
28. Yang, F. F.; Bai, X. Y.; Guo, H. Y.; Li, C. C. *Tetrahedron Lett.* **2013**, *54*, 409–413.
29. Hong, B. Q.; Yang, F. F.; Guo, H. Y.; Jiao, Z. Y. *Tetrahedron Lett.* **2014**, *55*, 252–255.
30. Guo, H. Y.; Yang, F. F.; Liu, W. W.; Lai, J. B. *Tetrahedron Lett.* **2015**, *56*, 866–870.
31. Jin, C. M.; Lu, G. Y.; Liu, Y.; You, X. Z.; Wang, Z. H.; Wu, H. M. *Chin. J. Chem.* **2002**, *20*, 1080–1085.
32. Yonetake, K.; Nakayama, T.; Ueda, M. *J. Mater. Chem.* **2001**, *11*, 761–767.
33. Komori, T.; Shinkai, S. *Chem. Lett.* **1993**, *8*, 1455–1458.
34. Xu, B.; Swager, T. M. *J. Am. Chem. Soc.* **1993**, *115*, 1159–1160.
35. Xu, B.; Swager, T. M. *J. Am. Chem. Soc.* **1995**, *117*, 5011–5012.
36. Patel, R. V.; Panchal, J. G.; Rana, V. A.; Menon, S. K. *J. Incl. Phenom. Macrocycl. Chem.* **2010**, *66*, 285–295.
37. Pedersen, C. J. *J. Am. Chem. Soc.* **1967**, *89*, 7017–7036.
38. Kaller, M.; Tussetschl ger, S.; Fischer, P.; Deck, C.; Baro, A.; Giesselmann, F.; Laschat, S. *Chem. Eur. J.* **2009**, *15*, 9530–9542.