Tetrahedron Letters 51 (2010) 3286–3289

Contents lists available at ScienceDirect

Tetrahedron Letters

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

New fluorescent and colorimetric chemosensors based on the rhodamine and boronic acid groups for the detection of Hg^{2+}

Sook Kyung Kim[a,†], K. M. K. Swamy[a,b,†], So-Young Chung[a], Ha Na Kim[a], Min Jung Kim[a], Yongsuk Jeong[c], Juyoung Yoon[a,c,*]

[a] *Department of Chemistry and Nano Science BK21, Ewha Womans University, Seoul 120-750, Republic of Korea*
[b] *Department of Pharmaceutical Chemistry, V. L. College of Pharmacy, Raichur 584 103, India*
[c] *Department of Bioinspired Science, Ewha Womans University, Seoul 120-750, Republic of Korea*

ARTICLE INFO

Article history:
Received 25 February 2010
Revised 9 April 2010
Accepted 16 April 2010
Available online 20 April 2010

ABSTRACT

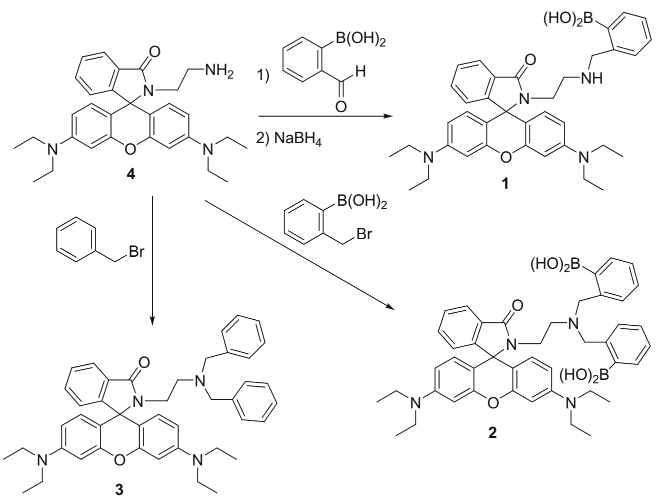
Novel rhodamine B (RB) derivatives bearing mono and bis-boronic acid groups were investigated as Hg^{2+} selective fluorescent and colorimetric sensors. These derivatives are first examples of reversible fluorescent chemosensors for Hg^{2+} which utilized boronic acid groups as binding sites. Two new RB-boronic acid derivatives displayed selective '*Off–On*'-type fluorescent enhancements and distinct color changes with Hg^{2+}. Selective fluorescent enhancement of two rhodamine derivatives was attributed to ring opening from the spirolactam (nonfluorescent) to ring-opened amide (fluorescent).

Sensors based on the ion-induced changes in fluorescence have been actively investigated due to the simplicity and high detection limit of the fluorescence.[1] Inorganic mercury is one of the most prevalent toxic metals in the environment, and gains access to the body orally or dermally. When absorbed in the human body, these species result in damage to the brain, kidneys, and endocrine system.[2] Due to the high toxicity of mercury, considerable attention has been devoted to the development of new fluorescent chemosensors for the detection of mercury and mercuric salts with sufficient selectivity.[3,4]

Boronic acids are known to have high affinities for substances that contain vicinal diol groups (e.g., carbohydrates) and, consequently, they have been used in novel boronic acid-based fluorescent chemosensors for carbohydrates.[5] Recently, boronic acid derivatives have been also utilized as sensors for fluoride[6] or cyanide ions.[7] However, only one example is available for the use of boronic acid-based fluorescent chemosensor to detect metal ion (Cu^{2+}) directly.[8]

Herein, we report two new rhodamine derivatives bearing mono and bis-boronic acid groups (**1** and **2**) as selective fluorescent and colorimetric sensors for Hg^{2+}, in which spirolactam (nonfluorescent) to ring-opened amide (fluorescent) process[9] was utilized for the detection of Hg^{2+}. Even though various rhodamine derivatives have been reported as fluorescent chemosensors or chemodosimeters,[9] no precedents existed for the use of boronic acid-based rhodamine to detect Hg^{2+} directly.

For the syntheses of rhodamine-boronic acid derivatives, first of all, rhodamine ethylamine **4** was prepared following the reported procedure.[4g] Intermediate **4** was then reacted with 2-formylphenylboronic acid in ethanol, which was refluxed for 6 h. The imine intermediate was further reacted with $NaBH_4$ to give **1**[10] (41%) as pink solid after the silica column chromatography using CH_2Cl_2–MeOH (95:5, v/v) as eluent (Scheme 1). On the other hand, bis-boronic acid derivative **2**[11] was prepared in 37% yield by treat-



Scheme 1. Synthesis of compounds **1–3**.

---

[*] Corresponding author. Tel.: +82 2 3277 2400; fax: +82 2 3277 2384.
E-mail address: jyoon@ewha.ac.kr (J. Yoon).

[†] Contributed equally to this work.

0040-4039/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2010.04.067

ment of **4** with 2-bromomethylphenylboronic acid followed by silica column chromatography using CH_2Cl_2–MeOH (96:4, v/v) as eluent (Scheme 1). The control compound **3**[12] was prepared following the similar procedure using benzyl bromide in 54% yield. These new compounds were fully characterized by NMR and high resolution FAB mass spectroscopy. The ^1H NMR, ^{13}C NMR spectra are explained in Supplementary data.

The perchlorate salts of Ag^+, Ca^{2+}, Cd^{2+}, Co^{2+}, Cs^+, Cu^{2+}, Hg^{2+}, K^+, Li^+, Mg^{2+}, Mn^{2+}, Na^+, Ni^{2+}, Sr^{2+}, and Zn^{2+} ions were used to evaluate the metal ion binding properties of compounds **1** and **2** (3 μM) in CH_3CN–water (9:1, v/v). The fluorescence spectra were obtained by excitation of the rhodamine fluorophore at 510 nm. Among these metal ions (50 equiv), both of these probes showed large fluorescence enhancements only with Hg^{2+} (Figs. 1 and 2) even though there were relatively smaller fluorescence enhancements with Cu^{2+}. Upon the addition of Hg^{2+} to a colorless solution of compound **1** or **2**, both a red color and the fluorescence characteristics of rhodamine B appear. Due to the weakening of both upon the addition of excess EDTA (Supplementary Fig. 9) to the solution of **2** and Hg^{2+}, it is believed that this process is reversible. The large fluorescence enhancement as well as the colorimetric change can be attributed to the spirolactam ring opening, which was induced by the complexation of Hg^{2+}. The time-dependent fluorescence responses of probe **2** (3 μM) to Hg^{2+} (50 equiv) were monitored at 580 nm under pseudo-first-order kinetic conditions (Supplementary Fig. 8). Under these conditions, the observed rate constants (k_{obs}) at CH_3CN were found to be 0.01733 min^{-1} for Hg^{2+}. The fluorescence emissions were obtained after 30 min after the addition of metal ions.

Figures 3 and 4 explain the fluorescent titrations of **1** and **2** with Hg^{2+} in CH_3CN–water (9:1, v/v). The association constants of **1** and **2** with Hg^{2+} were calculated as 3.3×10^3 M^{-1} and 2.1×10^4 M^{-1} (error <15%).[13] The 1:1 stoichiometry was also confirmed by the Job plots as shown in the Supplementary data. Bis-boronic probe **2** displayed as high as ninefold tighter binding with Hg^{2+} compared to mono-boronic probe **1**, which can be attributed to an additional boronic acid ligand in the case of **2**. On the other hand, compound **3**, which does not contain any boronic acid group, did not show large fluorescent changes with metal ions even though there was a very small enhancement with Cu^{2+} (Fig. 5). This observation along with larger binding constant of **2** suggests that boronic acid moiety plays an important role in the binding with Hg^{2+}. The carbonyl oxygen as well as oxygens of boronic acid groups can make a nice binding pocket for the Hg^{2+}.

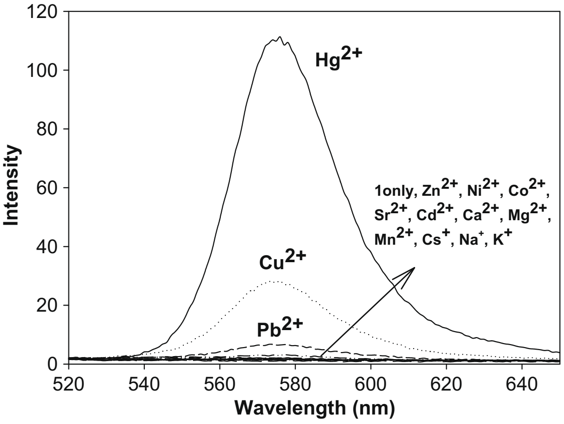


Figure 1. Fluorescent changes of **1** (3 μM) with various metal ions (150 μM) in CH_3CN–H_2O (9:1, v/v) (λ_{ex} = 510 nm, Slit: 3 nm/5 nm).

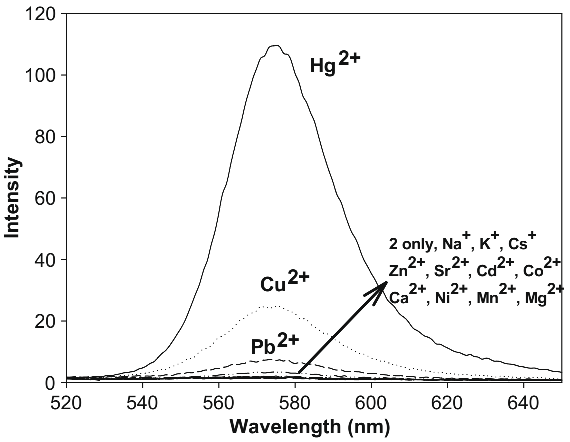


Figure 2. Fluorescent changes of **2** (3 μM) with various metal ions (150 μM) in CH_3CN–DDW (9:1, v/v) (λ_{ex} = 510 nm, Slit: 3 nm/3 nm).

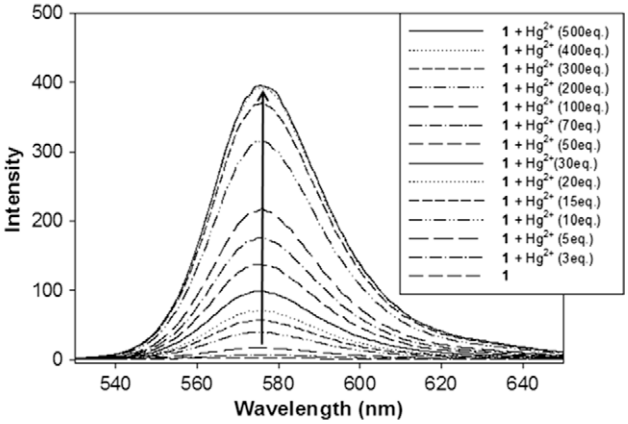


Figure 3. Fluorescent titrations of **1** (3 μM) with Hg^{2+} in CH_3CN–H_2O (9:1, v/v) (λ_{ex} = 510 nm, Slit: 3 nm/5 nm).

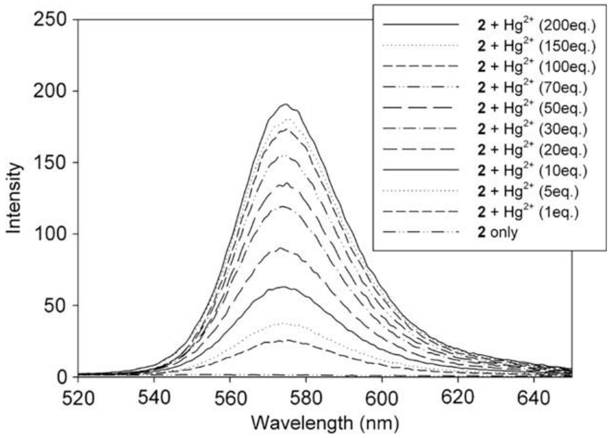


Figure 4. Fluorescent titrations of **2** (3 μM) with Hg^{2+} in CH_3CN–H_2O (9:1, v/v) (λ_{ex} = 510 nm, Slit: 3 nm/3 nm).

For probe **2**, the fluorescent changes were examined in 100% CH_3CN and CH_3CN–HEPES buffer (pH 7.4, 0.01 M) (9:1, v/v) too. In 100% CH_3CN, only Hg^{2+} induced large fluorescence enhancement even though there were small fluorescent changes with Cu^{2+}, Pb^{2+}, and Zn^{2+} (Supplementary Fig. 8). From the fluorescent titration experiments with Hg^{2+}, the association constant was calculated as 9.8×10^4 M^{-1} (error <15%).[13] Possibly, the binding of **2** with Hg^{2+} can compete with that of water with Hg^{2+}. Indeed, most

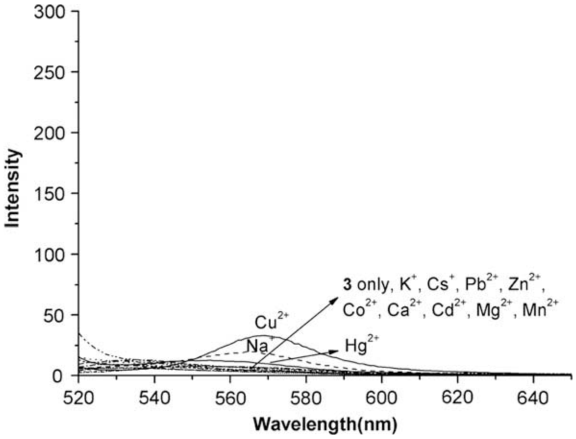


Figure 5. Fluorescent changes of **3** (3 μM) with various metal ions (150 μM) in CH_3CN–DDW (9:1, v/v) (λ_{ex} = 510 nm, Slit: 3 nm/5 nm).

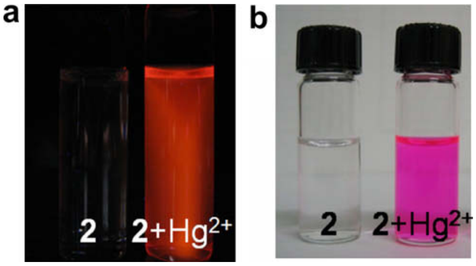


Figure 6. Fluorescent changes (a) and colorimetric changes (b) of **2** (30 μM) with Hg^{2+} (50 equiv) in CH_3CN.

precedent rhodamine-based sensors bearing amide-linked binding sites were studied in 100% organic solvent system or in the presence of small amount of aqueous system if they are reversible probes.[9] The UV absorption changes of **2** with Hg^{2+} in CH_3CN are also explained in the Supplementary data. On the other hand, in the presence of buffer (pH 7.4) solution the selectivity for Hg^{2+} was enhanced dramatically (Supplementary Fig. 11). However, the fluorescent enhancement process in this solvent system [CH_3CN–HEPES buffer (pH 7.4, 0.01 M) (9:1, v/v)] was also substantially slowed down. The pH dependence of probe **2** was checked (Supplementary Fig. 12) and the pK_a of this probe was calculated as around 2.4, which means that this probe has relatively a large pH window between pH 6–9. Finally Figure 6 shows the fluorescent change and colorimetric change of **2** with Hg^{2+} in CH_3CN. The addition of Hg^{2+} induced a selective '*Off–On*' fluorescent change and distinct color change from colorless to dark pink.

In conclusion, rhodamine-boronic acid derivatives **1** and **2** were synthesized as selective fluorescent and colorimetric sensors for Hg^{2+} in aqueous solution. '*Off–On*'-type fluorescent and colorimetric changes were observed for Hg^{2+}, in which the spirolactam (nonfluorescent) to ring-opened amide (fluorescent) process was utilized. Most importantly, boronic acid group was utilized as a binding unit for the Hg^{2+} selective fluorescent chemosensor for the first time. The present study successfully demonstrated that boronic acid group can serve as a unique and novel ligand for the recognition of metal ions, which will be utilized for various receptors in the future.

Acknowledgments

This work was supported by the Basic Science Research Program (20090083065) through the National Research Foundation of Korea (NRF) and the Converging Research Center Program through NRF funded by the Ministry of Education, Science and Technology (2009-0093677). Mass spectral data were obtained from the Korea Basic Science Institute (Daegu) on a Jeol JMS 700 high resolution mass spectrometer.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2010.04.067.

References and notes

1. (a) Czarnik, A. W. *Acc. Chem. Res.* **1994**, *27*, 302; (b) de Silva, A. P.; Gunaratne, H. Q. N.; Gunnlaugsson, T. A.; Huxley, T. M.; McCoy, C. P.; Rademacher, J. T.; Rice, T. E. *Chem. Rev.* **1997**, *97*, 1515; (c) Kim, S. K.; Lee, D. H.; Hong, J.-I.; Yoon, J. *Acc. Chem. Res.* **2009**, *42*, 23; (d) Kim, J. S.; Quang, D. T. *Chem. Rev.* **2007**, *107*, 3780; (e) Xu, Z.; Chen, X.; Kim, H. N.; Yoon, J. *Chem. Soc. Rev.* **2010**, *39*, 127; (f) Kim, S. K.; Kim, H. N.; Zhu, X.; Lee, H. N.; Lee, H. N.; Soh, J. H.; Swamy, K. M. K.; Yoon, J. *Supramol. Chem.* **2007**, *19*, 221; (g) Chen, X.; Kang, S.; Kim, M. J.; Kim, J.; Kim, Y. S.; Kim, H.; Chi, B.; Kim, S.-J.; Lee, J. Y.; Yoon, J. *Angew. Chem., Int. Ed.* **2010**, *49*, 1422; (h) Lee, C.-H.; Miyaji, H.; Yoon, D.-W.; Sessler, J. L. *Chem. Commun.* **2008**, 24.
2. (a) ATSDR, Toxicological Profile for Mercury, U.S. Department of Health and Human Services, Atlanta, GA, 1999.; (b) Harada, M. *Crit. Rev. Toxicol.* **1995**, *25*, 1.
3. Nolan, E. M.; Lippard, S. J. *Chem. Rev.* **2008**, *108*, 3443.
4. (a) Kwon, J. Y.; Soh, J. H.; Yoon, Y. J.; Yoon, J. *Supramol. Chem.* **2004**, *16*, 621; (b) Yang, Y.-K.; Yook, K.-J.; Tae, J. *J. Am. Chem. Soc.* **2005**, *127*, 16760; (c) Liu, B.; Tian, H. *Chem. Commun.* **2005**, 3156; (d) Ros-Lis, J.; Marcos, M. D.; Martínez-Máñez, R.; Rurack, K.; Soto, J. *Angew. Chem., Int. Ed.* **2005**, *44*, 4405; (e) Zheng, H.; Qian, Z.-H.; Xu, L.; Yuan, F.-F.; Lan, L.-D.; Xu, J.-G. *Org. Lett.* **2006**, *8*, 859; (f) Lee, Y. J.; Seo, D.; Kwon, J. Y.; Son, G.; Park, M. S.; Choi, Y.-H.; Soh, J. H.; Lee, H. N.; Lee, K. D.; Yoon, J. *Tetrahedron* **2006**, *62*, 12340; (g) Wu, D.; Huang, W.; Daun, C.; Lin, Z.; Meng, Q. *Inorg. Chem.* **2007**, *46*, 1538; (h) Lee, M. H.; Cho, B.-K.; Yoon, J.; Kim, J. S. *Org. Lett.* **2007**, *9*, 4515; (i) Yang, H.; Zhou, Z.; Huang, K.; Yu, M.; Li, F.; Yi, T.; Huang, C. *Org. Lett.* **2007**, *9*, 4729; (j) Soh, J. H.; Swamy, K. M. K.; Kim, S. K.; Kim, S.; Lee, S.-H.; Yoon, J. *Tetrahedron Lett.* **2007**, *48*, 5966; (k) Chen, X.; Nam, S.-W.; Jou, M. J.; Kim, Y.; Kim, S.-J.; Park, S.; Yoon, J. *Org. Lett.* **2008**, *10*, 5235; (l) Lee, M. H.; Lee, S. W.; Kim, S. H.; Kang, C.; Kim, J. S. *Org. Lett.* **2009**, *11*, 2101; (m) Choi, M. G.; Kim, Y. H.; Namgoong, J. E.; Chang, S.-K. *Chem. Commun.* **2009**, 3560; (n) Santra, M.; Ryu, D.; Chatterjee, A.; Ko, S.-K.; Shin, I.; Ahn, K. H. *Chem. Commun.* **2009**, 2115; (o) Zhang, X.; Xiao, Y.; Qian, X. *Angew. Chem., Int. Ed.* **2008**, *47*, 8025; (p) Coskun, A.; Akkaya, E. U. *J. Am. Chem. Soc.* **2006**, *128*, 14474; (q) Kwon, S. K.; Kim, H. N.; Rho, J. H.; Swamy, K. M. K.; Shanthakumar, S. M.; Yoon, J. *Bull. Korean Chem. Soc.* **2009**, *30*, 719.
5. (a) Cao, H.; Heagy, M. D. *J. Fluoresc.* **2004**, *14*, 569. and reference therein; (b) Yoon, J.; Czarnik, A. W. *J. Am. Chem. Soc.* **1992**, *114*, 5874; (c) Zhao, J.; Davidson, M. G.; Mahon, M. F.; Kociok-Köhn, G.; James, T. D. *J. Am Chem. Soc.* **2004**, *126*, 16179; (d) Swamy, K. M. K.; Jang, Y. J.; Park, M. S.; Koh, H. S.; Lee, S. K.; Yoon, Y. J.; Yoon, J. *Tetrahedron Lett.* **2005**, *46*, 3453; (e) Jang, Y. J.; Jun, J. H.; Swamy, K. M. K.; Nakamura, K.; Koh, H. S.; Yoon, Y. J.; Yoon, J. *Bull. Korean Chem. Soc.* **2005**, *26*, 2041; (f) Zhang, X.; Chi, L.; Ji, S.; Wu, Y.; Song, P.; Han, K.; Guo, H.; James, T. D.; Zhao, J. *J. Am. Chem. Soc.* **2009**, *131*, 17452.
6. (a) Kubo, Y.; Ishida, T.; Minami, T.; James, T. D. *Chem. Lett.* **2006**, *35*, 996; (b) Swamy, K. M. K.; Lee, Y. J.; Lee, H. N.; Chun, J.; Kim, Y.; Kim, S.-J.; Yoon, J. *J. Org. Chem.* **2006**, *71*, 8626; (c) Xu, Z.; Kim, S. K.; Han, S. J.; Lee, C.; Kociok-Kohn, G.; James, T. D.; Yoon, J. *Eur. J. Org. Chem.* **2009**, 3058.
7. (a) Xu, Z.; Chen, X.; Kim, H. N.; Yoon, J. *Chem. Soc. Rev.* **2010**, *39*, 127. and reference therein; (b) Swamy, K. M. K.; Ko, S.-K.; Kwon, S. K.; Lee, H. N.; Mao, C.; Kim, J.-M.; Lee, K.-H.; Kim, J.; Shin, I.; Yoon, J. *Chem. Commun.* **2008**, 5915; (c) Xu, Z.; Pan, J.; Spring, D. R.; Cui, J.; Yoon, J. *Tetrahedron* **2010**, *66*, 1678.
8. Swamy, K. W. K.; Ko, S.-K.; Kwon, S.; Lee, H.; Mao, C.; Kim, J.-M.; Lee, K.-H.; Kim, J.; Shin, I.; Yoon, J. *Chem. Commun.* **2008**, 5915.
9. (a) Kim, H.; Lee, M.; Kim, H.; Kim, J. S.; Yoon, J. *Chem. Soc. Rev.* **2008**, *37*, 1465. and references therein; (b) Kwon, J. Y.; Jang, Y. J.; Lee, Y. J.; Kim, K.-M.; Seo, M.-S.; Nam, W.; Yoon, J. *J. Am. Chem. Soc.* **2005**, *127*, 10107; (c) Li, H.; Fan, J.; Wang, J.; Tian, M.; Du, J.; Sun, S.; Sun, P.; Peng, X. *Chem. Commun.* **2009**, 5904; (d) Jou, M. J.; Chen, X.; Swamy, K. M. K.; Kim, H. N.; Kim, H.-J.; Lee, S.-g.; Yoon, J. *Chem. Commun.* **2009**, 7218; (e) Shiraishi, Y.; Sumiya, S.; Kohno, Y.; Hirai, T. *J. Org. Chem.* **2008**, *73*, 8571; (f) Kou, S.; Lee, H. N.; Noort, D. v.; Swamy, K. M. K.; Kim, S. H.; Soh, J. H.; Lee, K.-M.; Nam, S.-W.; Yoon, J.; Park, S. *Angew. Chem., Int. Ed.* **2008**, *47*, 872; (g) Chen, X.; Jou, M. J.; Lee, H.; Kou, S.; Lim, J.; Nam, S.-W.; Park, S.; Kim, K.-M.; Yoon, J. *Sens. Actuators, B: Chem.* **2009**, *137*, 597.
10. *Monoboronic acid-RB* (***1***): Rhodamine ethylamine (**4**) (0.2 g, 0.4 mmol) was dissolved in 20 mL of absolute ethanol. After 2-formylphenylboronic acid (0.093 g, 0.62 mmol) was added, the reaction mixture was refluxed in an air bath for 6 h. Then, the solution was cooled and concentrated to 10 mL and allowed to stand at room temperature overnight. Ethanol was evaporated completely under reduced pressure. The imine intermediate was dissolved in 10 mL of absolute methanol. Sodium borohydride was then added slowly with stirring at room temperature for 4 h. The resulting solution was extracted with methylene chloride (3 × 100 mL), washed the organic layer with 50 mL of

water, dried on Na_2SO_4, and evaporated the solvents to get the crude product. Purification by silica column chromatography (CH_2Cl_2–MeOH = 95:5, v/v) afforded 0.10 g of **1** (41%) as pink solid. Mp: 152 °C; ^{1}H NMR ($CDCl_3$+MeOD three drops, 250 MHz) δ 7.78 (m, 1H), 7.42 (m, 2H), 7.27 (m, 1H), 7.12 (m, 2H), 7.05 (m, 1H), 6.95 (m, 1H), 6.37 (s, 1H), 6.33 (s, 1H), 6.30, (d, 2H, J = 2.5 Hz), 6.21 (dd, 2H, J = 8.9 Hz & 2.5 Hz), 3.33 (m, 12H), 2.73 (t, 2H, J = 6.4 Hz), 1.08 (t, 12H, J = 6.9 Hz); ^{13}C NMR ($CDCl_3$+MeOD three drops, 62.5 MHz) δ 170.0, 153.5, 153.3, 149.0, 133.2, 130.2, 128.5, 128.3, 127.3, 126.7, 124.1, 122.8, 108.4, 104.1, 97.7, 66.1, 54.5, 44.3, 38.5, 12.6; HRMS (FAB) m/z = 619.3377 $(M+H)^+$, calcd for $C_{37}H_{44}BN_4O_4$ = 619.3373.

11. *Bis-boronic acid-RB (**2**)*: Procedure A. To a 250 mL flask, rhodamine ethylamine (**4**) (0.3 g, 0.62 mmol) was dissolved in 30 mL of anhydrous chloroform. 0.86 g (6.2 mmol) of anhydrous potassium carbonate was added followed with 0.4 g, (1.86 mmol) 2-bromomethylphenylboronic acid. The reaction mixture was stirred at room temperature until the disappearance of amine. Solvent was evaporated and purified the crude product on column (silica; CH_2Cl_2–MeOH = 96:4, v/v) to give 0.17 g of **2** (37%) as pink solid. Mp: 168 °C; ^{1}H NMR ($CDCl_3$+MeOD three drops, 250 MHz) δ 7.83 (m, 1H), 7.43 (m, 2H), 7.04 (m, 5H), 6.82 (m, 2H), 6.31 (s, 1H), 6.28 (s, 1H), 6.26, (d, 2H, J = 2.3 Hz), 6.20 (dd, 2H, J = 8.8 Hz & 2.5 Hz), 3.49 (m, 2H), 3.41 (s, 4H), 3.34 (s, 4H), 3.31 (q, 8H, J = 7.0 Hz), 2.65 (t, 2H, J = 6.4 Hz), 1.10 (t, 12H, J = 7.0 Hz); ^{13}C NMR ($CDCl_3$) δ 168.4, 153.4, 149.0, 138.4, 132.9, 130.8, 128.7, 128.5, 127.4, 124.1, 123.0, 108.2, 104.8, 97.8, 65.4, 61.4, 44.4, 34.9, 12.6; HRMS (FAB) m/z = 753.3916 $(M+H)^+$, calcd for $C_{44}H_{51}BN_4O_6$ = 753.3919.
12. *Bisphenyl-RB (**3**)*: Application of procedure A to rhodamine ethylamine (0.13 g, 0.27 mmol) and benzyl bromide (0.092 g, 0.54 mmol) gave 0.075 g of **3** (54%) as a light pink semi-solid after purification of the crude product on column (silica; CH_2Cl_2–MeOH; 96:4). Mp: 168 °C; ^{1}H NMR ($CDCl_3$, 250 MHz) δ 7.87 (m, 1H), 7.41 (m, 2H), 7.21 (m, 4H), 7.16 (m, 4H), 7.17 (m, 1H), 7.05 (m, 1H), 6.40 (s, 1H), 6.37 (s, 1H), 6.31 (d, 2H), 6.21 (dd, 2H, J = 8.8 Hz & 2.5 Hz), 3.44 (s, 4H), 3.35 (t, 2H), 3.30 (q, 8H), 2.31 (m, 2H), 1.17 (t, 12H, J = 7.0 Hz); ^{13}C NMR ($CDCl_3$, 62.5 MHz) δ 167.8, 153.6, 153.2, 148.6, 139.3, 132.2, 131.4, 128.9, 128.0, 127.9, 126.6, 123.7, 122.6, 107.9, 105.6, 97.7, 64.8, 57.4, 51.4, 44.3, 38.1, 12.6; HRMS (FAB) m/z = 665.3856 $(M+H)^+$, calcd for $C_{44}H_{51}BN_4O_6$ = 665.3856.
13. (a) Association constants were obtained using the computer program ENZFITTER, available from Elsevier-BIOSOFT, 68 Hills Road, Cambridge CB2 1LA, United Kingdom.; (b) Conners, K. A.. *Binding Constants*. In *The Measurement of Molecular Complex Stability*; Wiley: New York, 1987.