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Solid-emissive rhodamine: hydrogen bonding-assisted efficient intermolecular fluorescence resonance energy transfer in the solid state

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Solid-emissive rhodamine: hydrogen bonding-assisted efficient intermolecular fluorescence resonance energy transfer in the solid state

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Solid-emissive rhodamine complexes are obtained by mixing commercial rhodamine B (RhB) with the recently developed solid-emissive boron 2-(2'-pyridyl)imidazole (BOPIM) derivatives. The formation of intermolecular hydrogen bonds between RhB and BOPIM dyes plays a key role in the emission of RhB in the solid state. The disappearance of emissions from BOPIM dyes indicates the occurrence of efficient intermolecular fluorescence resonance energy transfer (FRET). The hydrogen bond also helps prevent the intermolecular interaction between the carboxyl moieties on RhB to alleviate concentration-induced fluorescence quenching because the emission of the complexes can be directly lightened by excitation at the RhB absorption (510 nm). Our results indicate that intermolecular FRET assisted by non-covalent interactions can be an efficient tool for constructing red or near-infrared solid emitters.

Keywords: hydrogen bond; FRET; solid emission; rhodamine B; boron-fluorine

Introduction

Organic fluorescent dyes are attracting considerable attention because of their potential applications in optoelectronic devices. The main concern is the improvement of the emission efficiency of solid-state fluorescent materials because highly emissive solids are key materials in a range of technologies, including displays and processing, chemical sensors and bio-imaging (1, 2). Although conventional dyes tend to aggregate with fluorescence quenching in the solid state, solid-emissive dyes can be obtained by introducing bulky groups around the chromophore to inhibit intermolecular $\pi - \pi$ stacking or by constructing non-covalent bonds to facilitate nonparallel packing (3-6). However, dyes that can emit deepred or near-infrared (NIR) light with significant efficiency in the condensed phase are less developed (7, 8). Recent reports on red solid emitters focus on large π -conjugated heterocycles. The synthesis for these dyes is normally tedious with low emission efficiency. Intramolecular energy transfer can be another efficient method of developing red or NIR solid emitters because solidemissive dyes in the short wavelength region are usually more available. For example, 2,2'-biindene is structurally simple but emits intense blue fluorescence in the solid state. When the 4,4-difluoro-4-bora-3a,4a-diaza- s-indacene (BODIPY) chromophore is conjugated with 2,2'biindene, an intense long-wavelength emission of BODIPY can be observed in the solid state because of the efficient intramolecular fluorescence resonance energy transfer (FRET) from 2,2'-biindene to the BODIPY core (9). The same phenomenon has been observed for an oligothiophene derivative containing a BODIPY chromophore (10). Intense solid emission has been observed for BODIPY because BODIPY absorbs the fluorescence of oligothiophene in the solid state. Therefore, synthesised dyads have unusually large Stoke shifts. However, the two chromophores (donor and acceptor) are linked in a conjugated manner, which increases synthesis difficulty.

Comparatively, intermolecular FRET is a simple and efficient method of solving this problem. Intermolecular energy transfer is based on the distance dependence between a donor and an acceptor through dipole-dipole or electron exchange interaction, resulting in decreased donor and acceptor emission. A large number of commercially available red-emissive dyes that emit in solutions exist, but these dyes show no fluorescence in the solid state. Given that solid-emissive dyes with a short wavelength are more available, simply mixing two chromophores together may enable efficient intermolecular FRET to produce longwavelength emission. However, some requisites must be met for this strategy. First, the donor should emit in the solid state with medium to high-quantum efficiency. Second, the donor emission must match the acceptor absorption. Finally and most importantly, the distance of the two chromophores must be limited to a few nanometres to facilitate energy transfer with high efficiency.

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Rhodamine B (RhB) is a popular dye with red emission, and the derivatives of RhB are widely used for chemical sensing and fluorescent labelling (11, 12). Solidemissive rhodamines can efficiently absorb visible light and emit at around 600 nm, which can be applied in a lightharvesting system (13, 14). However, few examples of solid-emissive rhodamine derivatives exist because these derivatives are compactly packed in the solid state (15, 16). Therefore, we propose to adopt the intermolecular FRET technique to produce solid-emissive rhodamines. Recently developed boron 2-(2'-pyridyl)imidazole (BOPIM) dyes are adopted as donors because these dyes are solid emissive with a fluorescent quantum yield that ranges from 0.10 to 0.37. The fluorescence of these dyes also matches well with the absorption of the rhodamines (17-19). Numerous techniques have been reported for holding chromophores together to shorten the intermolecular distance between donor and acceptor such as the construction of an intermolecular hydrogen bond (20, 21), $\pi - \pi$ interaction (22–29) and even van der Waals force (30). BOPIM dyes have a naked N atom on the imidazole ring that may form an intermolecular hydrogen bond with the carboxyl group of RhB as indicated in Scheme 1. We report a unique example of the highly solid-emissive rhodamine complexes by constructing efficient FRET in the solid state using an intermolecular hydrogen bond.

Results and discussion

The formation of an intermolecular hydrogen bond can affect the electronic environment of donor and acceptor, which further change the properties compared with precursors. ¹H NMR was obtained for the precursors and

Scheme 1. Self-assembly of the studied compounds.

the self-assembled complexes to verify the hydrogen bond formation between the imidazole in BOPIM dyes and the carboxylic acid in RhB during self-assemblies. During these assemblies, the BOPIM dyes act as acceptors to accept the proton, and RhB acts as the proton donor. Organic carboxylic acid is weakly acidic but can lower the electronic density of the BOPIM core once a hydrogen bond is formed. Figure 1 shows an array of resonances that correspond to the aromatic protons in the precursors and the self-assembled complexes. The signal of the carboxylic acid does not appear because of the fast proton exchange with a minimal amount of water in the solution. All samples show well-resolved resonances in CDCl₃. The protons on the pyridine rings (H1, H2 and H3) in the assembled sample SA1 significantly shift downfield compared with pure BOPIM1. This immediate shift indicates a decrease in electronic density and leads to a lower shielding effect on these protons. The proton on the imidazole slightly shifts upfield, and no chemical shift change is observed for the other protons. The different changes in the protons may be due to the anisotropic field effect of the carboxylic acid to the π system of the BOPIM chromophore. The formation of the hydrogen bond clearly affects the chemical environment of the BOPIM core more severely than the terminal substituted groups (H or phenyl rings) because almost no chemical shift change occurs for the protons on phenyl rings. A similar trend is observed for SA2 with BOPIM2 as the proton acceptor. The protons on the pyridine rings shift downfield, as shown in Figure 1.

The protons on RhB are also affected by the intermolecular interactions, especially the protons located

Figure 1. ¹H NMR of BOPIM dyes, RhB and the assemblies (in $CDCl_3$, * solvent).



close to the carboxyl unit. These protons (Ha, Hb and Hc) shift upfield, indicating that the electronic density is enriched because of proton loss during the formation of the intermolecular hydrogen bond. The other protons far from the carboxyl moiety are barely affected; thus, no chemical shift change is observed. However, the effect of the hydrogen bond is usually weak, and the largest chemical shift change is no more than 0.09 ppm. This result proves the formation of the intermolecular hydrogen bond and excludes the hypothesis of protonation. Deprotonation of RhB by NaOD induced a 0.347 ppm upfield shift for Ha. In order to prove that the hydrogen bond is formed between carboxyl and imidazole, ¹⁹F NMR was recorded for BOPIM1 and SA1. As expected, they show almost the same resonance patterns (single quarter: -156.19 ppm for BOPIM1 and -156.021 ppm for SA1), which excludes the possible interactions of carboxyl with F atoms.

FT-IR is another useful tool for characterising intermolecular hydrogen bonds. RhB shows a characteristic absorption band at $1693 \,\mathrm{cm}^{-1}$ because of the stretching vibration of the carboxylic acid dimers (the monomer should show an absorption band at longer wave number), as shown in Figure 2. This band diminishes and new bands centred at 1710 and 1708 cm⁻¹ arose in the self-assembled SA1 and SA2, respectively, due to the complex formation between the imidazole unit of the BOPIM dyes and the carboxyl unit of RhB. Another evidence for the self-assembled complexes are the presence of broad bands at 1920 and 2444 cm^{-1} for SA1, and at 2025 and 2428 cm^{-1} for SA2, which indicate a neutral O-H...N hydrogen bond interaction between the carboxylic acid on RhB and the N atom on imidazole moieties (31, 32).

An efficient FRET process requires spectral overlapping between the emission band of the donor and the absorption band of the acceptor. The fluorescence of BOPIM dyes (donor) ranging from 470 to 600 nm matches the absorption of RhB (acceptor), as shown in Figure 3(A).

BOPIM 1

SA 1

RhB

SA 2

BOPIM 2

Therefore, FRET can be incurred if the distance is limited to several nanometres as verified by the concentrationdependent fluorescent measurement of SA1 (Figure 3(B)). In a dilute solution (10^{-6} M) , only the emission ascribed to BOPIM1 is observed, and no emissive peak exists at around 580 nm because the fluorescent intensity of BOPIM1 is much higher than that of RhB under 365 nm excitation (the molar absorption coefficient of BOPIM1 at 365 nm is larger). This result proves that no FRET occurs in such a dilute solution. With increased concentration of 10^{-5} M, a shoulder emission ascribed to RhB appears at 572 nm. The increase in concentration facilitates the shortening of the distance between BOPIM1 and RhB by hydrogen bond formation. Therefore, the fluorescence intensity ratio IRhB/IBOPIM1 continues to increase with increasing concentration $(I_{\rm RhB}/I_{\rm BOPIM1} = 0.12, 0.36$ and 36.54 at 10^{-5} , 10^{-4} and 10^{-3} M, respectively). In fact, the emission peak of BOPIM1 in 10^{-3} M solution becomes very small, and the red emission centred at 598 nm becomes the main emissive peak with >97% FRET efficiency. Further increasing concentration can reach quantitative because the emission of BOPIM1 completely disappears. A sample containing the same RhB concentration as the blank was compared to elicit the fluorescent enhancement ascribed to FRET. The fluorescence intensity of RhB (10^{-2} M) is only 25% that of SA1 (10^{-2} M). This result indicates that most of the red fluorescence originates from the emission of BOPIM1. Similar results are obtained for SA2, as shown in Figure 3(C). The quantum yield of BOPIM2 is notably higher than that of BOPIM1 (17), and the fluorescence of BOPIM2 also better matches with that of RhB (Figure 1(A)). Consequently, much stronger red fluorescence is observed for SA2. Taking the fluorescence intensity of blank RhB as the standard (concentration = 10^{-2} M), the fluorescence ratio $I_{\text{SA1}}/I_{\text{RhB}}$ is 4.07, but $I_{\text{SA2}}/I_{\text{RhB}}$ is raised to 6.53.

The association constant is also important for their fluorescent properties. By fluorescent titration, their association constants are measured to be $3.71 \times 10^4 \,\text{M}^{-1}$



3000

3500

2428

2500

2025

2000

1500

1000





Figure 3. (A) Spectral overlap of the emissions of BOPIM dyes and absorption of RhB in chloroform; (B) concentration-dependent fluorescent spectra of SA1 in chloroform; (C) concentration-dependent fluorescent spectra of SA2 in chloroform. (Ex: 365 nm) and (D) excitation spectra of SA1, SA2 and mixtures of BOPIM dyes with RhBE.

for SA1 and $5.19 \times 10^4 \,\mathrm{M^{-1}}$ for SA2. Higher association constant for SA2 may make it show higher fluorescent intensity than SA1 at the same concentration. The reason may lie in that the phenyl ring in SA1 rotates fast in solutions (*17*), which makes it more difficult to form the hydrogen bond.

Given the above results, FRET may efficiently occur in the solid state because this state is the most concentrated form. BOPIM derivatives show intense emissions in solutions and in the solid state because of the non-parallel packing mode in the solid state induced by the formation of multiple intermolecular non-covalent bonds (such as C-H...N, C-H...B and C-H...F) (17–19). These derivatives also have a large Stokes shift given the efficient intramolecular charge transfer from the electron-rich groups to the electron-accepting BOPIM skeleton. BOPIM2 shows almost the same emissive band in the solid state as that in the dilute solution because the terminal two phenyl rings act as insulators to further inhibit aggregate formation. A shoulder peak at around 470 nm is observed for BOPIM1 in the prepared solid film. This emission peak is ascribed to the aggregate form because of the small steric hindrance of the form (17). The aggregate form is about 15% through the integration of the fluorescent band.

RhB is a highly fluorescent dye in the dilute solution. The fluorescence of RhB is completely quenched in the solid state with an absorption that broadens because of the aggregate formation through the intermolecular interactions between carboxyl groups (Figure 4(A)). However, the formation of the intermolecular hydrogen bond between BOPIM dyes and RhB can significantly decrease the aggregation degree of RhB. Figure 4(A)–(C) shows that the absorption bands of RhB in SA1 and SA2 become much narrower than before. The half-peak width is 78 nm in SA1 and 77 nm in SA2, which are much smaller than that of pure RhB (110 nm) and indicates that the formation of the intermolecular hydrogen bond can significantly alleviate aggregate formation.

The self-assemblies show efficient FRET in the concentrated solution and in the solid state. Figure 4(B)



Figure 4. (A) Spectral overlap of the emissions of BOPIM dyes and absorption of RhB in solid film; (B) UV–vis absorption of SA1, fluorescence of SA1 and RhB in solid film (Ex: 365 nm); (C) UV–vis absorption of SA2, fluorescence of SA2 and RhB in solid film (Ex: 365 nm); (C) UV–vis absorption of SA2, fluorescence of SA2 and RhB in solid film (Ex: 365 nm) and (D) fluorescent spectra in solid film (Ex: 510 nm for SA1, SA2 and RhB; 365 nm for RhBE + BOPIM1 and RhBE + BOPIM2).

shows that a sharp emissive peak ascribed to RhB appears and that the emission from BOPIM1 significantly decreases as shown in the solution. However, one small peak at around 470 nm exists, which occupies 15% of the entire emission in accordance with the fluorescence of BOPIM1 in the solid state. The aggregate form of the BOPIM1 cannot convert its fluorescence to RhB. The aggregate is probably formed through the N...N interaction, which inhibits the formation of an intermolecular hydrogen bond between BOPIM1 and RhB.

We investigated SA2 with BOPIM2 as the donor to prove this hypothesis. BOPIM2 has two phenyl rings at the terminal ends and can inhibit aggregate formation because of the steric effect. Only one emissive peak accordingly appears at 524 nm in the solid state. The fluorescence spectrum of SA2 expectedly shows only one sharp, longwavelength emission peak, which is ascribed to RhB. The emission peak from BOPIM2 completely disappears. BOPIM dyes are mixed with rhodamine B ethyl ester (RhBE) to investigate the function of the intermolecular hydrogen bond. No intermolecular hydrogen bond is formed because no free carboxyl unit exists. No red emission is observed in the mixtures, proving that the intermolecular hydrogen bond between BOPIMs and RhB plays a key role in this approach (Figure 4(D)). And the green emissions observed are ascribed to BOPIM dyes. The hydrogen bond can also alleviate aggregate formation because SA1 and SA2 also show red solid-emission under a 510 nm excitation, where no FRET occurs (Figure 4(D)). Therefore, the excitation spectra of SA1 and SA2 show two excitation bands around 410 and 510 nm (Figure 3(D)).

Conclusions

Unique solid-emissive rhodamine complexes are developed by simply mixing RhB with BOPIM dyes. The intermolecular hydrogen bond can significantly alleviate aggregate formation. Most importantly, the bond facilitates intermolecular energy transfer from BOPIM dyes to RhB, which increases the emission intensity of RhB. Our work provides a unique strategy for constructing red or NIR solid-emissive materials.

Experimental

Materials and measurements

All starting materials and solvents were obtained from commercial supplies and were used as received. ¹H NMR was recorded on Bruker 400 NMR spectrometers. Chemical shifts are reported in ppm with TMS as reference. IR measurements were carried out on Nicolet 360 FT-IR. UV-vis and fluorescent spectra were obtained on Hitachi U-3010 and F-4500, respectively.

Sample preparation

The synthesis of solid-emissive BOPIM dyes described here has been reported by our group previously (17). BOPIM dyes and commerically available RhB were mixed with molar ratio 1:1 in chloroform, and the mixtures were allowed to stir at room temperature for half an hour. After evaporation of solvent, the solid-emissive two-component assembled complexes were obtained as red powders. The solid films for photophysical measurements were obtained by coating the concentrated solution $(1.0 \times 10^{-2} \text{ M in} \text{ chloroform})$ onto a quartz plate.

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References

- (1) Shimizu, M.; Hiyama, T. Chem. Asian J. 2010, 5, 1516–1531.
- (2) D'Aleo, A.; Gachet, D.; Heresanu, V.; Giorgi, M.; Fages, F. *Chem. Eur. J.* 2012, *18*, 12764–12772.
- (3) Xiao, S.Z.; Cao, Q.; Dan, F.J. Curr. Org. Chem. 2012, 16, 2970–2981.
- (4) Zhao, Z.J.; Lam, J.W.Y.; Tang, B.Z. Curr. Org. Chem. 2010, 14, 2109–2132.
- (5) Hong, Y.N.; Lam, J.W.Y.; Tang, B.Z. Chem. Soc. Rev. 2011, 40, 5361–5388.
- (6) Hong, Y.N.; Lam, J.W.Y.; Tang, B.Z. Chem. Commun. 2009, 29, 4332–4353.
- (7) Qian, G.; Wang, Z.Y. Chem. Asian J. 2010, 5, 1006-1029.
- (8) Pansare, V.J.; Hejazi, S.; Faenza, W.J.; Prudhomme, R.K. *Chem. Mater.* 2012, 24, 812–827.

- (9) Zhang, Z.Y.; Xu, B.; Su, J.H.; Shen, L.P.; Xie, Y.S.; Tian, H. Angew. Chem. Int. Ed. 2011, 50, 11654–11657.
- (10) Benniston, A.C.; Copley, G.; Harriman, A.; Rewinska, D.B.; Harrington, R.W.; Clegg, W. J. Am. Chem. Soc. 2008, 130, 7174–7175.
- (11) Beija, M.A.; Afonso, C.A.M.; Martinho, J.M.G. *Chem. Soc. Rev.* **2009**, *38*, 2410–2433.
- (12) Kim, H.N.; Lee, M.H.; Hyun, J. Chem. Soc. Rev. 2008, 37, 1465–1472.
- (13) Zhang, K.L.; Yuan, L.J.; Xi, M.Y.; Yu, Y.Z.; Sun, J.T. Wuhan Univ. J. Nat. Sci. 2002, 7, 365–367.
- (14) Springer, J.W.; Parkes-Loach, P.S.; Reddy, K.R.; Krayer, M.; Jiao, J.Y.; Lee, G.M.; Niedzwiedzki, D.M.; Harris, M. A.; Kirmaier, C.; Bocian, D.F.; Lindsey, J.S.; Holten, D.; Loach, P.A. J. Am. Chem. Soc. **2012**, 134, 4589–4599.
- (15) Wang, L.Z.; Liu, Y.L.; Chen, F.; Zhang, J.L.; Anpo, M. J. Phys. Chem. C. 2007, 111, 5541–5548.
- (16) Bujdak, J.; Chorvat, D.; Iyi, N. J. Phys. Chem. C. 2010, 114, 1246–1252.
- (17) Mao, M.F.; Xiao, S.Z.; Li, J.F.; Zou, Y.; Zhang, R.H.; Pan, J. R.; Dan, F.J.; Zou, K.; Yi, T. *Tetrahedron*. **2012**, *68*, 5037–5041.
- (18) Cao, Q.; Xiao, S.Z.; Mao, M.F.; Chen, X.H.; Wang, S.; Li, L.; Zou, K. J. Organomet. Chem. 2012, 717, 147–151.
- (19) Yao, L.; Dan, F.J.; Cao, Q.; Mao, M.F.; Xiao, S.Z. Appl. Organomet. Chem. 2012, 26, 707–711.
- (20) Balan, B.; Vijayakumar, C.; Ogi, S.; Takeuchi, M. J. Mater. Chem. 2012, 22, 11224–11234.
- (21) Xiao, S.Z.; Zou, Y.; Wu, J.C.; Zhou, Y.F.; Yi, T. J. Mater. Chem. 2007, 17, 2483–2489.
- (22) Ajayaghosh, A.; Praveen, V.K.; Vijayakumar, C.; George, S.J. Angew. Chem. Int. Ed. 2007, 46, 6260–6265.
- (23) Praveen, V.K.; George, S.J.; Varghese, R.; Vijayakumar, C.; Ajayaghosh, A. J. Am. Chem. Soc. 2006, 128, 7542–7550.
- (24) Ajayaghosh, A.; Vijayakumar, C.; Praveen, V.K.; Babu, S. S.; Varghese, R. J. Am. Chem. Soc. 2006, 128, 7174–7175.
- (25) Fan, L.S.; Hu, Y.W.; Wang, X.; Zhang, L.L.; Li, F.H.; Han, D.X.; Li, Z.G.; Zhang, Q.X.; Niu, L. *Talanta*. **2012**, *101*, 192–197.
- (26) Jager, K.; Bats, J.W.; Ihmels, H.; Granzhan, A.; Uebach, S.; Partrick, B.O. *Chem. Eur. J.* **2012**, *18*, 10903–10915.
- (27) Wu, S.J.; Duan, N.; Ma, X.Y.; Xia, Y.; Wang, H.X.; Wang, Z.P.; Zhang, Q. Anal. Chem. **2012**, 84, 6263–6270.
- (28) Wang, Y.H.; Bao, L.; Liu, Z.H.; Pang, D.W. Anal. Chem. 2011, 83, 8130–8137.
- (29) Roquelet, C.; Lauret, J.S.; Alain-Rizzo, V.; Voisin, C.; Fleurier, R.; Delarue, M.; Garrot, D.; Loiseau, A.; Roussignol, P.; Delaire, J.A.; Deleporte, E. Chem-PhysChem. 2010, 11, 1667–1672.
- (30) Yu, Y.M.; Feng, J.C.; Liu, Y. Acta Chim. Sin. 2011, 69, 190–198.
- (31) Aakeroy, C.B.; Desper, J.; Fasulo, M.E. CrystEngComm. 2006, 8, 586–588.
- (32) Jin, S.W.; Guo, M.; Wang, D.Q.; Wei, S.S.; Zhou, Y.; Zhou, Y.P.; Cao, X.C.; Yu, Z.Y. J. Mol. Struct. 2012, 1020, 70–82.

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