Front. Chem. China 2010, 5(2): 134–149
DOI 10.1007/s11458-010-0116-6

FEATURE ARTICLE

Chromophore-functionalized dendrimers for sensing applications

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Chromophore-functionalized dendrimer sensors represent a new class of highly sensitive sensing materials. Here we review various strategies regarding dendrimer sensors, with specific attention being paid to how to achieve signal amplification using dendrimers' unique geometric features.

Keywords dendrimer, sensor, conjugated structures, energy transfer, organic electronics

1 Introduction

Dendrimers represent a class of hyper-branched, structurally well-defined, monodispersed macromolecules [1–3]. As shown in Figure 1, a dendrimer is comprised of a central core, several layers of branching units, and a large number of surface groups. The whole structure of a dendrimer resembles a tree, whence dendrimers derive their name (Greek, *dendra*) [4]. In 1985, Tomalia et al. synthesized the first dendrimer PAMAM and coined the word "dendrimer" [5]. Since then, many different types of dendrimer structure have been reported, such as the Fréchet-type poly(aryl ether) dendrimer [6], the Newkome-type arborol [7], and the Müllen-type polyphenylene dendrimer [8]. Dendrimers' unique topologies and properties have aroused considerable interest in various scientific communities, including those of chemistry, biology, and materials science [9,10]. Typical topological structures of a dendrimer are shown in Figure 2.

Incorporating conjugated units into the dendrimer scaffold renders the molecule many desirable properties, which can be fine-tuned to meet different requirements. These chromophores can be introduced as the core, attached to the surface, or distributed as branching units. The unique architecture of dendrimers, combined with the vast number of conjugated units in the literature, offers unlimited potential molecular designs.

All above-mentioned properties make conjugated dendrimers particularly promising as sensing materials. Compared to their small molecule counterparts, dendrimers possess larger numbers of repeating units, which suggest the possibility of signal amplification. Such amplification ability would allow dendrimers to achieve high sensitivity. Meanwhile, a well-defined structure also makes sensing results more reproducible than those of conjugated polymers. This is particularly important for high-accuracy quantitative measurement. The incorporation of chromophores would also allow multiple detection methods including absorption, electrochemical change, and fluorescence quenching or

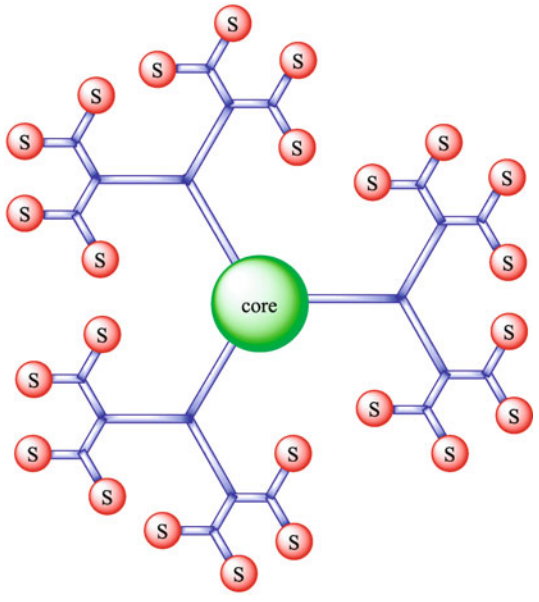

Figure 1 Schematic representation of a dendrimer.

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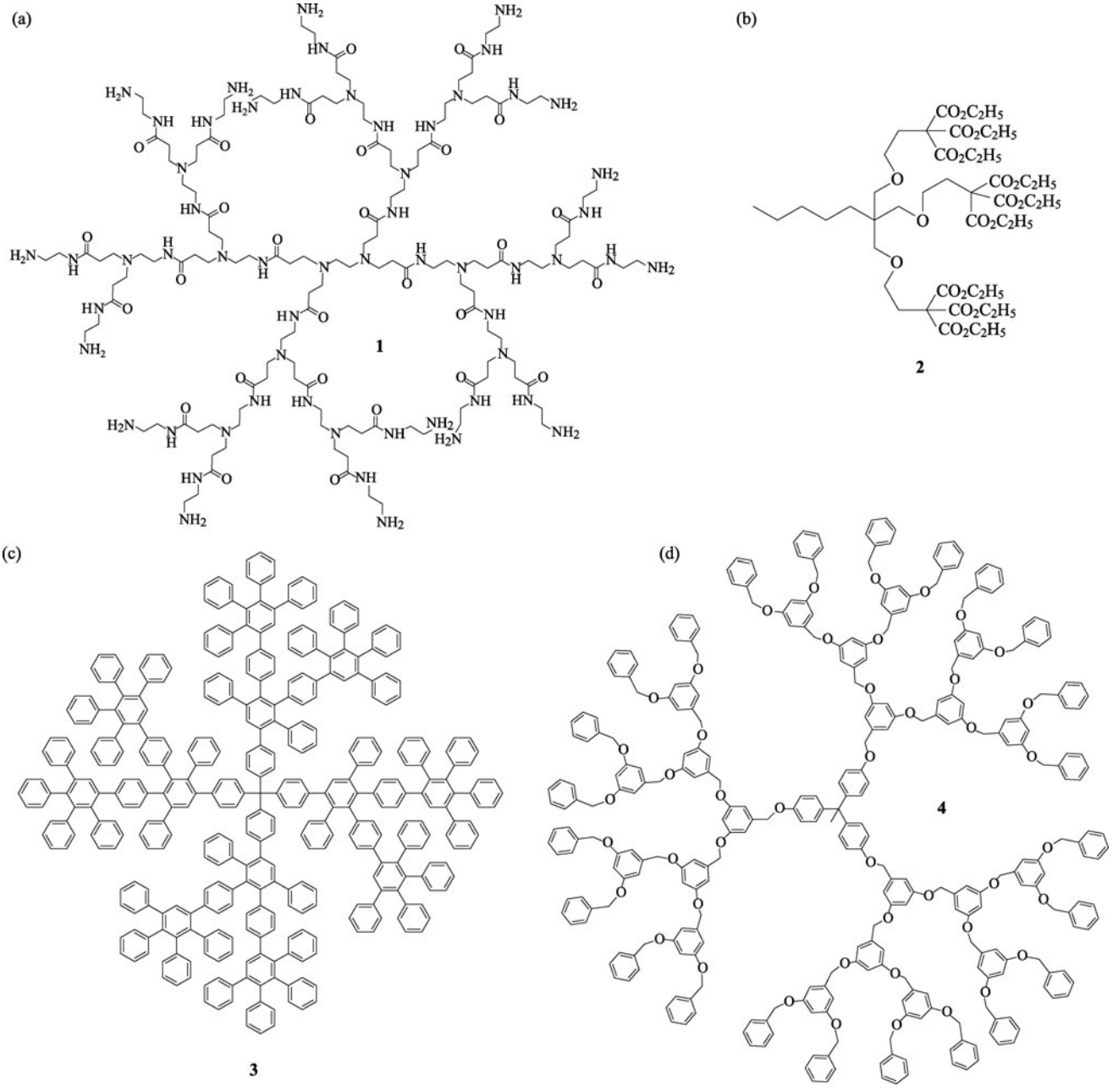

Figure 2 Typical chemical structures of a dendrimer. (a) second generation PAMAM dendrimer; (b) second generation Newkome-type arborol; (c) second generation Müllen-type polyphenylene dendrimer; (d) third generation Fréchet-type poly(aryl ether) dendrimer.

enhancement to be utilized. The ability of dendrimers to concentrate a large number of chromophores in a confined space may further amplify this effect through chromophore-chromophore interactions.

Herein, we review recent progress in the field of sensors using chromophore-functionalized dendrimers. We divide the topic into four parts according to different molecular designs.

2 Various strategies for chromophore-functionalized dendrimer sensors

2.1 Placing the conjugated units on the dendrimer surface

The most basic strategy for molecular sensing is the linkage of a reporter group to a receptor for a specific analyte (Figure 3(a)) [11]. Recognition of the analyte by the receptor

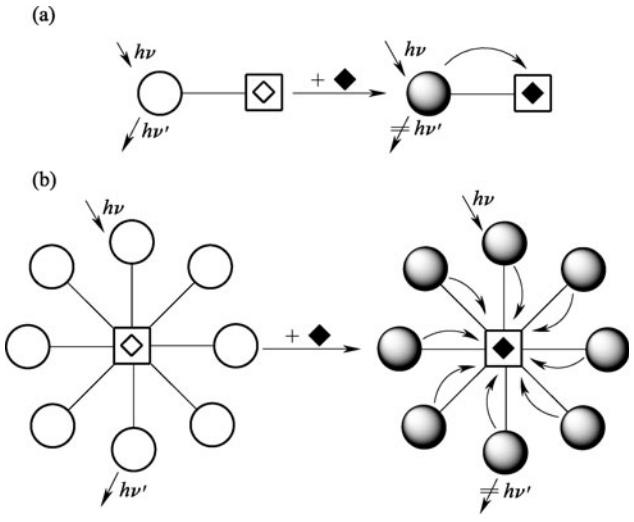

Figure 3 Schematic representation of the signal amplification ability of surface-functionalized dendrimers: (a) typical sensing event in small molecules; (b) sensing event in a surface-functionalized dendrimer. Binding of an analyte quenches the fluorescence of all the chromophores on the surface of the dendrimer.

causes a property change in the reporter, which is then detected instrumentally. Extending this strategy to dendrimers, Vögtle et al. have reported a fluorescent sensor using poly(propylene amine) dendrimer **5** (Figure 4) [11]. Thirty-two dansyl groups serving as the fluorescent reporters were attached to the periphery of this fourth generation dendrimer. As schematically depicted in Figure 3(b), a single recognition event inside the dendrimer caused fluorescence quenching of all the chromophores at the surface, clearly demonstrating the advantage of this strategy.

In acetonitrile-dichloromethane (5∶1 *v*/*v*) solution, dendrimer **5** exhibited intense absorption bands in the near UV absorption region and strong fluorescence in the visible region. Addition of Co^{2+} caused strong fluorescence quenching without affecting the absorption spectrum. The author attributed such quenching to the coordination of the Co^{2+} ion by the aliphatic amine groups inside the dendrimer. Since the dendrimer did not have a specific receptor for Co^{2+}, multiple Co^{2+} ions could coordinate with one dendrimer at high Co^{2+} concentration. Only at low concentrations did the dendrimer work as per the original design. The author did not report a

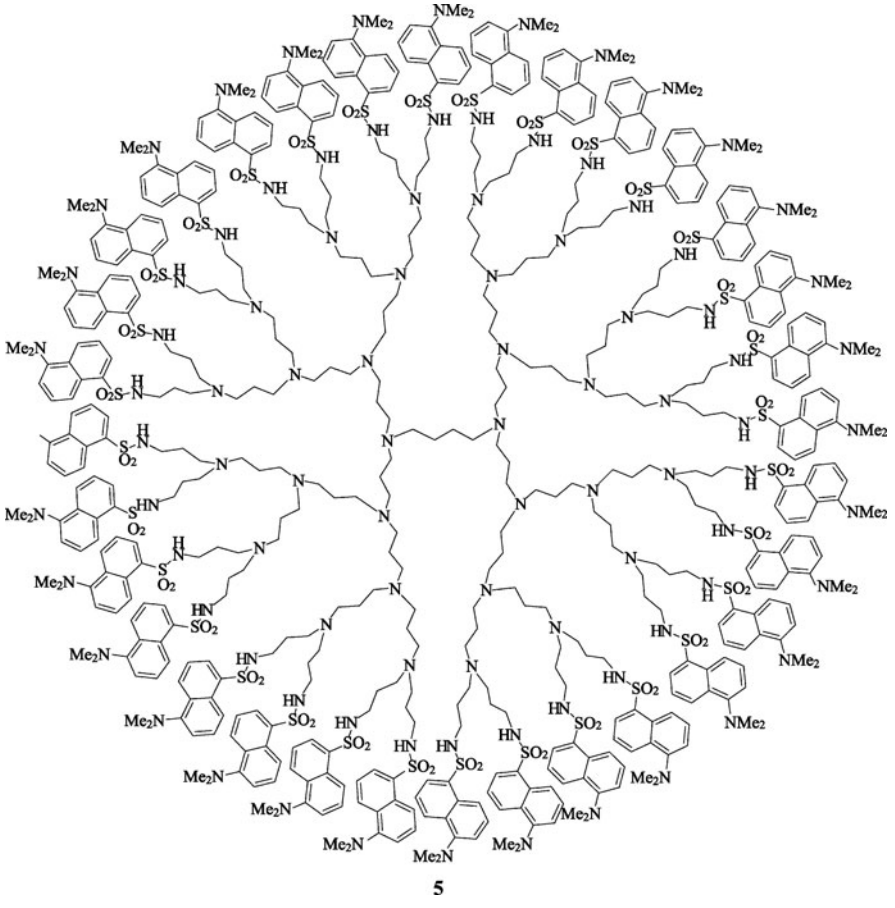

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Figure 4 Molecular structure of dansyl-group-functionalized poly(propylene amine) dendrimer **5**.

control experiment with a small molecule analog or the selectivity of the dendrimer sensor.

Following success in strand-specific detection of DNA and RNA using water soluble polyfluorenes or oligofluorenes [12,13], Bazan et al. have reported a series of cationic PAMAM dendrimers functionalized with oligofluorenes at the periphery [14]. Up to fourth generation dendrimers were synthesized to study generational effects and the collective behavior of these optical units on the surface. Here, the affinity between the dendrimer and the analyte resulted from interactions between the surface groups and the analyte; the dendrimer backbone merely served as a scaffold to localise these chromophores.

At near neutral pH, the polycationic nature of the surface groups render the dendrimer water soluble; meanwhile, these cationic sites are contained at the surface, to minimize exposure of the hydrophobic interior to water. The authors then measured the photophysical properties of this series of dendrimers in a 0.05 $mol \cdot dm^{-3}$ potassium phosphate buffer at pH 6, a condition relevant for biological assays. Notably, the ratio of the extinction coefficient to the number of conjugated units drops as the generation increases, indicating chromophore-chromophore interactions. 9,10-Anthraquinone-2,6-disulfonate (AQS) was then used as an electron receptor to investigate such electronic communication. The quenching process followed the Stern-Völmer equation:

$$\frac{F_0}{F} = 1 + K_{sv}[Q]$$

where F_0 is the fluorescence emission intensity in the absence of the quencher and F is the fluorescence emission intensity in the presence of the quencher. $[Q]$ is the quencher concentration and K_{sv} is Stern-Völmer constant. Fourth generation dendrimers exhibited the highest value of K_{sv} with AQS, demonstrating again the advantage of dendrimer sensors. Such an observation is the combined result of the energy-transfer process among optical units on the surface and a higher association constant with AQS for higher generation dendrimers. The author then performed a fluorescence resonance energy transfer experiment between the dendrimer and double/single-strand DNA. Fluorescein (C^*) was attached to the DNA, since its absorption spectrum overlaps with the emission spectrum of the dendrimers. After addition of ds-DNA-C^* or ss-DNA-C^* to the dendrimer solution, fluorescence from the fluorescein was observed, while that from the dendrimers became negligible. The sensing ability increased steadily from first to third generation dendrimers, reaching a plateau in the fourth generation. This result was attributed to the decreased extinction coefficient per conjugated unit, as mentioned above. Control experiments with small molecule analogs (Figure 5) justified the use of dendrimers as superior sensors: the dendrimers not only showed higher sensitivity but also better selectivity towards ds-DNA versus ss-DNA. This work demonstrated that collective properties among optical units in surface-functionalized dendrimers could be utilized to achieve better sensing results.

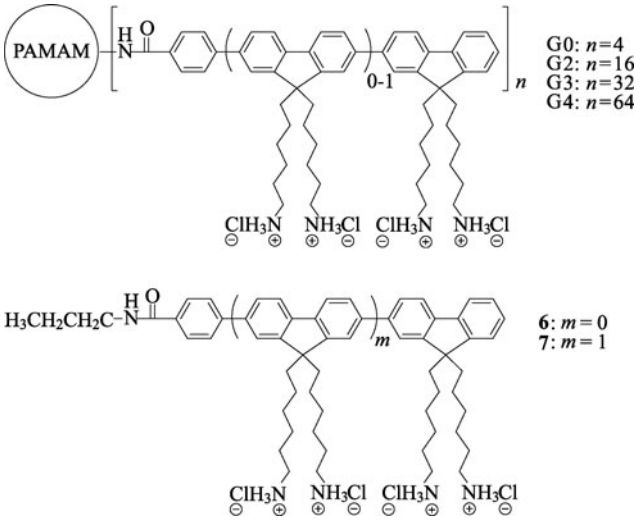

Figure 5 Oligofluorene-functionalized PAMAM dendrimers and their small molecule model compounds.

Another strategy was reported by Goodson et al. using dendrimer **8** (Figure 6), which showed good two-photon absorption (TPA) properties (with a TPA cross section of 56 000 GM per dendrimer molecule) [15]. This strong TPA property allowed the use of infrared light as the excitation source, which circumvented many problems regarding the application of visible light to remote sensing, such as scattering, absorption in the atmosphere, and the risk of eye damage. The strong TPA property of dendrimer **8** is itself a result of the dendrimer architecture, which concentrates a large amount of TPA-efficient chromophores in an ordered, confined geometry [16]. Due to the electron-rich nature of the

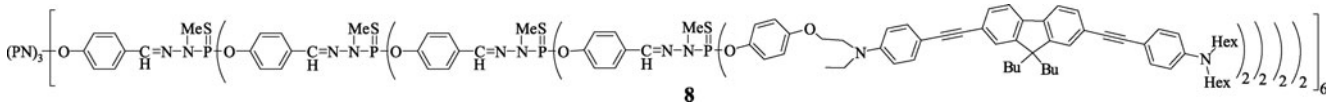

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Figure 6 The chemical structure of a two-photon absorbing dendrimer sensor. Only the structure of the fourth generation dendrimer is shown.

chromophore in this dendrimer, interaction with electron deficient analytes, especially nitrated organic compounds such as TNT, was logically expected. Meanwhile, similar to previous work, the rapid migration of excitons among these surface-anchored chromophores allowed the effective sampling of many different receptor sites. Last, the author noted that the internal and external void of the dendrimers allowed analyte molecules to diffuse easily through films, exposing as many receptors as possible to analyte molecules.

Fluorescence quenching (one-photon and two-photon) by TNT was carried out by micro-titration in dendrimer solution. In both excitation routes, the fluorescence of the dendrimers was very sensitive to the presence of TNT. The quenching process also followed the Stern-Völmer relationship, with a value of $K_{sv} = 1400\ \mathrm{L \cdot mol^{-1}}$ for dendrimer **8**. Compared to the TNT sensitive pentipcene-containing polymer developed by Swager et al., the author noticed a twofold improvement. Also, the systems showed stability for at least one year.

Using a femtosecond time-resolved fluorescence upconversion experiment, the authors have shown that the quenching mechanism was, unlike previous examples, largely dynamic. However, the time scale of diffusion of TNT molecules (about 100 ns) was much slower than the picosecond photophysical process. By using time-resolved fluorescence anisotropy measurements, the authors showed that dynamic quenching was caused by fast exciton migration on the quasi-two-dimensional dendrimer surface. Therefore, only a small number of TNT molecules is required to quench the emission of the whole dendrimer surface, a phenomenon similar to, but more efficient than the amplified quenching along one-dimensional polymer chains.

Most of the studies in this section utilized the photophysical properties of the dendrimer. However, we should mention that other signals, such as electrochemical changes, can also be used. For example, metallocene dendrimers are another type of surface-decorated dendrimer, which show unique redox properties. If an analyte affects the redox properties of a dendrimer, it can also be detected by electrochemical measurement. Interested readers are referred to a recent review by Astruc et al. [17].

2.2 Burying the chromophore inside the dendrimer

A reversed molecular design for dendrimer sensors is to bury the receptor inside the dendrimer, usually as the central core. Such a strategy sacrifices the advantages detailed in the previous section, since the number of chromophores is limited. However, the microenvironment inside a dendrimer is different to the external environment, in a phenomenon similar to a micelle. This opens new possibilities for recognition events that require a different environment from the working conditions. In fact, biological molecules such as proteins commonly contain buried active sites (usually hydrophobic) inside their hydrophilic surface [18]. However, due to the flexibility in the configuration of a dendrimer, precise molecular arrangement, as occurring in biomolecules, is very hard to achieve. Therefore, current literature contains only limited reports [19].

Smith and Diedrich have reported an interesting series of enantiomerically pure dendritic cleft receptors, named "dendroclefts," as shown in Figure 7 [20]. 2,6-Di(carboxamido)-pyridine moieties gave the dendrocleft the ability to bind carbohydrate guests, the central optically pure 9,9'-spirobi[9*H*-fluorene] core provided chiral selectivity, and the polyether dendrons rendered the dendrocleft highly soluble in various solvents, especially in water. Molecular recognition studies were performed by ^{1}H NMR titration in anhydrous $CDCl_3$ at 298 K using 1-*O*-octyl glucopyranosides (**12**–**14**) as guests (Figure 8). The association constants between dendroclefts **9**–**11** and **12**–**14** ranged from 100 to 600 $\mathrm{L \cdot mol^{-1}}$. Here, no generation effect was observed, since the dendrons were only playing a solubilizing role. Interestingly, while the enantioselectivity (referring to the difference in the association constants with **12** and **13**) is reduced upon introducing the dendrons, the diastereoselectivity (referring to the difference in the association constants between **13** and **14**) increased. This means that the dendrons, to some extent, modify the recognition event inside the core. However, the exact complexing motif is difficult to obtain. This might reflect an inherent disadvantage in this "buried-in" strategy for dendrimer sensors.

2.3 Fully conjugated dendrimers for sensors

Fully conjugated dendrimers contain conjugated chromophore units at the periphery, in the branching units and the core, together forming a large, continuous conjugated system [21]. Due to the inherent rigidity of this conjugated system, such a dendrimer usually has a rigid scaffold and a stable conformation. This on the other hand poses great difficulty for their synthesis, since classical C-C bond-forming coupling reactions usually require harsh conditions, and yields are often unsatisfactory. Nevertheless, the unique properties of fully conjugated dendrimers have attracted considerable interest, for scientific reasons as well as novel optical or electronic applications [22].

Several groups have developed different fully conjugated dendrimer systems [23,24]. For example, Müllen et al. have focused on polyphenylene denrimers using Diels-Alder-retro-Diels-Alder chemistry [25]; their sixth generation dendrimer remains the largest dendrimer synthesized so far [26]. Moore et al. have extended the architecture by introducing acetylene units (Figure 9(a)) [27], and so have developed the concept of

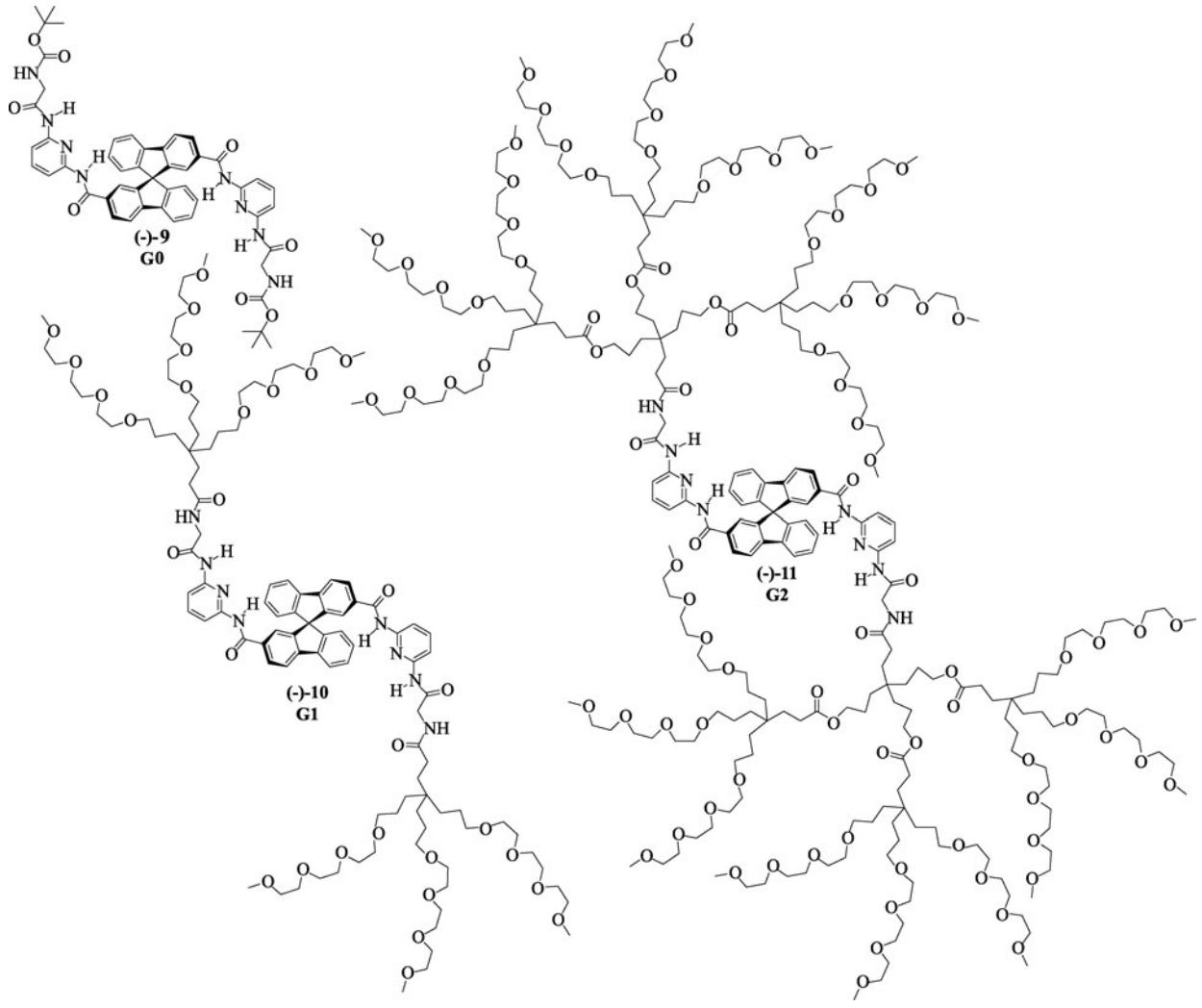

Figure 7 Chemical structures of "dendroclefts" **(-)-9**, **(-)-10**, **(-)-11** (G0, G1, G2).

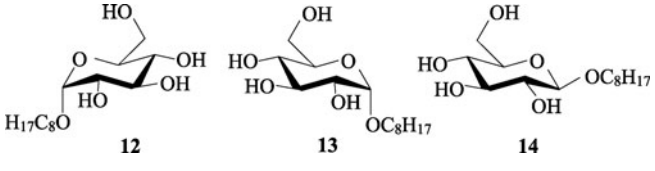

Figure 8 Chemical structures of analytes for dendroclefts: octyl α-L-glucoside **12**, octyl α-D-glucoside **13**, octyl β-D-glucoside **14**.

an "extended dendrimer". In these dendrimers, the length of the branching unit increases from the core to the periphery. Such a molecular design obviates steric crowding in the synthesis of larger generation dendrimers. At the same time, it creates an energy gradient from the periphery to the core, resulting in highly efficient, directional, cascade energy transfer processes (schematically shown in Figure 9(b)) [28], similar to those in natural photosynthetic systems [29].

Our group has developed a series of large dendrimer or star-shaped molecules incorporating a truxene unit **16**, a planar, C_3 symmetric unit containing four six-membered rings and three five-membered rings [30–33]. We have successfully synthesized dendrimers comprised solely of truxene units, up to the second generation (Figure 10) [34]. The dendrimer's rigid scaffold results in strong steric repulsion in the solid state, giving this molecule an almost identical photoluminescence spectrum in the solid state as in solution. We recently fabricated organic light-emitting devices using these dendrimers, which showed excellent performance and stability [35]. By applying the concept of an "extended dendrimer", we have further synthesized the largest second generation dendrimer to date, as shown in Figure 11 [36]. A fast and directional energy transfer process was observed in these dendrimers, setting a good platform for future development as sensors and other optoelectronic devices.

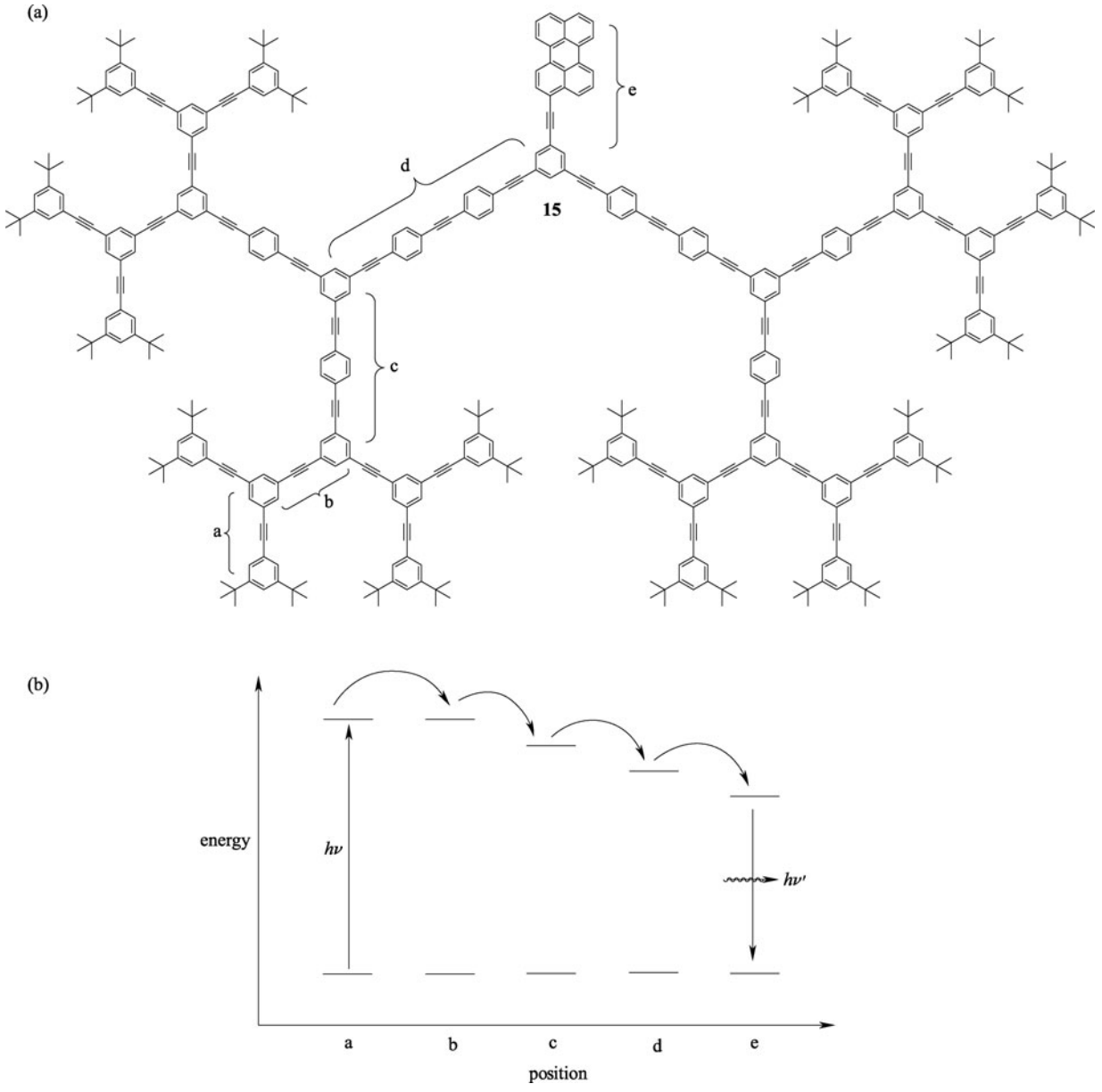

Figure 9 Molecular design of an extended dendrimer: (a) an extended dendrimer with a perylene core; (b) energy diagram for an extended dendrimer.

Such a light-harvesting process suggests the possibility of large signal amplification, if a suitable receptor is introduced as the central core. Using this concept, Pu's groups have developed a series of chiral sensors by combining the well-known chiral 1,1-binaphnol and conjugated dendrons [37]. 1,1-Binaphnols are known to have different affinities towards different amine-group-containing small molecules. Pu et al. introduced benzene-acetylene type dendrons to the 4(4′) and 6 (6′) positions of the binaphnol core (Figure 12) [38], which greatly increased the fluorescence of the molecule using the light-harvesting ability of the surface chromophores. Such an amplification mechanism greatly enhanced the sensitivity of the dendrimer sensors compared to the parent core. After screening many chiral amino alcohols and amines, they found that the enantiomers of 2-amino-3-phenyl-1-propanol ((*R*)- and (*S*)-**22**) quenched the fluorescence of dendrimer **21** both quickly and efficiently. More importantly, (*R*)- and (*S*)-**22** showed different quenching abilities towards the same dendrimer. From the Stern-Völmer plot, the Stern-Völmer constants were calculated to be 556 $L \cdot mol^{-1}$ for (*S*)-**22** and 473 $L \cdot mol^{-1}$ for (*R*)-**22**. These values are much larger than the constant between **22** with the parent core (121 $L \cdot mol^{-1}$ for (*S*)-**22** and 118 $L \cdot mol^{-1}$ for (*R*)-**22**), highlighting the large signal amplification ability of the dendrimer architecture.

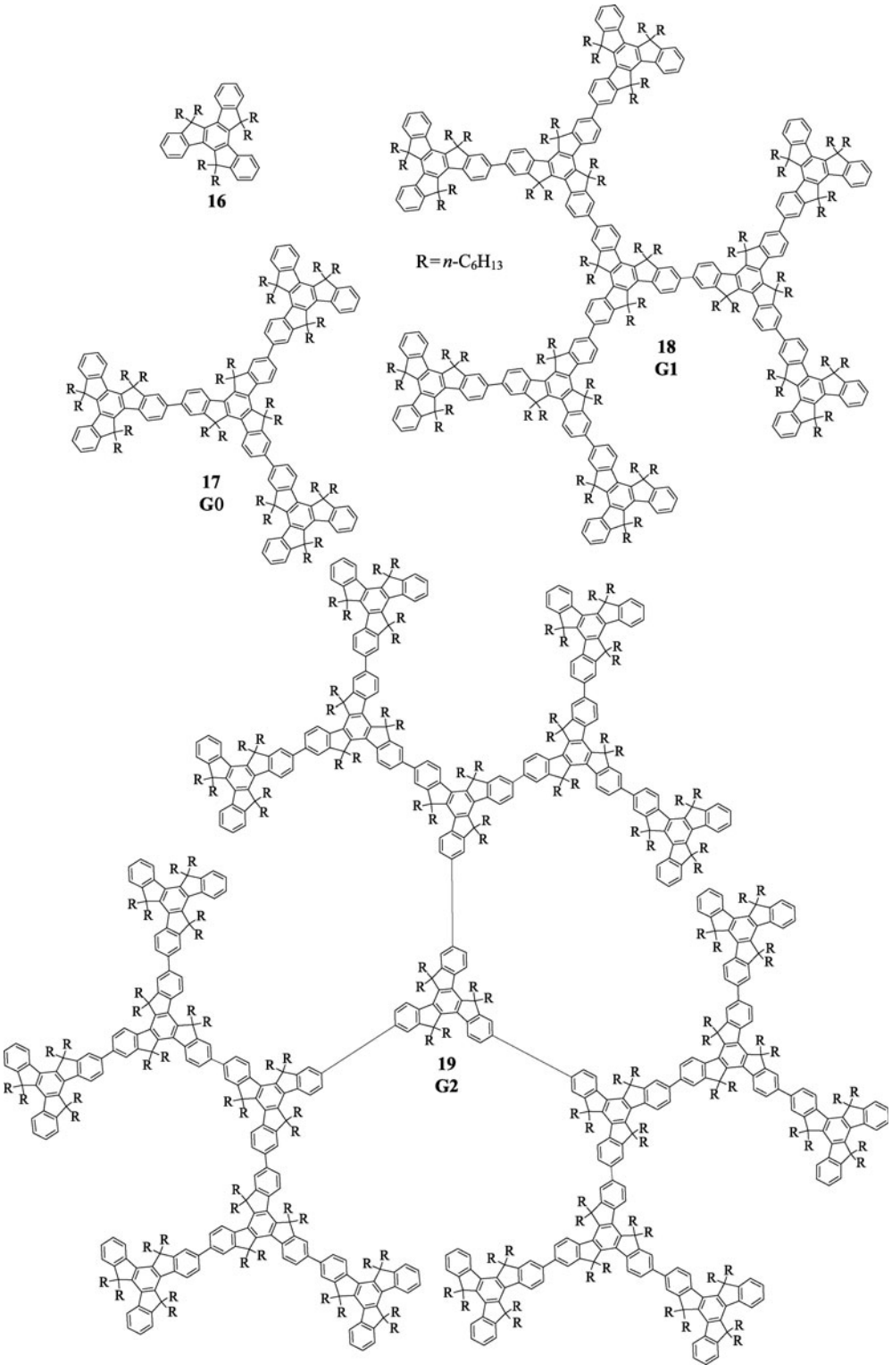

Figure 10 Dendrimers comprised solely of truxene units.

Moreover, the enantioselectivity of the dendrimer sensor was also much larger than the parent core ($K_{sv}^{S}/K_{sv}^{R} = 1.8$ for dendrimer **21** and 1.03 for the parent core).

When different mixtures of (*R*)-**22** and (*S*)-**22** were used, a linear relationship between the value of K_{sv} and the composition ratio was observed. Therefore, the system might be useful in high-throughput combinatorial searches or for asymmetric catalysts and reagents. The sensing

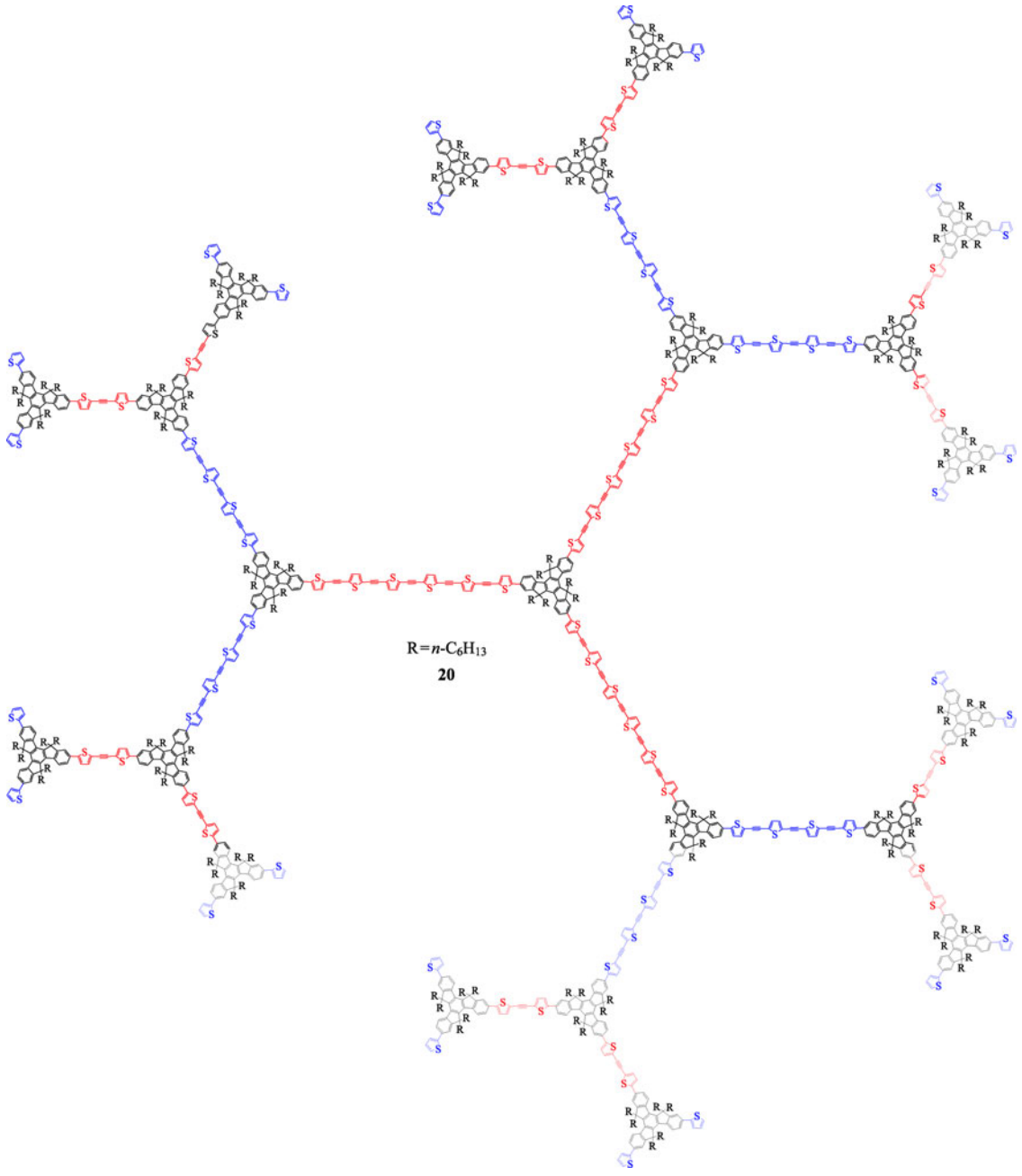

Figure 11 Second generation extended dendrimer constructed from truxenes and oligo(thienylethynylene)s.

mechanism was tentatively assigned to the formation of a hydrogen-bonded complex between **21** and **22**, which then becomes a poorly emissive proton-transfer complex in the excited state. In a subsequent work, this group also reported phenylene-based chiral dendrimers **23**, and observed similar results [39].

By combining the two parent cores of **21**, a new type of receptor can be constructed, as shown in Figure 13 [40]. According to molecular modeling, receptor **24** can bind mandelic acid **25** using multiple hydrogen bonding interactions. The receptor is non-fluorescent, because the presence of amine group quenches the fluorescence of the binaphelene units by photoinduced-electron-transfer. Hydrogen bonding between **24** and **25** restores the fluoresence. The parent core shows an association constant of 348 $L \cdot mol^{-1}$ toward (*S*)-**25** and 163 $L \cdot mol^{-1}$ toward (*R*)-**25**. The enantiomeric fluorescence difference ratio is therefore as high as 2.49.

Next, they introduced phenylene-type dendritic branches onto the parent receptor, as shown Figure 13. Due to the light-harvesting ability of the branches, the fluoresence intensity of the receptor increased dramatically when excited in the shorter-wavelength region. Thus, fourteenfold and

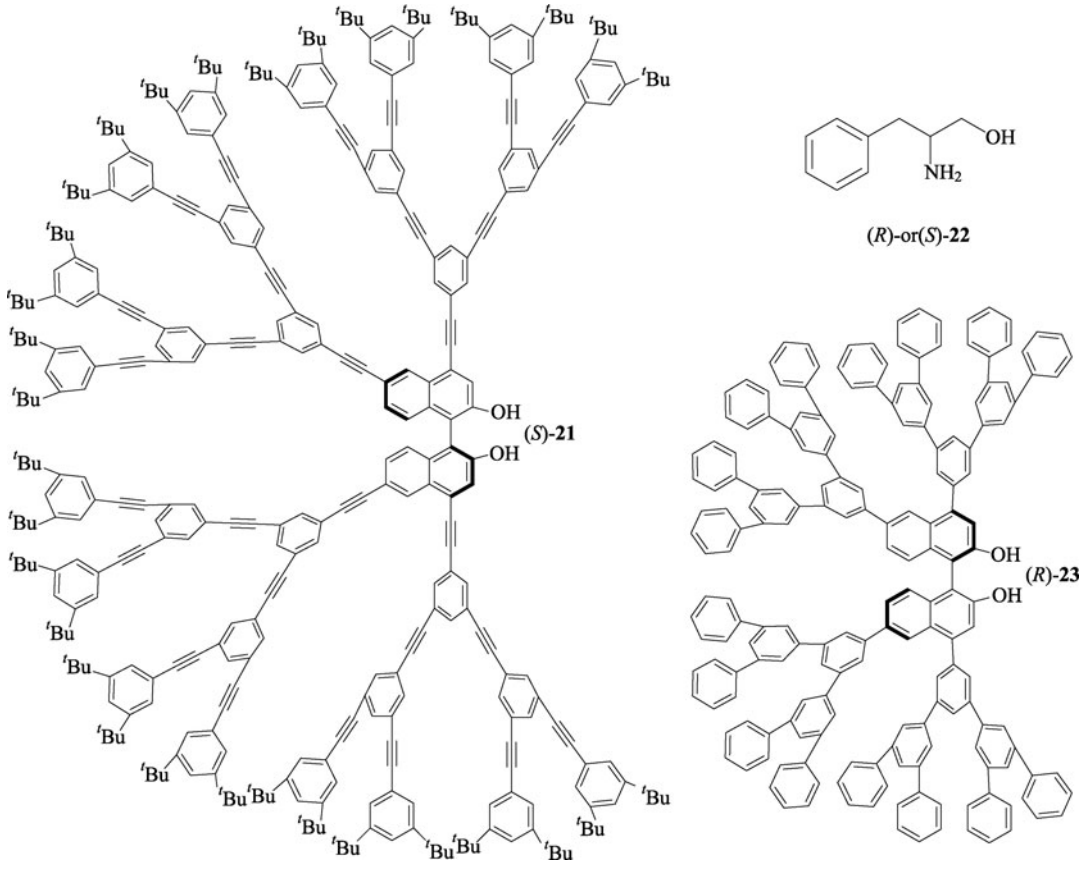

Figure 12 Molecular structures of dendrimer-based enantioselective fluorescent sensors: phenyleneacetylene-type dendrimer **21**, its analyte **22**, and phenylene-type dendrimer **23**.

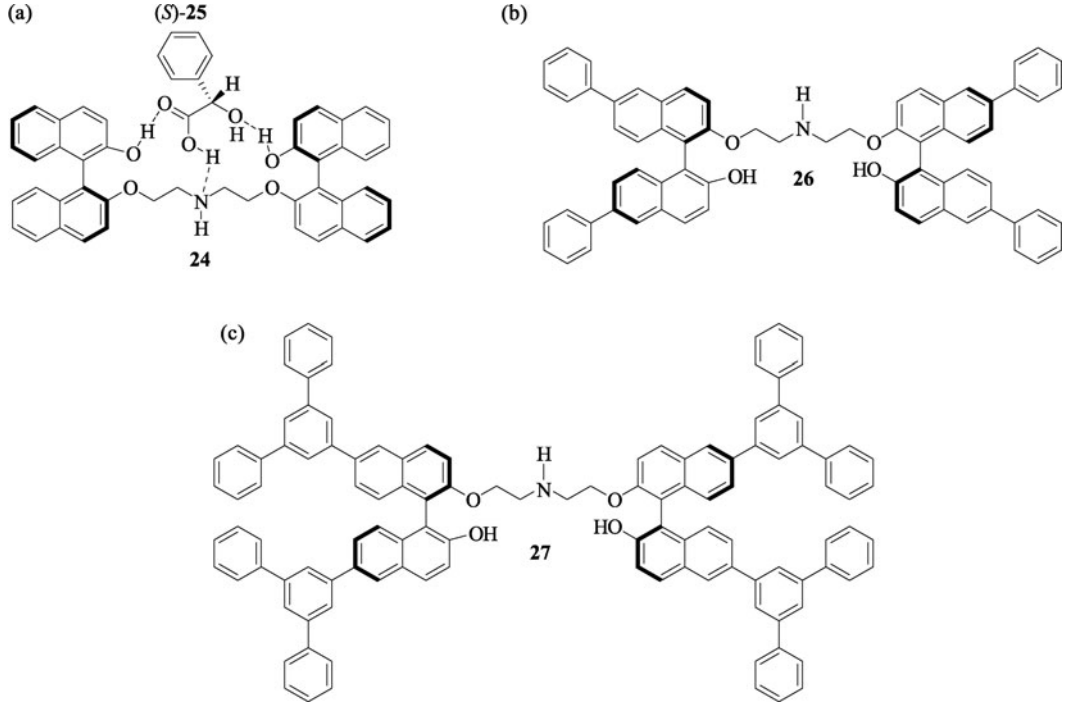

Figure 13 Fluorescent sensors for enantioselective recognition of mandelic acid: (a) complexing mode of (*S*)-mandelic acid **25** with parent core **24**; enatioselective receptor with (b) zero generation dendritic branch; (c) first generation dendritic branch.

twenty-twofold increases in the fluorescence enhancement were observed for **26** and **27**, when exposed to mandelic acid. However, the enantioselectivity decreased significantly as the generation increased (2.05 for **26** and 1.49 for **27**). The origin of such a decrease remains elusive. Again, this reflects a common problem in dendrimer sensors; the exact binding mechanism is hard to elucidate (unlike crystallizable small molecules), rendering systematic optimization difficult.

Besides fluorescence measurement, other properties of the fully conjugated dendrimers can also be utilized. For example, Müllen et al. reported a novel sensing strategy, using their polyphenylene dendrimers (PDs) (Figure 14) [41]. Because of their rigid framework, PDs contain stable internal voids that can be used to trap small molecules. This property sets them apart from other dendrimers containing flexible aliphatic groups, whose internal voids collapse in the solid state. Müllen et al. combined this unique property with use of a quartz microbalance (QMB), which is widely used to monitor the concentration of volatile organic compounds (VOC). QMBs are mass-sensitive devices [42]; their properties depend strongly on the type of sensor-active layer coated on top. Using PDs as the active layer, they successfully achieved quantitative sensing of different VOCs. Unsubstituted PDs react selectively to polar aromatic VOCs, such as acetophenone, aniline, benzaldehyde, benzonitrile, fluorobenzene, nitrobenzene, and 2-methyl-benzonitrile. Such selectivity was attributed to the electron-donor-acceptor interaction between analytes and the PD backbone. By changing the functional groups at the periphery of the PD, they were able to obtain QMBs selective to different types of analytes. For example, the COOH-coated PD **28c** showed strong affinity to molecules bearing amine substituents such as 1-methyl-2-pyrrolidine. Control experiments showed that QMB coated with hyperbranched polyphenylenes and aliphatic PAMAM lack reproducibility, justifying the use of shape persistent fully conjugated dendrimers as sensing layers in QMB-based techniques.

2.4 Other strategies

Usually, conjugated units are permanently introduced into the dendrimer scaffold. An interesting alternative design is to decompose the dendrimer into respective building blocks, triggered by an initiation event (schematically shown in Figure 15) [43]. If the initiation step involves a recognition event, then such a strategy could be used to detect analytes

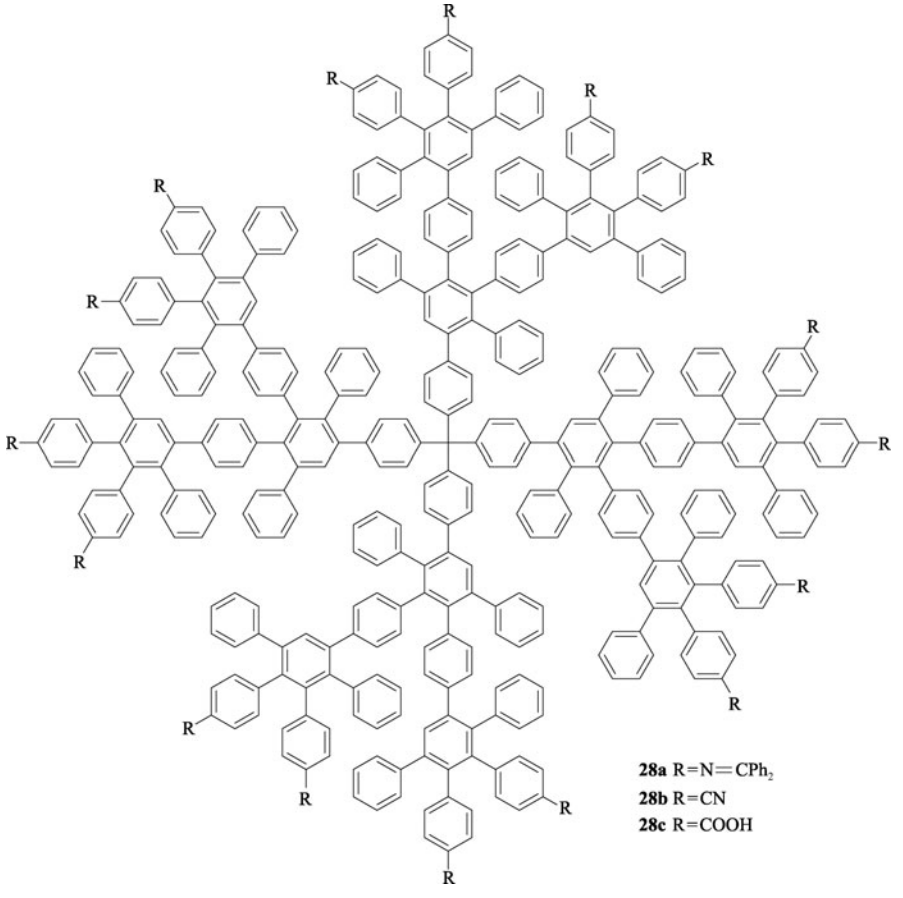

Figure 14 Molecular structures of polyphenylene dendrimers used as sensing material for a QMB.

sensitively because of the signal amplification nature of this strategy.

Around 2003, three groups independently reported the idea of dissociation of the dendrimer backbone following a single initiation event. De Groot et al. used the chemistry shown in Figure 16 to achieve the disassembly process [44]. After removing the protecting group R, two 1,8-elimination reactions could occur, releasing two L groups. By constructing dendrimers including these building blocks and drug molecules as L groups, they were able to show multiple drug release by a single chemical reaction.

McGrath et al. used a reaction involving dendron **29** (Figure 17), which contains multiple chromophores on the surface, to achieve this so-called dendritic amplification [45].

A third version of the disassembly strategy was reported by Shabat et al. [46]. The basic chemistry was somewhat similar; but the design was more elaborate. Using a photolabile trigger, the whole dendron (the largest dendron **30** is shown in Figure 18)

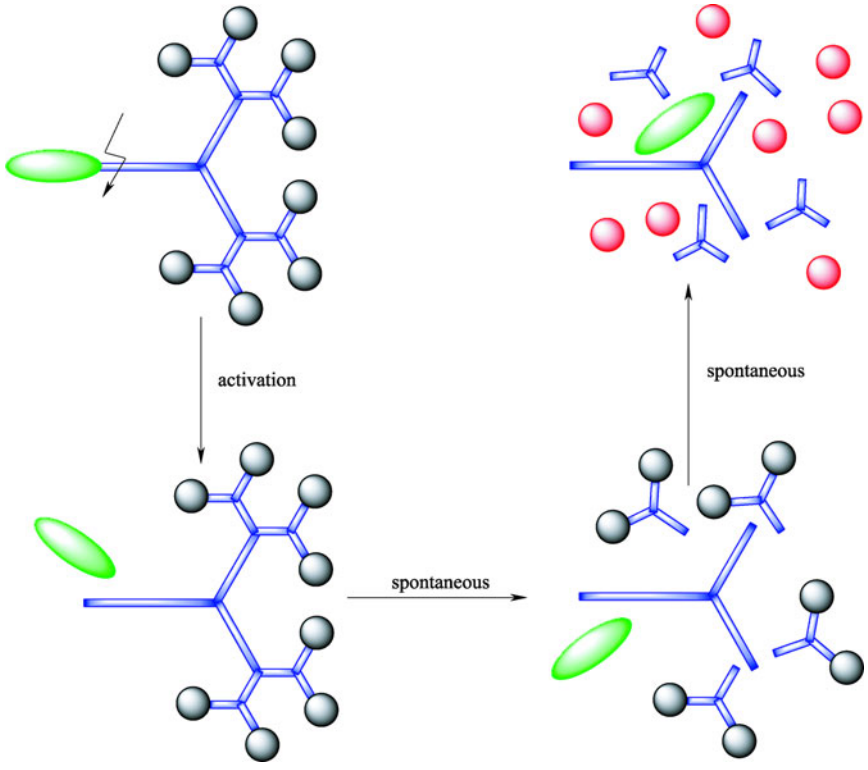

Figure 15 Schematic representation of dendrimer disassembly. After an activation event, the core (green) is first released, followed by spontaneous breakdown of the dendrimer scaffold. All surface groups (initially black) are then released (red).

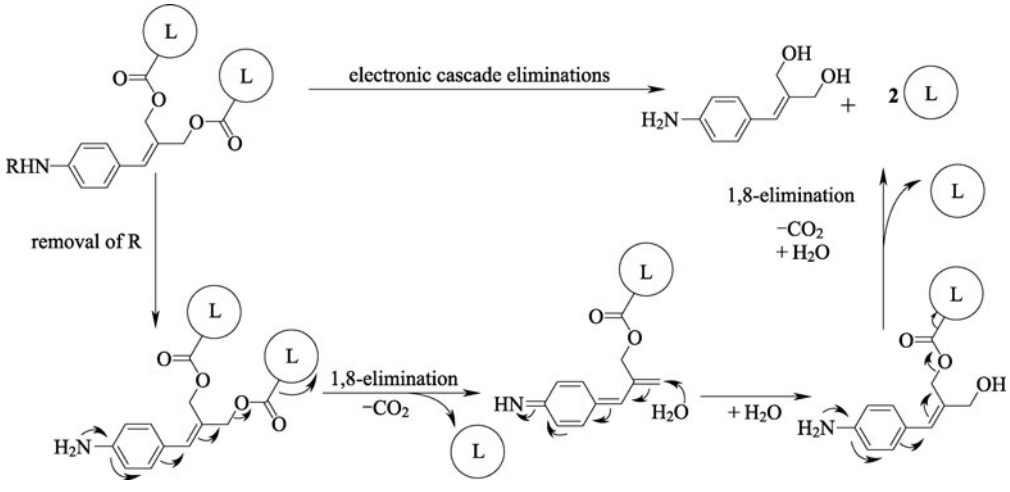

Figure 16 Electronic cascade eliminations used by De Groot et al. to achieve dendrimer disassembly.

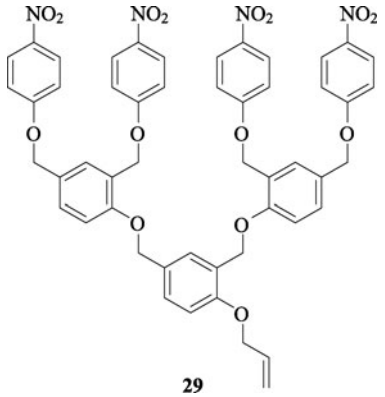

Figure 17 Second generation dendron reported by McGrath et al. that incorporated an allyl trigger group and multiple nitrophenoxy reporter groups.

could be disassembled and 8 reporter molecules released. They named their molecules "self-immolative dendrimers" .

As a step further, the Shabat group has developed the first "self-immolative" dendritic sensor for triacetone triperoxide (TATP) [47]. The structural design of the sensor involves two new concepts: first, the trigger event is coupled to a chemical reaction involving the sensor molecule. In this case, TATP would generate hydrogen peroxide in the presence of acid, and the reactive H_2O_2 served then as the trigger. Accordingly, a boronic ester group was used as the protecting group in the dendron, which can be cleaved efficiently by H_2O_2. Second, the reporter molecules have different photophysical properties in the bound state and free state. In their previous work, the reporters were analyzed by HPLC, which is slower and less convenient and sensitive than fluorescence measurement. In this paper, they used amine **31** since its photoluminescence spectra in its free amine form and in the dendrimer are significantly different. Figure 19(a) shows the whole design for the sensing process. Figure 19(b) shows the dendrimer structure **32** which embodies all the concepts mentioned above, and its model compound **33**.

They first incubated the probes **32** and **33** in hydrogen peroxide for 90 min in aqueous $NaHCO_3$, and monitored the fluorescence intensity change at 560 nm, where the bound amine form has very low fluorescence intensity. The increase

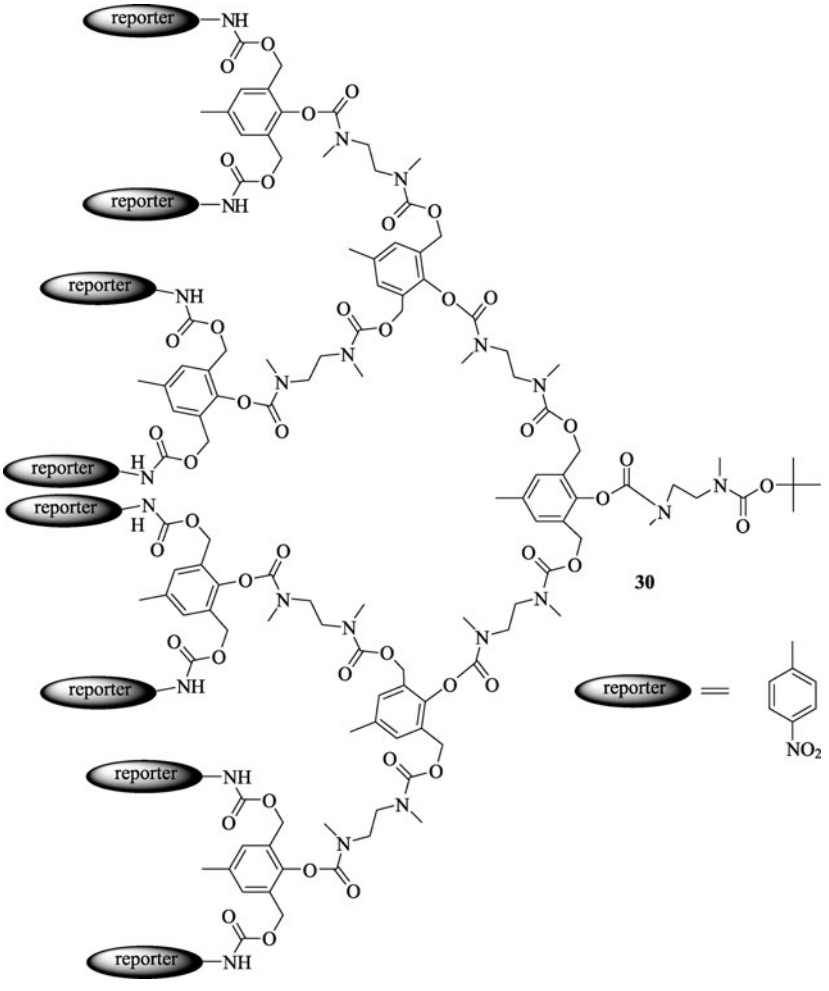

Figure 18 The largest self-immolative dendron synthesized by the Shabat group.

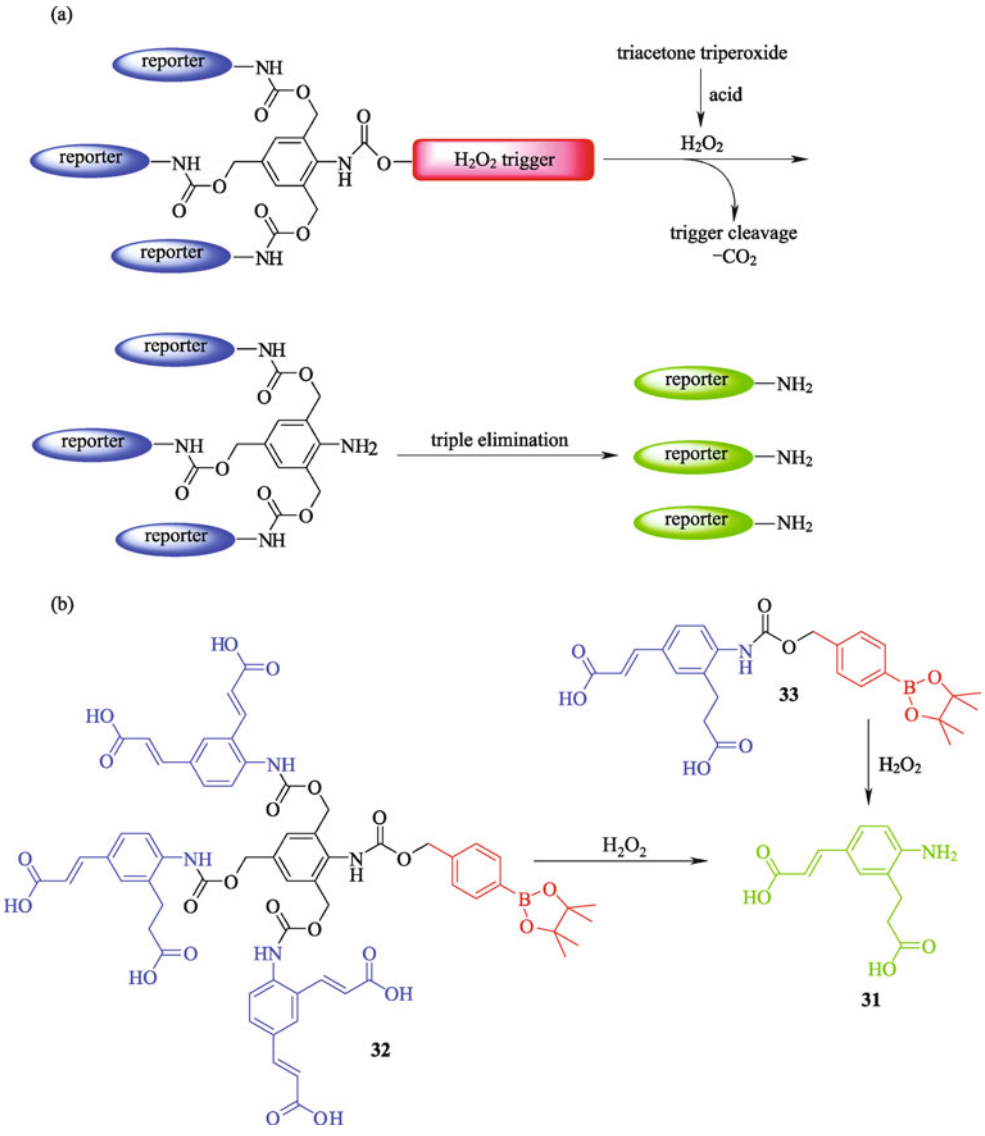

Figure 19 (a) Sensing mechanism of self-immolative dendrimer triggered by triacetone triperoxide; (b) molecular structures of a self-immolative dendrimer sensor and its model compound.

of fluorescence intensity at this wavelength indicated that free amine was released by H_2O_2. Next, the probes were exposed to TATP without any pretreatment. As expected, the sensitivity of probe **32** was three times higher than that of **33**. Using this method, TATP samples can be conveniently detected on a microgram scale. Also, the author noted that the sensitivity of this method could be further increased by using higher generation dendrimers.

We see such disassembling dendrimers as a promising platform for dendrimer sensors. The analyte can itself serve as the trigger, or it can be chemically coupled to the trigger event. The vast number of potential chemical trigger reactions gave such strategy unlimited possibilities. However, we note that only limited work has been reported in this direction. Apart from synthetic difficulties, the reporting mechanism might also pose a hurdle. In the previous example, the contrast between the bound reporter and free reporter is still unsatisfying. Meanwhile, no collective behavior was seen in the dendrimer, so the resulted amplification is still limited. One possibility is to combine the disassembled dendrimer concept with concepts from previous chapters. For example, one could deliberately introduce a quencher molecule into the scaffold, which quenched the fluorescence of all the surface groups. After the trigger event and cascade dissociation event, the quenching process would no longer exist due to the large distance between the reporter and the quencher in the solution (also due to the small numbers of the quencher). Such a turn-on strategy might further improve the detection limit.

3 Conclusion and Perspectives

In this article, we reviewed various strategies using chromophore-containing dendrimers for sensing applications. By changing the structural positioning of the chromophores, dendrimers with different sensing properties can be created. The role of the dendrimer scaffold is also versatile. It can serve as a solubilizing group, or it can be used to promote electronic communication among the chromophores. In the case of a fully conjugated dendrimer, the rigid scaffold promotes efficient and directional energy transfer from the surface group to the core, when a recognition event occurs. In the fourth strategy, the scaffold could even be destroyed by the sensing event. In all cases, judicious design of the dendrimer architecture results in enhanced selectivity and sensitivity.

There is still room for further development in this area. Apart from applying dendrimer sensors to more analytes, exploring a wider range of strategies would be scientifically more profound. The disassembling dendrimers represent a good example to this end. Regarding this aspect, we might think what other phenomena, known for use of conjugated units, could be utilized.

Furthermore, the signaling method should not be limited only to absorption or fluorescence. An interesting and practical possibility is to integrate the dendrimer into electronic devices and monitor the recognition event by electric signal, which is fast and can be automated. Conjugated small organic molecules or polymers have shown great potential in application in optoelectronic devices such as solar cells, light-emitting diodes, field-effect transistors, optical waveguides, and so on [48–52]. For example, field-effect transistors using dendrimers might be used as a new type of sensing device. In this case, various parameters could be used as a signal, such as the source-drain current change, gate voltage shift, etc. The application of chromophore-functionalized dendrimers in sensors is still in its early stages, and much work should be carried out to fully explore the potential of such a combination of structural elegance (dendrimer structures) and practical application (sensors).

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