Organic luminescent materials: The concentration on aggregates from aggregation-induced emission

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INTRODUCTION

Luminescent materials that emit bright emission in aggregate have drawn considerable attention for their wide applications. However, for traditional organic luminogens with planar conformation, they often suffered from the aggregation-caused quenching (ACQ) effect. As shown in Figure 1A, perylene could give bright blue emission in its dilute solution, while becoming nearly nonemissive in aggregate or solid state. Its single crystal structure clearly shows the existence of strong $\pi$--$\pi$ interactions, which can lead to the formation of multiple metastable energy levels, thus resulting in the increased nonradiation channels and quenched emission in solid state. Actually, the discovery of ACQ phenomenon could be dated back to as early as 1954 by Förster and the ACQ effects for many aromatic luminogens have been summarized by Birks in his book *Photophysics of Aromatic Molecules* in 1970. Regardless of the long history, the ACQ problem has never been solved completely.

In 2001, Ben Zhong Tang and coworkers accidentally discovered the phenomenon of enhanced emission upon aggregation for some hexaphenylsilole (HPS) derivatives (Figure 1B). For these luminogens, they all shared the twisted molecular conformation with free peripheral rotors against the silole core. Accordingly, the dominated nonradiative rotation could lead to the quenched emission in solution. Upon aggregation, the restriction of intramolecular rotation (RIR) was achieved with the aid of intermolecular C-H...$\pi$ interaction and hydrophobic interaction, thus resulting in the strong emission. This phenomenon was coined as “aggregation-induced emission (AIE)” effect. Inspired by this abnormal emissive behavior and the related potential applications, many scientists devoted themselves into this area. Thus, with just a few years of development, the AIE family has been largely expanded. Particularly, a series of classical AIE building blocks were successfully developed based on the RIR and analogous RIV (restriction of intramolecular vibration) mechanisms, such as TPE by Tang et al., polyphenylbenzene by Li et al., DSA by Tian et al., PentPP by Dong et al., THBA by Miao et al., dp-TCAQ by Hu et al. (Figure 1C).

More excitedly, their AIE character could often be inherited after decorating them with other functional groups, which gave rise to the colorful AIE materials with diverse functions, including organic light emitting diodes (OLEDs), bioimaging, stimulus response, sensors, and optical waveguide (Figure 2).

In the early studies on AIE, scientists seemed more concerned about the effect of molecular structure on its AIE property. With time going on, it was found that not all emission phenomena can be explained by molecular structure, especially for the polymorphisms with different emissive properties. On the other hand, AIE was a typical...
Organic luminescent behaviors in solid state

Aggregation-induced delayed fluorescence (AIDF)

For AIEgens with efficient emission in solid state, one of the most important applications was to act as emitting layer in nondoped OLEDs. However, limited by low exciton utilization (just 25%) for normal AIE fluorescent materials, their external quantum efficiency (EQE) for OLEDs was hard to exceed 5%. In 2011, Adachi and coworkers reported the first example of purely organic thermally activated delayed fluorescence (TADF) luminogen, which opened up a new way to utilize the additional triplet excitons (75%), thus promoting the corresponding OLED efficiency. In order to relieve ACQ effect of TADF materials, they were frequently dispersed into host materials to construct doped OLEDs. With it, the high OLED efficiency could be achieved, but it also brought about some side problems, such as complicated process, high cost, and inferior stability from the potential phase separation.

In 2015, Chi and coworkers successfully integrated AIE and TADF into one luminogen, thus realizing the abnormal AIDF. As shown in Figure 3A, for normal TADF luminogens of SF2tC and SF2C, diphenyl sulfone acted as electron acceptor (A) and planar carbazole derivatives as electron donor (D). This would lead to the intense intermolecular π–π interaction in solid state and resultant ACQ effect. When one or two carbazole units were replaced by the twisted phenothiazine to yield SFPC and SF2P, the π–π stacking was well restricted, thus resulting in the AIE effect with PL efficiencies up to 93.3% and 52.8% in solid state. On the other hand, because of the restricted exciton quenching effect upon...
aggregation in AIDF luminogens, their solid samples could show obviously delayed component up to milliseconds in photoluminescence (PL) decay curves, while no delayed one was observed for normal TADF materials (Figure 3B). Based on it, the great potential in nondoped OLEDs for AIDF materials could be expected.

Intrigued by the abnormal phenomenon of AIDF, scientists devoted great enthusiasm to explore the corresponding internal mechanism. Pioneering works have been done by Zhao and coworkers in recent years. As shown in Figure 4A, DMF-BP-PXZ, consisting of electron-donating phenoxazine (PXZ) and fluorene derivatives coupled with an electron-withdrawing benzoyl core, just showed a faint emission with quantum efficiency as low as 2.6% and a short emission lifetime of 2.3 ns in THF solution. With the addition of large volume of water to form aggregate, the PL intensity was gradually enhanced and the fluorescence lifetime became much longer with notable delayed fluorescence in the microsecond level, showing the typical AIDF. To make a deep insight of the internal mechanism, the radiative ($k_r$) and nonradiative ($k_{nr}$) rates, intersystem crossing ($k_{ISC}$), and reverse intersystem crossing ($k_{RISC}$) rates in solution and solid states were calculated. As shown in Figure 4B, a dominated nonradiative transition from excited singlet state ($S^*$) to ground state ($S_0$) could be observed with $k_{F,nr}$ of $4.17 \times 10^8$ s$^{-1}$ in solution, which should be the main reason for the weak emission without delayed fluorescence. As for solid state, the intramolecular motion was well restricted for DMF-BP-PXZ, thus leading to a much decreased nonradiative rate ($1.3 \times 10^7$ s$^{-1}$) and enhanced PL efficiency (45.4%). At the same time, its $k_{ISC}$
and \( k_{RISC} \) were calculated to be \( 9.7 \times 10^6 \) s and \( 1.0 \times 10^6 \) s, respectively, which were large enough to compete with \( k_{F,nr} \) to some extent, thus resulting in the delayed fluorescence. Based on these results, it could be concluded that the restricted nonradiative transition in aggregate should be the main reason for the resultant AIDF effect.

Further on, the applications of AIDF materials in OLEDs were explored.\(^{[35–37]}\) For normal delayed fluorescence materials, they were often doped into host with a small ratio to construct OLEDs, thus to restrict the possible ACQ effect. As for AIDF emitters, things could be changed, since bright emission and significant delayed fluorescence could be both realized in a nondoped film. Taking AIDF lumogen of DBT-BZ-DMAC as an example, it showed a high PL efficiency of 80.2% and great delayed component of 64.5% in neat film (Figure 5).\(^{[37]}\) Thus, when it acted as emitter in nondoped OLED, a maximum EQE of 14.2% was achieved (Figure 5B). More important, it retained high electroluminescence (EL) efficiency as luminance increased, demonstrating greatly advanced efficiency stability of nondoped OLEDs. As for the doped OLEDs based on DBT-BZ-DMAC, although comparable EQE values (13.0% to 17.9%) could be obtained, they showed obvious efficiency roll-off up to 39%. Experimental results indicated that the decreased energy gap between \( S_1 \) and \( T_1 (\Delta E_{ST}) \) from doped film to the nondoped one should be mainly responsible for it. Since this could lead to the much shorter delayed fluorescence lifetime and larger delayed fluorescence component in neat film, the promoted EL efficiency and stability in nondoped OLEDs were both achieved (Figure 5A).

**Room temperature phosphorescence (RTP)**

In the study of AIE effect, it was found that some organic luminogens presented the interesting crystallization-induced emission (CIE).\(^{[38]}\) That is to say, these luminogens are non-missive in solution or amorphous state, while bright emission can be just obtained in crystal for the effectively restricted intramolecular motion. More excitingly, the rigid environment in crystal state could even lead to the appearance of RTP, showing the unique crystallization-induced phosphorescence (CIP) effect.\(^{[39]}\) As shown in Figure 6A, for some benzophenone derivatives and 4,4′-dibromobiphenyl, they could give bright emission in crystal state with the emission color ranging from blue to orange, regardless of their short intramolecular conjugation. The corresponding PL decay measurements indicated that they were phosphorescence with lifetime up to millisecond level. The finding of CIP effect largely expanded the concept of AIE, and urged scientists to realize the importance of intermolecular interaction and the corresponding molecular packing in solid state luminescence behaviors.

For organic RTP luminogens, the long emission lifetime is one of the key parameters, as this can greatly affect their practical applications, including time-resolved anticounterfeiting and bioimaging.\(^{[40–42]}\) To prolong RTP lifetime, scientists have tried a lot, and particularly a series of crystal engineering was carried out.\(^{[43–46]}\) As one of the impressive examples, Huang and coworkers proposed that \( H \)-aggregation stabilized the triplet excitons through enhancing intersystem crossing process, in pursuit of ultralong phosphorescence at room temperature with lifetime up to 1.35 s (Figure 6B).\(^{[43]}\) On the other hand, Li and coworkers introduced the boric acid units to form strong intermolecular hydrogen bonds, which could largely restrict the molecular motion, thus resulting in the ultralong RTP lifetime of 2.24 s in PBA–MeO (Figure 6C).\(^{[44]}\) Further on, they found that the intermolecular \( \pi-\pi \) stacking could prolong the RTP lifetime of phenothiazine 5,5-dioxide derivatives with the decreased phosphorescence radiative and nonradiative rates (Figure 6D).\(^{[45,46]}\) More excitingly, their intermolecular \( \pi-\pi \) stacking in solid state could be partially controlled through rational molecular design, in which the introduction of electron withdrawing groups could decrease the electron cloud density of \( \pi \)-system, thus promoting \( \pi-\pi \) stacking and the resultant RTP lifetime.

Besides crystal engineering, the development of host–guest doping system was also an efficient way to realize ultralong RTP emission.\(^{[47–51]}\) In 2017, Kabe and Adachi successfully realized a long persistent luminescence more than 1 h in a host–guest doping system, which could be even comparable to the most outstanding inorganic phosphors (Figure 7A).\(^{[47]}\) In their system, the host material of
PPT acted as electron donor and guest of TMB as electron acceptor. Upon photo-excitation, the long-lived charge-separated state of exciplex between TMB and PPT could be formed, thus resulting in the ultralong luminescence lifetime. Further on, Liu and coworkers introduced the similar mechanism to explain the RTP effect of carbazole derivatives (Figure 7B).\cite{49} They discovered that the presence of a carbazole isomeric impurity (Bd) in commercial carbazole sources, with concentrations less than 0.5 mol%, was the main origin for the RTP emission of carbazole systems, as the long-lived charge-separated state could be formed between carbazole derivatives and corresponding isomers, just like CPhBd to CPhCz and DPhBdT to DPhCzT. On the other hand, Li and coworkers innovatively utilized the distance-sensitive Förster resonance energy transfer (FRET) to develop efficient RTP system with stimulus-response characteristic (Figure 7C).\cite{50} In their system, the DMAP with rigid crystal environment was selected as host/energy donor, and Cdp with potential RTP emission acted as guest/energy acceptor. As shown in Figure 7C, although no obvious RTP emission could be observed for individual DMAP or Cdp sample, their cocrystal with mass ratio of 100:1 presented ultralong green phosphorescence. Further on, grinding or heating the mixtures of DMAP and Cdp could also lead to the turn-on RTP effect for the promoted FRET process between them. Based on them, the application of encrypted thermal printing was realized for the first time, showing great practical potential. All these works have well indicated the significance of intermolecular interactions in RTP effect, further certifying the accuracy of the “MUSIC” concept.

**Through-space interaction**

Besides the intermolecular interaction, the intramolecular through-space interaction could also largely affect the emission property of organic molecules.\cite{52,53} In the early time, it was believed that the development of highly efficient fluorophores relied on high electronic conjugation greatly. Thus, most of the earlier studies were carried out based on the strict $\pi$-conjugated systems. With time going on, it was found that some organic molecules with nonconjugated structures could also show bright emission in visible region.\cite{54} As shown in Figure 8, for $s$-TPE, although the four peripheral phenyl rings were linked by a nonconjugated C–C bond, strong blue emission peaked at 467 nm could be realized in solid state with fluorescence quantum efficiency up to 69%, which even surpassed most of the conjugated one.\cite{1} Theoretical calculations showed that the twisting angle of phenyl rings attached to the same carbon atom in $s$-TPE increased to about 90° in the excited state and the distance between them was short enough to form an almost cofacial dimer structure. With this structure, the electron clouds of the associated two phenyl rings were delocalized in the excited state, thus resulting in the through space conjugation (TSC). As for compound $s$-TPE-TM, it possessed much weaker TSC than $s$-TPE due to the crowded structure, which could be verified by its short emission peak at 397 nm. Based on this work, the significant role of TSC in the promotion of emission property could be well proved.

In addition to promote the emission efficiency and color, through-space interaction also showed great potential in...
realizing other special luminescent properties, including TADF. Great contribution has been made by Liao and coworkers in the development of TADF luminogens based on through-space charge transfer. As shown in Figure 9, in their work, three kinds of D/A pairs, namely, fixed D/A, flexible D/A, and distant D/A, were built with 10-phenyl-9,10-dihydroacridine as donor and 2,4,6-triphenyl-1,3,5-triazine as acceptor. When they were connected by a rigid linker of fluorene to form a fixed D–A pair, efficient electronic coupling between the donor and acceptor units could be formed. With...
it, the minimized energy gap between $S_1$ and $T_1$, as well as the efficient TADF emission, were both well realized in compounds DM-B, DM-Bm, and DM-G. Accordingly, the OLEDs based on them presented excellent EL performance with EQEs up to 27.4%, 21.7%, and 18.5%, respectively. If the rigid linker of fluorene was replaced by flexible one of diphenylmethane to yield DM-X, the PL/EL efficiency would be largely decreased for the intensive nonradiative motion. As for DM-Z with distant D/A pair, no charge transfer could be realized between donor and acceptor for their long distance, then resulting in the non-TADF effect. Thus, the through-space electronic interaction, as a unique intramolecular interaction, is indeed an important means to regulate the optoelectronic property of organic luminogens.

Nonaromatic emission

As presented above, the through-space interaction could lead to bright emission for nonconjugated $\pi$-system, as it promoted the electronic coupling and conjugation of the adjacent aromatic units. Similarly, some nonaromatic compounds were also found to show visible emission in aggregate for the efficient intermolecular electronic coupling. For these compounds, the heteroatoms of N, O, S, P, etc. were frequently presented, since the lone pair electrons of them could contribute much to the electronic coupling effects, such as hydrogen bonding, $\pi$–$\pi$ coupling, $n$–$\pi$ coupling (Figure 10A). It was believed that the intermolecular $\pi$–$\pi$ and $n$–$\pi$ couplings could generate electron delocalization by orbital overlap and largely extend the conjugation, while strong hydrogen bonds restricted nonradiative motion, thus leading to the visible emission in aggregate for nonaromatic systems. As shown in Figure 10B, because of the existence of O/P heteroatoms, the nonaromatic compound of NDP1 showed a bright blue emission in concentrated solution with the formation of aggregates. Furthermore, Yuan and coworkers observed the fluorescence–phosphorescence dual emissions in a series of amino acid solids (Figure 10C), although the corresponding phosphorescence lifetimes were rather short, less than 0.1 ms.

In 2018, Li and coworkers reported the first example of a nonaromatic pure organic small molecule with persistent RTP property. As shown in Figure 11, compound CAA containing N/O heteroatoms presented an obvious blue emission under 365 nm UV irradiation, while a green afterglow appeared after turning off the UV light. The RTP decay curve at 506 nm clearly showed an ultralong emission lifetime up to 862 ms, which was even longer than most of the aromatic RTP materials. To make clear the internal mechanism, the single crystal structure of CAA was carefully analyzed. It was found that intermolecular hydrogen bonds with $d_{O-O} = 2.6337$ Å existed between the adjacent two carboxy groups, which was much shorter than the threshold value of strong hydrogen bond ($d_{O-O} = 3.2$ Å). This could largely increase the molecular rigidity and lead to the minimized nonradiative motion. On the other hand, a layered molecular packing was formed through self-assembly of hydrogen bonds, and the interlayer spacing was measured to be as short as 3.0225 Å. With this packing mode, the extended through-space delocalization and conjugation of electron clouds could be well realized for the intermolecular $n$–$\pi$ and $\pi$–$\pi$ electron couplings. At last, the persistent RTP emission appeared in CAA crystal. Thus, similar to aromatic luminogens, the nonaromatic ones could also show diverse emission properties upon aggregation, regardless of their nonconjugated molecular structures, further certifying the wide applicability of “MUSIC” concept.
FIGURE 10  (A) The proposed mechanism of non-aromatic emission; (B) PL behavior of NDP1 in methanol solution with concentration of 2 mg mL\(^{-1}\);[60] (C) PL behaviors of a series of amino acids in solid state[61]

FIGURE 11  (A) The fluorescence and phosphorescence spectra of CAA crystal at room temperature; (B) the RTP decay curve of CAA crystal; (C) the single crystal structure of CAA. Reproduced with permission.[62] Copyright © 2019, Royal Society of Chemistry

**Mechanoluminescence (ML)**

For some organic solids, a light emission could be directly induced by mechanical stimulus, such as grinding, rubbing, or shaking. Accordingly, this light-emitting process was termed as ML.[63,64] Since its first discovery in sugar in 1605,[64] the research of ML has drawn much attention for the great potential applications in pressure sensor, signal transmission, heartbeat monitor, and so on. However, the ML emissions from traditional organic materials were rather weak and hard to meet the demand of practical applications, as well as the exploration of internal mechanism. Until 2015, the marriage of ML and AIE opened up a new door to dramatically enhance ML emission in organic luminogens.[1,32] As shown in Figure 12A, Chi and coworkers developed an unsymmetrical AIE luminogen of SPFC, whose PL efficiency could be up to 93.3% in solid state for the largely restricted nonradiative transition.[32] Accordingly, a bright green emission could be observed upon mechanic stimulus on it. Similarly, Tang and coworkers observed the bright ML emission in an organometallic complex of Cu-TBP-I with AIE effect, further certifying the AIE effect as an efficient way to promote bright ML emission (Figure 12B).[1] Moreover, the ML intensity of Cu-TBP-I could be enhanced with the increase
in force strength, indicating their positive correlation, which provided a foundation of pressure sensing application for ML materials.

Inspired by the great promotion of AIE effect in the development of bright ML luminogens, more and more scientists devoted themselves into this field.\[68-72\] Within just a few years, a series of bright ML materials have been developed with the similar strategy. Based on them, the internal mechanism was carefully studied and deeply understood, especially for the relationship between molecular packing and ML emission (Figure 13). For example, Li and coworkers successfully cultured two crystalline polymorphs for one AIE luminogen of TMPE, in which, one was ML active and the other was not (Figure 13A).\[73\] Through careful comparison of their single crystal structures, it was found that the strong intermolecular interactions played the key role in the achievement of ML effect, as it could largely reduce the possible energy loss via nonradiative motion during the mechanical stimulus. On the other hand, Chi and coworkers reported a new AIE luminogen of CDpP with different ML colors in two crystalline polymorphs, further disclosing the great influence of molecular packing in ML property (Figure 13B).\[74\] For examples, Xu and coworkers successfully observed a yellow “afterglow ribbon” lasting for about 1 s in both the PL and ML processes for the ImBr crystal with H-aggregation;\[78\] Zhang and coworkers realized persistent RTP through both photo-irradiation and mechanical action on CX crystal with intermolecular n–π electronic coupling;\[79\] Li and coworkers reported a fluorene derivative with tricolor ML emissions, for the existence of persistent mechanophosphorescence leading by strong Br–Br interactions.\[80\] Based on these results, it could be well demonstrated that just like in the PL and EL processes, inherent energies like the singlet (S) and triplet (T) states also exist in the ML process.

Besides internal mechanism, the exploration of practical application for ML is also very important. However, almost of the organic ML could only be realized in crystal state, while it become weak and even disappeared upon the

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**FIGURE 12** (A) The molecular structure and mechanoluminescence (ML) behavior of SFPC with AIE effect. Reproduced with permission.\[32\] Copyright © 2015, WILEY VCH. (B) The molecular structure, AIE and ML behaviors of Cu-TBP-I. Reproduced with permission.\[1\] Copyright © 2015, American Chemical Society.
FIGURE 13  (A) The relationship between molecular packing and ML effect based on TMPE. Reproduced with permission.[73] Copyright © 2016, Royal Society of Chemistry. (B) The relationship between molecular packing and ML color based on CDpP. Reproduced with permission.[74] Copyright © 2018, Royal Society of Chemistry. (C) The relationship between chirality and ML effect based on (R)-lmNT, (S)-lmNT, and their mixture. Reproduced with permission.[75] Copyright © 2019, Royal Society of Chemistry. (D) The relationship between molecular conformation and ML color based on FCO-CzS[76]

FIGURE 14  (A) The mechanophosphorescence behavior of DPP-BO with AIE effect.[77] (B) Some typical strategies to develop organic luminogens with persistent mechanophosphorescence[78–80]
continuous stimulus. This has largely limited its applications. Thus, to develop organic materials with bright and long-held ML emission was of great importance. Until 2020, Li and coworkers successfully realized it through innovatively utilizing the self-assembly of molecules (Figure 15).[81] In their work, the AIE building block of triphenylethylene (tPE) and thiophene (Th) units with self-assembly potential were integrated into one luminogens, with the aim to realize the both bright and long-held ML emission under continuous mechanical stimulus. Taking tPE-2-Th as an example, it could show bright blue ML emission after grinding heavily for more than 1 min. Based on it, the quantitative relationship between ML intensity and force strength was successfully built: the higher the pressure, the stronger the emission. Accordingly, flexible and wearable ML devices were fabricated based on the small crystals of tPE-2-Th. With them, the applications of encrypted communication, information storage, impact strength warning, and heartbeat detection were all successfully realized. In particular, when the ML device was attached to the wrist, the ML signal could well correspond to the human heartbeat: nearly no ML signal as heart rate less than 120 beats/min, weak ML signal (<10) at 150 beats/min and higher, than the user defined threshold value as heart rate more than 180 beats/min. Based on it, a quick response to the human heartbeat could be easily achieved, thus offering a new approach for the monitoring of force stimulus in daily life.

**SUMMARY AND PERSPECTIVES**

Herein, the research of AIE has demonstrated vigorous vitality. With just about 20 years of development, great progresses have been achieved from molecular design, mechanism exploration, and material application. Particularly, some other solid state luminescence behaviors that were derived from or parallel to AIE were carried out, including AIDF, RTP, ML, nonaromatic fluorescence and phosphorescence, TSC. These have largely enriched the content of AIE effect, and expanded it from a simple luminescent phenomenon to broad range of integrated disciplines related to aggregate. At this time, aggregation science should be a better concept to represent these studies, as nearly all of them happened in aggregate and showed the obvious “MUSIC” effect. Thus, for the further development, the adjustment of molecular packing or intermolecular interactions would be of great importance.
For single-component luminescent materials, the adjustment of molecular packing would be mainly relied on the rational design of molecular structure. As different packing modes may benefit different emissive properties, the corresponding molecular design strategy should be also changed. For examples, AIE effect was mainly realized in the systems without π–π stacking, thus the molecules with twisted molecular conformation should be a good choice. In some cases, the intermolecular π–π stacking would be helpful, such as excimer emission and persistent RTP emission. At this case, the molecules with planar conformation would be better. Further on, additional electron-withdrawing substituent could be introduced to the π system to lower the corresponding electron cloud density at the surface, thus to decrease the intermolecular π–π repulsion and promote the final π–π stacking. Besides, the strong intermolecular hydrogen bonds could contribute to most of the emissive behaviors for the restricted intramolecular motion and resultant nonradiative transition. Thus, the introduction of heteroatoms (N, O, F, etc.) should be useful. On the other hand, to culture single crystal of organic luminogens in different environments, including temperatures and solvents, was also frequently utilized to adjust the molecular packing of same molecules, regardless of its uncertainty.

As for multicomponent luminescent materials, the intermolecular interactions between the different components should be paid more attentions. For examples, the FRET system relied on matched energy level and short intermolecular distance between energy donor and acceptor, thus to realize energy transfer between them. Also, the formation of exciplex needed the effective intermolecular interaction between energy donor and acceptor. Thus, to shorten the distance between different components should be the key point for multicomponent luminescent materials. To realize it, two main strategies could be applied: one was to employ components with planar conformation favoring close packing, the other was to integrate electron-donor and acceptor into one system to promote their interaction through electrostatic effect. Further on, the high-pressure technology was also an efficient way to shorten the intermolecular distance, thus promoting the corresponding luminescent behaviors.

The luminescent behaviors in solid state are indeed more complicated than that in solution, and that is part of the appeal for aggregation science. Thus, more and more scientists have devoted themselves into the research of it in recent years.\[82–91\] Especially, Ruren Xu and coworkers proposed “Towards a new discipline of condensed matter chemistry” in 2018.\[82,83\] It is believed that after constant exploration, the molecular structure—packing property relationship could be revealed clearly and the adjustment of luminescence property in aggregation state could be easily realized from the source of molecular design.

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