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Isophthalate-Based Room Temperature Phosphorescence: From Small Molecule to Side-Chain Jacketed Liquid Crystalline Polymer

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Supporting Information

ABSTRACT: Isophthalate with the simple chemical structure is identified as an effective phosphor for room temperature phosphorescent (RTP) materials. With -Br, -CH₃, and $-CH=CH_2$ at the 5-position of the benzene ring of didecyl isophthalate, the three crystalline small molecules of DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂ demonstrate ultralong RTP with lifetime of 236, 650, and 184 ms, respectively, although no specific interactions are recognized in the crystals. Radical polymerization of DDIP-CH=CH₂ readily results in Poly-1, which is the first RTP liquid crystalline polymer.



Direct attachment of isophthalate phosphor to every repeating unit of polyethylene backbone through a single carbon-carbon bond leads to a significant side-chain jacketing effect, greatly reducing the motion of phosphor moieties. Poly-1 renders a columnar LC phase constructed by parallel packing of the supramolecular column that is composed of two Poly-1 chains. In the column, the isophthalate phosphor is confined in between the core of polymer backbones and the shell of decyl tails, and thus the nonradiative process is further suppressed. The materials design of Poly-1 can be widely applied for developing new RTP polymers.

■ INTRODUCTION

Phosphorescence, a specific type of photoluminescence (PL) originated from the radiative transition from the excited triplet state to the ground singlet state, has attracted considerable attention due to its fundamental importance and applications in the field of optoelectronics, $f^{1,2}$ displays, 3 biological imaging, $^{4-6}$ information storage and security, $^{7-9}$ and so forth. Up to now, room temperature phosphorescence (RTP) is mainly limited to metal-containing complexes.^{10,11} Pure organic phosphorescence is scarcely found at room temperature due to the forbidden nature of intersystem crossing (ISC, from excited singlet state to triplet state), nonradiative vibrations, and external quenching of triplet excitons.^{12,13} Compared with metal-containing phosphors, pure organic RTP materials have the advantages of low cost, good processability, appreciable stability, and good biocompatibility.¹⁴ Recently, significant progress has been achieved in the field.^{9,13,15–28} Most of the works reported are based on two strategies: (1) enhancing the ISC from excited singlet state to triplet state and (2) prohibiting the nonradiative process of the

excited triplet state.^{12,23,28} Many fascinating organic RTP phosphors have been designed and successfully synthesized. The crystalline structures that can endow the rigid environment to the small molecules have been empha-sized.^{9,15-17,19,20,22-24,29-31} Hydrogen bonding,^{20,32-34} halogen bonding,¹⁶ $\pi - \pi$ interactions,²⁴ and other strong intermolecular interactions are introduced to increase the molecular rigidity and thus to reduce the nonradiative vibrations. Meanwhile, strong intermolecular interactions, such as H-aggregation^{9,35} and electron coupling,²² have also been employed to obtain persistent and efficient organic RTP in an ambient environment.

A very interesting question is whether the strong intermolecular interactions are necessary to suppress the nonradiative process of the triplet state of phosphors, considering that they are often absent in ordinary crystals of

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small molecules. If not, we can greatly expand the scope of exploration of organic RTP materials. Along this line, one may further ask when using other confinements that are less rigid than crystal, for instance, introducing phosphors to polymers or to liquid crystals, whether the materials can still present RTP properties. Organic small molecular crystals usually have problems such as poor mechanical property and cycling performance, which in fact limit their commercialization. In this context, polymeric RTP systems become a fascinating choice for problem-solving, although the crystalline structure may be sacrificed. The phosphor molecules can be doped in a polymer matrix or be introduced as the minor portion of side groups into amorphous polymers.^{36–41} Intriguingly, it is recently reported that amorphous poly(styrenesulfonic acid),⁴² crystalline poly(lactic acid)-based polymer,⁴³ and poly(ethylene terephthalate)⁴⁴ are RTP materials. The suppression of nonradiative vibrations is realized through the hydrogen bonding cross-linked networks or crystalline structures. While the progress of polymer-based RTP materials is remarkable, new and rational design of RTP polymers is still highly desired.

In this work, we first investigated whether ordinary organic crystals without strong intermolecular interactions could produce phosphorescence at room temperature (RT). Isophthalic acid (IPA) has been reported to have persistent and efficient RTP.²⁰ We designed and synthesized a series of isophthalate derivatives, namely DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂ (Scheme 1), with a bromine atom, a methyl

Scheme 1. Chemical Structures of DDIP-Br, DDIP-CH₃, DDIP-CH=CH₂, and Poly-1 and Synthetic Route of Poly-1



group, and a vinyl group at the 5-position of the benzene ring, respectively. All these molecules in the crystal phase show persistent phosphorescence with lifetimes of 236, 650, and 184 ms at RT, respectively, though no strong intermolecular interactions are found in their molecular packing. The result indicates that isophthalate is a simple but effective phosphor for RTP materials. More interestingly, we obtained a RTP polymer, Poly-1, by radical polymerization of DDIP-CH= CH₂, which shows a lifetime of 22.3 ms and PL efficiency of 13.6%. Here, the molecular design of Poly-1 actually adopts the concept of side-chain jacketing effect;⁴⁵⁻⁴⁷ namely, the isophthalate phosphors are directly connected to the polyethylene backbone through a single carbon-carbon bond. The resultant polymer has the main chain strongly coupled with the side chain, and thus the side-chain motion is restricted in a great extent. Moreover, it is important that Poly-1 can form a columnar liquid crystalline (LC) phase that can provide

confined environment for the phosphors. To the best of our knowledge, this is the first reported RTP liquid crystalline polymer (LCP). As a typical soft matter, the LCP without very rigid environment imposed on the phosphor moieties has excellent processability and appreciable mechanical properties.

RESULTS AND DISCUSSION

Synthesis. DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂ were facilely synthesized through esterification reaction from IPA derivatives with high yields (see the Supporting Information), and the chemical structures were fully characterized using ¹H NMR, ¹³C NMR, mass spectrometry, and elemental analysis (Figures S2–S5, Supporting Information). Poly-1 with number-average molecular weight of ~10⁵ g mol⁻¹ (measured using gel permeation chromatography calibrated by polystyrene standards) was obtained by radical polymerization of DDIP-CH=CH₂. The polymer product was purified by being dissolved in THF and then precipitated with methanol for several times. The detailed synthetic route and characterization are shown in the Supporting Information.

Photophysical Properties in Solution. The photophysical properties of DDIP-Br, DDIP-CH₃, and DDIP-CH₂ in solution were investigated by UV-vis and steady-state fluorescence spectroscopy (Figures S9–S11). In dichloromethane (DCM) dilute solution, the absorption spectra of DDIP-Br and DDIP-CH₃ are similar. DDIP-Br shows two absorption peaks with similar intensity at 293 and 302 nm, respectively. The absorption of DDIP-CH₃ is slightly blue-shifted because of the electron-donating effect of methyl group. For DDIP-CH=CH₂, there exists obviously red-shifted absorption due to the conjugation between the vinyl group and benzene ring. Meanwhile, fluorescence spectra in DCM dilute solutions of DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂ show emission peaks of 319, 312, and 343 nm, respectively.

RTP Behaviors of DDIP-Br. It is interesting that all the three small molecules show RTP properties. DDIP-Br can form a spindle-shaped crystal and shows blue-violet emission upon the illumination of a 365 nm UV lamp and green afterglow that last for more than 4 s after the UV lamp was turned off (Figure 1e). Figure 1a depicts its photoluminescent and phosphorescent spectra in the solid state at RT, of which the excitation wavelengths were selected based on the excitation spectra (Figures S11 and S12). With a delay time (t_d) of 5 ms, the maximum emission of DDIP-Br crystal is at 520 nm with quantum yield of 8.2% (Table 1). Time-resolved photoluminescent measurement determines that the phosphorescence lifetime is up to 236 ms (Figure 1d). Different from that showed in the fluorescence spectrum of solution, the DDIP-Br crystal emission presents not only a peak at 329 nm but also with a long tail ranging from 370 to 600 nm when excited at 280 nm. This indicates that the RTP property is limited to its solid sample. When temperature dropped to 77 K, the glassy DCM solution of DDIP-Br shows very bright blue phosphorescence with the emission peak at 440 nm (Figure 1a) because the cryogenic temperature can inhibit the molecular motion. At 180 K, the phosphorescence lifetime of DDIP-Br crystals is 394 ms. The prolonged phosphorescence lifetime at lower temperature confirms the triplet feature. Temperature-dependent phosphorescence measurements show the intensity decreasing with increasing temperature, supporting that the emission is phosphorescence rather than delayed fluorescence (Figure S14).



Figure 1. Photophysical properties of DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂. (a-c) PL spectra of DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂ under different conditions. Including fluorescence of DCM solution at 293 K (black line, excited at 280 nm), phosphorescence of DCM solution at 77 K (green line, excited at 280 nm, $t_d = 5$ ms), PL of crystal at 293 K (red line, excited at 280 nm), and phosphorescence of crystal at 293 K (blue line, excited at 320 nm for DDIP-Br and DDIP-CH₃ and at 345 nm for DDIP-CH=CH₂, $t_d = 5$ ms). (d) Phosphorescence decay profiles at RT for the crystals of DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂. (e) Photographs of DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂ taken before and after removal of excitation source and their phosphorescence quantum yields and lifetimes.

Table 1. Photophysical Data of DDIP-Br, DDIP-CH₂, DDIP-CH=CH₂, and Poly-1 in Solid State

compound	$\lambda_{\rm ex}^{\ a}$ (nm)	$\lambda_{\mathrm{PL}}{}^{a}$ (nm)	$\Phi_{ ext{PL}}{}^{a}$ (%)	$\lambda_{\mathrm{Phos}}{}^{a}$ (nm)	$ au_{ m Phos}{}^{a}~(m ms)$	$\Phi_{ ext{Phos}}{}^{a}$ (%)
DDIP-Br	273	329	11.4	520	236	8.2
DDIP-CH ₃	285	314	10.1	505	650	5.6
DDIP-CH=CH ₂	289	347	6.3	610	184	1.7
Poly-1	280/365	389/470	13.6	550	22	2.7

 ${}^{a}\lambda_{ex}$: photoluminescence excitation peaks; λ_{PL} : photoluminescence emission peaks; Φ_{PL} : absolute photoluminescence quantum yields; λ_{Phos} : phosphorescence emission peaks; τ_{Phos} : phosphorescence lifetimes; Φ_{Phos} : phosphorescence quantum yields.

Compared with that observed from the solution, the emission of DDIP-Br crystal with obvious red-shift indicates that the phosphorescence in crystal state is related to the molecular packing. DDIP-Br single crystal was analyzed, of which the result indicates a triclinic structure. In the crystal, the molecular core of benzene ring and carbonyls are coplanar, and the two alkyl tails with trans-conformation reach out to two opposite directions. Figures 2a and 2b show that the extended planar molecules can assemble into a sheet-like structure. In the sheet, one row of molecules is aligned along the direction of dipole at the molecular center, and the adjacent rows present the dipole with the opposite direction, giving an antiparallel arrangement. Unlike the short distance (e.g., 2.86 Å) of strong halogen bonding reported,¹⁶ the distance between one bromine atom and the two neighboring oxygen atoms on the carbonyl groups are 3.43 and 4.92 Å, respectively, indicating only the weak halogen bond. In the crystal, the "sheets" are stacked together (Figure 2c), wherein the distance between two adjacent sheets is 3.33 Å. However, the sheets glide along the a-axis relative to each other. Consequently, the distance between neighboring benzene rings

in the adjacent sheets is 8.41 Å, and thus no $\pi-\pi$ interactions can form. Worth to mention here is that although there are no strong intermolecular interactions in the crystal of DDIP-Br, the molecular packing scheme can still effectively suppress the nonradiative transition, demonstrated by the persistent phosphorescent emission.

The phosphorescent property of DDIP-Br was also confirmed by theoretical calculations. The molecular energy level in both singlet and triplet excited states of isolated molecule in gas phase was calculated by time-dependent density functional theory (TD-DFT). Estimation of molecular energy level in crystal state was performed by the combined quantum mechanics and molecular mechanics (QM/MM) method. The detailed calculation can be found in the Supporting Information. Figure 3 shows the energy level diagrams of DDIP-Br molecule in gas and crystal phase, respectively. The results are in good agreement with the emission wavelengths of the PL spectra in dilute solution and crystal. From gas to crystal phase, the energy levels of the lowest singlet state and triplet state decrease, which is consistent with the trend of red-shifted emission wavelength.

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Figure 2. (a-c) Single-crystal structure and molecular packing of DDIP-Br.



Figure 3. Energy level diagrams of DDIP-Br in gas and crystal phase.

In the crystal phase, the energy gap between the lowest singlet ($E_{S1} = 4.10 \text{ eV}$) and the triplet ($E_{Tm} = 3.97 \text{ eV}$) is much closer, which enhances the singlet-triplet ISC process.

RTP Behaviors of DDIP-CH₃ and DDIP-CH=CH₂. Note that the chemical structure of DDIP-Br is consistent with the design principles of RTP molecules. The two aromatic carbonyl groups can facilitate the transition of $n-\pi^*$ and thus the ISC process. Meanwhile, the bromine atom at the 5position of benzene ring will further promote the spin-orbit coupling through heavy atom effect. It is interesting that when the bromine atom is replaced with methyl or vinyl group, the resultant DDIP-CH₃ and DDIP-CH=CH₂ also show ultralong RTP (Figure 1e). The DDIP-CH₃ crystal possesses the phosphorescence emission in a wide region ($\lambda_{max} = 505$ nm, Figure 1b) with a lifetime of 650 ms and quantum yield of 5.6% (Table 1), along with the PL maximum emission at 314 nm. Compared to DDIP-Br, DDIP-CH₃ shows an apparently prolonged phosphorescence lifetime and decreased quantum yield, consistent with the influence of heavy atom effect on increasing quantum yield by sacrificing phosphorescence lifetime. The phosphorescence spectrum of DDIP-CH=CH₂ looks more complicated (Figure 1c). Except for the maximum emission at about 610 nm corresponding to a red

phosphorescence emission, there are more shoulder peaks at near 655 nm, suggesting the presence of more than one emission species. The phosphorescence lifetime at 610 nm is 184 ms, and the phosphorescence quantum yield is 1.7% (Table 1). Comparison of the emission wavelengths suggests that from DDIP-CH=CH₂ to DDIP-Br to DDIP-CH₃ the blue shifts of emission may be due to the increased electron-donating ability of the substituent.

The single-crystal structure of DDIP-CH₃ (Figure S22) shows that its molecular packing is almost identical to that of DDIP-Br. For DDIP-CH=CH₂ crystal, a similar packing behavior could be found (Figure S23). The theoretical calculations of energy levels can support the experimental observations of DDIP-CH₃ and DDIP-CH=CH₂ (Tables S3 and S4, Figures S24 and S25). From the gas to crystal phase, the energy levels of the lowest singlet state and triplet state of DDIP-CH₃ and DDIP-CH=CH₂ decrease, consistent with the trend of red-shifted emission wavelength. For DDIP-CH₃ and DDIP-CH₂ in crystal phase, the energy gap between the lowest singlet and the triplet is also closer, resulting in the observed RTP.

On the basis of the results obtained from the small molecules with different substituents, we consider that the phosphorescence shall come from isophthalate. The unsubstituted didecyl isophthalate (DDIP-H) is a liquid at room temperature and shows no RTP. When cooled to below its melting point (280 K), such as 263 K, ultralong phosphorescence with a lifetime of 1.37 s is observed (Figure S19). This outcome further illustrates that isophthalate, which just possesses the simple chemical structure, is an effective phosphor. It should be noted that although the strong intermolecular interactions are absent in the small molecular crystals studied here, the quantum yields measured are comparable to that of the typical organic RTP molecules such as IPA, terephthalic acid, 4,6-diphenyl-2-carbazolyl-1,3,5-triazine, and so forth.^{9,20}



Figure 4. (a) PL spectra of Poly-1 under different conditions, including fluorescence of DCM dilute solution at 293 K (black line, excited at 280 nm), PL of solid at 293 K (red line, excited at 365 nm), and phosphorescence of solid at 293 K (blue line, excited at 365 nm, $t_d = 5$ ms). (b) Phosphorescence decay profiles for the solid of Poly-1 at RT. (c) Photographs of Poly-1 with different shapes obtained by molding under room light and 365 nm UV lamp.

among phosphors in the crystals of the isophthalates are far enough to reduce quenching.

RTP Properties of Poly-1. Inspiringly, when the phosphor of isophthalate was attached to every repeating unit of polyethylene backbone through a single carbon–carbon bond, namely, after polymerization of DDIP-CH= CH_2 , the resultant Poly-1 is also RTP-active. We consider that it shall be attributed to both the chemical structure and molecular packing of Poly-1, which are essentially different from that of the small molecules we studied.

We compared the photophysical properties of Poly-1 with that of DDIP-CH₃ that can be viewed as a model compound for Poly-1. The absorption spectra of the DCM dilute solution of Poly-1 show that the maximum absorption wavelengths locate at 289 and 296 nm (Figure S9), similar to that of DDIP-CH₃. However, as shown in Figure 4a, the DCM dilute solution of Poly-1 with a monomer concentration of $\sim 10^{-4}$ M excited at 280 nm presents the fluorescence emission peak at 388 nm, which is significantly red-shifted compared with the emission wavelength of DDIP-CH₃ (Figure 1b). A similar difference is also found in the PL spectra of solid DDIP-CH₃ and Poly-1 (Figure S10) excited at 280 nm. This phenomenon should be derived from the particular placement of pendant groups on the polymer chain of Poly-1. Note that the isophthalate phosphors are directly connected to every repeating unit of the polyethylene main chain; namely, the phosphors are tightly anchored together along the backbone. Consequently, even in the dilute solution the single chain looks like a cluster of phosphors, wherein some degree of $\pi - \pi$ interactions may exist among the neighboring isophthalate groups. This will lead to the red-shifted emission.

The particular chemical structure of Poly-1 can cause multiple interaction modes between the isophthalate phosphors. As different luminescent species are formed, the emission wavelength varies with the excitation wavelength. In the solid state, the maximum excitation wavelength peaks at 365 nm (Figure S17). When excited with a 365 nm UV lamp, the solid Poly-1 demonstrates a strong emission peak located at 470 nm, which in fact corresponds to the cyan emission shown in Figure 4c. On the contrary, under 365 nm excitation, dilute DCM solution of Poly-1 showed a detectable PL spectrum; however, its quantum yield is very low (<0.01%), and thus the solution is basically nonemissive. Therefore, in solution the cluster-like structure of phosphors of Poly-1 still possesses many pathways of nonradiative transition. To turn on phosphorescence of Poly-1, condensed packing of chains is required. For solid Poly-1, the absolute emission quantum yield of total photoluminescence is 13.6% (Table 1). In the phosphorescence spectra, the maximum emission peaks at 550 nm. The phosphorescence lifetime is measured to be 22 ms at RT (Figure 4b), and the phosphorescent quantum yield is 2.7% (Table 1), confirming the RTP feature of Poly-1.

For pure organic phosphors, promoted spin-orbit coupling is essential to the RTP behavior. This can be achieved in polymers using the isophthalate with two carbonyl groups as the side chain. On the other hand, suppression of the vibrational dissipations is also crucial for RTP. In general, when the rigid environment of phosphor is relaxed, the RTP phenomenon will be turned off.³⁶ Poly-1 is different from the reported RTP polymers. As described above, the isophthalate phosphors in Poly-1 surround densely and tightly the polymer backbone. Conceivably, this chemical structure itself can help



Figure 5. (a) 2D XRD pattern of an oriented Poly-1 film recorded at RT with X-ray beam perpendicular to the stretching direction. (b) Reconstructed relative electron density map of Poly-1.



Figure 6. (a, b) Molecular model of Poly-1 in columnar LC phase. (a) Top view of double-chain supramolecular column of Poly-1. (b) Two backbones of Poly-1 at the column center and side group attached to the backbone (for clarity, only one side group is shown for each Poly-1 chain). (c) Some intermolecular interaction modes among isophthalate cores in the supramolecular column.

restricting intramolecular motion of phosphors. Worthy to emphasize here is that Poly-1 can form columnar LC phase,^{48,49} which takes advantage of the side-chain jacketing effect in liquid crystalline polymers. Figure 5a depicts the twodimensional X-ray diffraction (XRD) pattern of a Poly-1 sample orientated by stretching. The diffractions up to the fourth order, of which the scattering vector ratio follows $1:3^{1/2}:4^{1/2}:7^{1/2}$, are clearly recognized along the direction perpendicular to the stretch direction, indicating a rather perfect packing of hexagonal structure. The lattice parameter a is 2.90 nm. Detailed structure analysis indicates that two chains of Poly-1 self-assemble into a supramolecular column, which is the building block of columnar phase.⁴⁹ An important feature of this supramolecular column is the nanosegregation along radial direction. Shown in Figure 5b is the relative electron density map calculated based on the XRD result. It is identified that the core (yellow colored) and shell (blue colored) of the column possess the intermediate and lowest electron density, respectively, corresponding to the polyethylene backbones and the decyl tails. Consequently, the phosphors of isophthalate

have to be located between the main chain core and alkyl shell (see Figures 6a and 6b). The supramolecular arrangement imposes the confinement on the phosphors, further restricting the molecular motion. As a LC polymer, Poly-1 is a typical soft matter. It is interesting that the way to suppress nonradiative transitions in Poly-1 is different from that of the crystal. Although more or less soft, it is sufficient to turn on RTP emission. We note that the LC structure is essential to this type of RTP polymer based on isophthalate. We synthesized a polymer analogous to Poly-1, just using hexyl to replace decyl. This polymer cannot form LC phase, and no RTP behavior was observed (Figure S21).

We used Materials Studio to model the molecular packing in the double-chain supramolecular column of Poly-1. Figure 6 shows the results after energy minimization. The top view (Figure 6a) indicates the column diameter of 2.9 nm, in agreement with the XRD result. Figure 6b depicts that the two Poly-1 backbones at the column center are quite extended along the columnar axis, and the side chains are largely perpendicular to the backbone. We are interested in the

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arrangement of isophthalate moieties unveiled by the modeling. It is found that they adopt planar conformation and can form $\pi-\pi$ interactions among each other, as shown by Figure 6c. In the 2D XRD pattern (Figure 5a), a diffraction at 0.38 nm observed along the stretch direction shall come from the side chains of Poly-1, manifesting the existence of $\pi-\pi$ interaction within the supramolecular column. As the neighboring isophthalate cores in the column may form dimers or a sort of J-aggregation structure (Figure 6c), the PL of Poly-1 red-shifts when compared with the small isophthalate molecules studied.⁵⁰ On the other hand, the type of crowded phosphor packing promotes RTP.

Poly-1 demonstrates excellent processability. A variety of self-supporting shapes can be easily prepared, and it can be highly oriented by stretching or shearing (Figures 4c and 5a). Another interesting phenomenon is that although the phosphorescence intensity of Poly-1 gradually weakens during heating, it persists until the polymer enters the isotropic state at around 90 °C. In other words, when the LC phase remains, the phosphorescence can be detected even at the temperature much higher than RT (Figure S20). This result further elucidates that the LC phase of Poly-1 plays a crucial role in the generation of RTP. As mentioned above, the phosphorescent quantum yield of Poly-1 is not high at RT, probably because the polymer is soft with a pretty low glass transition temperature. The active alkyl tail motion may also induce nonradiative transition of the isophthalate phosphor. We anticipate that introducing some specific molecular interactions (e.g., hydrogen bonding) or cross-links into the supramolecular columns of Poly-1 can make a more rigid environment to the isophthalate phosphors and thus improve the RTP performance of Poly-1. The research of better RTP liquid crystalline polymers is underway in our laboratory.

CONCLUSIONS

In summary, we have studied the RTP materials based on isothphalate phosphor, including both small molecule and polymer. Ultralong RTP is recognized in the three isophthalate derivatives, i.e., DDIP-Br, DDIP-CH₃, and DDIP-CH=CH₂. Single-crystal analysis reveals that the small molecules are packed together only based on conventional van der Waals interactions. Namely, without strong intermolecular interactions, the crystals can provide enough restriction to suppress the nonradiative vibration, leading to the ultralong RTP. We anticipate that many other pure organic phosphors without specific intermolecular interactions can also render RTP properties. We polymerized the vinyl monomer of DDIP-CH=CH₂. The resultant Poly-1 is the first example of RTP polymer with LC structure. As isophthalate units are directly attached to polyethylene backbone at every repeating unit, the side-chain jacketing effect reduces the molecular motion. Meanwhile, the columnar LC structure endows the phosphor with nanoconfined environment. The significance of Poly-1 is that instead of crystal or strong hydrogen bonding network, LC phase can also be employed to realize RTP. It opens up new possibilities for the design and preparation of RTP polymers. Proper selection of side chains bearing phosphor moieties may synergistically enhance the RTP performance and the thermal and mechanical properties of the LCPs. This will prompt more RTP materials with practical applications to emerge. Considering the orientation of LCPs, this research may pave the way to pure organic room temperature polarized phosphorescent materials.

ASSOCIATED CONTENT

S Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.macro-mol.9b00171.

Experimental details of synthesis, characterization, photophysical data, single-crystal data and calculational data (PDF) Video S1 (AVI)

Video S1 (AVI) Video S2 (AVI)

Video S3 (AVI)

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Notes

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