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1. Introduction

Flat-on ambipolar triphenylamine/C₆₀ nano-stacks formed from the self-organization of a pyramid-sphere-shaped amphiphile[†]

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A giant amphiphile, which is constructed with an amorphous nano-pyramid (triphenylamine, TPA) and a crystalline nano-sphere (C₆₀), was synthesized. Structural characterization indicates that this pyramidsphere-shaped amphiphile (**TPA-C**₆₀) forms a solvent-induced ordered phase, in which the two constituent units self-assemble into alternating stacks of two-dimensional (2D) TPA and C₆₀ nanosheets. Due to the complexity of the molecular structure and the amorphous nature of the nanopyramid, phase formation was driven by intermolecular C₆₀-C₆₀ interactions and the ordered phase could not be reformed from the **TPA-C₆₀** melt. Oriented crystal arrays of **TPA-C₆₀**, which contain flaton TPA/C₆₀ nano-stacks, can be obtained *via* a PDMS-assisted crystallization (PAC) technique. The flaton dual-channel supramolecular structure of **TPA-C₆₀** delivered ambipolar and balanced chargetransport characteristics with an average μ_e of 2.11 × 10⁻⁴ cm² V⁻¹ s⁻¹ and μ_h of 3.37 × 10⁻⁴ cm² V⁻¹ s⁻¹. The anisotropic charge-transport ability of the pyramid-sphere-shaped amphiphile was further understood based on the lattice structure and the lattice orientation of **TPA-C₆₀** revealed from electron diffraction analyses.

Giant amphiphiles are synthesized by covalently binding various nm-sized molecular building blocks (or so-called molecular nanoparticles (MNPs)).¹ Their self-assembly processes are driven by competitive or cooperative physical interactions among the MNPs and are largely influenced by the preferred packing scheme of the constituent MNPs. The giant amphiphiles contain a wide range of emerging materials^{1,2} such as sphere-cube,¹ sphere-board,^{3–5} sphere-disc,^{6–19} discoticrod,^{20,21} cube-disk,²² and cube-board²³-shaped amphiphiles. Among these giant molecules, those built with p-type and n-type conjugated moieties have attracted much attention, because of their potential applications as active units in supramolecular optoelectronics.^{5,24,25}

Giant molecules can be constructed from crystalline mesogenic, quasicrystalline and amorphous MNPs,²⁶ but so far, most giant amphiphiles are made with MNPs that are intrinsically crystalline. Triphenylamine (TPA)-based conjugated molecules are widely used in organic light emitting diodes (OLEDs),^{27,28}

of their good morphological stability and p-type semiconducting characteristics. However, they are rarely reported as MNPs of giant amphiphiles, probably due to their nonplanar structure and amorphous nature.27,28 The incorporation of this pyramidal nano-building block raises interesting questions, such as whether the self-organization of a giant amphiphile will be compromised due to the presence of an amorphous nanopyramid, or on the other hand, whether the amorphous nanopyramid will self-organize because the other MNP of the giant amphiphile tends to crystallize. To explore these questions, a giant pyramid-sphere-shaped amphiphile, TPA-C₆₀, which is constructed with the amorphous nano-pyramid (TPA) and the crystalline nano-sphere (C_{60}) , was designed and synthesized based on Steglich esterification and copper-catalyzed azidealkyne cycloaddition (CuAAC), as shown in Scheme 1. The phase behavior and phase structure of TPA-C₆₀ were investigated via differential scanning calorimetry (DSC) and electron diffraction (ED). The field effect transistor (FET) characteristics of TPA-C₆₀ were evaluated with oriented TPA-C₆₀ crystal arrays prepared via the PDMS-assisted crystallization (PAC) method.³¹ The results show that the pyramid-sphere-shaped amphiphile selforganized into an ordered phase containing stacks of alternating two-dimensional (2D) C60 and TPA nanosheets. Moreover, this dual-channel supramolecular structure of TPA-C₆₀ delivered ambipolar and balanced charge-transport characteristics in organic field-effect transistors (OFETs). Previous

polymer solar cells (PSCs),29 and perovskite solar cells,30 because

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Scheme 1 Synthetic route of TPA-C₆₀. Reagents and conditions: (i) 8-azidooctan-1-ol, copper(II) sulfate pentahydrate, sodium ascorbate, THF/ $H_2O(1/1, v/v)$; (ii) *p*-toluenesulfonic acid, 4-dimethylaminopyridine, 1-(3-dimethylaminopropyl)-2-ethylcarbodiimide hydrochloride, CS₂.

studies showed that TPA and C_{60} have preferable physical interactions and tend to form a mixed TPA/ C_{60} domain in the solid-state.³²⁻³⁴ However, with respect to functions, the mixed TPA/ C_{60} domain is not conducive to ambipolar charge transport. Our study thus gives the first example of flat-on ambipolar TPA/ C_{60} nano-stacks obtained *via* the self-organization of a pyramid-sphere-shaped amphiphile.

2. Results and discussion

2.1. Synthesis of TPA-C₆₀

Scheme 1 shows the synthetic route of TPA-C₆₀. 4-Ethynyl-N,Ndiphenylaniline, 8-azidooctan-1-ol, and fullerenoacetic acid (C₆₀-COOH) were synthesized according to the literature.³⁵ Reacting 4-ethynyl-N,N-diphenylaniline with 8-azidooctan-1-ol via the CuAAC reaction allowed the formation of a p-type pyramid unit, 8-(4-(triphenylamino)-1H-1,2,3-triazol-1-yl)octan-1-ol (TPA-OH) in 67% yield. The final product, TPA-C₆₀, was then synthesized in 74% yield by reacting TPA-OH and C₆₀-COOH via Steglich esterification. TPA-C₆₀ was characterized by ¹H NMR, ¹³C NMR, and mass spectrometry. As shown in Fig. S1,† the formation of TPA-C₆₀ was identified by the downfield shift of the methylene protons of TPA-OH (denoted as H_a in Fig. S1[†]) and the appearance of a methine proton (H_b in Fig. S1b[†]) at $\delta = 4.88$ ppm, which belongs to the C₆₀ moiety. The multiple peaks between $\delta = 135$ and 145 ppm in the ¹³C-NMR spectrum of TPA-C₆₀ (Fig. S2b[†]), are also characteristic of the sp^2 carbons on the mono-adduct C_{60} moiety. Furthermore, as shown in Fig. S3,[†] the $[M + H]^+$ peak of the final product has an m/z value of 1201.267, which matches well with the calculated monoisotopic mass (1201.24 Da). All the results clearly indicate the success of the reaction and confirm the chemical identity and purity of TPA-C₆₀.

2.2. Thermal stability and phase transition

After vacuum drying using a cryo pump, thermogravimetric analysis (Fig. S4a[†]) showed a 5% weight loss temperature of TPA-C₆₀ at 388 °C. As shown in Fig. S4b,[†] an additional weight loss peak at 131 °C was observed for a TPA-C₆₀ sample that was only vacuum dried under a mechanical pump. The results indicate that the as-precipitated TPA-C₆₀ contains residual solvent molecules that can be removed under high vacuum. DSC was then applied to identify the phase behaviour of the two MNPs and the pyramid-sphere-shaped amphiphile. As shown in Fig. S5a,† 4-ethynyl-N,N-diphenylaniline shows an endothermic first-order transition at 108 °C during the 1st heating, suggesting that the as-precipitated sample self-organized into an ordered phase. However, a corresponding exothermic transition in the subsequent cooling was not observed, indicating that 4-ethynyl-N,N-diphenylaniline was vitrified rather than crystallized during the cooling process. Consequently, in the 2nd heating (Fig. S5b[†]), the endothermic transition at 108 °C disappeared. As shown in Fig. S5c,[†] TPA-OH exhibits only a glass transition temperature at 10 °C. Thus, the results show the easily disturbed self-organization behaviour of the TPA unit, i.e. although 4-ethynyl-N,N-diphenylaniline self-organizes from the solution, this behaviour is lost in the melt and when a flexible alkyl group is attached. For TPA-C₆₀, three first-order transitions at 190, 226 and 239 °C were found in the 1st heating curve of TPA-C₆₀ (Fig. S5d[†]), indicating that TPA-C₆₀ packs into an ordered solid-state structure. The multiple transitions suggest that instead of directly transforming into the isotropic melt, the ordered phase of TPA-C60 may lose its structural order (conformational, orientational, and positional orders) in a stepwise way. In the cooling curve, no exothermic peak was observed, indicating that although self-organization of TPA-C₆₀ from solution is possible, reforming the ordered packing from the melt is difficult, probably due to the structural complexity of TPA-C₆₀. In short, the DSC results revealed the amorphous nature of the alkylated TPA nano-pyramid and the crystalline characteristics of the TPA-C₆₀ amphiphile. More importantly, it was found that the amorphous alkylated nano-pyramid (TPA) can self-assemble under the assistance of favourable intermolecular interactions among the crystalline nano-spheres (C₆₀).

2.3. Phase morphology of TPA-C₆₀

TPA-C₆₀ tends to form tiny crystals in drop-cast thin films. To obtain crystals large enough for device fabrication and to introduce better crystal orientation, the PAC method³¹ was applied to produce a crystal array of TPA-C₆₀. Fig. 1 shows TPA-C₆₀ films obtained from different solvents. As shown in Fig. 1a and b, the crystal sizes were small when TPA-C₆₀ was processed from *m*-xylene and CS₂ solutions. However, the bright blue or yellow POM images suggested that TPA-C₆₀ has birefringence and structural order in the cast films. Large crystalline TPA-C₆₀ sheets were obtained from o-dichlorobenzene (ODCB) and 1,2,4-trichlorobenzene (TCB) solutions (Fig. 1c and d). Intriguingly, as shown in Fig. S6,† the color of the crystalline sheet was only observed when the incident light was polarized (Fig. S6c and d[†]) and the crystal does not turn dark even when its growth direction is along the polarization direction of the polarizer or the analyzer. A similar phenomenon was observed in the blue phases of highly chiral liquid crystals.36 The origin of the blue or yellow POM images of TPA-C₆₀ falls outside the scope of the current study and will be investigated separately.

The AFM topography and cross-section profiles in Fig. 2 show that the TPA-C₆₀ film prepared from ODCB solution is a polycrystalline thin film with a very rough surface (max. thickness \sim 80 nm), but the one prepared from TCB solution has an insignificant crystalline boundary and a uniform surface (thickness \sim 150 nm). The crystal array prepared from TCB was further examined with transmission electron microscopy (TEM) and electron diffraction (ED). Similar to the AFM result, the TPA-C₆₀ crystal has a uniform appearance in the TEM image (Fig. 3a). The clear diffraction spots in the ED pattern (Fig. 3b) are evidence of the formation of an ordered solid-state structure, and more importantly, the well-oriented crystal lattices in the TPA-C₆₀ crystal array formed by the PAC method. These morphological characterization methods thus confirmed that the pyramid-sphere-shaped amphiphile, TPA-C₆₀, can assemble into an ordered phase, and a good lattice orientation can be induced via the PAC method.



Fig. 2 AFM topography and cross-section profiles of TPA- C_{60} processed via the PAC method with ODCB (a) and (b) and TCB (c) and (d).

2.4. Phase structure of TPA-C₆₀

Due to the structural complexity, preparation of a large single crystal of TPA-C₆₀ for single-crystal structural characterization was difficult. In addition, the ED patterns along different zone axes are still useful for revealing the 2D lattice projections of the **TPA-C**₆₀ crystal. Using the drop-cast sample, a^*b^* and the b^*c^* reciprocal lattices (Fig. 4b and c) were observed. The lattice parameters deduced from Fig. 4b are a = 22.8 Å, b = 10.7 Å, $\gamma =$ 90°; and from Fig. 4c are b = 10.7 Å, c = 51.0 Å, and $\alpha = 90^{\circ}$. The measured density of the TPA-C₆₀ crystal is 1.28 g cm⁻³. Assuming that $\beta = 90^{\circ}$, the density provides the information that the orthorhombic lattice (a = 22.8 Å, b = 10.7 Å, c = 51.0 Å, $\alpha = \beta = \gamma = 90^{\circ}$) contains 8 **TPA–C₆₀** molecules per unit cell. The powder X-ray diffraction (XRD) pattern of TPA-C₆₀ is shown in Fig. S7.[†] The theoretical *d*-spacings of various lattice planes calculated from the abovementioned lattice parameters also match the measured ones (Table S1[†]). Furthermore, the (100) and (010) diffractions in Fig. 4b are significantly weaker than the (200) and (020) diffractions, suggesting that in the lattice, the electron density on the (100) planes is close to that on the (200) planes and that on the (010) planes is similar to that on the (020) planes. A lattice model was then built using the Cerius² software package, based on the abovementioned information,



Fig. 1 POM images of TPA- C_{60} processed via the PAC method with different solvents. (a) m-Xylene, (b) CS₂, (c) ODCB, and (d) TCB.



Fig. 3 (a) TEM image and (b) the enlarged ED pattern of the $TPA-C_{60}$ crystal array prepared *via* the PAC method using TCB as solvent.



Fig. 4 ED patterns of $TPA-C_{60}$ crystal prepared from (a) the PAC method, (b) and (c) by drop-casting. Projections of the a*b* and the b*c* reciprocal lattices can be observed in (b) and (c).

and is shown in Fig. 5. The simulated ED patterns (Fig. S8†) generated from the [001] and [100] zones of the model resemble the experimental ones in Fig. 5, showing the validity of the model. The lattice of **TPA–C₆₀** features a dual-channel structure containing continuous but separated 2D n-type C₆₀ sheets and p-type TPA sheets (Fig. 5b). It is noteworthy that the C₆₀-to-C₆₀ distance along the *a* axis (11.4 Å) is different from that along the *b* axis (10.7 Å). The ED pattern of the crystal array prepared by PAC (Fig. 4a) shares the zone axis, [001], with the pattern in Fig. 4b. Thus, it is confirmed that in the PAC method, the growth direction of the crystal array is along the *b* axis of the **TPA–C₆₀** lattice, and the 2D C₆₀ and TPA sheets adopt a flat-on orientation of the substrate.

2.5. Optical and electrochemical properties

The UV-Vis absorption spectrum and cyclic voltammogram (CV) of **TPA–C₆₀** are shown in Fig. S9 and S10.[†] For comparison, the absorption spectra and the CVs of [6,6]-phenyl-C₆₁-butyric acid methyl ester (PCBM) and **TPA-OH** are also included in the figures. As shown in Fig. S6,[†] the absorption maximum of **TPA–**C₆₀ is similar to that of PCBM. The slightly stronger absorption at 315 nm was attributed to the TPA moiety of **TPA–**C₆₀.



Fig. 5 The lattice model of $TPA-C_{60}$. (a) The *ab* and the *bc* lattice projections and (b) the projection view of the lattice.

Fig. S10[†] shows three reversible reductions and one oxidation. The reduction potential, oxidation potential, and HOMO and LUMO energies of the three compounds are summarized in Table S2.[†] The HOMO and LUMO energies of **TPA-C**₆₀ are close to the HOMO energy of **TPA-OH** and the LUMO energy of PCBM, suggesting that the C₆₀ and TPA moieties of **TPA-C**₆₀ retain their individual characteristics in the molecule.

2.6. OFET performance

The charge transport properties of the oriented TPA-C₆₀ crystal arrays prepared by the PAC method were investigated in OFET devices with a bottom-gate, top-contact configuration. Because the ED results confirmed that the *b* lattice axis of TPA- C_{60} is parallel to the crystal growth direction induced by PAC, as shown in Fig. 6, the source and drain electrodes were arranged parallel or perpendicular to the growth direction, so that the anisotropic charge-transport characteristics of the TPA-C₆₀ crystal arrays along the a and b axes could be studied. The output and transfer plots of the best-performing device are shown in Fig. 7. The TPA-C₆₀ crystal array demonstrated the pchannel characteristics under a negative gate-to-source voltage (V_{GS}) (Fig. 7a) and the n-channel characteristics under a positive $V_{\rm GS}$ (Fig. 7b). The hole mobilities ($\mu_{\rm h}$ s) and electron mobilities $(\mu_{e}s)$ deduced from the transfer plots of the devices in saturation regimes are summarized in Table 1. The averaged $\mu_{\rm b}s$ values are $3.37 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ for the parallel devices and $5.43\,\times\,10^{-5}~\text{cm}^2~\text{V}^{-1}~\text{s}^{-1}$ for the perpendicular devices. In the database we have searched, the highest OFET $\mu_{\rm h}$ of a TPA-star burst conjugated molecule was around 3 \times 10 $^{-4}$ cm 2 V $^{-1}$ s $^{-1}$ 37 Thus, the 2D sheets of TPA in the TPA-C₆₀ crystal array retained their hole-transporting ability and delivered one of the best $\mu_{\rm h}$ values among the triarylamine-based molecules. On the other hand, the 2D sheets of the mono-adduct C60 delivered averaged $\mu_{e}s$ values of 2.11 \times 10⁻⁴ cm² V⁻¹ s⁻¹ for the parallel devices and 3.54 \times $10^{-5}~\text{cm}^2~\text{V}^{-1}~\text{s}^{-1}$ for the perpendicular devices. Thus, the TPA-C₆₀ crystal array has ambipolar charge transport characteristics and delivers balanced hole and electron charge mobilities. Moreover, the anisotropic charge-transport characteristics of the TPA–C₆₀ crystal array are obvious, because the $\mu_{\rm h}$ and μ_e values along the growth direction (b lattice axis) are about one order of magnitude higher than those perpendicular to the growth axis (a lattice axis). The difference can be attributed to shorter TPA-TPA and C_{60} - C_{60} distances along the *b* axis,



Fig. 6 OM images of the TPA-C₆₀ OFET devices with the gold (Au) source and drain electrodes arranged (a) parallel and (b) perpendicular to the crystal growth direction.



Fig. 7 The output (up) and transfer (down) characteristics of the TPA– C₆₀ crystal arrays under (a) negative V_{GS} and (b) positive V_{GS} .

Table 1 OFET characteristics of the TPA-C₆₀ crystal arrays^a

	$\begin{array}{l} \mu_{\rm e \ average} \\ \left({\rm cm}^2 \ {\rm V}^{-1} \ {\rm s}^{-1} \right) \end{array}$	$I_{\rm on}/I_{\rm off}$	$V_{\rm th}$ (V)	$ \begin{array}{c} \mu_{\rm h \ average} \\ \left({\rm cm}^2 \ {\rm V}^{-1} \ {\rm s}^{-1} \right) \end{array} $	$I_{\rm on}/I_{\rm off}$	V _{th} (V)
Parallel Perpendicular	$2.11 imes 10^{-4} \ 3.54 imes 10^{-5}$	$\begin{array}{c} 3 \times 10^4 \\ 1 \times 10^1 \end{array}$	32 16	$3.37 imes 10^{-4} \ 5.43 imes 10^{-5}$	$\begin{array}{c} 6 \times 10^3 \\ 2 \times 10^3 \end{array}$	$-22 \\ -15$
^{<i>a</i>} The μ s values of the parallel devices were averaged from 8 devices, and those of the perpendicular device were averaged from 6 devices.						

as shown in the *ab* lattice projection in Fig. 5a. The lower μ_e of the **TPA–C₆₀** crystal array compared to the best-performing C₆₀ OFETs may be related to the longer C₆₀–C₆₀ distance and the lower coordination number of C₆₀s in the **TPA–C₆₀** crystal lattice.^{31,38} In addition, the smeared ED pattern in Fig. 4a suggests a certain degree of orientational disorder in the crystal array, which is also detrimental to the μ_e .

3. Conclusions

In summary, a synthetic route for a giant amphiphile (TPA-C₆₀), which is constructed with an amorphous pyramid (TPA) and a crystalline sphere (C_{60}) , was developed. DSC results show that the pyramid-sphere-shaped amphiphile forms a solventinduced ordered phase, because of the strong crystalline nature of the C₆₀ moiety. Structural characterization confirmed that $\textbf{TPA-C_{60}s}$ self-assemble into separated 2D C_{60} and TPA sheets in the ordered phase. Processing by the PAC method produced oriented crystal arrays of TPA-C₆₀. ED results indicate that the 2D C60 and TPA sheets adopt a flat-on orientation on the substrate with the *b* lattice axis pointing in the crystal growth direction. The flat-on n-type C₆₀ nano-sheets and p-type TPA nano-sheets provide electron and hole-transporting channels. Ambipolar and balanced charge-transport characteristics were delivered by the TPA-C₆₀ crystal arrays in OFET devices. The dual-channel supramolecular structure of TPA-C₆₀ delivered an averaged μ_e of 2.11 \times 10 $^{-4}$ cm 2 V $^{-1}$ s $^{-1}$ and a μ_h of 3.37 \times 10 $^{-4}$

cm² V⁻¹ s⁻¹. The $\mu_{\rm h}$ is comparable to the best-performing triarylamine-based p-type conjugated molecules, whereas the modest $\mu_{\rm e}$ delivered by the C₆₀ nano-sheets was attributed to the longer C₆₀–C₆₀ distance, the lower C₆₀ coordination number in the **TPA–C₆₀** crystal lattice and the less orientational order of the **TPA–C₆₀** crystal array, compared to the pristine C₆₀ crystals. Although a 2D crystal array of C₆₀ has been recently disclosed,³⁹ our study revealed the first example of a dual-channel selforganized structure and the ambipolar characteristics of a novel giant pyramid-sphere-shaped amphiphile.

4. Experimental section

4.1. General measurement and characterization

UV-Vis experiments were carried out using a HITACHI U-4100 spectrophotometer with a 10⁻³ M solution concentration in odichlorobenzene. The cyclic voltammetry (CV) data were analyzed with a CH Instruments Model 611D with a carbon glass serving as the working electrode and an Ag/Ag⁺ electrode as the reference electrode, with 0.1 M tetrabutylammonium hexafluorophosphate (Bu_4NPF_6) as the electrolyte and 10^{-2} M of the desired compound dissolved in o-dichlorobenzene. Thermogravimetric analysis (TGA) was conducted on a Perkin-Elmer Pyris under an inert atmosphere with a heating rate of 10 °C min⁻¹ and differential scanning calorimetry (DSC) was performed on a TA O200 Instrument at a temperature ramp rate of 5 °C min⁻¹. For 1D XRD patterns, a Bruker APEX DUO single crystal diffractometer and an APEX II CCD camera equipped with a INCOATEC 18 kW rotating I microfocus X-ray generator (Cu Ka radiation (0.1542 nm)) were used. Transmission Electron Microscopy (TEM) observations were performed on a JEOL JEM-2010 transmission electron microscope with an accelerating voltage of 160 kV and a Gatan-831 CCD camera. Crystal simulation and drawing were based on a Cerius² software product from Accelrys.

4.2. OFET fabrication

A n-type heavily doped Si wafer with a SiO₂ layer of 300 nm and a capacitance of 11.5 nF cm⁻² as the gate electrode and dielectric layer was ultrasonically cleaned sequentially in detergent, water and isopropyl alcohol. N-Octadecyltrichlorosilane (ODTS) was used as a self-assembled monolayer. The TPA-C₆₀ crystal arrays were prepared via the PDMS-assisted crystallization (PAC) method.31 The gold source and drain electrodes (40 nm in thickness) were then deposited on the organic layer by vacuum evaporation through a shadow mask, affording a bottom-gate, top-contact device configuration. OFET measurement was carried out at room temperature under a nitrogen atmosphere using an Agilent Technologies 4156C instrument. The mobility calculation was based on the equation $I_{\rm ds} = (W/2L)\mu C_{\rm i}(V_{\rm g} - V_{\rm t})^2$ in the saturation regime, where $I_{\rm ds}$ is the drain-source current, W is the channel width (1 mm), L is the channel length (100 μ m), μ is the field-effect mobility, C_i is the capacitance per unit area of the dielectric layer, $V_{\rm g}$ is the gate voltage, and V_t is the threshold voltage.

4.3. Synthesis

All chemicals were purchased from Aldrich, Acros or TCI and used as received unless specified otherwise. ¹H and ¹³C NMR spectra were obtained in deuterium-substituted chloroform, $CDCl_3$, as the reference with 0.5 wt% TMS, using Varian 400 MHz spectrometers.

4.4. 8-(4-(Triphenylamino)-1*H*-1,2,3-triazol-1-yl)octan-1-ol (TPA-OH)

To a solution of 4-ethynyl-N,N-diphenylaniline 3 (0.5 g, 1.86 mmol), copper(II) sulfate pentahydrate (0.046 g, 0.184 mmol) and sodium ascorbate (0.11 g, 0.56 mmol) was added 8-azidooctan-1-ol 5 (0.382 g, 2.23 mmol) in THF/H₂O 50 ml (1/1, v/v). The reaction mixture was stirred at room temperature for 3 hours then extracted with dichloromethane and water. The organic layer was collected and dried with MgSO4. After removal of the solvent under reduced pressure, the residue was purified by silica gel chromatography with ethyl acetate/hexane (1/3, v/v)as the eluent to give a beige solid (0.55 g, 67%). ¹H NMR (400 MHz, CDCl₃): δ 1.31–1.34 (m, 8H), 1.54 (t, 2H, J = 7 Hz), 1.93 (t, 2H, J = 7 Hz), 3.62 (t, 2H, J = 6.6 Hz), 4.37 (t, 2H, J = 7.2 Hz), 7.02 (t, 2H, J = 7.2 Hz), 7.12 (d, 6H), 7.24 (d, 2H), 7.26 (d, 2H), 7.66 (d, 2H), 7.69 (s, 1H). ¹³C NMR (CDCl₃, 100 MHz): δ 25.6, 26.4, 28.9, 29.1, 30.3, 32.6, 50.3, 62.9, 118.8, 123.0, 123.8, 124.5, 124.7, 126.6, 129.3, 147.5, 147.7. MS (EI, C28H32N4O): calcd, 440.58; found, 440.5.

4.5. 8-(4-(Triphenylamino)-1*H*-1,2,3-triazol-1-yl)octyl acetate C_{60} (TPA- C_{60})

To a solution of C₆₀-COOH (70 mg, 0.09 mmol), p-toluenesulfonic acid (17 mg, 0.09 mmol), 4-dimethylaminopyridine (11 mg, 0.09 mmol) and 1-(3-dimethylaminopropyl)-2-ethylcarbodiimide hydrochloride (17 mg 0.09 mmol) was added 8-(4-(triphenylamino)-1H-1,2,3-triazol-1-yl)octan-1-ol (60 mg, 13.6 mmol) in carbon disulfide (20 ml), the reaction mixture was stirred at room temperature for 12 hours. After removal of the solvent under reduced pressure, the residue was purified by neutral aluminum oxide chromatography with toluene to give a brown solid (79 mg, 74%). ¹H NMR (400 MHz, $CDCl_3$): δ 1.30– 1.59 (m, 8H), 1.85 (t, 2H, J = 7.4 Hz), 1.95 (t, 2H, J = 7.4 Hz), 4.38 (t, 2H, J = 7.2 Hz), 4.45 (t, 2H, J = 6.6 Hz), 4.78 (s, 1H), 7.02 (t, J = 6.6 Hz), 7.02 (t, J2H, J = 7.2 Hz), 7.10 (d, 6H), 7.24 (d, 2H), 7.26 (d, 2H), 7.67 (d, 2H), 7.69 (s, 1H). ¹³C NMR (CDCl₃, 100 MHz): δ 25.9, 26.4, 28.6, 30.0, 30.4, 39.1, 50.3, 66.4, 70.6, 77.2, 118.8, 123.0, 123.8, 124.5, 124.8, 126.6, 129.3, 136.4, 140.4, 140.9, 141.1, 142.0, 142.1, 142.2, 142.4, 142.8, 143.0, 143.1, 143.2, 143.7, 143.9, 144.4, 144.6, 144.7, 145.0, 145.1, 145.2, 145.3, 145.6, 145.8, 147.5, 147.6, 147.7, 148.3, 166.4; MS (C₉₀H₃₂N₄O₂): calcd, 1201.24; found (FAB), 1200.9; found (MALDI-TOF), 1201.267.

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