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AIE-active mechanochromic materials based N-phenylcarbazol-substituted tetraarylethene for OLED applications

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Multifunctional optoelectronic materials are important in both theoretical and practical application aspects. In this study, three luminogen-based N-phenylcarbazol-substituted tetraarylethene, namely NPCE, MeNPCE and MeONPCE, were designed and synthesised via Friedel–Crafts acylation and McMurry coupling reaction. All of the luminogens show typical aggregation-induced emission (AIE) characteristics with high solid-state efficiency of up to 83%. The dyes also exhibit excellent thermal stability (T_d of up to 434 °C) and prominent morphological stability. In addition, only MeONPCE reveals obvious mechanochromism (emission wavelength change of up to 64 nm). This proved introduce methoxy group in one of the phenyl rings at para position can easily obtain mechanochromic materials. The organic light-emitting diodes (OLEDs) that use these dyes as nondoped emission layer emit cyan light with current efficiency and external quantum efficiency of 7.87 cd A^{-1} and 3.87%, respectively. In comparison, the mutilayer organic light-emitting diodes adopting MeONPCE as nondoped emission layer revealing that MeONPCE is an eximious p-type light emitter.

Introduction

Organic fluorescent dyes have drawn considerable attention because of their unique photochemical properties. Efficient organic fluorescent materials have been designed and synthesised for application in various fields, such as chemosensors and organic light-emitting diodes (OLEDs).[1-7] However, most traditional dyes suffered from the thorny aggregation-caused quenching (ACQ) problem due to molecular aggregation. Therefore, most practical applications of organic fluorescent materials were restricted, especially for optoelectronics and biophotonics.[8-11] Fortunately, Tang's group discovered an intriguing aggregation-induced emission (AIE) phenomenon compared with ACQ effect; AIE dyes are more efficiently emit in the aggregated state than in the dissolved form. The AIE phenomenon is caused by the restriction of intramolecular rotations (RIR) in the aggregated solid, which offers the possibility to obtain high solid-state efficiency and an active area of research for their potential applications.[12-14]

Recently, a great deal of attention is being paid to the AIE-active mechanochromic materials and electroluminescence materials. On the one hand, solid emitters that show changes in fluorescence colour upon mechanical stimuli can be applied in memory chips, sensors, camouflaging security inks and other optoelectronic devices because of their fundamental importance and potential applications.[7, 15-19] AIE molecules with propeller-like twisted conformation can bring about loose molecular packings, which are easily destroyed under external mechanical stimuli, resulting in changes of fluorescence colour.[16] Hence, AIE-active compounds have been considered as a well of mechanochromic materials. On the other hand, AIE molecules exhibit high solid fluorescence quantum efficiency owing to restrictinintramolecular motion, which is helpful to enhance the maximum external quantum efficiency (EQE_{max}) of light emitting layer in OLEDs. Normally, AIE-active luminogens, even nondoped OLEDs, exhibit great performance owing to their high solid-state efficiencies.[20-22]

Although AIE-active mechanochromic or electroluminescence luminogens are no longer novel materials after years of wide investigation, multifunctional optoelectronic materials with AIE-active, mechanochromic and electroluminescence are rarely found. To achieve a multifunctional optoelectronic material, herein, one N-phenylcarbazol-substituted tetraarylethene luminogens, namely MeONPCE (Chart 1), was designed and synthesised. Carbazole units in MeONPCE will facilitate on possessing electroluminescence and hole-transporting properties.[23, 24] More importantly, methoxy groups can influence packing pattern of MeONPCE on the solid state, thereby easily obtaining mechanochromic materials by conversion of morphology or polymorphs, and enhancing solid state emission by restricting rotation of intramolecular[25, 26]. For comparison, NPCE and MeNPCE were also designed and synthesised (Chart 1).

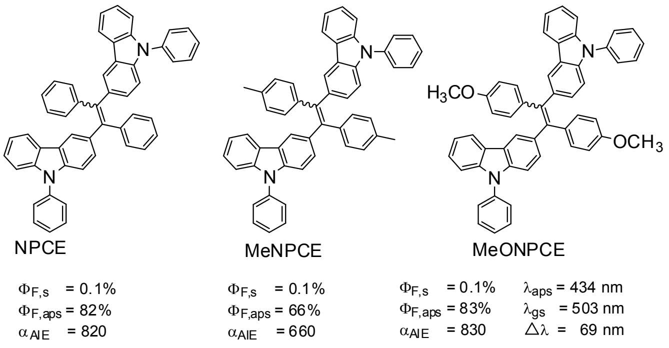

Chart 1 Chemical structures and photophysical properties of NPCE, MeNPCE and MeONPCE; λ_{aps} and λ_{gs} stand for the maximum emission wavelength of as prepared solid and ground solid, $\Phi_{F,s}$ and $\Phi_{F,aps}$ stand for the quantum efficiencies of the dye molecules in dilute solution and in as prepared solid, α_{AIE} stand for the corresponding AIE factors.

Three compounds exhibit typical AIE-active, excellent thermal stability and high solid-state photoluminescence quantum yields (PLQY) of up to 83%. The organic light-emitting diodes utilizing these dyes as light emitter and hole transporter simultaneously emit cyan light with current efficiency and *EQE* of 7.87 cd A^{-1} and 3.87%, respectively. As ~~was~~ expected, MeONPCE also shows distinct mechanochromism (emission wavelength change of up to 64 nm), the hole-transporting properties as well as 4,4'-bis [N-(1-naphthyl)-N-phenyl-amino] biphenyl (NPB).

Results and discussion

Synthesis

The molecular structures of the three new AIE luminogens were designed. Scheme S1 shows the synthetic route of the carbazole-containing AIE luminogens NPCE, MeNPCE and MeONPCE. Firstly, the Friedel-Crafts acylation of benzoyl chloride derivatives and 9-phenyl-carbazole synthesised 1a–1c (Scheme 1),[27] which were ~~then~~ converted into three target compounds by a Zn/$TiCl_4$-catalysed McMurry coupling reaction afterwards.[28, 29] All of the intermediates and final products were carefully purified and fully characterized by NMR and mass spectroscopy, from which satisfactory data corresponding to the expected molecular structures were obtained. Details of the synthetic procedures and characterization data were presented in the ESI. McMurry coupling of NPCE, MeNPCE and MeONPCE resulted in two different isomers with a ratio of about 1:1 calculated from the ^1H NMR spectra. All of the luminogens are soluble in common organic solvents, such as tetrahydrofuran, chloroform toluene and dichloromethane, but are insoluble in water.

Optical properties

When the target compounds were dissolved in pure THF solvent, no visible light was observed under UV light, whereas their aggregated powders emitted bright yellow-green light and blue light. The emission spectra of the luminogens were further determined in THF and THF/water mixtures. Water was used because it is a typical poor solvent for the target compounds in which they are aggregated. The target compounds are almost non-fluorescent in pure THF solutions (10 μM). As depicted in Fig. 1A, at water fractions (f_w) ≤ 60%, the fluorescence intensity of MeONPCE shows extremely weak signals, which is attributed to the dissolved luminogens with active intramolecular rotations. When the water fraction is increased to 70%, the emission intensity of MeONPCE increases because the solvating power of the mixture is worsened, thereby leading to molecular aggregation. The molecular aggregation can result in planarized conformations, which generate increased effective conjugation lengths, thus producing much redder emissions.[30] (Fig.1A). Moreover, the mixture polarity has also a little impact on spectral shift for D-π-D conjugated molecules. At a f_w of 90%, the emission is significantly strengthened by <144-fold compared with that in pure THF (Fig. 1B). Moreover, the contrast images given in the inset of Fig. 1B shows that its AIE nature. Similar phenomena are also observed in NPCE and MeNPCE, with an emission enhancement of >111- and 102-fold with 90% water content compared with those in THF (Fig. S9 and S10). Clearly, the emission of luminogens is induced by aggregate formation. In a dilute solution, the rotation of multiple phenyl rings effectively consumes exciton energies and the nonluminescent molecules in solutions. In the aggregated state, the restriction of RIR allows the dye molecules to emit intensely. However, aqueous mixtures have no precipitate in the macroscopic view, indicating that the aggregates are nanodimensional. To prove this point, transmission electron microscope (TEM) images were obtained (Fig. S11) and the absorption of the luminogens in THF and THF/water mixtures were tested. As shown in Fig. S12, their absorption spectra show obvious level-off tails at the long-wavelength region with high water content, which is due to the scattering effect of the luminogen nanoparticles.[31, 32]

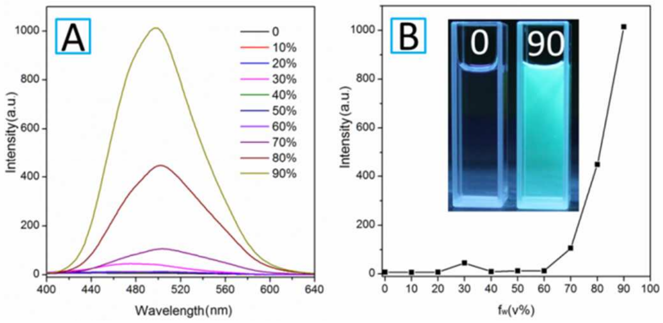

Fig. 1 (A) Emission spectra of MeONPCE in THF and THF/water mixtures with varying water fractions (f_w). (B) Emission intensity increase of MeONPCE in different aqueous mixtures. Concentration: 10 μM; excitation wavelength: 360 nm. The photographs in (B) are MeONPCE in THF and 10/90 THF-water mixture taken under 365 nm UV light illumination.

To evaluate the emissions quantitatively, the quantum efficiencies of the dye molecules in dilute solution ($\Phi_{F,s}$) and in as-prepared solid ($\Phi_{F,aps}$) states were further investigated. The $\Phi_{F,s}$ values of NPCE, MeNPCE and MeONPCE are as low as 0.1%, 0.1% and 0.1%, respectively, which were estimated in THF using quinine sulfate ($\Phi_{F,s}$ = 54% in 0.1 N H_2SO_4) as standard. However, the $\Phi_{F,aps}$ of NPCE, MeNPCE and MeONPCE, which were measured using a calibrated integrating sphere, are as high as 82%, 66% and 83%, respectively, with the corresponding AIE factors ($\alpha_{AIE} = \Phi_{F,aps}/\Phi_{F,s}$) of 820, 660 and 830 (Chart 1). These results further validate their AIE activity. In addition, MeNPCE shows a lower efficiency of 66% than NPCE and MeONPCE, which might be attributed to the vibration and rotation of the methyl group, thereby leading to exciton energy consumption even in the solid state.[8]

Mechanochromic

The AIE characteristic and high solid-state efficiency render the dyes promising mechanochromic materials.[16] Therefore, their solid emission properties were examined by grinding the as-prepared solids of luminogens. Interestingly, aside from the high quantum efficiencies of the solid states, another remarkable difference was that the luminogens MeONPCE showed mechanochromic fluorescent behaviour. As shown in Fig. 2, the as-prepared solid powder of MeONPCE emits a sky-blue light at 441 nm wavelength. When the as-prepared solid powder was ground with a mortar, the sky-blue powder turned into cyan-emissive solids with a maximum at 505 nm. Normally, luminogens with mechanochromic character can be easily restored by annealing or fuming treatment. However, when MeONPCE was heated at 60, 80, 100 and 120 °C for more than 5 h (even overnight), the cyan emission colours cannot be restored. The result proves its stable conformations due to the high glass-transition temperature (T_g = 134.2 ºC) of ground powders (Fig. 3A). Such steady conformation and emission are beneficial for optoelectronic applications.[33] Nevertheless, upon further fuming with dichloromethane or ethyl acetate vapour for 3 min, the original blue emission is recovered. The reversibility of mechanochromic conversion was checked by the grinding–vapour exposure processes. As depicted in Fig. S13, switching between blue and green emission colours can be repeated with many cycles without fatigue because of the non-destructive nature of the mechanical stimuli. These surveys further demonstrate the remarkable morphological stability of amorphous solids. The mechanochromic fluorescent behaviour of luminogens normally transforms from crystals to amorphous solids,[34-36] and amorphous solids are always applied in OLEDs. Thus, the research suggests that MeONPCE has potential applications for EL material because of its excellent thermal stability and efficient solid-state emission.

To obtain information on the mechanism, powder X-ray diffraction (XRD) analysis was conducted. The as-prepared powder exhibits much intense and sharp diffraction peak in Fig. 2B, which is indicative of their regular crystalline structure. No diffraction peak is observed with mechanical grinding, which reflects a disordered molecular packing. When fumed with solvent, sharp diffractions emerge again, which indicated the restoration of an ordered crystalline lattice. The results further prove that mechanochromism was extremely associated with the arrangement of molecules, which highly influence the photophysical properties.[37] However, similar phenomena are not observed in NPCE and MeNPCE. Mechanochromic usually depends on the mode of these molecular packing.[16] This further proved introduce methoxy group in one of the phenyl rings at para position can easily obtain mechanochromic materials.

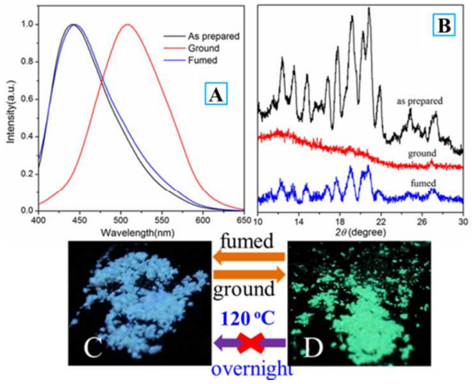

Fig. 2 (A) Emission spectra of the as-prepared, ground and fumed MeONPCE solids, (B) their XRD patterns and (C and D) their photographs taken under UV illumination.

Thermal and electrochemical properties

In terms of device fabrication and operation, high thermal and morphological stability is vitally important. Thus, the thermal properties of the luminogens were evaluated. Thermal gravimetric analysis (TGA) (Fig. 3 and S14) results indicated that all luminogens are thermally stability, with T_d (defined as the temperature at which a sample loses its 5% weight) values from 278 °C to 434 °C. The curves obtained by differential scanning calorimetry (DSC) (Fig. 3A), which was used to study the behaviour of as prepared MeONPCE under heating, showed two glass-transition temperatures (T_{g1} = 35.9 °C and T_{g2} = 93.9 °C) caused by the coexistence of cis- and trans-isomers of the MeONPCE molecule. The T_g value of NPCE and MeNPCE are as high as 106.6 and 138.6 °C, respectively. These performances are sufficient for their potential applications in OLED preparation.

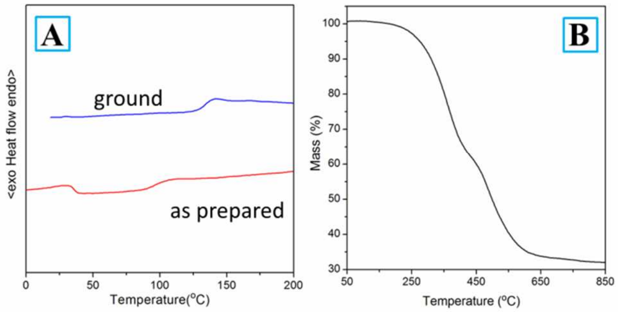

Fig. 3 (A) DSC of the as prepared and ground MeONPCE solids. (B) TGA thermograms of MeONPCE recorded under nitrogen atmosphere at 10 °C min−1 scan rates.

Carbazole derivatives are known to possess high energy levels of highest occupied molecular orbital (HOMO) and excellent charge transport properties.[38] Thus, the electrochemical properties of luminogens were investigated by cyclic voltammetry at 50 mV·s^{-1} scan rate. As shown in Fig. 4, MeONPCE displayed reversible oxidation process in dry DCM solution. The oxidation peak was found at 0.80 V. Therefore, HOMO energy was obtained from the onset oxidation potential corresponding to −5.2 eV. The E_g value of 3.34 eV was obtained from solution absorption spectra according to published method.[39, 40] The LUMO of MeONPCE was −1.86 eV, obtained by subtracting its E_g value from its HOMO value. Similar results were obtained in NPCE and MeNPCE (Fig. S15). The band gap energies, HOMO and LUMO levels of NPCE, MeNPCE and MeONPCE are summarized in Table S1. The electrochemical properties that characterize the dye molecules can be applied in electroluminescent devices.[41]

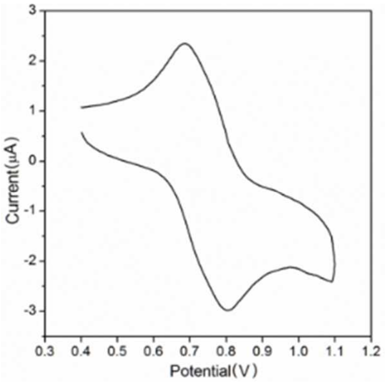

Fig. 4 Representative cyclic voltammogram of MeONPCE measured in dry dichloromethane solution with 0.1 M $TBAPF_6$ at 25 °C.

Electroluminescence properties

The high photoluminescence (PL) efficiency and good thermal stability of luminogens encouraged us to evaluate their electroluminescence (EL) properties. Three simple OLEDs were fabricated with non-doped dyes as emissive layer. NPB doped with 6% 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4-TCNQ) was used as hole-injection layer (HIL), and 1,3,5-tris(N-phenylbenzimidazole-2-yl)benzene (TPBI) was used as electron-transporting layer, followed by 1 nm LiF as electron injection layer. Hence, the basic device structure is ITO/NPB:F4-TCNQ (20 nm, 6%)/X (30 nm)/TPBI (40 nm)/LiF (1 nm)/Al, where X is NPCE (device I), MeNPCE (device II) or MeONPCE (device III). All devices emit cyan light with maximum EL (λ_{EL}) of 498, 487 and 492 nm, respectively, which are similar to the PL emissions of amorphous solids (502, 498 and 499 nm). The results reveal that the EL originated from the amorphous film (Fig. S16). Moreover, the device with MeNPCE as emissive layer (EML) exhibits a maximum *EQE* of 3.87%, which is quite high for non-doped EML OLED (Table 1). All three devices have turn-on voltages below 3.5 V, which strongly prove that NPCE, MeNPCE and MeONPCE possess good hole-transporting property. The three AIE materials possess a slightly higher HOMO level than NPB (5.4 eV); hence, the hole-injection barrier between HIL and EML can be neglected. Therefore, the order of the hole-transporting capability can be roughly estimated from their current density–voltage (*J*–*V*) characteristics (Fig. 5A): MeONPCE > MeNPCE > NPCE. This order agrees well with the donor power of the three compounds.

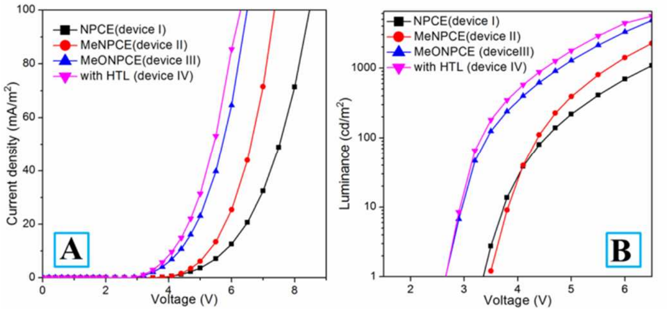

Fig. 5 (A) Current density and (B) luminance vs voltage characteristics of the four devices.

For comparison, a device with 10 nm NPB instead of 10 nm dye layer in device III was constructed and its configuration is ITO/NPB:F4-TCNQ (20 nm, 6%)/NPB (10nm)/ MeONPCE (20 nm) /TPBI (40 nm)/LiF (1 nm)/Al (device IV). Devices IV and III had almost identical *J*–*V* characteristics (Fig. 5A), which was a strong hint that MeONPCE has similar hole-transporting ability to NPB. Significantly, the CIE coordinates were almost kept unchanged from (0.23, 0.37) to (0.23, 0.39) in Fig. S17. These results implied the inherent hole-transporting capability of carbazole-containing luminogens. Fig. 5B shows that all devices have better luminance when the current were set to compliance. Fig. 6 describes the current efficiency (CE) and EQE vs. voltage characteristics of the four devices. All EL data are summarized in Table 1. Although these devices are not yet further optimized, the results clearly prove that carbazole-containing AIE luminogens as solid light emitters or hole-transporting materials are promising for the construction of advanced OLEDs.

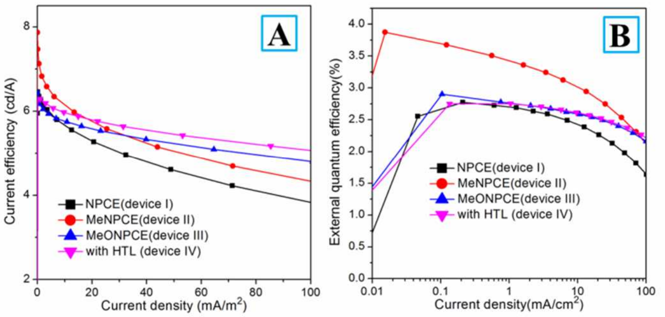

Fig. 6 (A) Current efficiency and (B) external quantum efficiency (%) vs voltage characteristics of the four devices.

Table 1. EL performances of NPCE, MeNPCE and MeONPCE.[a]

Device	λ_{max} (nm)	V_{on} (v)	CE_{ma} (cd A^{-1})	EQE (%)
I	498	4.4	6.45	2.77
II	485	4.4	7.87	3.87
III	490	3.2	6.44	2.90
IV	494	3.2	6.82	2.75

[a] Device structures: without HTL, ITO/NPB:F4-TCNQ (20 nm,6%)/X (30 nm)/TPBI (40 nm)/LiF (1 nm)/Al; X = NPCE (I), MeNPCE (II), MeONPCE (III); with HTL, ITO/NPB:F4-TCNQ (20 nm, 6%)/NPB(10 nm)/ MeONPCE (20 nm)/TPBI (40 nm)/LiF (1 nm)/Al (IV). Abbreviations: λ_{EL} = EL maximum, V_{on} = turn-on voltage at 1 cd m^{-2}, CE_{max} = maximum current efficiency, EQE_{max} = maximum external quantum efficiency.

Conclusions

The rational design of luminescent molecules is of importance to achieve efficient multifunctional optoelectronic materials with AIE-active, mechanochromic and electroluminescence. In this study, three dyes based on N-phenylcarbazol-substituted tetraarylethene, namely NPCE, MeNPCE and MeONPCE were designed and synthesized. The impacts of substituent groups in tetraarylethene on AIE-active, mechanochromic and electroluminescence properties of the luminogens were investigated in detail. With the increase of the electron-donating ability of the substituents, it was found that the hole-transporting properties were enhanced in OLEDs. Three luminogens all show typical AIE characteristics with high solid-state efficiency of up to 83%, excellent thermal stability (T_d up to 434 °C) and high morphological stabilities. Among them, only MeONPCE exhibits remarkable mechanochromism conversion ($\Delta\lambda$□up to 64 nm). Moreover, the mechanochromism can be repeatedly switched many times without fatigue by simple grinding–fuming processes, which indicated the introduction of hydrophilic groups in hydrophobic tetraarylethene can easily change molecule packing pattern on the solid state, and obtain mechanochromic materials. The OLEDs that were fabricated using the luminogens as both hole-transporting and light-emitting layer materials shown high CEmax and EQE of up to 7.87 cd A^{-1} and 3.87%, respectively. To compare MeONPCE with traditional hole-transporting material, a device with HTL was constructed, and the results indicate that the hole-transporting ability of NPB and MeONPCE are almost the same. The results show that carbazole-containing AIE luminogens are promising solid light emitters or hole-transporting materials for the construction of advanced OLEDs.

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Notes and references

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References

1. A. Mishra, C. Uhrich, E. Reinold, M. Pfeiffer and P. Bäuerle, *Adv Energy Mater*, 2011, 1, 265-273.
2. R. Fitzner, E. Mena-Osteritz, A. Mishra, G. Schulz, E. Reinold, M. Weil, C. Körner, H. Ziehlke, C. Elschner and K. Leo, *J Am Chem Soc*, 2012, 134, 11064-11067.
3. P. L. Wu, X. J. Feng, H. L. Tam, M. S. Wong and K. W. Cheah, *J Am Chem Soc*, 2008, 131, 886-887.
4. B. K. An, J. Gierschner and S. Y. Park, *Accounts Chem Res*, 2011, 45, 544-554.
5. Y. H. Jiang, Y. C. Wang, J. L. Hua, J. Tang, B. Li, S. X. Qian and H. Tian, *Chem Commun*, 2010, 46, 4689-4691.
6. W. Z. Yuan, Y. Y. Gong, S. Chen, X. Y. Shen, J. W. Y. Lam, P. Lu, Y. Lu, Z. Wang, R. Hu, N. Xie, H. S. Kwok, Y. Zhang, J. Z. Sun and B. Z. Tang, *Chem Mater*, 2012, 24, 1518-1528.
7. Y. Y. Gong, Y. Zhang, W. Z. Yuan, J. Z. Sun and M. Y. Zhang, *J Phys Chem C*, 2014, 118, 10998-11005.
8. Y. Y. Gong, Y. Tan, J. Liu, P. Lu, C. Feng, W. Z. Yuan, Y. Lu, J. Z. Sun, G. He and M. Y. Zhang, *Chem Commun*, 2013, 49, 4009-4011.
9. S. Kim, Q. Zheng, G. S. He, D. J. Bharali, H. E. Pudavar, A. Baev and P. N. Prasad, *Adv Funct Mater*, 2006, 16, 2317-2323.
10. Z. R. Grabowski, K. Rotkiewicz and W. Rettig, *Chem Rev*, 2003, 103, 3899-4032.
11. S. W. Thomas, G. D. Joly and T. M. Swager, *Chem Rev*, 2007, 107, 1339-1386.
12. J. D. Luo, Z. L. Xie, J. W. Y. Lam, L. Cheng, H. Y. Chen, C. F. Qiu, H. S. Kwok, X. W. Zhan, Y. Q. Liu and D. B. Zhu and B. Z. Tang, *Chem Commun*, 2001, 21, 1740-1741.
13. C. Y. K. Chan, J. W. Y. Lam, Z. Zhao, S. Chen, P. Lu, H. H. Y. Sung, H. S. Kwok, Y. Ma, I. D. Williams and B. Z. Tang, *J Mater Chem C*, 2014, 2, 4320-4327.
14. W. Z. Yuan, P. Lu, S. Chen, J. W. Lam, Z. Wang, Y. Liu, H. S. Kwok, Y. Ma and B. Z. Tang, *Adv Mater*, 2010, 22, 2159-2163.
15. Y. Sagara and T. Kato, *Nat Chem*, 2009, 1, 605-610.
16. Z. Chi, X. Zhang, B. Xu, X. Zhou, C. Ma, Y. Zhang, S. Liu and J. Xu, *Chem Soc Rev*, 2012, 41, 3878-3896.
17. W. Z. Yuan, Y. Tan, Y. Y. Gong, P. Lu, J. W. Y. Lam, X. Y. Shen, C. Feng, H. H. Y. Sung, Y. Lu, I. D. Williams, J. Z. Sun, M. Y. Zhang and B. Z. Tang, *Adv Mater*, 2013, 25, 2837-2843.
18. X. Luo, J. Li, C. Li, L. Heng, Y. Q. Dong, Z. Liu, Z. Bo and B. Z. Tang, *Adv Mater*, 2011, 23, 3261-3265.
19. B. Xu, M. Xie, J. He, B. Xu, Z. Chi, W. Tian, L. Jiang, F. Zhao, S. Liu, Y. Zhang, Z. Xu and J. Xu, *Chem Commun*, 2013, 49, 273-275.

20. H. S. Kwok and B. Z. Tang, *Chem Commun*, 2013, 49, 594-596.
21. Z. Guo, W. Zhu and H. Tian, *Chem Commun*, 2012, 48, 6073-6084.
22. X. P. Wang, Y. Qian, T. J. Zhu, M. M. Cai, B. X. Mi, X. Y. Jiang, Z. Q. Gao, W. Huang and Z. L. Zhang, *Phys Status Solidi A*, 2012, 209, 373-377.
23. X. Huang, S. Zhong, X. Yan, X. Ke, N. Srisanit and M. R. Wang, *Synthetic Met*, 2004, 140, 79-86.
24. C. S. Oh, C. W. Lee and J. Y. Lee, *Dyes Pigments*, 2013, 98, 372-376.
25. D. Frath, J. Massue, G. Ulrich and R. Ziessel, *Angewandte Chemie*, 2014, 53, 2290-2310.
26. P. Galer, R. C. Korosec, M. Vidmar and B. Sket, *J Am Chem Soc*, 2014, 136, 7383-7394.
27. Y. Feng, Q. R. Chen, W. S. Li and C. Xie, *Chem Res Appl*, 2007, 19, 1162-1165.
28. R. Hu, J. L. Maldonado, M. Rodriguez, C. Deng, C. K. W. Jim, J. W. Y. Lam, M. M. F. Yuen, G. Ramos-Ortiz and B. Z. Tang, *J Mater Chem*, 2012, 22, 232-240.
29. X. F. Duan, J. Zeng, Z. B. Zhang and G. F. Zi, *J Org Chem*, 2007, 72, 10283-10286.
30. M. Grell, D. Bradley, G. Ungar, J. Hill and K. Whitehead, *Macromolecules*, 1999, 32, 5810-5817.
31. Z. Zhao, S. Chen, J. W. Y. Lam, P. Lu, Y. Zhong, K. S. Wong, H. S. Kwok and B. Z. Tang, *Chem Commun*, 2010, 46, 2221-2223.
32. Y. Liu, X. Ye, G. Liu, Y. Lv, X. Zhang, S. Chen, J. W. Y. Lam, H. S. Kwok, X. Tao and B. Z. Tang, *J Mater Chem C*, 2014, 2, 1004-1009.
33. Y. Y. Gong, J. Liu, Y. Zhang, G. He, Y. Lu, W. B. Fan, W. Z. Yuan, J. Z. Sun and M. Y. Zhang, *J Mater Chem C*, 2014, 2, 7552-7560.
34. L. Bu, M. Sun, D. Zhang, W. Liu, Y. Wang, M. Zheng, S. Xue and W. Yang, *J Mater Chem C*, 2013, 1, 2028-2035.
35. X. Sun, X. Zhang, X. Li, S. Liu and G. Zhang, *J Mater Chem*, 2012, 22, 17332-17339.
36. W. Mao, K. Chen, M. Ouyang, J. Sun, Y. Zhou, Q. Song and C. Zhang, *Acta Chim Sinica*, 2013, 71, 613-618.
37. H. Zhang, Z. Zhang, K. Ye, J. Zhang and Y. Wang, *Adv Mater*, 2006, 18, 2369-2372.
38. K. S. Yook and J. Y. Lee, *Adv Mater*, 2012, 24, 3169-3190.
39. E. W. R. Cristiano, I. H. Bechtold, A. J. Bortoluzzi and H. Gallardo, *Tetrahedron*, 2007, 63, 2851-2858.
40. H. Zhao, Y. Wang, Z. Liu and B. Dai, *RSC Adv*, 2014, 4, 13161-13166.
41. M. T. Lee, H. H. Chen, C. H. Liao, C. H. Tsai and C. H. Chen, *Appl Phys Lett*, 2004, 85, 3301-3303.

AIE-active mechanochromic materials based N-phenylcarbazol-substituted tetraarylethene for OLED applications

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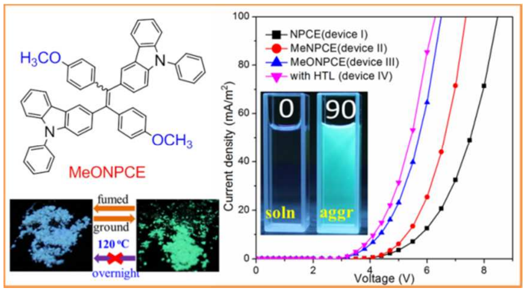

Well-designed AIE-active luminogens as both hole-transporting and light-emitting layer materials can be utilized to fabricate metal free and nondoped OLEDs.