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Influence of the anion on the optoelectronic characteristics of triphenylsulfonium salts modified polymer light emitting devices



SYNTHETIC META

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ABSTRACT

Triphenylsulfonium salts addition in the emitting layer of polymer light emitting diodes (PLEDs) has been shown to be beneficial for charge injection and transport due to both ionic effects and π -conjugation in the phenyl rings of the cation. In some cases the emission profile can be also modified through an electroplex formation. Herein we investigate the effect of four TPS-salts with different counter anions on the overall PLED performance upon blending each salt with the conjugated polymer poly[2-(6-cyano-6-methyl-heptyloxy)-1,4-phenylene] (CN-PPP). In particular, three perfluoroalkanesulfonate organic anions of increasing size (triflate, nonaflate, PFOS) and a perfluorinated inorganic anion (SbF₆) are compared. It is shown that the anion size affects primarily the turn-on and operational voltage, whereas its chemical nature is crucial for achieving high luminance values. The counteranion exerts also a direct impact on the dispersion properties of the salt in the polymer matrix, and thus, the film morphology, which in turn influences the emission colour and efficiency of an electroplex that is proposed to be formed at the sulfonium salt/polymer interfaces in the bulk. This study highlights the importance of properly selecting the counterions of the salts added in the emitting layer of PLEDs, which, in addition to their various functionalities, significantly influence device performance.

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1. Introduction

Organic light-emitting diodes (OLEDs) based on solutionprocessable conjugated small molecule or polymeric materials (i.e. polymer light emitting diodes, PLEDs) have attracted a great deal of research activity within the last decade due to their potential for fabricating low-cost, light-weight and flexible devices [1]. However, their efficiency has been limited by the need for using air-stable cathode materials (e.g. Al, Ag) instead of the lower workfunction but reactive ones (Ca, Ba, etc.). This usually creates a large energetic barrier to the injection of electrons from the cathode to the relatively high-lying lowest unoccupied molecular orbital (LUMO) of the polymers. A common strategy to surmount this limitation is either to insert a suitable electron injecting layer (EIL)

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at that interface [2] or to incorporate mobile ions in the active layer, resulting in a slightly different type of devices, namely lightemitting electrochemical cells (LECs). The luminescent materials in LECs are either ionic species, such as ionic transition-metal complexes (i-TMCs) [3], or luminescent polymers blended with ionic salts (PLECs) [4]. In these devices, application of a small bias leads to ions redistribution and movement towards the respective electrodes, thus forming *in situ* a p-i-n junction and, practically, Ohmic contacts [5,6]. In this manner, charge-balanced devices and subsequently high recombination rates are achieved, resulting in luminescent devices with high efficiencies and low turn-on and operating voltages for a wide range of electrode materials and active layer thicknesses [7]. Optimisation of these devices was achieved with the implementation of either ionic liquids (ILs) [8], novel electrolyte systems [9] or elaborate device architectures [10] and chemically fixed homojunctions [11] that led to highly efficient stable light-emitting devices.

Triphenylsulfonium (TPS) salts have been previously used by our group to achieve photochemically induced emission tuning and subsequent definition of the three subpixels (R-G-B) in a poly(9-vinylcarbazole) (PVK)-based single-layer PLED containing two fluorescent emitters [12]. The colour tuning approach

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was based on the controlled protonation of the emitters' basic sites after irradiation of the polymer films, which contained a small amount of TPS-triflate acting as efficient photoacid generator [13]. This pivotal work motivated the investigation of the effect of adding this salt in higher concentrations into the emitting layer. By comparing two different polymer matrices, namely the green-emitting poly[(9,9-dioctylfluorenyl-2,7-diyl)co-(1,4-benzo-{2,1',3}-thiadiazole)], F8BT, and the blue-emitting poly[2-(6-cyano-6-methyl-heptyloxy)-1,4-phenylene], CN-PPP, it was found that a noticeable increase in current density and luminance, a lower turn-on and operation voltage and an overall improved efficiency was achieved by optimising the salt concentration in each polymeric system [14,15]. This was attributed, on one hand to enhanced hole injection, as a result of anions displacement, their pile-up at the anode/polymer interface and space charge formation, and on the other hand to enhanced electron injection and transfer via the relatively immobile triphenylsulfonium cations, which may act as electron transporting sites (depending on the LUMO level of the polymer), whereas the device characteristics resembled more to those of PLEDs rather than PLECs despite the presence of the salts in the emissive layer. Interestingly, the incorporation of TPS-triflate in the CN-PPP matrix resulted also in a modification in the emission characteristics, which included the formation of a new excited state emitting species, namely an electroplex [15].

Herein, we take our previous work one step further by examining the modifications in the PLED electrical and electroluminescence properties upon comparing four triphenylsulfonium salts varying in the anion type and size. Variations in the counterions of the salts involved in typical PLECs [16], of anionic and cationic conjugated polyelectrolytes (CPEs) [17,18], ILs [19] and i-TMCs [20] have shown that the ion size is closely related to the ion mobility and conductivity, and thus, plays a crucial role in the final device performance by influencing not only the energetics at the electrode interfaces but also the transport properties in the bulk of the emitting layer and, in some cases, the device stability [19]. Therefore, in this work we try to rationalise the effect of the anion both on the device performance as well as on the electroplex formation and also to provide direct evidence on the previously proposed device operating mechanism. To this end, we measure the optoelectronic properties of CN-PPP based PLEDs incorporating different TPS-salts and characterise their emission profile, which is found to correlate with the TPS-salts energy levels and the morphology of the salt-doped polymeric films.

2. Experimental details

The chemical structures of the materials used are depicted in Fig. 1. The poly(*para*-phenylene) derivative poly[2-(6-cyano-6-methyl-heptyloxy)-1,4-phenylene] (CN-PPP) was purchased from American Dye Source Inc. Poly(3,4ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS) was provided by Aldrich. The salts used are composed of the same triphenylsulfonium cation (TPS) and the counter anions hexafluoroantimonate (SbF₆), trifluoromethane sulfonate (triflate), perfluoro-1-butanesulfonate (nonaflate) and perfluoro-1-octanesulfonate (PFOS), all purchased from Midori Kagaku Co., Ltd. All materials were used as received without any further purification.

For absorption spectra a Perkin-Elmer Lambda-16 spectrometer was employed. Photoluminescence spectra were recorded with a Perkin-Elmer LS-50B fluorescence spectrometer. All films were spin-coated on quartz substrates and excited at 350 nm. Surface morphology of pristine polymer and blended polymeric films on quartz substrates was probed with an NT-MDT Atomic Force Microscope (AFM) operated in tapping (semi-contact) mode. Both height and phase signals were monitored simultaneously.

Single-layer polymer light-emitting diodes (PLEDs) were fabricated on oxygen plasma pre-cleaned transparent glass substrates coated with indium tin oxide (ITO). A 40 nm thick PEDOT:PSS film was spin-coated from a pre-filtered (through a 0.45 μm PVDF filter) aqueous solution onto ITO and annealed in air at 145 °C for at least 15 min. The emitting polymer layer was spin-cast on top of PEDOT:PSS from a 6 mg/ml chloroform solution containing 15 wt% of the sulfonium salt per polymer mass, resulting in \sim 80 nm thick films. All polymer films were annealed at 70 °C for 10 min in air. Finally, a ~200 nm thick Aluminium cathode was deposited by thermal evaporation through a shadow mask (defined active area of 12.56 mm²). Current-voltage characteristics were measured with a Keithley 2400 source-measure unit and luminance and electroluminescence spectral characteristics were recorded with an Ocean Optics spectrophotometer equipped with fibre optics, assuming a Lambertian emission profile (for the luminance measurements). All measurements were carried out in ambient conditions immediately after device fabrication without any encapsulation. Finally, it should be noted that the scan speed was kept the same in all measurements (about 4 V/s), none of the devices was electrically or thermally pre-treated and all shown results refer to the first scan of the device. At least five devices were tested for each sample and all showed similar operational characteristics.

3. Results and discussion

fabricated with the structure PLED devices were glass/ITO/PEDOT:PSS/active layer/Al, where the active layer is the poly(para-phenylene) derivative CN-PPP either alone (reference device) or after the addition of the examined triphenylsulfonium (TPS) salts (Fig. 1). The TPS-salts used were composed of the same triphenylsulfonium cation and four different counterions, all of them having similar chemical structure but differing in their size. To a first approximation, it should be noted that the anion type strongly influences the extent of dispersibility of the salt in the polymer matrix. This would imply a different optimum concentration for each salt rendering an isomolar concentration-based comparison of the anions effect on device performance, while keeping at the same time good solubility of the salt in the matrix, difficult to be realised. Therefore, we chose to present the data at a concentration of 15 wt% of the polymer mass for all TPS-salts, since it was found that in this concentration the rather good salt solubility was accompanied with satisfactory and reproducible PLED performance and because, by keeping the weight percentage concentration constant for all TPS-salts, a discussion of the obtained results would be facilitated.

With regard to the above, before characterising the PLED devices, the film forming properties of the corresponding polymer layers were investigated with atomic force microscopy (AFM) and the micrographs of the polymer alone and blended with various triphenylsulfonium salts are presented in Fig. 2. We recorded both height and phase contrast, since phase imaging has been proven extremely useful for differentiating between component phases of composite materials and producing contrast on heterogeneous samples. The regular round features of the pristine CN-PPP film (Fig. 2a) tend to become smaller when adding TPS-nonaflate, whereas the film RMS roughness drops to 1.78 nm (Fig. 2b). Upon addition of TPS-triflate (Fig. 2c), the film surface becomes even smoother (RMS = 1.56 nm) and rather featureless, depicting good miscibility of these TPS-salts in CN-PPP at this concentration. Note that, the phase-contrast images, that are also shown for each polymer layer at the right side of each height-contrast image, do not provide any additional information, since they resemble to a great

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Fig. 1. Chemical structures of the CN-PPP polymer matrix and of the TPS-salts with different counteranions and the energy level diagram of the corresponding PLED device in a flat band configuration.

extent the topographic ones. On the contrary, the surface of films with TPS-SbF₆ (Fig. 2d) and TPS-PFOS (Fig. 2e) added in CN-PPP are distinctly different from the previously discussed ones. Specifically, although the morphology of the TPS-SbF₆ in CN-PPP film surface (Fig. 2d) initially seems to be smooth (RMS roughness = 2.63 nm), the respective phase-contrast image on the right interestingly provides us some new information. Since phase-contrast is very sensitive to material composition, and given that the inorganic anion contains the antimony metal, which is expected to show a stronger interaction with the tip than does the organic part of the rest of the film, a totally different high contrast area is unveiled. Finally, the height-contrast micrograph of TPS-PFOS in CN-PPP film (Fig. 2e) depicts a rough (RMS roughness = 4.12 nm) and rather randomly structured surface. In particular, there are some interconnected islands formed on the surface, whose boundaries are significantly enhanced in the phase-contrast image. Note that, the tendency of the highly hydrophobic (due to the high fluorination degree) PFOS anion to segregate towards the free surface of the film when blended with different polymeric hosts has been observed before [21]. Therefore, we conclude that the film forming properties depend strongly on the anion type of the salt resulting in different solubility window in the same polymer matrix for each anion used.

Coming back to the PLED devices based on these films, our initial hypothesis was that the anion should be more mobile, since it is substantially smaller (with the exception of PFOS which is intentionally used as a counterexample) and less rigid than the triphenylsulfonium cation. The latter comprises three phenyl rings that are out of plane with regard to the central sulphur atom, resulting in non-planar ground state geometry. To this end, the values of the van der Waals surface area [22] of each ion are given in Table 1 as a relative measure of their size. We notice that hexafluoroantimonate (SbF_6^-) has the smallest molecular volume (75 Å³), followed closely by trifluoromethane sulfonate (triflate, 77 Å³) and perfluoro-1-butanesulfonate (nonaflate, 118Å³), whereas perfluoro-1-octanesulfonate (PFOS) is much larger (235 $Å^3$), almost reaching the volume of the TPS cation (251 Å^3) . Thus, upon application of an external forward bias, anions are expected to move towards the anode, where a space charge should be formed, leading to band bending at the anode/polymer interface and improved hole injection, while the cations are considered to be rather immobile [14]. On the other hand, TPS-cations are expected to assist electron injection and also transport in the bulk due to the π -conjugation of the phenyl rings, as demonstrated earlier [15]. In this regard, the different molar ratios (also given in Table 1 for each salt), derived from the different molecular weight of each anion, should be taken into account in the discussion of each device's operational characteristics, since they more readily reflect the effect of the different TPS-content on device performance.

The current density-voltage (J-V), luminance-voltage (L-V) and luminous efficiencies versus luminance characteristics of CN-PPP based PLEDs with 15 wt% of each TPS-salt are presented in Fig. 3a-c, respectively, and the main results are summarised in Table 1. In all cases (except for PFOS, which will be discussed in detail below) the TPS-salt containing devices show a steeper evolution of the current and luminance curves compared to the reference device, clearly indicating an increased conductivity of these films. The latter is also confirmed by an independent study of the conductivity of Al/CN-PPP:TPS-salt/Al diodes, the detailed results of which will be presented in a forthcoming publication. By taking into account the aforementioned proposed mechanism, we observe that the turnon voltage of current density decreases along with the anion size; for instance the TPS-SbF₆ J-V curve turns-on at 2.5 V and then shows a very large (almost 90 degree) slope, whereas the rectification of the TPS-PFOS J-V curve starts at about 22 V and its slope is much smaller, indicating a much higher film resistance. This is in accordance with a faster piling-up of the smallest size anions (i.e. $SbF_6^- < triflate < nonaflate < PFOS$) to the polymer/anode interface and likely with a lower ionic conductivity, respectively. The lowest luminance turn-on voltage is obtained for the TPS-triflate containing device (9V), which has the highest TPS-content, followed by the TPS-SbF₆ containing PLED (9.5 V), which has a slightly smaller TPS-content as revealed by the comparison of their molar ratios. This straightforward correlation of the TPS-content with the electroluminescence turn-on voltage of the devices supports the proposed argument of the TPS-sites participating in electron injection and transport. It is important to note also that the presence of ions does not cause a significant delay to the turn-on time of the devices as depicted in Fig. 4a. In particular, a correlation between anion size and light turn-on time can be identified with the smallest anion (SbF₆⁻) responding faster than the larger ones and PFOS showing the slowest light response (and also luminance increase, see Fig. 3b) with time. Furthermore, Fig. 4b shows that the dominant wavelength of each device remains stable over time, which implies that the observed colour is an intrinsic characteristic of



Fig. 2. AFM micrographs $(3 \mu m \times 3 \mu m)$ of (a) pristine CN-PPP film and of films containing 15 wt% (b) TPS-nonaflate, (c) TPS-triflate, (d) TPS-SbF₆, and (e) TPS-PFOS. Both height (left) and phase (right) contrast images are depicted. The RMS roughness of the topography is also noted.

TPS-salt	Anion size (van der Waals molecular volume) (Å ³)	TPS-content (% mol)	Current turn-on voltage (V)	Light turn-on voltage (V)	Maximum current density (A/m ²)	Maximum luminance (cd/m ²)	Maximum luminous/power efficiency (cd/A)/(lm/W)
TPS-SbF ₆	75	3	2.5	9.5	684	26	0.038/0.008
TPS-triflate	77	3.6	3.5	9	528	108	0.29/0.045
TPS-nonaflate	118	2.6	6	13	394	88	0.23/0.036
TPS-PFOS	235	1.7	22	21	151	105	0.7/0.056

Table 1
Properties of 15 wt% TPS-salt:CN-PPP based PLED devices

the blend, as will be discussed in detail below, and it is less likely to be attributed to, e.g., water-induced side reactions, as previously reported by other groups for similar systems measured in air [23].

Finally, it turns out that the device based on the TPS-triflate:CN-PPP blend has the best overall performance, since it exhibits the highest luminance and has very low turn-on and operational voltage, leading to high efficiencies (Fig. 3c). This is attributed to both the good film forming properties, which result from the homogeneous distribution of the salt in the polymer matrix (see AFM images above), and the relatively high TPS-content (compared to the other salts at the same weight concentration) leading to enhanced hole and electron injection and transport. TPS-nonaflate behaves slightly worse than the TPS-triflate containing device (but still better than the reference device), likely due to its bigger and more fluorinated anion and to its lower TPS-content. Finally, the rather poor luminance of the PLED containing the SbF₆ anion, despite its abrupt current rectification and large current flow, can be rationalised by the "heavy atom" quenching effect owing to the presence of the Sb atom [24]. If we shift now our attention to the TPS-PFOS containing PLED, we notice, as already mentioned above, that the considerably less steep J-V curve is strongly suggestive of an increased bulk resistivity. This is explained by considering the large size of the PFOS anion, compared to the others, and the poor miscibility of this compound in the CN-PPP matrix, since PFOS comprises the highly hydrophobic perfluorinated -C₈F₁₇ chain that tends to strongly segregate from CN-PPP and stratify at the free film surface, as already mentioned in the AFM discussion above. Interestingly, and despite the high operation voltage, the TPS-PFOS containing device showed high luminance and the best luminous efficiencies from all TPS-salts (see Table 1 and Fig. 3c). This can be explained mainly by the low current density, indicative of a lower



Fig. 3. (a) Current density-voltage, (b) luminance-voltage and (c) luminous efficiency-luminance characteristics of PLEDs based on CN-PPP (black squares), 15 wt% TPS-triflate (red circles), 15 wt% TPS-nonaflate (green triangles), 15 wt% TPS-SbF₆ (magenta diamonds) and 15 wt% TPS-PFOS (blue pentagons) in CN-PPP. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)



Fig. 4. (a) Normalised electroluminescence transients of CN-PPP-based PLEDs with 15 wt% of the examined TPS-salts recorded at a bias close to the light turn-on voltage of each device. (b) Dominant wavelength *versus* time for the same PLEDs. The dominant wavelength is related to the emitted colour as it is derived from the CIE colour coordinates.

conductivity, whereas the high TPS density at the cathode/polymer interface probably enhances electron injection/hole blocking processes, ultimately resulting in a charge balanced device. Therefore, we deduce that the completely different performance of TPS-PFOS containing PLED is not related to the limited long-range ionic movement expected in this case but rather to TPS-mediated electron transport *via* a self-organised cathode interfacial layer.

At this point, it should be noted that none of the above TPS-salts containing devices behaved as the typical Polymer Light-Emitting Electrochemical Cells (PLECs) in spite of the presence of ions in the active layer. The fact that no discrete p-n junction was actually formed can be substantiated by the following experimental observations: (1) the turn-on voltage was not comparable to the optical band gap of CN-PPP (which is about 3.1 eV), meaning that at least one of the contact electrodes was not ohmic, (2) the devices did not emit light symmetrically, i.e. in both forward and reverse bias, and showed clear and significant rectification which is a hallmark of diode operation, (3) the device turn-on time was in the regime of some hundreds milliseconds (see Fig. 4a), which is rather typical for PLEDs and faster even than the response times reported for conjugated polyelectrolytes used as EILs in PLEDs [25] and (4) the lowering of the turn-on voltage was apparent from the first scan, without applying any thermal and/or electrical pre-treatment for the activation of the ions, as is usually required in other saltcontaining systems [8,26]. We infer that this deviation from the typical ion-incorporating devices behaviour may be rationalised with regard to the high degree of homogeneous distribution of some of the TPS-salts in the polymer matrix that further enhances the intrinsic - due to their high phenyl ring content - conductivity of TPS cations, which - according to the proposed mechanism remain rather immobile in the polymer matrix.

The photoluminescence (PL) spectra of the TPS-salt containing polymer films that are presented in Fig. 5a are generally characterised by a strong luminescence quenching, which may be attributed to the relative placement of the TPS-salts/CN-PPP LUMO levels (see Fig. 1). In particular, excitation of the polymer may be followed by electron transfer to the TPS-salt molecules and subsequent non-radiative, faster decay of the TPS excited state. This quenching behaviour is more prominent in the case of TPS-SbF₆ due to the "heavy atom" effect induced by the antimony (Sb) atom. Note that the shape of the PL spectra is not influenced by the salt addition, as revealed in the normalised spectra shown in the inset of Fig. 5a, all of them being similar to the primary excitonic emission of the polymer with the main peak appearing at 410 nm. This is not the case in the electroluminescence spectra of the respective PLED devices, which, apart from this primary CN-PPP emission peak, are also characterised by a secondary red-shifted emission band, peaking at about 480–500 nm (Fig. 5b). This new emission peak has been previously ascribed to a bimolecular charge transfer excited state complex, a so-called electroplex, which is supposed to be formed upon electrical excitation in the excited state between TPS-triflate acceptor molecules and polymeric donor chains [15].

Electroplex emission has been reported in devices incorporating blends of small organic molecules [27] and it has been proposed to serve as an attractive alternative towards fabrication of white OLEDs [28,29]. Heterocomplexes of this kind are generally characterised by: (1) the absence of any relevant features in the absorption and PL spectra of the blends, (2) a usually unstructured, red-shifted emission, with a peak that corresponds to the LUMO–HOMO energetic difference of the involved species (acceptor–donor, respectively) and (3) strong electric field dependence. All these requirements are met in our case. More specifically, by taking into account the following expression for the electroplex emission energy at maximum intensity:

$$h\nu_{\rm max} = {\rm HOMO}({\rm D}^+) - {\rm LUMO}({\rm A}^-) - E_{\rm C}$$

where a positively charged polaron of CN-PPP acts as the donor (D⁺) and a negatively charged TPS-salt molecule as the acceptor (A⁻), we calculate the binding energy of the Coulombic attraction of the $D^+ - A^-$ charge transfer complex $E_C = 0.14 \text{ eV}$, which is a rather acceptable empirical value for such systems [30,31]. From this value, by using the relation $E_C = e^2/4\pi\varepsilon_0\varepsilon r$, where the CN-PPP polymer dielectric constant, ε , was regarded equal to 3, we can extract the mean distance of the $D^+ - A^-$ molecules, which is calculated as r = 3.4 nm. This means that the TPS molecules must be in close contact with the CN-PPP polarons to give rise to the electroplex emission. This can be achieved by increasing either the salt concentration or the applied voltage (see for example Fig. 5d). Additionally, by comparing the EL spectra of devices comprising different anion TPS-salts, we infer that the addition of equal weight percentage concentration of each TPS salt has a strong influence on the EL spectrum. Specifically, the greater the perfluorinated part, the easier and more dominant the electroplex formation. Compare for instance the spectrum corresponding to the triflate anion, which depicts a superposition of both emissions, and the extreme case of PFOS, where the electroplex emission dominates completely over the excitonic CN-PPP emission resulting in a broad emission band



Fig. 5. (a) Photoluminenscence (inset: normalised) and (b) normalised electroluminescence spectra of pristine CN-PPP films and CN-PPP with 15 wt% TPS-salts with varying counter anion. All spectra were recorded at $L \approx 90 \text{ cd/m}^2$ except TPS-SbF₆-based device, recorded at $L \approx 30 \text{ cd/m}^2$. (c) Normalised EL spectrum of a PLED device containing 15 wt% TPS-PFOS and its deconvolution into three Gaussian components, where A1, A2 and A3 represent the respective area under the fitted Gaussian profiles. (d) Normalised EL spectra of 15 wt% TPS-PFOS in CN-PPP based PLEDs upon increasing the driving voltage.

spanning the whole visible spectrum. Accordingly, in Fig. 5c we show the deconvolution of the EL spectrum of the TPS-PFOS containing device into three Gaussians. These can be ascribed to the primary exciton emission of CN-PPP (λ_1 = 423 nm) and to two electroplex emission bands, a strong one ($\lambda_2 = 510$ nm) and a secondary one ($\lambda_3 = 620$ nm). As it can be seen from the calculated area of each Gaussian profile, almost 90% of the EL spectrum is assigned to electroplex emission. We suggest that the strong difference in polarity between the polymer and the highly hydrophobic, due to the long perfluorinated chain, PFOS induces a large macroscopic phase separation in the blend (vide supra), which favours the TPS $(LUMO) \rightarrow CN-PPP$ (HOMO) cross transition giving rise to strong and efficient electroplex emission. This may also imply that, in this case, the recombination zone is shifted towards the cathode side. Finally, in Fig. 5d we observe that the electroplex emission is enhanced as voltage increases, since the probability for e-h cross recombination is directly proportional to injection and accumulation rate that increases with the applied field [29,32]. Therefore, the electroplex formation and the final emitting colour of the device can be finely tuned by proper selection of the anion and its concentration in the active polymer blend.

4. Conclusions

To sum up, we have explored possibilities offered by varying anion triphenylsulfonium salts on the improvement of PLED devices' performance. The selection of the charge compensating anion is shown to be crucial not only for the injection and transport of the charge carriers but also for the emission profile of the OLED. This work highlights the possibility to significantly modify the optoelectronic properties of triphenylsulfonium salt-modified PLEDs by choosing counterions of different size, chemical structure, thermal properties and/or electrochemical stability and solubility in the polymer matrix. The versatility offered by these compounds allows tuning of critical device characteristics by selecting not only different cations, which directly affect the energetics of the system, but also from a large gamut of anions that modify ionic transport and dispersibility in the polymer matrix, controlling thus conductivity, emission spectrum and luminous efficiency of the PLED.

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