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全溶液法制备有机发光二极管及PEIE浓度对器件光电性能的影响

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摘　要:对溶液化发光层成膜参数及电子传输层浓度进行调控,优化发光层成膜效果及器件发光性能,同时使用导电聚合物聚(3,4-乙烯二氧噻吩)-聚苯乙烯磺酸(PEDOT:PSS)作为透明阳极,刮涂导电银浆作为阴极,通过全溶液法制备了高效率的OLED。研究发现,发光层成膜参数的调整有效改善了其成膜效果。且适当的电子传输层材料浓度可以改善器件的载流子注入平衡,有效降低阴极的功函数,提高器件的发光性能;酸后处理的PEDOT:PSS薄膜导电性大大提升,在可见光范围的透过率与ITO相当。全溶液制备的发光器件最大电流效率为1.441 cd/A,与以ITO为电极的器件相比,增加了近50倍。

关键词:全溶液处理;有机发光二极管;PEDOT:PSS;PEIE浓度;酸处理

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0　引言

有机发光二极管(Oganic Light-Emitting Diodes,OLED)由于其轻量化、宽视角、自发光、低功耗等特点,已经在显示技术、标识和照明领域广泛应用[1-4]。1987年TANG C W等[5]首次开发出具有高效率、低电压的OLED,掀起了研究人员对电致发光器件研究的热潮。随着加工技术的进步,OLED的性能和应用前景都有了很大的提高[6-8]。然而,这些发光器件的有机功能层和阴极的制备高度依赖于真空蒸发沉积技术,这种蒸镀技术设备价格昂贵,且材料利用率低,无法实现大面积、低成本的生产[9-11]。全溶液处理技术被认为是一种极具潜力的制造方式,通过选择合适的成膜方法及材料,OLED的所有功能层包括电极都可以实现溶液化处理,进而达到有效降低成本和大面积制造的目的[12-15]。

由于聚合物基有机发光器件中不存在电荷阻挡层,电子和空穴的传输不平衡会严重影响发光器件的效率。而大多数发光聚合物的电子迁移率要低于空穴迁移率,所以电子的注入比空穴的注入更加重要[16-18]。目前最常用的电子注入层材料是LiF,但是LiF层是通过蒸镀法在发光层上沉积一层超薄的膜层,无法实现溶液化处理[19-21]。乙氧基化聚乙烯亚胺(Ethoxylated Polyethyleneimine,PEIE)作为常用的可溶液化处理的功能层材料,具有良好的溶解性能,可以实现低温加工,满足环境空气中溶液制备的要求以及具有合适的导带能级,已被广泛用作LiF的替代品[22-24]。但是由于PEIE具有绝缘特性,浓度过高会导致电子无法传输到发光层,所以探究合适的PEIE浓度是实现高效发光器件的关键。

除了有机功能层的制备,电极的溶液化沉积也是实现器件全溶液制备的重要因素。氧化铟锡(Indium Tin Oxide,ITO)由于其高功函数、导电性强、透过率高的特点,通常被用作有机电致发光器件的阳极[25-26]。

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但是，由于地球上铟的稀缺，高成本和机械脆性等问题使得ITO不适用于未来卷对卷的大规模生产方式。为了取代ITO电极，碳纳米管、石墨烯、金属栅极、导电聚合物等被广泛研究[27-31]。其中聚(3,4-乙烯二氧噻吩)-聚苯乙烯磺酸(PEDOT:PSS)在溶液加工性能、机械柔韧性、光学性能等方面具有巨大优势，可以作为有机光电器件的电极使用[32-33]。高质量的PEDOT:PSS薄膜可以通过低成本的溶液处理技术，如旋涂和印刷技术制备。但是未经处理的薄膜往往存在导电性低的缺点，它的导电率低于1 S/cm，这比ITO的导电率要低好几个数量级。因此制备高导电的PEDOT:PSS薄膜是光电器件溶液化电极实现的关键。而增加其电导率的一种有效方法是使用酸对其进行后处理，酸中解离出来的氢离子与PSS-基团相结合，冲洗后可以降低PSS-基团的含量使得导电的PEDOT基团含量增加，从而提升导电性。XIA Y等[34]使用浓硫酸对PEDOT:PSS薄膜进行后处理，使其电导率提高至3 065 S/cm，并成功制作了无ITO的光电器件。这是在众多后处理溶剂中对导电性提升较为明显的方法。

虽然有机电致发光器件各功能层及阳极已经实现了溶液化的处理，但是顶部阴极的制备工艺一直无法突破，真空蒸镀技术仍然是制备阴极的主要方法。刮涂高粘度银浆制备顶部阴极可以很好的解决溶液渗透的问题。ZENG W J等[35]使用刮涂银浆的方式制备了具有红、绿、蓝三色的聚合物有机发光二极管，制备的器件性能与蒸镀Ba/Al阴极的器件性能相当。LIANG J J等[36]使用刮涂的方式制备了比蒸镀更高性能的发光电化学池器件，在优化全溶液处理技术和进一步提高器件性能的研究中，为低成本、高性能聚合物发光器件和显示器的制造开辟一条新途径。但是，这些研究都是针对发光器件的某一功能层进行溶液化处理，并未实现器件的全溶液化制备。本文对溶液化发光层成膜参数及电子传输层浓度进行调控，优化发光层成膜效果及器件发光性能，同时使用导电聚合物PEDOT:PSS作为透明阳极，刮涂导电银浆作为阴极，通过全溶液法制备了高效率的OLED。

1 实验部分

1.1 实验材料

本实验所用异丙醇(IPA)、丙酮(CP)、无水乙醇(EA)、甲苯(TL)、浓硫酸均购买于天津大茂化学试剂有限公司，乙氧基化聚乙烯亚胺(PEIE)、2-乙氧基乙醇购买于上海阿拉丁生化科技股份有限公司，发光聚合物超级黄SY-PPV(Super Yellow)、PEDOT:PSS，Clevios™ AI 4083以及PH 1000水溶液，购买于西安宝莱特光电科技有限公司，ITO导电玻璃购买于辽宁优选科技材料有限公司，加热固化型导电银浆购买于深圳鹿仙子科技有限公司。实验中材料不再进一步提纯。

1.2 溶液配置

将PEDOT:PSS(AI 4083)与IPA按照质量比1:1的比例混合，将混合溶液常温搅拌1 h并超声振荡30 min，作为发光器件的空穴传输材料。发光聚合物SY溶于甲苯，浓度为5 mg/mL，常温下搅拌6 h，作为发光器件的发光层材料。PEIE溶于2-乙氧基乙醇中，分别制备浓度为0.5、1、2、3、4 mg/mL的溶液，并在60 ℃搅拌6 h，作为发光器件的电子传输层材料。

1.3 OLED器件制备

ITO导电玻璃使用清洗剂擦洗干净后依次用去离子水、丙酮、无水乙醇超声清洗10 min，然后使用氮气吹干备用。对清洗干净的ITO玻璃进行氧等离子处理10 min，将配置好的PEDOT:PSS(4083)溶液使用0.45 μm过滤头进行过滤，并以4 000 r/min的转速旋涂在ITO基底上，制备的PEDOT:PSS薄膜在120 ℃退火10 min除去水分。将发光层以1 000 r/min的转速旋涂在PEDOT:PSS薄膜上，然后在80 ℃热台上干燥10 min。将不同浓度的电子传输层溶液分别以5 000 r/min的转速涂覆在发光层上30 s，然后在110 ℃下退火5 min。将样品转移到真空镀膜设备中沉积150 nm厚的铝阴极。对于全溶液器件的制备来说，阳极的制备是将PEDOT:PSS(PH 1000)溶液旋涂在玻璃上，并使用浓硫酸在160 ℃热台上对其进行后处理，提高导电性。顶部阴极采用刮涂银浆的方式制备，在80 ℃热台上使用四方涂布器对电极进行刮涂，然后在100 ℃下干燥10 min，面积为150 mm^2。其它功能层的制备与上述ITO电极器件相同。图1展示了器件的全溶液制备示意图。本实验溶液的配置及器件的制备均在空气环境中进行。

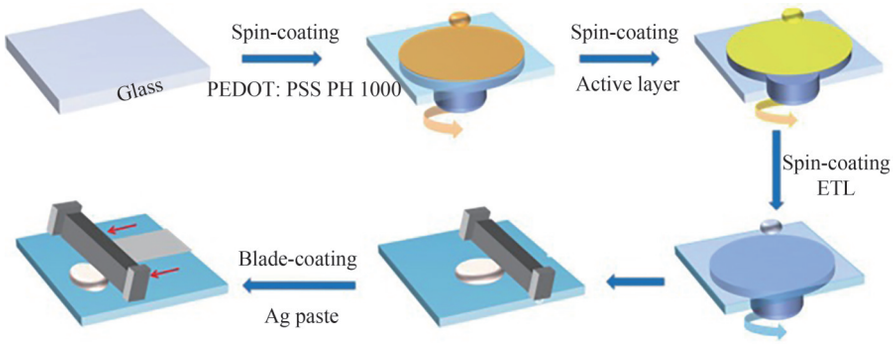


图1　全溶液有机发光器件制备流程

Fig.1　Schematic of preparation process for all-solution processed OLED

1.4　测试与表征

超景深三维显微镜(KH8700,日本浩视公司)以及原子力显微镜(Agilent 5100,AFM,美国Agilent公司)用于发光层薄膜成膜均匀性的评价,并通过快速傅里叶变换(Fast Fourier Transform, FFT)图像对其成膜效果进一步定量分析。荧光光谱仪(FS5,英国爱丁堡公司)用于发光层光致发光(Photoluminescence, PL)光谱的测量。紫外-可见-近红外分光光度计(Cary 5000,美国安捷伦科技公司)用于电极透过率的测试。空穴和电子传输层的载流子迁移率是通过霍尔效应测试系统(CH-50,北京翠海佳诚磁电科技有限公司)。电流-电压-亮度特性通过Keithley 2400型数字源表和PR-650光谱扫描光度计进行测试,电致发光(Electroluminescence,EL)光谱通过PR-650分光光度计测试,电极方阻通过RTS-9型双电测四探针测试仪测试,铝电极通过OLED-V型真空镀膜设备制备,全溶液OLED器件顶部电极是通过四方涂布器制备的。

2　结果与讨论

2.1　溶液化发光层的成膜分析

全溶液器件制备中,发光层成膜参数会影响薄膜的形貌特征,平整且均匀的发光层薄膜有利于载流子的注入并减少载流子泄漏,进而增强器件载流子复合平衡及发光性能。图2是不同成膜参数下发光层薄膜的超景深三维显微3D模型图(模型中不同颜色代表不同景深,颜色均一程度表明薄膜的平整程度)以及FFT图像(FFT图可以定性的来分析薄膜形貌的均匀度,理想的均匀薄膜表示为图像中心的单个点[37])。如图2(a)和(c)所示,过低及过高的转速都会对薄膜表面形貌产生影响,薄膜的3D图像颜色分布不均,差异较大,FFT图像中心点周围出现较大的条形光晕,表明此时的薄膜厚度不均匀,表面不平整。如图2(b)所示,合适的成膜参数会使得薄膜均匀性大大增加,此时的3D模型图像颜色较为均一且FFT图像可见明亮、清晰的中心点。

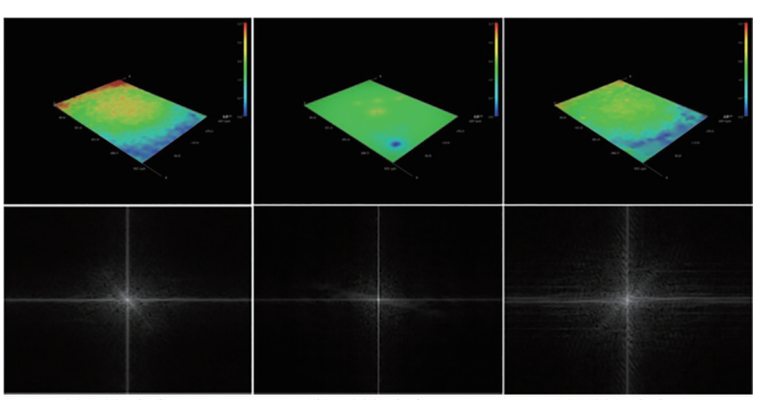


图2　不同成膜参数下发光层薄膜的3D模型及FFT图像

Fig.2　Three-dimensional morphology and FFT images of luminescent film spin-coated at different rotation speeds

为了更好地探究成膜参数对发光层形貌的影响，分析了不同成膜参数下制备的发光层AFM图像，如图3所示。从图3(a)可以看出，低转速下薄膜表面会形成面积比较大的岛，薄膜的均匀性较差；当提高转速时，薄膜的形貌如图3(b)，与低转速相比，薄膜表面形成的岛面积明显减小，薄膜的整体密度提升，均匀性大大增加；而当进一步增大旋涂速度时，虽然薄膜表面形成的岛与低转速时相比大大减小，但是表面出现较大的沟壑，使得薄膜形貌更加不平整。通过粗糙度分析可知，图3(a)、(b)、(c)对应的均方根粗糙度分别为1.85，1.10，2.42 nm，采用适当的成膜参数可以显著降低薄膜表面的粗糙度。分析原因可知，低转速时作用于基底上的离心力过小，导致基底上的溶液无法铺展开而出现堆积的现象。而离心力过大时则会导致成膜不均匀甚至会有放射状条纹的产生，而这些不规则、不均匀的薄膜将会严重影响器件的发光性能使得器件的发光效率大大降低。

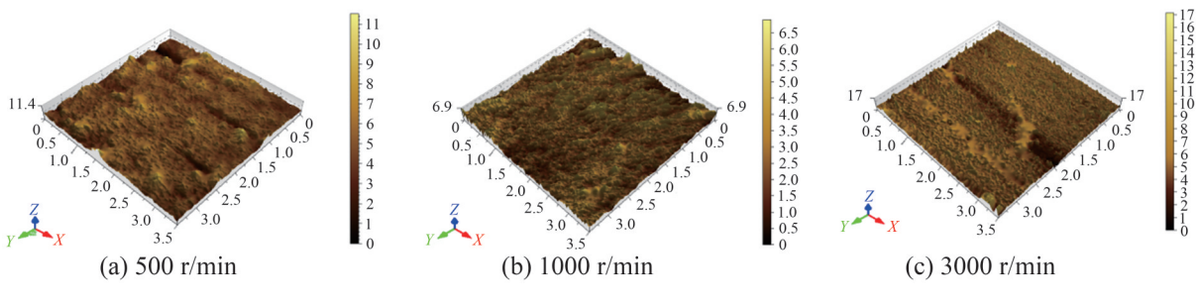


图3 不同成膜参数下发光层薄膜的三维AFM扫描图

Fig.3 AFM morphology of luminescent layer spin-coated at different rotation speeds

成膜参数的改变有效的改善了成膜效果，1 000 r/min的转速所产生的离心力使得溶液在基底上的铺展效果最为合适。

2.2 溶液化电子传输层的优化

在上述发光层最佳成膜参数的基础上，为了进一步探究PEIE电子传输层对器件光电性能的影响，制备了不同浓度PEIE电子传输层的有机电致发光器件，器件结构图如图4所示。

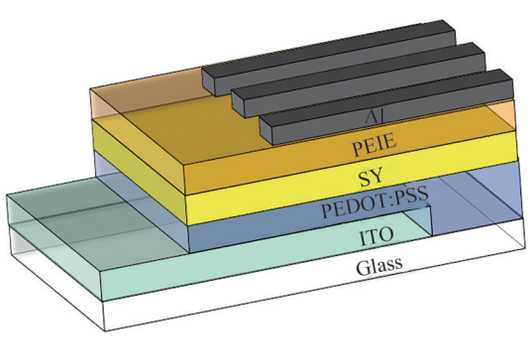


图4 ITO基器件结构示意图

Fig.4 Schematic diagram of the device structure

对其进行光电性能表征，实验结果如图5所示。结果显示，PEIE浓度为0.5、1、2、3、4 mg/mL器件的最大亮度分别为199.3 cd/m^2、469.9 cd/m^2、534.2 cd/m^2、168 cd/m^2、116.6 cd/m^2。当PEIE浓度为2 mg/mL时，器件的性能最好，达到的最大亮度以及效率分别为534.2 cd/m^{2}以及0.054 cd/A。由图5(a)～(d)可知，当PEIE的浓度较小时即在0.5～2 mg/mL的区间，器件的性能随着PEIE浓度的增加逐渐提高，这是因为浓度较小时旋转涂覆的电子传输层厚度较小，对空穴的阻挡能力比较弱，无法有效的阻止空穴向阴极传输，从而导致部分空穴无法和电子在发光层发生复合。而随着PEIE浓度的提升电子传输层的厚度也随之增加，从而有效的阻挡了空穴泄露，使得电子和空穴更加平衡的注入发光层。而当浓度继续提升时即PEIE浓度大于2 mg/mL时，所得器件的性能明显下降，这是由于PEIE自身具有绝缘特性。虽然小浓度时的增加会有效阻止空穴的泄露，但是当厚度较大时也会同时阻止电子从阴极向发光层的传输，从而导致激子复合率下降，器件性能降低。图5为发光薄膜的归一化光致发光光谱图，器件的发光波长在550 nm附近。由图5(e)也可

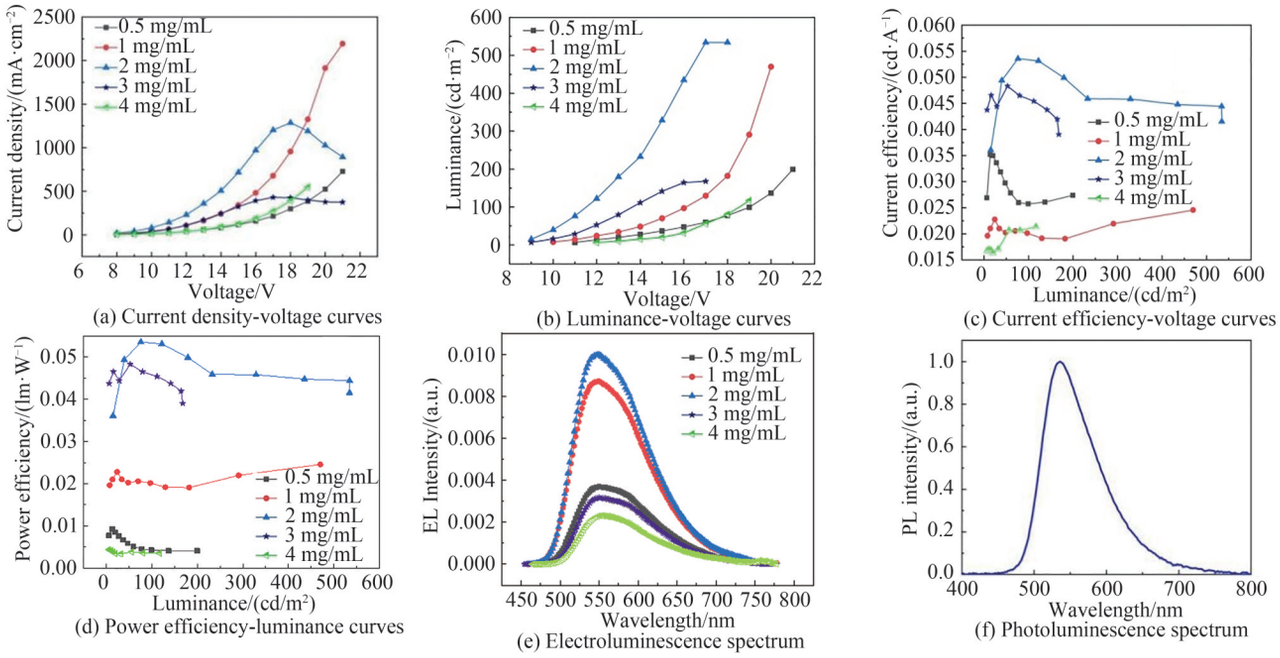


图5　不同PEIE浓度器件的光电性能

Fig.5　Photoelectric performance of OLED at different PEIE concentrations

以看出PEIE浓度为2 mg/mL时发光强度是高于其他器件的,并且由于浓度的改变EL光谱的发光峰也并未发生变化这说明PEIE浓度的改变并不会影响器件的发光波长。

对于发光器件来说,载流子迁移率可以表示器件内部电子和空穴整体的运动快慢,运动越快,迁移率越大,相应的电导率就越高。通过相同电流时,消耗的功率就会变小。在保证较高迁移率的同时,电子和空穴的传输平衡同样十分重要,增强载流子传输平衡,从而减轻激子在电极附近的猝灭现象。

对空穴及电子传输层进行载流子迁移率测试,结果如表1所示,空穴的载流子迁移率略高于电子传输层。随着PEIE浓度的增加,其电子迁移率逐渐上升,当浓度为2 mg/mL时,电子迁移率为961.7 $cm^3/V·S$,与空穴迁移率相差最小,此时载流子传输较为平衡。而且,亮度达到最大534.2 cd/m^2,这也说明了载流子传输的平衡以及迁移率的增加可以有效提高空穴和电子的复合效率,增大器件的亮度及效率。

表1　不同功能层的载流子迁移率

Table 1　Carrier mobility in different functional layers

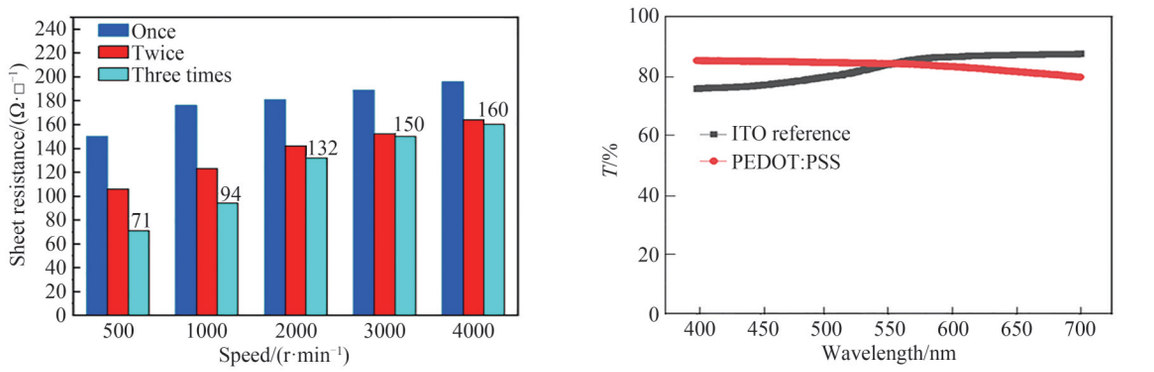
Different functional layers	Carrier mobility/($cm^2•V^{-1}•s^{-1}$)	Maximum brightness /($cd•m^{-2}$)
PEDOT:PSS(4 083)	1 173.8	—
PEIE(0.5 mg/mL)	549.0	199.3
PEIE(1 mg/mL)	639.4	469.9
PEIE(2 mg/mL)	961.7	534.2
PEIE(3 mg/mL)	801.2	168
PEIE(4 mg/mL)	564.8	116.6

2.3　全溶液OLED器件的制备

为了实现全溶液无ITO电致发光器件的制备,使用导电聚合物PEDOT:PSS(PH 1000)作为阳极代替ITO。对不同转速下制备的薄膜进行硫酸后处理,如图6(a)所示,在经过硫酸后处理之后,其方阻有了显著的下降。由图6可以看出PEDOT:PSS薄膜的旋涂转速以及后处理次数都会对薄膜的导电性产生影响。随着旋涂转速的增加薄膜的厚度在不断减小,酸处理后的方阻也在不断增加。经过一次酸处理之后,转速为500 r/min旋涂的薄膜方阻最低为150 Ω/□,随着转速的增加方阻不断增大,最大方阻为转速4 000 r/min时的196 Ω/□。这是因为转速的提高薄膜的厚度不断的降低,相应的PEDOT的含量减少,从而导致方阻的增加,导电性的下降。而随着处理次数的增加,其方阻也在不断下降。最小的方阻为转速为500 r/min时经过

酸处理三次，为71 Ω/□。经过多次酸处理后可以更有效的去除PSS-基团，提高薄膜的导电性。

对于全溶液有机电致发光器件来说，由于顶部是不透光的银电极，所以光必须从器件的底部发出。因此PEDOT:PSS薄膜在可见光范围内的透过率对器件的发光性能也有重要的影响。图6(b)为ITO电极与1 000 r/min下旋涂PEDOT:PSS并经过酸后处理三次后薄膜的透过率。通过对比发现经过三次处理后的PEDOT:PSS薄膜在550 nm处的透过率为85%，与ITO相同，在小于550 nm处的透过率略高于ITO。



(a) Sheet resistance of PEDOT:PSS film post-treated with acid　(b) Transmittance of PEDOT:PSS film after acid post-treatments

图 6　PEDOT:PSS薄膜酸处理后的方阻和透过率

Fig.6　Sheet resistance and transmittance of PEDOT:PSS films after acid post-treatments

酸处理的过程会导致薄膜形貌的改变，所以酸处理的次数并非越多越好，还要结合酸处理后薄膜的形貌进行分析。作为有机电致发光器件的阳极，在保持良好导电性的前提下还需要保证薄膜的均匀性和平整性，否则会对器件的性能产生破坏，甚至出现短路的现象。对其三次酸后处理的3D形貌模型图、2D形貌以及FFT图像进行分析，如图7所示。图7(a)左图3D模型图显示出多种不同的颜色，表示此时的薄膜表面并不平整。而随着转速的提高，PEDOT:PSS薄膜的3D模型图颜色变得单一，表面更加平整，如图7第一例图所示。从2D形貌图中也可以看出，在转速为500 r/min时，薄膜表面明显出现了不规则的裂纹，在提高了转速之后情况有了很大的改善，如图7第二列图所示。同时，在转速较低时制备的薄膜经过酸后处理之后，图像中心出现了较大的光圈，由图7(a)FFT图像所示。当转速为3 000 r/min时FFT图像为中心的一个点，表明此时的形貌最均匀、平整。分析出现此现象的原因，当转速较低时旋涂的薄膜厚度比较大而且溶液堆积容易导致薄膜厚度不均匀，此时的薄膜虽然电导率较高，但是经过酸后处理时由于厚度不均匀，在冲洗时很容易导致薄膜的破裂造成表面凹凸不平。随着转速的增加，薄膜的厚度逐渐降低，表面变得光滑、平整，由于原始薄膜表面的平整，处理过后的薄膜就会表现出更好的薄膜形貌。综合PEDOT:PSS薄膜的导电特

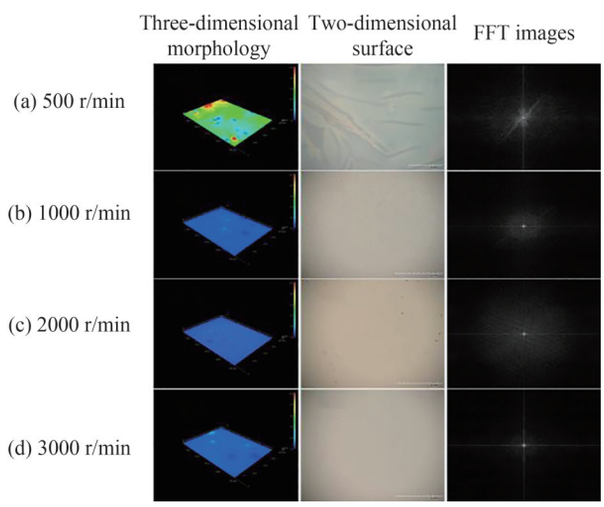
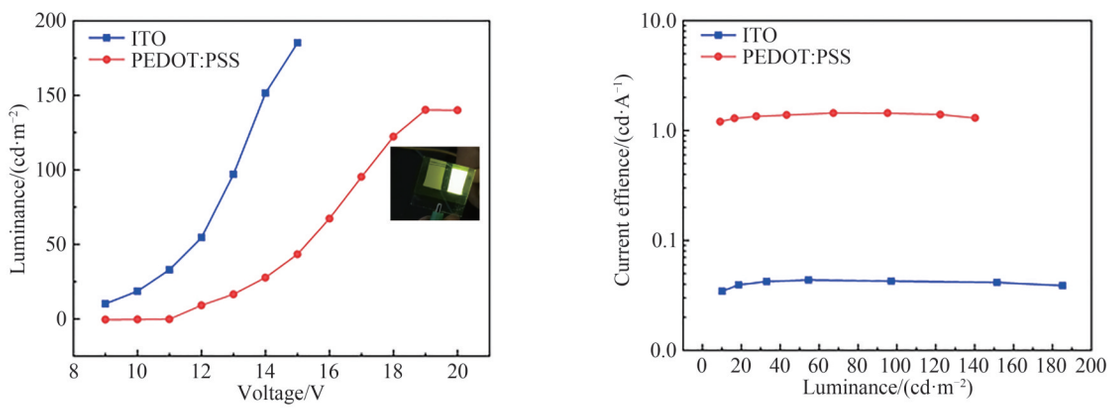


图 7　PEDOT:PSS薄膜形貌图

Fig.7　Morphology of PEDOT:PSS films spin-coated at the different speeds

性，当转速1 000 r/min时制备的薄膜最适合作为发光器件的阳极使用。

最后，使用处理后的PEDOT：PSS薄膜作为阳极，刮涂低温导电银浆作为阴极制备器件，其中发光层及电子传输层使用上述最优成膜参数及配方，对比了ITO电极及全溶液法制备OLED器件的光电特性，实验结果如图8所示，全溶液制备的OLED电流效率明显高于ITO电极的器件，表现出优异的性能。如图8(a)所示，以ITO为电极的器件最大亮度为185.2 cd/m^2，高于全溶液制备器件的最大亮度140.4 cd/m^2，而且ITO基器件的开启电压也要更小。这是因为在本实验中，ITO的导电性远高于PEDOT：PSS薄膜，使得注入发光层的空穴数量较多，电子与空穴复合形成的激子数增多，导致发光增强。虽然ITO基器件的亮度略高于全溶液制备的器件，但是从图8(b)可知，全溶液OLED的电流效率为1.441 cd/A，这比ITO基器件电流效率0.029 cd/A高出近50倍。效率增加的原因是PEDOT：PSS的功函数高于ITO，有利于空穴的注入，促进了载流子传输平衡。图8(a)中的插图为点亮状态下的全溶液印刷式制备的有机电致发光器件的实物图。



(a) Luminance-voltage curves　　(b) Current efficiency-voltage curves

图8　全溶液OLED的光电性能

Fig.8　Photoelectric performance of all-solution processed OLED

3　结论

本文提出了一种简单的全溶液制备高效率有机电致发光器件的方法，对发光层成膜参数进行调控，优化了发光层成膜效果，旋涂转速为1 000 r/min时所产生的离心力使得溶液在基底上的铺展效果最为合适，此时的薄膜较为平整；探究了PEIE浓度对发光器件光电性能的影响，发现当浓度为2 mg/mL时，器件的亮度及效率最高，最大亮度为534.2 cd/m^2；使用硫酸对PEDOT：PSS薄膜进行三次后处理，有效提高了薄膜导电性，其方阻为94 Ω/□且表面形貌较为平整，可以有效代替ITO电极；最终，以PEDOT：PSS为阳极，刮涂导电银浆作为阴极，结合上述最优发光层成膜参数及电子传输层溶液浓度，成功制备了电流效率为1.441 cd/A的全溶液有机电致发光器件，与ITO为电极的器件相比增加了近50倍。

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Organic Light-emitting Diodes Prepared by All-solution Processing and the Effect of PEIE Concentration on Photoelectric Properties of Devices

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Abstract: Organic Light-emitting Diode (OLED) has attracted extensive attention in display and lighting due to its low power consumption and high contrast. Since a high-efficiency and low-voltage electroluminescent device firstly came out in 1987, there has been a surge of research on the performance improvement of electroluminescent devices. With the progress of processing technology, the performance of OLED has been dramatically improved. However, the production of these OLED is highly dependent on vacuum evaporation technology and requires high thermal stability of their materials. OLED prepared by solution method can overcome these limitations, while it can also present the characteristics of low cost and easy large-scale production, which can meet the demand of the future market for OLED products. Solution treatment of functional layer and matching of energy levels are the key factors to realize the luminescence of devices. However, how to achieve all-solution processed OLED has been a challenge.

In the preparation of all-solution processed OLED, the unbalance of electron and hole transport will seriously affect the efficiency of light-emitting devices. Moreover, the electron mobility of most luminescent polymers is lower than the hole mobility, so electron injection is more important than hole injection. At present, the most commonly used material of the electron injection is LiF, but LiF layer is an ultra-thin film layer deposited frequently on the luminescent layer by the evaporation method, which can not be processed into a solution. Ethoxylated Polyethyleneimine (PEIE), as a widely used electron transport material with good solubility, can be processed at a relatively low temperature in ambient air and shows a suitable energy level, which is able to be a substitute for LiF. However, due to its insulating properties, the high concentration of electrons will not be able to transmit from the cathode to the luminescent layer, so exploring the appropriate concentration is a major concern to achieve efficient luminescent devices.

In addition, the preparation of transparent electrodes is indispensable for the fabrication of light-emitting devices by the all-solution process. Conductive polymer poly (3, 4-ethylenedioxythiophene) -polystyrene sulfonic acid (PEDOT:PSS) is one of the most important transparent conductive materials. It has great advantages that other conductive polymers cannot compare with, and is expected to become the next generation of transparent electrode materials. The conductive film prepared with PEDOT:PSS often displays high transparency, good mechanical flexibility and excellent thermal stability, which also can be

dissolved well in water and polar solvents. PEDOT:PSS, however, presents a very low conductivity of less than 1 $S \cdot cm^{-1}$, so it is necessary to improve its conductivity by resorting to post-treatment, such as an acid post-treatment onto the prepared PEDOT:PSS film.

In this paper, aiming at the formation of functional layers for building an all-solution processed OLED, the emitting layer by spin-coating with a rotation speed of 1000 rpm/min shows an optimal effect of film forming, confirmed by morphology features based on ultra-deep field three-dimensional images and Atomic Force Microscope (AFM) images. Besides, due to the insulating properties of PEIE, different concentrations of PEIE as an electron transport layer can impact on the brightness and efficiency of obtained OLEDs. The measured results have shown that the brightness and efficiency of the device in the low concentrations ranging from 0.5 mg/mL to 2 mg/mL can be enhanced with the increase of concentrations, as the thin PEIE layer formed at a very low concentration is weak for the hole blocking, and cannot prevent hole leakage effectively. However, these characteristics at the high concentrations ranging from 2 mg/mL to 4 mg/mL are decreased as the concentration of PEIE increases. This is because a relatively thick PEIE layer prevents not only hole leakage but also electron injection as well at high concentrations. When the concentration of PEIE is 2 mg/mL, the hole leakage can be effectively prevented and the maximum injected electrons can enhance the balance of carrier transport. Additionally, the sheet resistance of prepared PEDOT:PSS film can be deceased by post-treatment with sulfonic acid, reaching as low as 94 Ω/□, only slightly higher than that of Indium Tin Oxide(ITO), but the transmittance of PEDOT:PSS can reach the same level with ITO electrode. Finally, on the basis of these optimal parameters for the formation of functional layers including emitting layer, electron transport layer and electrode layer, a full-solution processed OLED is prepared in this paper. The experimental results show that the maximum current efficiency is 1.441 cd/A, which are 50 times higher than that of OLEDs prepared with ITO electrode. Therefore, it is also a quite feasible to fabricate the OLEDs by all-solution method except for the vacuum evaporation technology.

Key words: All-solution processing; Organic light-emitting diode; PEDOT:PSS; PEIE concentration; Acid treatment

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