

推荐国家自然科学基金项目公示

项目名称	高效有机蓝光材料及其介观结构发光器件研究
推荐单位	教育部
推荐单位意见： <p>我单位认真审阅了推荐书及附件材料，确认全部材料真实有效，相关栏目均符合国家科学技术奖励工作办公室的填写要求。</p> <p>项目针对下一代平面显示技术-有机电致发光发展的短板，围绕高效蓝光，电子传输材料及介观光子结构器件等关键问题进行了系统研究，取得了一系列创新性成果。</p> <p>针对蓝色发光的载流子传输不平衡对器件性能的制约，利用σ-π弱共轭性调节能级及电荷传输能力，设计了新型宽禁带电子传输材料，实现了近100%的内量子效率发光，首次解决了宽能带与高效率的矛盾，为蓝色发光材料的设计开辟了新途径，工作发表于Adv Mater，入选SCI前1%高被引论文。并应邀为Adv Mater 撰写了发光材料与器件综述论文，入选SCI前1%高被引论文。</p> <p>设计了新型宽禁带深蓝发光材料。利用深蓝高发光性基团，结合高空间位阻抑制分子聚集与发光红移，其色度坐标达到NTSC蓝光标准，并获得接近理论极限的高效率发光，处于世界领先水平。开发了性能优异的高迁移率、高热稳定性的电子传输材料，成功利用绝缘体金属氧化物掺杂提高有机材料的电子传输性能及稳定性。通过超快光谱,研究了空间扭曲结构的分子体系光动力学过程，从微观层面上揭示了分子的结构与激子产生、复合、传输等过程的关联性。</p> <p>提出在金属电极外表面引入介观光子结构提高出光效率的普适方法，同时实现了折射率匹配作用及散射表面等离激元的功能，并避免了对器件电学性能的影响，是兼具低成本、大面积的有效光提取方法。</p> <p>项目人员经过十多年的努力，在高效有机蓝光材料及其介观光子结构发光器件研究方面形成了自己的优势，应邀为 Adv Mater 撰写了长篇综述论文，授权发明专利 7 项，其中 1 项专利成功转让，出版领域译著 1 本，8 篇代表性论文被 SCI 他引 875 次，项目获得 2015 年度教育部自然科学一等奖。</p> <p>对照国家自然科学基金授奖条件，特推荐申报 2017 年度国家自然科学基金二等奖。</p>	

项目简介:

有机电致发光 (OLED)是液晶后平面显示的趋势。项目围绕高效全彩显示发展的短板——蓝色发光,开展了高效、高色纯度蓝光材料及高迁移率电子传输材料的研究,结合介观光子结构,提出新型器件结构设计方案,突破传统器件的出光效率限制,取得如下科学成果:

1) 高效、高色纯度蓝光材料

利用深蓝发光基团,结合高空间位阻抑制分子聚集与发光红移,设计了新型宽禁带深蓝发光材料,其色度坐标达到 NTSC 蓝光标准,并获得接近理论极限的高效率发光,处于世界领先水平。论文被同行长篇引用和评价为“极具潜力的深蓝发光材料”。针对蓝光器件的载流子传输不平衡,利用 σ - π 弱共轭性调节能级深度及电荷传输能力,设计了新型宽禁带电子传输材料,实现了近 100%的内量子效率,首次解决了宽能隙与高效率的矛盾,为蓝光材料的设计开辟了新途径。工作发表于 *Adv Mater* 上,SCI 他引 184 次,入选 SCI 前 1%高被引论文,被 *Nature* 子刊杂志 *NPG Asia Materials* 以“有机发光二极管:蓝色的完美”为题专题报道,此方案“为蓝色发光器件的设计提供了新途径”。

2) 高迁移率、高热稳定性电子传输材料

结合高电子传输性及高热稳定性基团,设计了一系列新型电子传输材料,实现了高效、高稳定性发光器件。曹镛院士等在综述论文中评价为“采用萘啉...器件优于传统的电子传输材料”。成功利用有机-无机电荷转移态的能带弯曲,采用金属氧化物绝缘体掺杂提高了有机材料的电子传输性能,器件功率效率提高到 2.8 倍,并极大改善了器件的稳定性,性能显著优于通用的 LiF 器件。韩国著名学者 J.W.Lee 指名评述为“肖等人采用绝缘体 MnO 电子注入层实现了高效 OLED”。研究了一维有机半导体中分子扭曲及分子取向对激子动力学过程的影响规律,为 OLED 材料设计提供了支撑。应邀为 *Adv Mater* 撰写了发光材料与器件的综述论文,SCI 他引 589 次,入选 SCI 前 1%高被引论文。

3) 介观光子结构提升器件出光效率

由于波导及表面等离激元模式的存在,使得平面发光器件 80%以上的光子能量被束缚于器件之中。为提高器件的耦合出光效率,首次利用自聚集在顶发射金属电极外表面引入介观光子结构,同时实现了折射率匹配作用及散射表面等离激元能量的功能,并避免了对器件电学性能的影响,使器件的耦合出光效率提高到 2 倍以上。被德国著名有机发光专家 Karl Leo 等评价为“提高器件效率的普适方法”;著名有机发光器件专家 H.S.Kwok (郭海成)等在综述中长篇引用并评述为“兼具低成本、大面积的有效光提取方法”。

应邀为 *Adv Mater* 撰写了长篇综述论文,授权发明专利 7 项,其中 1 项专利成功转让,出版领域译著 1 本,8 篇代表性论文被 SCI 他引 875 次,项目获得 2015 年度教育部自然科学一等奖。

客观评价:

➤ 引用论文题目: Efficient blue organic light-emitting diodes employing thermally activated delayed fluorescence.

发表刊物: NATURE PHOTONICS 2014, 8, 326

作者: Qisheng Zhang, Bo Li, Shuping Huang, Hiroko Nomura, Hiroyuki Tanaka and Chihaya Adachi* (多层平面结构 OLED 器件及热致延迟荧光材料 TADF 的发明者, 日本学者)

引文: Analogous to blue PHOLEDs, the development of a high triplet energy host material with moderate bandgap and high charge mobility could be an approach to achieve stable blue TADF OLEDs.[42]

译文: 与蓝光有机电致磷光器件相似, 发展适中的带隙、高电荷迁移率、高三线态能级的主体材料是实现稳定热致延迟荧光 TADF 蓝光 OLED 的一种途径。(被引代表论文 1)

➤ 引用论文题目: Deep blue phosphorescent organic light-emitting diodes with very high brightness and efficiency

发表刊物: NATURE MATERIALS, 2016, 15(1):92-98

作者: Jaesang Lee, Hsiao-Fan Chen, Thilini Batagoda, Caleb Coburn, Peter I. Djurovich, Mark E. Thompson and Stephen R. Forrest (磷光发光材料及器件的世界权威, 美国专家)

引文: Figure 3 shows the structures of PHOLEDs using fac-mer-Ir(pmp)₃ along with the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) energies for all organic materials studied.²⁵

译文: 图三显示了使用 fac- 和 mer-Ir(pmp)₃ 制备的 PHOLEDs 的 HOMO 能级和 LUMO 能级数据。(被引代表论文 1)

➤ 引用论文题目: White Organic Light Emitting Diodes

刊物: Adv. Mater. 2011, 23, 233-248.

作者: MC Gather, A Köhnen, K Meerholz* (著名有机光电材料专家, Thomson Reuters 本领域前 1% 高被引作者, 德国学者)

引文: Organosilicon compounds, such as (triphenylsilyl) benzene and (triphenylsilyl) carbazoles, have been identified as promising matrix materials due to their large triplet energies and the relatively high stability of their charged form. [77-80]

译文: 有机硅化合物, 比如三苯甲硅烷基苯以及三苯甲硅烷基咪唑, 由于高的三态能级以及带电荷的高稳定性曾被认为是很有前景的母体材料[80]。(被引代表论文 2)

➤ 引用论文题目: Phenylcarbazole-Based Phosphine Oxide Host Materials For High Efficiency In Deep Blue Phosphorescent Organic Light-Emitting Diodes

发表刊物: Adv. Funct. Mater. 2009, 19, 3644-3649

作者: Soon Ok Jeon, KyoungSoo Yook, ChulWoong Joo, and Jun Yeob Lee* (磷光 OLED 专家, 韩国学者)

引文: Phosphorescent organic light-emitting diodes (PHOLEDs) have been actively studied for the last decade due to their merit of high quantum efficiency compared with fluorescent OLEDs. A high quantum efficiency over 20% has already been achieved in red and green PHOLEDs.[1,2] However, it was difficult to develop high efficiency deep blue PHOLEDs with x and y color coordinate less than 0.15 even though sky blue PHOLEDs with a high quantum efficiency over 20% have also been reported.[3]

译文: 相对于荧光器件量子效率较高的优势, 磷光有机二极管在近十年内取得了显著的成果。最近

的报道的红色和绿色磷光有机二极管器件量子效率高达20%。尽管如此，开发深蓝色磷光有机二极管，即色度坐标小于0.15还是比较困难，之前报道的天蓝光磷光有机二极管量子效率达到了20%【3】（被引代表论文2）。

➤ 引用论文题目：Solution-Processable Hosts Constructed by Carbazole/PO Substituted Tetraphenylsilanes for Efficient Blue Electrophosphorescent Devices

刊物：Adv. Funct. Mater. 2014, 24, 5881–5888

作者：He Liu, Qing Bai, and Yuguang Ma (磷光 OLED 器件的发明者，中国学者)

引文：Recently, some small molecule/Flrpic (iridium(III) bis(4,6-(difluorophenyl)-pyridinato-N,C2')picolate) PHOLEDs have achieved high efficiencies through vacuum-deposited method. [9]

译文：近来，一些小分子/Flrpic (iridium(III) bis(4,6-(difluorophenyl)-pyridinato-N,C2')picolate)结构通过真空制备方法实现了高效率。（被引代表论文2）

➤ 引用论文题目：Influence of the hole blocking layer on blue phosphorescent organic light-emitting devices using 3,6-di-,9-carbazolyl...-9-,2-ethylhexyl...carbazole as host material

发表刊物：APPLIED PHYSICS LETTERS 96, 093304 _2010_

作者：Nico Seidler, Sebastian Reineke, Karsten Walzer, Björn Lüssem, Ausra Tomkeviciene, Juozas V. Grazulevicius, and Karl Leo* (世界著名有机发光专家，白光 OLED 领军人物，德国学者)

引文：This fact has been reported recently by Xiao et al. [13] who used an organosilicon compound with low electron mobility as HBL to achieve high efficiencies close to the theoretical limit.

译文：这些事实在肖的文章中报道过【13】，他采用低电子迁移率的有机硅化合物作为空穴阻挡层实现了接近理论极限的高效率。（被引代表论文2）

➤ 引用论文题目：Nitrogen heterocycle-containing materials for highly efficient phosphorescent OLEDs with low operating voltage

发表刊物：J. Mater. Chem. C, 2014, 2, 9565

作者：Dongcheng Chen, Shi-Jian Su* and Yong Cao (著名光电材料与器件专家，曹镛院士，中国学者)

引文：“Naphthyridine consisting of two fused pyridine rings is also used as a building block to construct ETMs of DNPA (ETM-42) and DNPF (ETM-43), The device exhibits superior performance compared to the devices using traditional ETMs of BALq and Alq₃.”并引用分子结构图。

译文：含有2个吡啶环的萘啶由于其吸电子性质，可以用于建构电子传输材料DNPA (ETM-42) 与DNPF (ETM-43)……这些器件显示比普通的电子传输材料BALq与Alq₃更好的器件性能。（被引代表论文3）

代表性论文专著目录：（按照推荐书表格列出主要内容，不需再做表格）

1. Title: Recent Progresses on Materials for Electrophosphorescent Organic Light-Emitting Devices

Author(s): **Xiao, LX** (Xiao, Lixin); Chen, ZJ (Chen, Zhijian); Qu, B (Qu, Bo); Luo, JX (Luo, Jiaxiu); Kong, S (Kong, Sheng); **Gong, QH** (Gong, Qihuang); **Kido, JJ** (Kido, Junji)

Source: ADVANCED MATERIALS Volume: 23 Issue: 8 Pages: 926-952 DOI: 10.1002/adma.201003128

Published: FEB 22 2011

Times Cited in Web of Science Core Collection: 607(他引 589) IF 18.960

2. Title: Nearly 100% Internal Quantum Efficiency in an Organic Blue-Light Electrophosphorescent Device Using a Weak Electron Transporting Material with a Wide Energy Gap

Author(s): **Xiao, LX** (Xiao, Lixin); Su, SJ (Su, Shi-Jian); Agata, Y (Agata, Yuyo); Lan, HL (Lan, Hsinglin); **Kido, J** (Kido, Junji)

Source: ADVANCED MATERIALS Volume: 21 Issue: 12 Pages: 1271-+ DOI: 10.1002/adma.200302034

Published: MAR 26 2009

Times Cited in Web of Science Core Collection: 202(184)IF 18.960

3. Title: Highly Efficient Electron-Transporting/Injecting and Thermally Stable Naphthyridines for Organic Electrophosphorescent Devices

Author(s): **Xiao, LX** (Xiao, Lixin); Xing, X (Xing, Xing); Chen, ZJ (Chen, Zhijian); Qu, B (Qu, Bo); Lan, HL (Lan, Hsinglin); **Gong, QH** (Gong, Qihuang); **Kido, J** (Kido, Junji)

Source: ADVANCED FUNCTIONAL MATERIALS Volume: 23 Issue: 10 Pages: 1323-1330 DOI: 10.1002/adfm.201202194 Published: MAR 13 2013

Times Cited in Web of Science Core Collection: 26 (24) IF 11.382

4. Title: A Deep-Blue Emitter with Electron Transporting Property to Improve Charge Balance for Organic Light-Emitting Device

Author(s): Xing, X (Xing, Xing); Zhang, LP (Zhang, Lipei); Liu, R (Liu, Rui); Li, SY (Li, Suyue); Qu, B (Qu, Bo); Chen, ZJ (Chen, Zhijian); **Sun, WF** (Sun, Wenfang); **Xiao, LX** (Xiao, Lixin); **Gong, QH** (Gong, Qihuang)

Source: ACS APPLIED MATERIALS & INTERFACES Volume: 4 Issue: 6 Pages: 2877-2880 DOI: 10.1021/am300685b Published: JUN 2012

Times Cited in Web of Science Core Collection: 23 (21) IF 7.145

5. Title: Highly efficient organic light emitting devices with insulator MnO as an electron injecting and transporting material

Author(s): Luo, JX (Luo, Jiaxiu); **Xiao, LX** (Xiao, Lixin); Chen, ZJ (Chen, Zhijian); **Gong, QH** (Gong, Qihuang)

Source: APPLIED PHYSICS LETTERS Volume: 93 Issue: 13 Article Number: 133301 DOI: 10.1063/1.2960349 Published: SEP 29 2008

Times Cited in Web of Science Core Collection: 26 (19) IF 3.142

6. Title: Spirobifluorene derivative: a pure blue emitter (CIEy approximate to 0.08) with high efficiency and thermal stability

Author(s): Xing, X (Xing, Xing); **Xiao, LX** (Xiao, Lixin); Zheng, LL (Zheng, Lingling); Hu, SY (Hu, Shuangyuan); Chen, ZJ (Chen, Zhijian); Qu, B (Qu, Bo); **Gong, QH** (Gong, Qihuang)

Source: JOURNAL OF MATERIALS CHEMISTRY Volume: 22 Issue: 30 Pages: 15136-15140 DOI: 10.1039/c2jm32512h Published: 2012

Times Cited in Web of Science Core Collection: 16 (14) IF 6.626

7. Title: Enhancement of top emission for organic light-emitting diode via scattering surface plasmons by nano-aggregated outcoupling layer

Author(s): Wang, ZY (Wang, Ziyao); **Chen, ZJ** (Chen, Zhijian); Xiao, LX (Xiao, Lixin); **Gong, QH** (Gong, Qihuang)

Source: ORGANIC ELECTRONICS Volume: 10 Issue: 2 Pages: 341-345 DOI: 10.1016/j.orgel.2008.12.008 Published: APR 2009

Times Cited in Web of Science Core Collection: 15 (12) IF 3.471

8. Spatial Conformation and Charge Recombination Properties of Polythiophene Derivatives with Thienylene-Vinylene Side Chains Investigated by Static and Femtosecond Spectroscopy

By: **Meng, K** (Meng, Kang); **Ding, Q** (Ding, Qing); **Wang, SF** (Wang, Shufeng); **He, YJ** (He, Youjun); **Li, YF** (Li, Yongfang); **Gong, QH** (Gong, Qihuang)

JOURNAL OF PHYSICAL CHEMISTRY B, Volume: 114 Issue: 8 Pages: 2602-2606 DOI: 10.1021/jp909271e, Published: MAR 4 2010

Times Cited in Web of Science Core Collection: 15 (12) IF 3.187

主要完成人情况：

1. 肖立新，第一完成人，教授，北京大学，是该项目的主要负责人，负责高效蓝色发光及电子传输材料的设计与制备，首次解决了宽能带与高效率的矛盾，实现了近 100% 的内量子效率蓝色发光，为高效蓝光材料的设计开辟了新途径。对重要科学发现中所列的 1, 2 项作出了创造性贡献，是代表性论文【1-6】的通讯作者。
2. 陈志坚，第二完成人，教授，北京大学，提出采用介观光子结构对激子辐射和能量模式分布的影响，成功制备了可适用于 OLED 的介观光子结构，实现了器件出光效率的提升。对重要科学发现中所列的 1, 3 项做出了创造性贡献，是代表性论文【7】的通讯作者，代表性论文【1, 3-6】的重要作者。
3. 王树峰，第三完成人，副教授，北京大学，采用超快光动力学过程研究发给材料及器件中载流子输运过程，探讨分钟聚集态对材料光物理特性的影响规律，采用具有空间扭曲立体结构的一维有机半导体分子体系模型，研究了光激发时的原始激子行为、电荷迁移及其复合过程，揭示了无辐射复合及激子传输规律，为 OLED 材料及器件设计提供了支撑。对重要科学发现中第 2 项作出了创造性贡献，是代表性论文【8】的通讯作者。
4. 曲波，第四完成人，副教授，北京大学，参与有机发光器件介观结构优化及器件机理研究，对重要科学发现中所列第 2 项作出了重要贡献，是代表性论文【1】【3-4】的主要作者。
5. 龚旗煌，第五完成人，教授，院士，北京大学，围绕有机发光材料及器件结构、介观光子结构的设计与发光机理研究提出了指导性意见，对重要科学发现中第 1, 2, 3 项作出了创造性贡献，是代表性论文【1】【3-8】的通讯作者。

完成人合作关系说明：

肖立新负责材料方面的设计与合成，陈志坚负责器件方面的设计与制备，王树峰负责材料机理方面的研究，曲波协助材料及器件制备方面的工作，龚旗煌负责项目总体设计与指导。

肖立新与陈志坚，曲波共同承担科技部重大研究计划项目课题：“有机光电转换器件中金属 / 介质纳米异质结构的应用研究”（2009CB930504）；

龚旗煌负责国家自然科学基金创新群体项目：“飞秒光物理与介观光学研究”（11121091 10821062），肖立新，陈志坚，王树峰，曲波是其中骨干成员。

肖立新，陈志坚，曲波，龚旗煌共同发表代表性论文【1, 3, 4, 6】

肖立新，陈志坚，龚旗煌共同发表代表性论文【5, 7】

王树峰，龚旗煌共同发表代表性论文【8】

知情同意证明:



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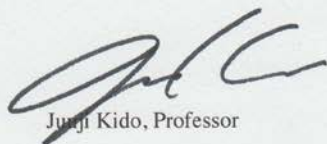
December 11, 2016

Verification Letter

Professor Lixin Xiao of the School of Physics, Peking University, has worked in my group at Yamagata University from April 2003 to March 2005. After he returned to China, we have kept collaborating on organic light-emitting diode (OLED) and have published several papers. I certify that Professor Lixin Xiao is the main contributor to the following five papers:

1. Yao-Hsien Chung, Lingling Zheng, Xing Xing, Lipei Zhang, Mengying Bian, Lixin Xiao, Zhijian Chen, Bo Qu, Qihuang Gong, and Junji Kido. "The Effect of Electron-Withdrawing Groups on Electron Transporting Silane Derivatives with Wide Energy Gap for Green Electrophosphorescent Devices" *Advanced Electronic Materials*, 2015, 1, 1400034
2. Lixin Xiao, Xing Xing, Zhijian Chen, Bo Qu, Hsinglin Lan, Qihuang Gong, Junji Kido, "Highly Efficient Electron-Transporting/Injecting and Thermally Stable Naphthyridines for Organic Electrophosphorescent Devices", *Adv. Funct. Mater.* 2013, 23, 1323-1330.
3. Lixin Xiao, Zhijian Chen, Bo Qu, Jiaxiu Luo, Sheng Kong, Qihuang Gong, and Junji Kido. "Recent Progresses on Materials for Electrophosphorescent Organic Light-Emitting Devices" *Advanced Materials* 2011, 23, 926-952
4. Lixin Xiao, Shijian Su, Yuya Agata, Hsinglin Lan, and Junji Kido, "Nearly 100% Internal Quantum Efficiency in an Organic Blue Electrophosphorescent Device Using a Weak Electron Transporting Material with Wide Energy Gap" *Advanced Materials*, 2009, 21, 1271.
5. Lixin Xiao, Hsinglin Lan, and Junji Kido, "Highly Efficient Electron-transporting Phenanthroline Derivatives for Electroluminescent Devices", *Chem. Lett.*, 2007, 36 (6), 802-803

I agree that the above papers can be used for the application for National Nature Science Awards in China.



Junji Kido, Professor

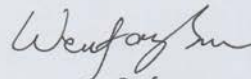
Verification Letter

Professor Lixin Xiao from the School of Physics, Peking University, has collaborated with my group in North Dakota State University, and we have one joint journal publication. This is to confirm that Professor Lixin Xiao is the main contributor to the following paper:

1. Xing, X; Zhang, LP; Liu, R; Li, SY; Qu, B; Chen, ZJ; Sun, WF; Xiao, LX; Gong, QH; //A Deep-Blue Emitter with Electron Transporting Property to Improve Charge Balance for Organic Light-Emitting Device //ACS APPLIED MATERIALS & INTERFACES Year:2012 Volume:4 Issue:6 Pages:2877-2880 DOI:10.1021/am300685b

I agree that the above paper can be used for the application of National Science Awards in China.

Wenfang Sun



Professor

Department of Chemistry and Biochemistry
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United States

Verification Letter

Professor Shufeng Wang from the School of Physics, Peking University, has collaborated with my group in Institute of Chemistry, Chinese Academy of Science, and we have one joint journal publication. This is to confirm that Professor Shufeng Wang is the main contributor to the following paper:

Spatial Conformation and Charge Recombination Properties of Polythiophene Derivatives with Thienylene-Vinylene Side Chains Investigated by Static and Femtosecond Spectroscopy. By: Meng, Kang; Ding, Qing; Wang, Shufeng; He, Youjun; Li, Yongfang; Gong, Qihuang. JOURNAL OF PHYSICAL CHEMISTRY B, Volume: 114 Issue: 8 Pages: 2602-2606 DOI: 10.1021/jp909271e, Published: MAR 4 2010

I agree that the above paper can be used for the application of National Science Awards in China.


Yongfang Li
Member of Chinese Academy of Sciences
Institute of Chemistry
Chinese Academy of Science

2016.12.25 .