# 行政院國家科學委員會專題研究計畫 期中進度報告

# 分子間電子交互作用之操控與有機元件應用(2/3)
## 期中進度報告(精簡版)

計畫類別：整合型
計畫編號：NSC 96-2120-M-002-006-
執行期間：96年08月01日至97年07月31日
執行單位：國立臺灣大學化學系暨研究所

計畫主持人：汪根欉
共同主持人：吳忠幟、徐秀福、許昭萍、吳志毅

處理方式：本計畫可公開查詢

中　華　民　國　97年06月05日

# 奈米國家型科技計畫研究重要成果表

## 1. 計畫背景：

計畫主持人及共同主持人（PI and Co-PIs）：
總主持人：汪根欉 (Wong Ken-Tsung)
共同主持人：吳忠幟 (Wu Chun-chih)、徐秀福(Hsu Hsiu-Fu)
許昭萍(Hsu Chao-Ping)、吳志毅(Wu Chih-I)

研究題目（Project Title）：分子間電子交互作用之操控與有機元件應用 (Manipulation of intermolecular electronic interactions and their device applications)

主持人執行機構（Organization）：國立臺灣大學 化學系暨研究所 (Department of Chemistry, National Taiwan University)

全程計畫執行期限（Project period）：自民國 95 年 08 月 01 日起至民國 98 年 07 月 31 日(2006, 8.1~ 2009, 7.31)

分年經費（Budget per year）：
2006~2007: NT$ 10,907,500
2007~2008: NT$ 7,700,000
2008~2009: NT$ 6,392,500

## 2. 計畫目標：

本計畫研究課題主要包括: (1) 液晶與自組裝分子之發展; (2) 表面修飾分子與材料之發展; (3)奈米尺度與圖案化之表面修飾技術發展; (4)自組裝結構與奈米結構之結構,物性,電子結構,光與電特性之探討; (5) 自組裝結構與奈米結構之元件應用與特性探討; (6)自組裝結構與奈米結構之物理化學與量子化學理論計算與探討。(1) functional mesogenic and self-assembled materials; (2) materials for surface modification; (3) nanoscale surface patterning; (4) structural, physical, and electronic/optical characterizations of self-assembled structures/nanostructures; (5) device applications and characterization; (6) theoretical investigation of self-assembled structures and nanostructures.

## 3. 參與計畫單位及人數：

國立臺灣大學化學系暨研究所：PI：1人；學生：6 人
國立臺灣大學光電工程學研究所：PI：2人；學生：9 人
淡江大學化學系：PI：1人；學生：8 人
中央研究院化學研究所：PI：1人

## 4. 限本奈米國家型計畫產生之研究成果統計表

| 篇數<br>統計類別 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|
| 國外期刊論文 | - | - | 9 | 24 |
| 國內期刊論文 |  |  |  |  |

5. 請列出最具代表性之論文或專利至多 6 篇：( 第二年成果)

**2007**

1. “An Unprecedented Ambipolar Charge Transport Material Exhibiting Balanced Electron and Hole Mobilities” Liao, Y.-L.; Lin, C-Y.; Liu, Y.-H.; Wong, K.-T.; Hung, W.-Y.; Chen, W.-J. *Chem. Commun.* **2007**, 1831. (SCI Journal, IF 4.521)
2. Li-Yin Chen, Tung-Huei Ke, Chung-Chih Wu, Teng-Chih Chao, Ken-Tsung Wong, Ching-Chao Chang , 2007, “Anisotropic Ambipolar Carrier Transport and High Bipolar Mobilities up to 0.1 cm$^{2}$V$^{-1}$s$^{-1}$ in Aligned Liquid-Crystal Glass Films of Oligofluorene” *Applied Physics Letters*, Vol. 91, No. 16, 163509 (SCI Journal, IF 4.308)
3. H.-C. Su, F.-C. Fang, T.-Y. Hwu, H.-F. Chen, K.-T. Wong, and C.-C. Wu, April 2007, “Highly efficient orange and green solid-state light-emitting electrochemical cells based on cationic Ir(III) complexes with superior steric hindrance,” *Advanced Functional Materials*, Vol. 17, No. 6, 1019-1027 (SCI Journal, IF 6.770)
4. H.-W. Lin, C.-L. Lin, C.-C. Wu, T.-C. Chao, K.-T. Wong, April, 2007, “Influences of molecular orientations on stimulated emission characteristics of oligofluorene films,” *Organic Electronics*, Vol. 8, No. 2-3, 186-197 (SCI Journal, IF 3.636)
5. “Optical properties of oligo(9,9-diarylfluorene) derivatives in thin films and their application for organic light-emitting field-effect transistors” T. Oyamada, C.-H. Chang, T.-C. Chao, F.-C. Fang, C.-C. Wu, K.-T. Wong, H. Sasabe, C. Adachi, *J. Phys. Chem. C* **2007**, *111*, 108. (SCI Journal, IF 4.033)
6. Liao, Y.-L.; Lin, C.-Y.; Wong, K.-T.; Hou, T.-H.; Hung, W.-Y. “A Novel Ambipolar Spirobifluorene Derivative that Behaves as an Efficient Blue-Light Emitter in Organic Light-Emitting Diodes” *Org. Lett.* **2007**, *9*, 4511. (SCI Journal, IF 4.659)

**2008**

1. “Solid-State White Light-Emitting Electrochemical Cells Using Iridium-Based Cationic Transition Metal Complexes” *Journal of the American Chemical Society* (**2008**), *130* (11), 3413.
2. “Surface Patterning with Fluorescent Molecules Using Click Chemistry Directed by Scanning Electrochemical Microscopy” *Journal of the American Chemical Society* (**2008**), *130* (8), 2392.
3. “Electrochemistry and Electrogenerated Chemiluminescence of 3,6-Di(spirobifluorene)-N-phenylcarbazole” *Journal of the American Chemical*

*Society* (**2008**), *130* (2), 634.

4. “Benzimidazole/Amine-Based Compounds Capable of Ambipolar Transport: Small Molecules for High Performance Single-Layer Blue-Emitting OLEDs and Host for Phosphorescent Emitters” *Angewandte Chemie International Ed.* (**2008**), *47*, 581.
5. “Star-shaped Mesogens of Triazine-Based Dendrimers and Dendrons as Nonconventional Columnar Liquid Crystals” Journal of Organic Chemistry (**2008**), *73*, 485.
6. “Reduce Turn-on Times of Single-Component Light-Emitting Electrochemical Cell by Tethering Ionic Iridium Complex with Imidazolium Moieties” *Chemistry-An Asian Journal* (**2008**), accepted.

## 6. 計畫已獲得之主要成就與成果（請列出相關文獻及圖表）：

**2007**

We have established a novel approach for micropatterning method by using scanning electrochemical microscopy (SECM). The present micropatterning method uses an ultramicroelectrode (UME) to synthesize Cu (I) locally in the small gap between the tip and substrate, and catalyze the subsequent “click chemistry”, in which acetylene containing fluorophore was covalently attached to an azido monolayer pretreated glass substrate by the formation of triazole (Figure 1). The patterning array can be observed by a fluorescent microscopy, as shown in Figure 2. 我們提出一個利用電化學掃描顯微鏡來製圖的新方法。這個方法是利用 click chemistry 將帶有特殊螢光官能基團的炔類分子，經由 SECM 產生之 Cu(I)催化與尾端有疊氮之自組裝分子修飾過之玻璃表面共價結合。利用電化學掃描顯微鏡產生之圖形可以經由螢光顯微鏡觀察。

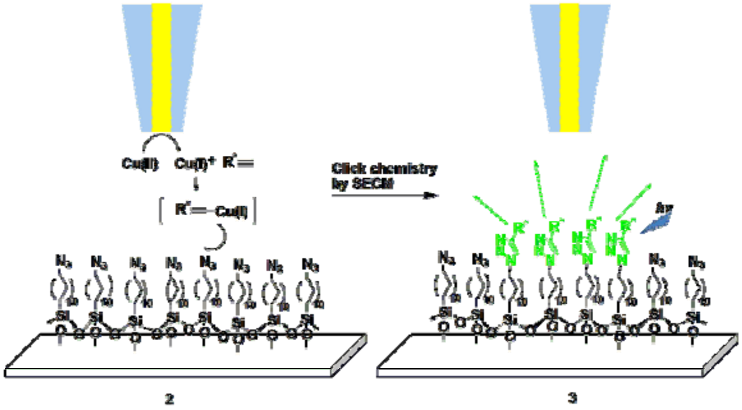


Figure 1: Local reduction of Cu(II) to Cu(I) at a gold microelectrode (left) and immobilization of acetylene fluorophore derivatives onto a glass substrate through click chemistry to form triazole with azido.

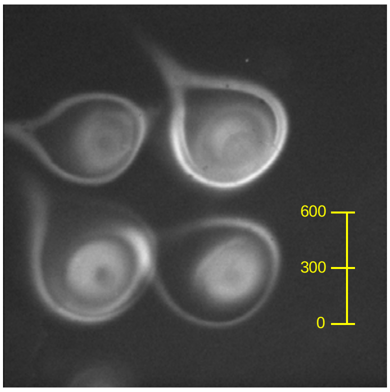
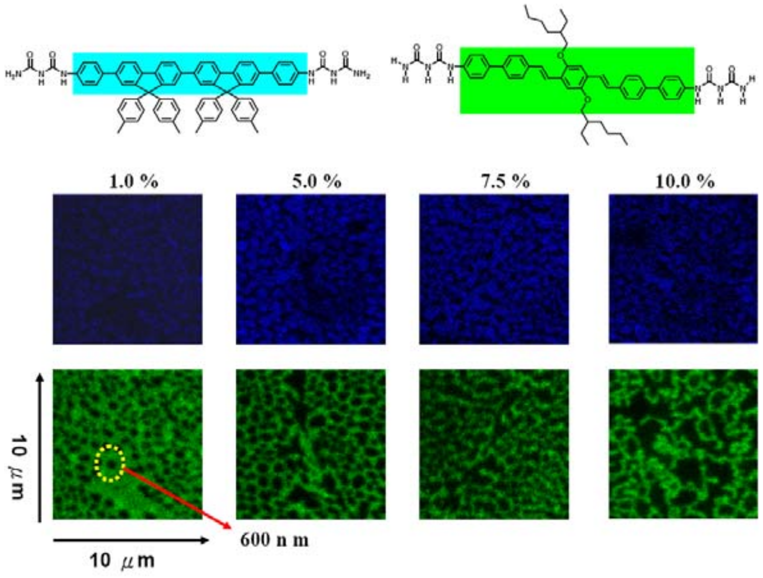


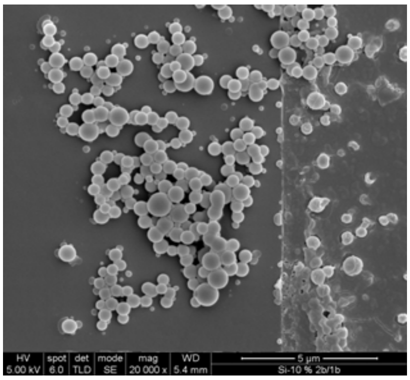
Figure 2. Typical fluorescence microscopy image of a patterned benzothiodiazole array on the glass substrate.

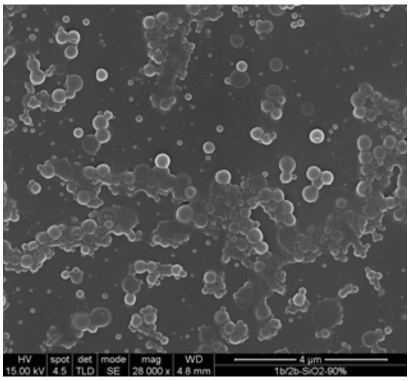
We have established an efficient synthesis of 4-pinacolatoboronic ester-benzenebiuret, which allows us to easily introduce the hydrogen-bonding biuret unit onto various π-conjugated scaffolds by common Pd-catalyzed Suzuki coupling reactions. This straightforward method of connecting a self-assembly recognition site into π-conjugated chromophores is an unprecedented strategy. We have successfully applied to synthesize π-conjugated materials such as oligofluorenes (donor), and oligo(*p*-phenylenevinylene) (acceptor) in good yields and studied their interactions and visualized by fluorescence confocal microscopy imaging. 我們成功開發出了一個全新的分子自組裝建構單元 4-pinacolatoboronic ester benzenebiuret 並將其與有機發光分子以鈴木反應來進行偶合，順利的得到具有分子自組裝單元的發光材料，此種合成策略首次被開發出來並成功應用在建構不同的具自組裝功能的分子合成。進一步研究其中兩個帶有分子自組裝辨識單元的藍光發光材料以及綠光發光材料在固態成膜性質及材料之間能量轉移的現象，並且利用螢光放光共焦顯微鏡來研究固態薄膜的特性。



The self-assembly behaviors of these compounds and mixtures were also probed by scanning electron microscopic (SEM). The donor formed vesicles in THF solution (left figure) and adhere to the worm-like acceptor (right figure) upon mixing them. The formation of vesicle in THF by small molecule with self-assembly motifs is very unique. The detail mechanism for vesicle formation is under investigating. 利用 SEM 觀察此兩

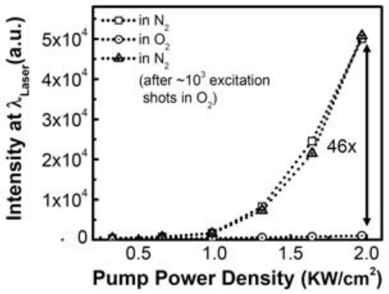
分子之自組裝形態發現，藍光分子會在表面自組裝成為 vesicle 結構(下圖左)，而與綠光分子混合時，這些藍光分子自組裝形成的 vesicle 結構會吸附在綠光分子所形成的纖維狀結構之上(下圖右)，此種利用小分子自組裝行為在 THF 中形成 vesicle 的現象甚為罕見，正深入研究其形成之機構。



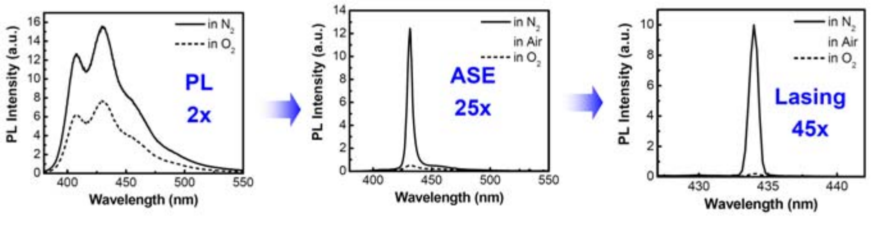


A thin film of the terfluorene was found to be sensitive to molecular oxygen with very fast response time and the sensitivity can be enhanced with ASE and Lasing. 開發一種可以感測氧氣的分子薄膜，此感測薄膜具有可以重複使用反應時間快且其感度可以分別利用 ASE 及 Lasing 提高近 10 及 20 倍。

**Sensitivity Gain with Lasing**

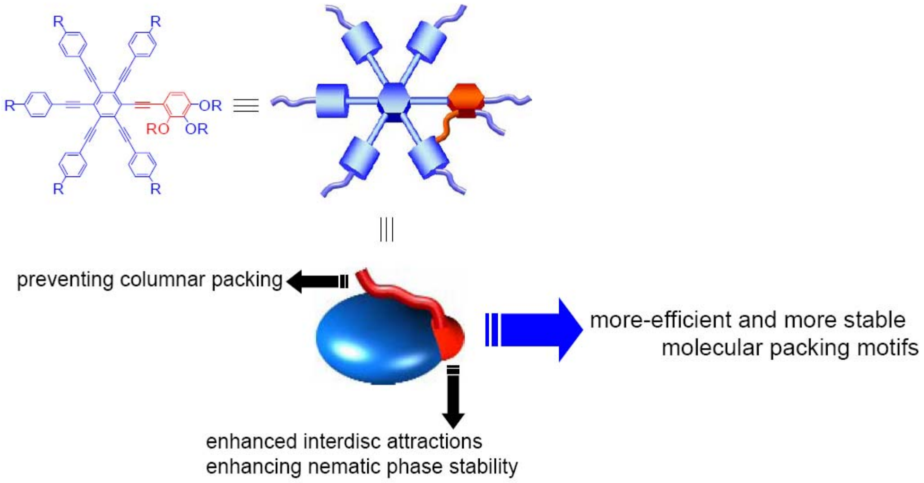


**Reversible and further improve sensitivity (2.5x to 46x)**

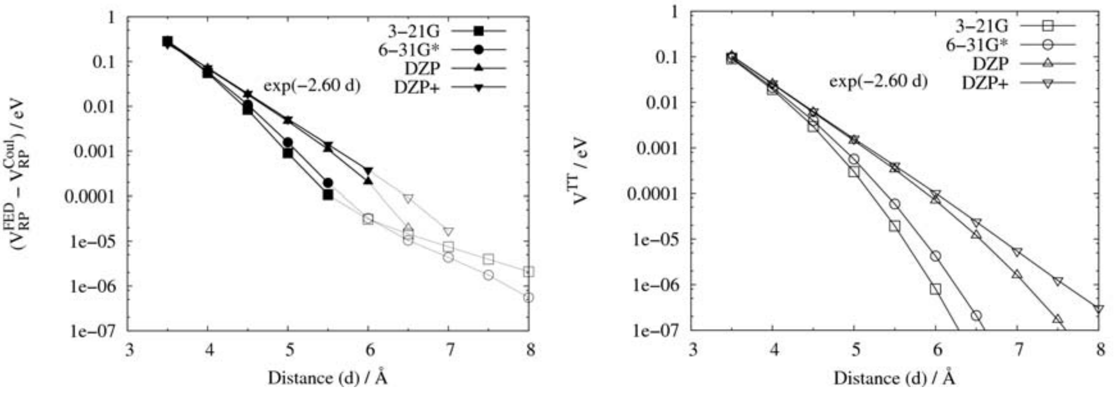


A new concept of replacing one sidearm of the discotic hexakis(4-hexyloxyphenyl)ethynyl)benzene with a laterally-substituted sidearm was proposed and stepwise developed to accomplish effective improvements of discotic nematic properties, i.e. lowering transition temperatures, manipulations of $N_D$ ranges, and preserving the discotic nematic superstructure while avoiding column formation. Employment of this concept to other conjugated discotic molecules are to be investigated. 在具共軛盤狀分子之堆疊操控方面，我們由難度最大之具最大排列亂度的向列結構著手，目前已能有效調控分子間整齊度。H.-F. Hsu, S.-C. Chien, H.-C. Chen, Chen, H.-H.; Yang, Y.-L.; Shih, T.-L.; and Lee, J.-J., "Stable, Low-Temperature Discotic Nematic Superstructures by Incorporating a Laterally Substituted Sidearm in

Hexakis(phenylethynyl)benzene Discogens," *Advanced Functional Materials*, Vol. *17*, 1896-1902 (2007) (SCI: 6.779).



We have developed a new scheme to account for the EET coupling for a general class of molecular systems. The short-range coupling, defined as the contribution from Dexter's exchange coupling and the overlap effect, was obtained as the difference of the EET coupling from this new scheme, and a precise account of the Coulomb coupling. To the best of our knowledge, the short-range couplings in EET is characterized precisely for the first time. For a pair of stacked naphthalenes, the short-range coupling is very similar to the triplet-triplet energy transfer coupling in both magnitudes and the distance dependence. This result confirms that the short-range coupling is similar to the triplet-triplet energy transfer, in both their physical grounds and the numerical values. This work will be important for characterizing the transportation of excitation energy as well as electron transport processes in the liquid-crystal forming materials. 關於激發能量轉移，我們發展了一嶄新的方法計算其電子耦合值。這個新方法通用於相當多種分子系統。能量轉移的耦合當中，來自 Dexter 交換積分和重疊效應的部分，是屬於短距離的耦合作用。我們首度以我們的新方法來計算這個短距耦合值，並且以三重態間的能量轉移耦合執比較，確認二者不但物理來源相似，數值和趨勢也相當接近。這項結果為我們進一步探討液晶材料的激發能量傳遞、以及電和傳遞，提供了重要的基礎。



The short-range component of EET (left) is very similar to the triplet-triplet spin-exchange coupling (right) in both the decay rate and basis set dependence. Shown are

calculations for a pair of stacked naphthalenes. 能量轉移當中的短距耦合 (左) 三重態，自旋交換的耦合值(左)。圖為該耦合值隨兩個上下重疊的 napthalene 分子間距離，還有計算採用的基底的變化情形。
Hsu, C.-P.*; You, Z.-Q.; Chen, H.-C., “Characterization of the Short-Range Couplings in Excitation Energy Transfer” *J. Phys. Chem. C*, **2007** (accepted).

## 2008

我們開發前所未有的以主—客離子性銥金屬錯合物為基礎之單層固態白光發光電化電池。此白光之電致發光元件在外部電壓為 2.9~3.3V 時具有 CIE 座標（x, y）=（0.45, 0.40）至（0.35, 0.39）的白光發光光譜，並有高達 80 的演色性指數（Color Rendering Index）。其最高外部量子效率及功率分別可達 4%及 7.8 lm/W。這是文獻中首見結果促使以主—客離子性過渡金屬錯合物材料的發光電化電池可在固體發光科技中成為極具前景的替代品(Fig. 1) (*J. Am. Chem. Soc.* **2008**, *130*, 3413)。在離子性化合物為基礎之單層固態發光電化電池常會遭遇啟動時間過長的缺點，我們成功地在離子性銥金屬錯合物中接上咪唑基團，可用來製作單一組成離子性過渡金屬的發光電化電池，此策略可增加在薄膜中可移動的離子而造成導電性提升，可有效降低發光電化電池的啟動時間(Fig. 2) (*Chem. Asian J.* **2008**, accepted)。我們同時成功合成一系列以芴為終端基團之雙極性新型高放光量子效率之材料以作為電致化學發光(Electrogenerated Chemiluminescence, ECL)之研究。因為這一些芴之衍生物具有大的立體障礙，會抑制 excimer 形成，其 ECL 放光波長可以藉由不同的中心基團調控(Fig.3) (*J. Amer. Chem. Soc.* **2008**, *130*, 634)。我們研究離子性之 Alq3 化合物，其具有各種不同的液晶相，如 smectic phoase, column phase 等，可形成自組裝結構或薄膜，並且具有良好發光特性(Fig. 4) (*Adv. Mater.* **2008**, in press)。利用在分子外圍引入不同數目的氟原子，可以有效調控分子間作用力，並進而形成不同整齊度的分子堆疊方式。隨著引進氟原子的數目的增加，分子的堆疊模式也愈趨整齊。而另一優勢則是隨著氟原子數目的增加，液晶形成溫度範圍也愈加擴大，同時熔點也隨著下降(Fig. 5)。我們研究可利用熱或光轉換之 pentacene 可溶性前驅物，利用溶液塗佈製程，據以製作具有良好特性之有機電晶體(Fig. 6) (*Org. Lett.* **2008**, in press) 。For the first time, eelectroluminescent (EL) emission from single-layered solid-state light-emitting electrochemical cells (LECs) based on host-guest cationic iridium complexes has been successfully demonstrated. The devices show white EL spectra (Commission Internationale de l'Eclairage coordinates ranging from (x, y) = (0.45, 0.40) to (0.35, 0.39) at 2.9~3.3 V with high color rendering indices up to 80. Peak external quantum efficiency and peak power efficiency of the white LEC reach 4 % and 7.8 lm/W, respectively. These results suggest that white LECs based on host-guest cationic transition metal complexes be a promising alternative for solid-sate lighting technologies. (Fig. 1) (*J. Am. Chem. Soc.* **2008**, *130*, 3413). We reported the significant reduction in turn-on times of LECs by tethering imidazolium moieties onto a cationic Ir-complex. The improvement is ascribed to increased concentrations of mobile counterions ($PF_6^-$) in neat films and consequent increase of neat-film ionic conductivity. These results demonstrate that such a technique is useful for molecular modifications of ionic transition metal complexes (ITMCs) to improve turn-on times of LECs and to realize single-component ITMC LECs compatible with simple driving schemes. (Fig. 2) (*Chem. Asian J.* **2008**, accepted). Electrogenerated chemiluminescences (ECL) of a series of highly fluorescent fluorene end-capped derivatives have been achieved. The terminal fluorene groups provide excellent steric hindrance for suppressing the excimer formation during the recombination of radical cations and anions, rendering efficient ECL. The emitting colors can be tuned by tailoring the structural features of central cores. (Fig.3) (*J. Amer. Chem. Soc.* **2008**, *130*, 634). Ionic self-assembly was used as a convenient process to template luminescent smectic and columnar liquid crystalline phases from ionic Alq$_3$ complexes. These are soluble in organic solvents and transparent and luminescent films can be obtained by slow evaporation or spin-coating. (Fig. 4) (*Adv. Mater.* **2008**, in press)。In order to manipulate inter-discotic interactions, fluoro groups have been introduced onto the periphery of disk-like compounds. By introducing different numbers of fluoro groups, intermolecular attractions can be modulated to form various packing motifs. As the specific intermolecular interactions with the aid of F groups increase, the packing of the molecules becomes more ordered. Moreover, the liquid crystalline temperature range also increases with increasing number F groups introduced (Fig. 5). A CO adduct of pentacene with unsymmetrical structure is synthesized, which is soluble and can be spin-coated into thin films. Pentacene is regenerated in near quantitative yield by either thermal or photo-induced elimination of CO. OTFT devices fabricated by this material exhibit typical FET characteristics. (Fig. 6) (*Org. Lett.* **2008**, in press).

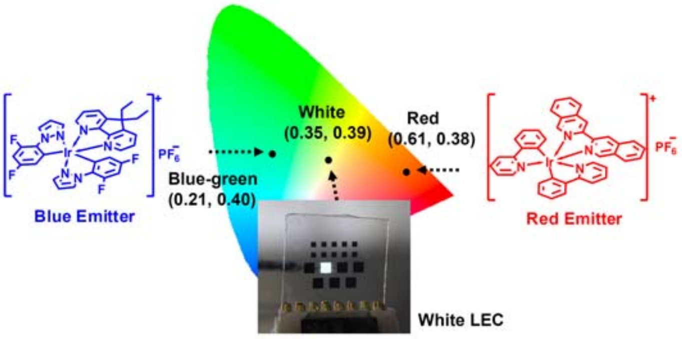


Fig. 1

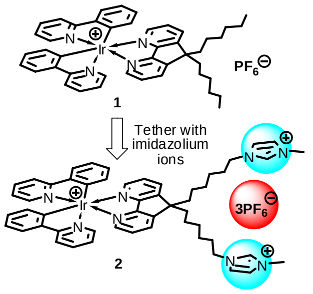


Fig. 2

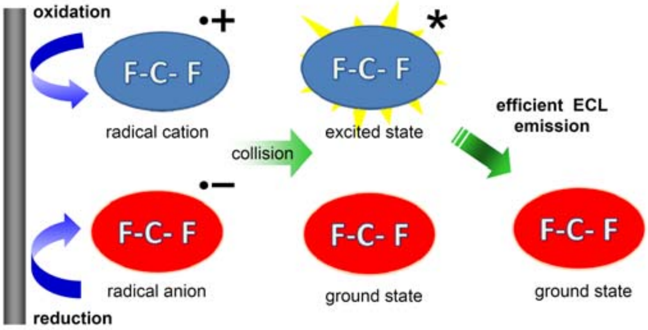


Fig. 3

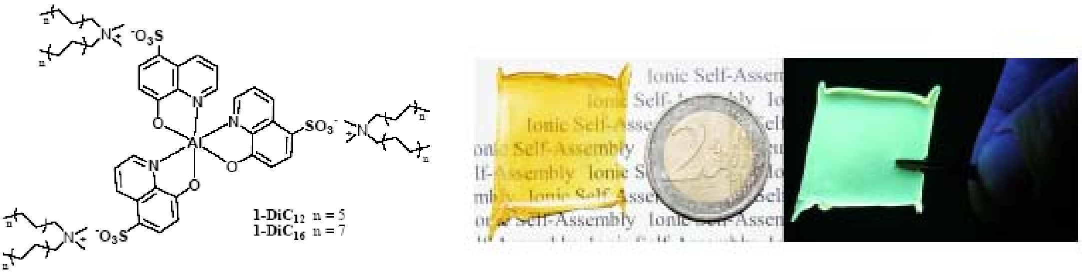
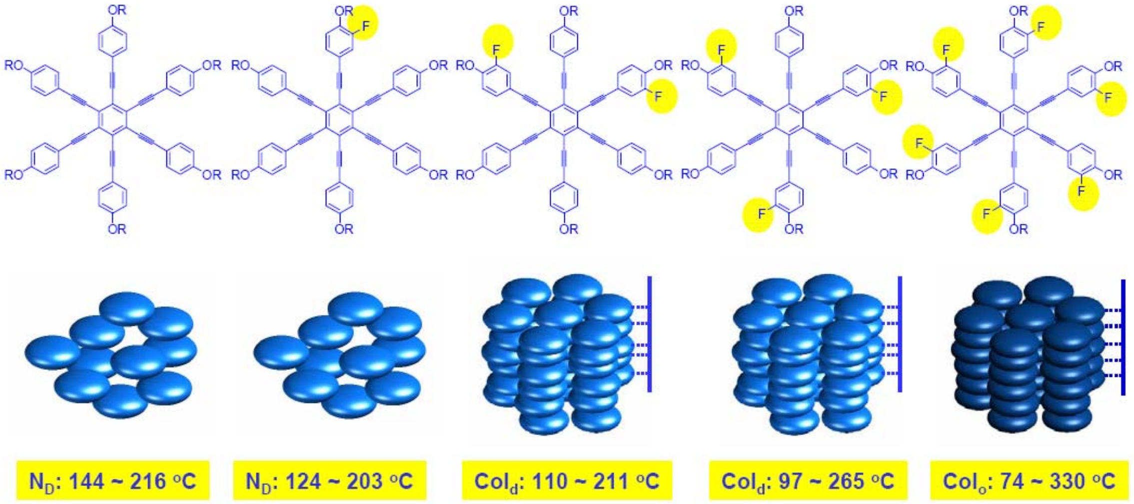


Fig. 4



R = $C_6H_{13}$

$N_D$: discotic nematic mesophase

$Col_d$: columnar mesophase with disordered intra-columnar correlations

$Col_o$: columnar mesophase with ordered intra-columnar correlations

Fig. 5

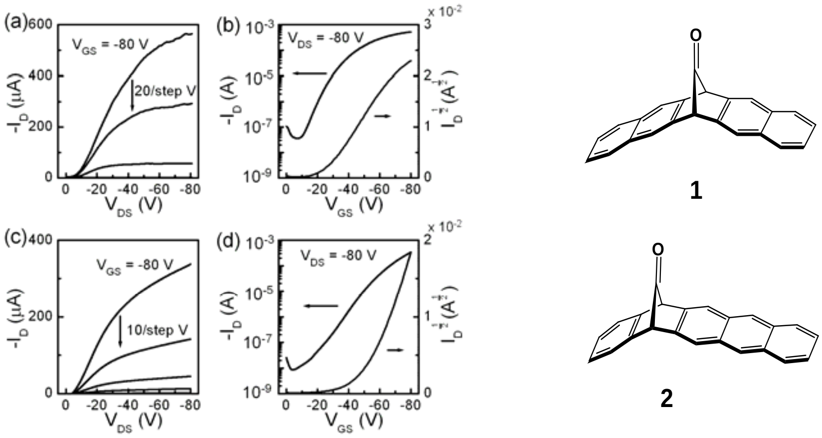


Fig. 6

7. 上述重大研究突破，與國際上類似領域之比較（內容以 500 字為限）：

**2007**

(1) Patterning methods use scanning electrochemical microscopy (SECM) either depend on a destructive modification of chemical contents on an insulating substrate or heavily relay on the electrochemical behaviors of the target materials that will be deposited onto a substrate under an applied potential. Here, we have established a

novel approach for micropatterning using SECM tip to generate Cu (I) locally for catalyzing the subsequent “click chemistry”, in which acetylene-containing fluorophore was covalently attached to an azido monolayer pretreated glass substrate. The resulting array can be visualized by a fluorescent microscopy. 一般而言電化學掃描製圖的方式分為兩種:一種是利用蝕刻的方式，藉著微電極產生一反應物侵蝕表面的樣品；另一種是反應物中具有電聚合的特性，藉由微電極提供適當電位而產生電聚合分子，此分子因溶解度低而沉積在樣品表面。我們在此提出一個利用電化學掃描顯微鏡來製圖的新方法。這個方法是利用 click chemistry 將帶有特殊螢光官能基團的炔類分子，經由 SECM 產生之 Cu(I)催化與尾端有疊氮之自組裝分子修飾過之玻璃表面共價結合再利用螢光顯微鏡觀察成像。

(2) An unprecedented strategy of connecting a self-assembly recognition site into π-conjugated chromophores has been established. The presenting method allows one to attach a self-assembly motif, here is biuret, to various designated scaffolds containing with specific functions. Interesting intermolecular interactions behaviors of oligofluorenes (donor) and oligo(*p*-phenylenevinylene) (acceptor) bearing with biuret groups and the mixtures of donor and acceptor have been characterized by fluorescence confocal microscopy imaging and scanning electron microscopic (SEM). The formation of vesicle in THF by small molecules with self-assembly motifs is very unique and rarely reported. 我們成功開發出了一個全新的分子自組裝建構單元 4-pinacolatoboronic ester benzenebiuret 並將其與有機發光分子以鈴木反應合成具有分子自組裝單元的發光材料，此種合成策略首次被開發出來並成功應用在建構不同的具自組裝功能的分子合成。利用螢光放光共焦顯微鏡及 SEM 來研究其中兩個帶有分子自組裝辨識單元的藍光發光材料以及綠光發光材料在固態成膜型態特性。藍光分子會在表面自組裝成為 vesicle 結構，此種利用小分子自組裝行為在 THF 中形成 vesicle 的現象甚為罕見。

(3) A neat film of oligofluorene shows unique oxygen sensing features including very fast response, repeatability and high emission efficiency. Taking advantage of the fact that this oligofluorenes is a good media, the sensity can be enhanced by over 10-fold and 20-fold using the ASE and lasing action, respectively. The results indicate that other than conventional dyes dispersed in polymer support, oligofluorenes thin film is another class of attractive material for oxygen sensing. 比起一般將染料混入高分子在體所製成的氧氣感應材料，利用 oligofluorene 所製成的薄膜則具有重複使用及反應時間快的優點，利用 oligofluorene 之光激發雷射效應可以進一步增加其螢光感測強度約 20 倍。

(4) To the best of our knowledge, the short-range couplings in EET is characterized precisely for the first time. This work will be important for characterizing the transportation of excitation energy as well as electron transport processes in the liquid-crystal forming materials. 我們首度發展了一通用於相當多種分子系統的嶄新方法計算其電子耦合值。這項結果為我們進一步探討液晶材料的激發能量傳遞、以及電和傳遞，提供了重要的基礎。

**2008**

我們所開發以主—客離子性銥金屬錯合物為基礎之單層固態白光發光電化電池是文獻中前所未有的，目前白光發光元件的發展大多是以不同放光波長的電中性銥金屬錯合物來建構的多層元件，雖然元件效能高，但製程相對複雜，我們利用單層白光發光固態電化電池可能在固體發光科技中成為極具前景的替代方案。我們在離子性銥金屬錯合物中接上咪唑基團，可用來製作”單一組成”離子性過渡金屬的發光電化電池，成功地解決在離子性化合物為基礎之單層固態發光電化電池常會遭遇啟動時間過長的缺點，此策略有別於文獻中利用混合離子液體來減

低啟動時間所常用的方法。我們同時成功合成一系列以具有大的立體障礙芴為終端基團之雙極性新型高放光量子效率之材料作為研究電致化學發光之材料。因為這一些芴之衍生物，會抑制 excimer 形成，其 ECL 放光波長可以藉由不同的中心基團加以調控。其中含 benzothiadiazole 之衍生物，即使是在亮室操作環境下可以直接由肉眼觀察到綠光 ECL 放光行為，此種高效率 ECL 放光特性在文獻中也相當少見。利用離子性或在分子外圍引入不同數目的氟原子來改變分子間作用力進而影響分子材料的液晶特性，其中首次利用 Alq3 為核心形成自組裝結構或薄膜，並且具有良好發光特性。我們利用熱或光轉換之 pentacene 可溶性前驅物，以溶液塗佈製程，製作具有良好特性之有機電晶體，此種前驅物策略是以 pentacene 為有機電晶體材料的重點發展方向之一。

## 8. 評估主要成果之價值與貢獻度：（請從學、技術創新、經濟效益、社會衝擊等影響面）：

**2007**

根據此計劃之主要目標：操控分子間之電子交互作用的行為，我們延續第一年的研究成果，在第二年我們已開發：(1) 以 SECM 輔助利用 click chemistry 做螢光成像的全新技術，雖受限於 SECM 電極的大小，成像解析度尚不高，但具有極高的技術創新新性；(2) 利用所開發出的全新分子自組裝建構單元彈性地建構具有功能性的自組裝分子用以調控分子間之相互作用行為，分子間相互作用可以共聚焦螢光顯微鏡及 SEM 技術成像，其中發現含 oligofluorene 的自組裝分子可以於 THF 中形成 vesicle 結構，此部份則具有學術價值上之特殊性；(3) 利用 oligofluorene 薄膜作為氧氣的感測，此種薄膜具有可重複使用及反應時間快的優點，並利用雷射現象提高感測靈敏度，此部份具有後續應用性開發之潛力；(4) 建構新的理論計算模型提供進一步探討液晶材料的激發能量傳遞以及電和傳遞重要的基礎。

**2008**

我們所開發以主—客離子性銥金屬錯合物為基礎之單層固態白光發光電化電池是文獻中前所未有的，Photonics Spectra 2008 年五月號以專文介紹此新技術，此項成果可發展成為新的白光 LED 可能為固體發光照明科技提供具前景的替代方案技術。 另外利用”單一組成”離子性過渡金屬的發光材料，可以成功地解決單層固態發光電化電池常會遭遇啟動時間過長的缺點。引入立體障礙芴為終端基團抑制 excimer 之形成成功開發具 ECL 放光特性之雙極性材料，為此領域提供一種新的分子設計概念。利用液晶特性來操控分子間相互作用的行為，增進材料的相關物理特性及應用性，並開發利用熱或光轉換之 pentacene 可溶性前驅物，以溶液塗佈製程，製作具有良好特性之有機電晶體。