Disordered Semiconductors

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PPV: prototypical semiconducting polymer:

Delocalised $\pi$-electrons provide both conduction and valence bands

$\pi$ electrons – delocalized, as in graphene?

$\pi$ electrons – localized, as in distyrylbenzene?
Organic Light-Emitting Diodes

iPhone X, LG OLED TV
Organic field-effect transistors – band-like mobilities.

- Improvements in performance through improved molecular design and better understanding of charge transport physics:
  - Solution processed small molecule OTFTs with mobilities > 10 cm$^2$/Vs
  - Polymer-based OFETs with mobilities 1-10 cm$^2$/Vs

Henning Sirringhaus
Sharpness of optical absorption edge

- Urbach energy of IDTBT $E_\mu = 24$ meV - Lowest among all conjugated polymers measured; Comparable to crystalline inorganic semiconductors (GaN)

doi: 10.1038/nature13854
Model for higher mobility organic system: Dynamic disorder due to non-diagonal electron-phonon coupling

- Transfer integrals sensitive to relative intermolecular distances and orientation
- Significant thermal fluctuations of transfer integral expected
- Thermal disorder in transfer integrals leading to localisation of the charge carrier wavefunction


Troisi, Chem. Mat. 17, 5024 (2005)
Organic solar cells - Electro-absorption: evidence for fast early time separation of hot carriers

- Electric field generated through charge photogeneration as early as 40 fsecs (PCDTBT:PCBM)
- Electric field energy of 150 meV requires electron-hole separation > 4 nm

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Lead Halide Perovskite: defect tolerant thin film semiconductors for PV and LEDs

Easy to process films (polycrystalline films from solution processing)

Unexpectedly good semiconductor properties and good solar cells

Easy to tune optical band gap by alloying both halide (Iodide/Bromide) and metal (lead/tin)

Solar cells – power conversion efficiency above 22% for single junction cells, 28% for silicon:perovskite tandem
CH$_3$NH$_3$PbI$_3$ ‘sharp’ optical absorption and high luminescence efficiency


Very sharp optical band edge: Urbach Energy 14 meV
Perovskite LEDs

Tan, Snaith, Friend et al. Nature Nanotechnology 9, 687 (2014)