Combinatorial Screening of Organic Field Effect Transistors

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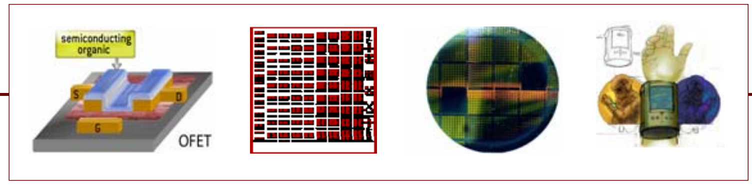
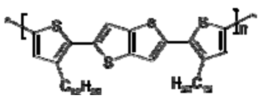
Motivation

- Organic semiconductors are used in developing applications such as organic light emitting diodes (OLEDs), photovoltaics, radio-frequency identification tags (RFIDs) and organic field effect transistors (OFETs)
- Microstructure of OFET active layer critically affects charge transport and device performance, which varies greatly due to processing conditions (*e.g.* casting solvent or spin speed)
- Advancing OFET technology requires understanding of the processing, structure and performance, yet current measurement methods used for traditional semiconductors cannot be always be directly transferred, and are stretched to cover a large variable space
- Combinatorial analysis covers a large processing parameter space, is systematic and high-throughput making research more productive and less wasteful



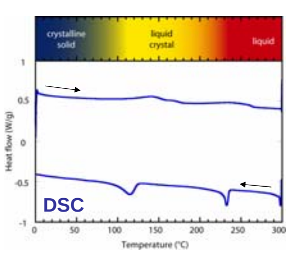
Objective



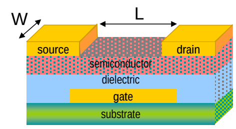
pBTTT-C12

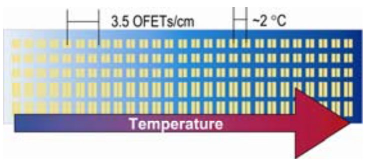
Goal: Using a gradient combinatorial approach, study effects of temperature on the microstructure and hole mobility of pBTTT-C_{12} thin films

Approach



- **pBTTT-C_{12}** is a high performance **solution processible** semiconductor developed by Merck (McCulloch *et. al. Nature Materials* 5, 243, 2006)
- Saturation hole mobility 0.2 $cm^2/V{\cdot}s$ (comparable to *a*-Si)
- Improved mobility after annealing to liquid crystal phase as mapped by powder differential scanning calorimetry (DSC)





Thermal Gradient

- pBTTT-C_{12} spin coated from warm dichlorobenzene onto OTS-SiO_2
- Top contact gold S/D electrodes where channel width (W) = 1 or 2 mm and channel length (L) = 80 to 220 μm
- Thermal gradient anneal in nitrogen $\Delta T \sim 75°C$
- Heated for 5 min, cooled to 80 °C (15 min)

Near Edge X-ray Absorption Fine Structure (NEXAFS) Spectroscopy

Features:

- High sensitivity to π bonding
- Directly measures molecular orientation
- Depth sensitive
- Collects chemistry and orientation information simultaneously
- Quantification

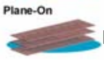
Resonance Intensity: $I(\Theta) = \int_{peak} PEY(\Theta)$

Dichroic Ratio: $R = \frac{I(90°) - I(0°)}{I(90°) + I(0°)}$

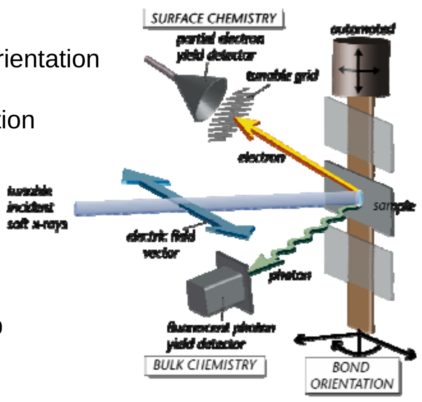
Edge-On

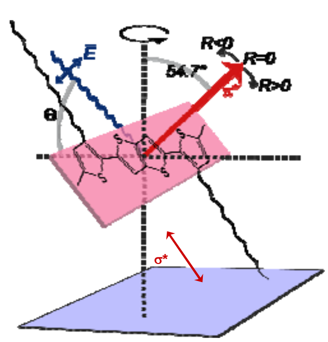
R = 0.70

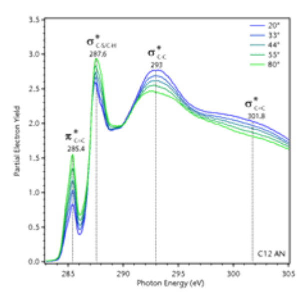
Plane-On



R = -1.00







Highlights

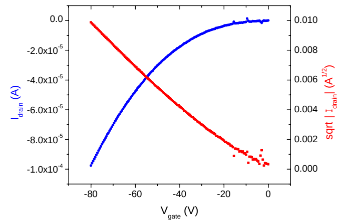
- Over 230 pBTTT-C_{12} OFETs were processed simultaneously on a single substrate on the temperature gradient stage
- OFETs tested on automated Cascade probe station and were characterized in saturation and modeled by

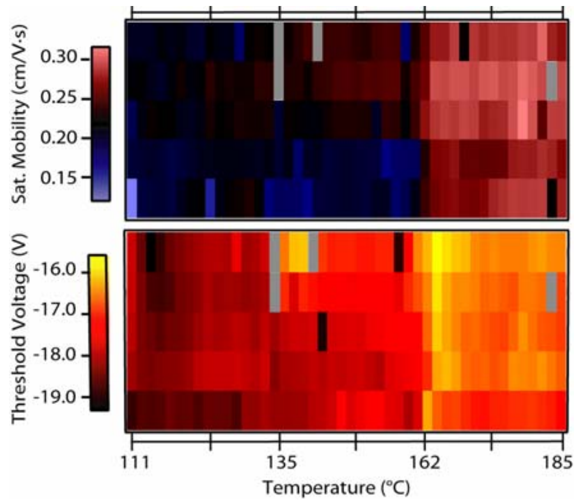
$$I_D = \frac{W C_i}{2L}\mu (V_G - V_T)^2$$

where

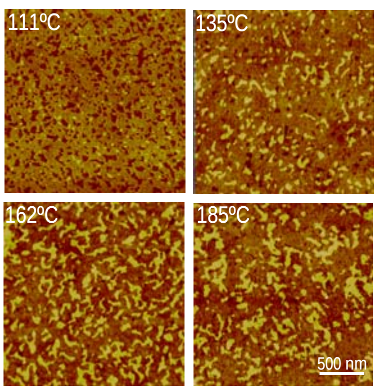
V_D - drain voltage
V_G - gate voltage
I_D - drain current
L - channel length
W - channel width

C_i - capacitance per dielectric unit area
V_T - threshold voltage
μ - field-effect mobility

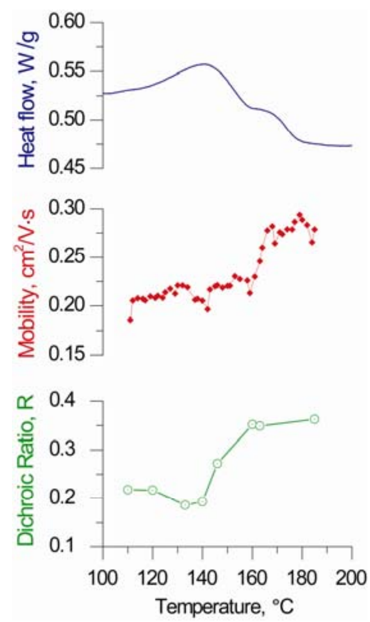




- Each pixel represents an individual transistor
- Mobility increases with temperature with transition region (160 to 165)ºC
- Highest mobility ~ 0.3 cm²/V·s



- Atomic force microscopy (AFM) reveals formation of lamellar terraces(~2 nm height) during annealing
- As cast-films are featureless
- Step height corresponds to lamellar spacing



- Increased mobility coincides with heating into LC phase (DSC)
- Edge-on orientation of conjugated plane increases with temperature due to decrease in disorder of the film

Summary

- Increase in carrier mobility coincides with heating pBTTT-C12 into liquid crystalline phase as determined by DSC
- Mobility enhancement coincides with an increase in crystal domain size as observed by AFM and edge-on conjugated plane orientation as measured by NEXAFS
- Smooth correlation (temperature, structure) made possible by use of combinatorial temperature gradient
- This combinatorial method may find general utility for screening OFET performance
- This high-throughput approach can be used to optimize heat treatment, investigate materials with multiple phase transitions, or determine the lowest thermal budget required to increase performance
- Complete results published in Lucas, L. A. *et. al.*, Appl. Phys. Lett. 90, 012112, 2007

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