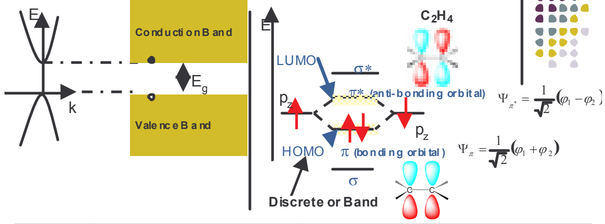
ORGANIC ELECTRONICS

Deepak Gupta
Materials & Metallurgical Engineering

Comparison with inorganic materials



	Inorganic solids	Organic solids
Bonding	Ionic, Covalent, Metallic (2-4 eV)	Ionic or covalent within molecule, the solid held together by Van der Waals forces (<0.01 eV); solid behaviour therefore governed by molecule.
Charge carriers	Electrons, holes, ions	Polarons, exciton diffusion
Mobility	100-10000 cm^2/Vs	10^{-6}-1 cm^2/Vs

Organic Electronics

Optical → Displays, Illumination Sources, Solar Cells
(Radiative Recombination/Generation and Charge transport)

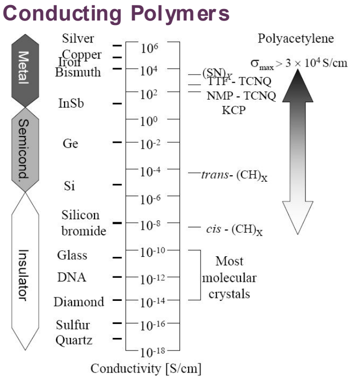
Electronics (TFTs)
(Charge transport)

Two Flavours:
1. Small Molecules
2. Polymers

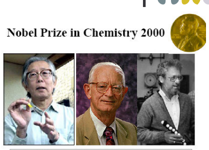
Two Stories

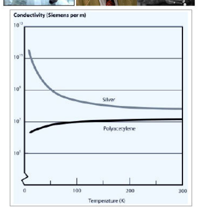
1. Conducting Polymers: Charge transport in polymers (in one slide!)
2. OLED: Light emission upon charge injection (commercialization)

Conducting Polymers



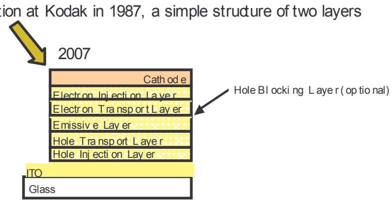
Nobel Prize in Chemistry 2000





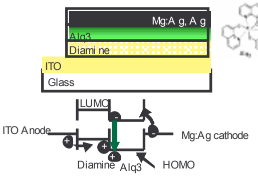
OLEDs

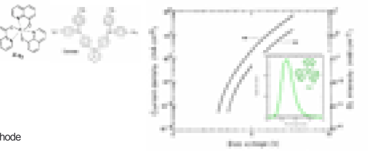
Invention at Kodak in 1987, a simple structure of two layers



MILESTONES
1.0 First Heterostructure OLED (bring voltage down)
2.0 Guest-Host Colour Tuning in 1989 (control colours)
3.0 Ir-Complexes based phosphorescent materials (nearly 100% efficiency)
4.0 Conductivity Doping (device operation at minimal voltage)

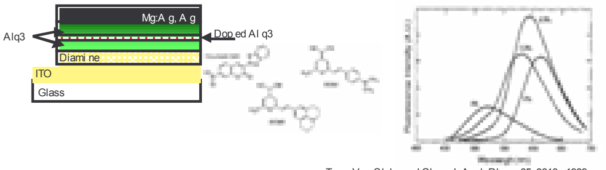
1.0 First Heterostructure OLED (bring voltage down)





Tang and Van Slyke, APL, 51, 913, 1987

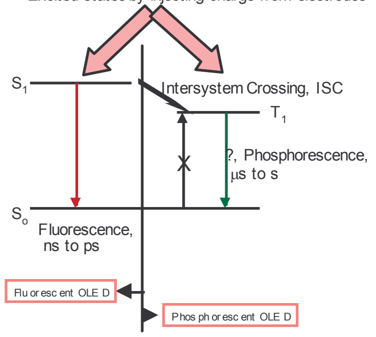
2.0 Guest-Host Colour Tuning in 1989 (control colours)



Tang, Van Slyke and Chen, J. Appl. Phys., 65, 3610, 1989

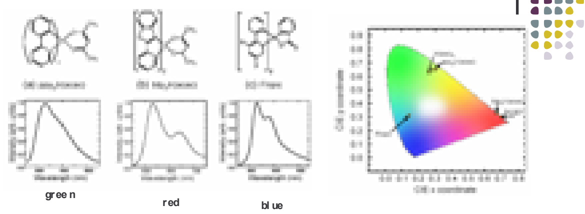
Fluorescence and Phosphorescence

Excited states by injecting charge from electrodes



- S represents Singlet State (S=0)
- T represents Triplet State (S=1)
- Subscript o is ground state, subscript 1 is excited state

3.0 Ir-Complexes based phosphorescent materials (nearly 100% efficiency)



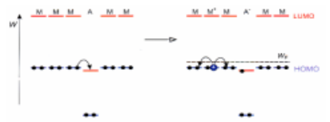
			J = 1 µA/cm²				J = 1 mA/cm²			
phosphor	host	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CBP	[illegible]	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	CBP	[illegible]	1.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PtOEP	CBP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

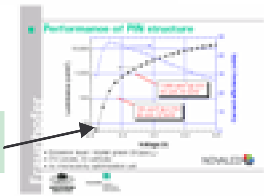
Source: M. Baldo, Ph.D. Dissertation, Princeton, 2001

4.0 Conductivity Doping (device operation at minimal voltage)

At what is the potential (voltage) are carrier injected? Meaning what about power efficiency.

P-type doping
Add acceptor whose LUMO is than HOMO of Matrix





Operation at theoretically lowest voltage

OLED History
http://www.oled-info.com/history

The Early Years
1996 - CDT gives world's first public demonstration of Light Emitting Polymer devices
1997 - UDC Demonstrates Flexible Flat Panel Display Technology
1997 - Pioneer Electronic Produces EL Display with 260,000 Colors
1998 - Kodak, Sanyo Show Full-Color Active Matrix Organic Display; First Color OEL Display Increases Threat to LCD Display Dominance
1998 - Green Organic LED Shows High Efficiency
2000 - Ritek plans to mass produce OLED
2000 - Toshiba Corp. plans to produce (organic EL) panels in 2001
2000 - Motorola Grants OLED Technology Rights To Universal Display And Takes Equity Position
2000 - UDC and PPG Industries Form Strategic Alliance for Development & Supply of Chemicals for OLED Manufacturers
2000 - Sanyo Electric to start mass production of color organic EL panels in 2001
2000 - NEC, Samsung To Develop Organic Wireless Displays
2000 - LG Electronics develops organic EL displays for mobile gadgets

2001
February - Sony Develops World's Largest Full Color OLED (13 inches diagonally with a resolution of 800x600 pixels.)
April - Universal Display Corporation and Sony Corporation Announce Joint Development Agreement Aimed at OLED Television Monitors.
April - Samsung Exhibits Color Organic EL LCD Panel for Mobile Phones at CeBIT (132 by 162 pixels).
May - Toshiba Develops World's First 260,000-Color Polymer OLED.
August - eMagin's OLED Microdisplay Selected by Air Force for F15E Aircraft.
October - Sony Demonstrates 13-Inch, Full-Color OLED Prototype.
October - Universal Display Corporation and Samsung SDI Announce Key Joint Development Agreement.
October - Universal Display Reports New Red Phosphorescent OLED Materials, Significant Power Efficiency Advances.
October - Samsung SDI Develops World's Largest Organic Display Panel (15.1 inch).
November - RiTdisplay opens new color OLED/PLED factory.

2002
February - Samsung SDI develops 2.2-inch AM OLED for mobile phones.
April - Philips Announces Industry's First Volume Shipments of Polymer-Based OLED Modules.
May - Kodak Announces Availability of Evaluation Kit For Active-Matrix OLED Display.
May - RiTdisplay reportedly receives orders for over one million mobile phone OLEDs.
June - AU Optronics develops world's first OLED prototype combining a-Si TFT LCD technology.
June - Epson, CDT form polymer OLED production venture.
November - Pioneer Supplies OLED to LG Electronics for Cell Phones.
December - DuPont Displays and Universal Display Corporation Form Strategic Alliance to Develop Next Generation Displays Combining Aspects of Small Molecule and Polymer OLEDs.

2003
January - Philips invents EL material to generate both red and green light.
January - Kodak, Sanyo invest in active-matrix OLED production.
January - Sanyo Unveils Mobile Phone with Organic EL Panel Designed for KDDI, announces plans to build full-color OLED production line.
February - RiTdisplay lands mobile phone OLED orders from Samsung and LGE.
February - Kodak Licenses Samsung NEC Mobile Display to Manufacture Passive-Matrix OLED Displays.
March - Kodak introduces the first digital camera with an OLED screen - the Kodak EasyShare LS633.
March - IDTech develops 20-inch full-color OLED display.
April - DuPont forges 'Olight' brand for emerging OLEDs.
April - Sony testing 24-inch OLED screen.
May - AUO and UDC develop 4-inch, a-Si TFT backplane-based, red phosphorescent AMOLED.
May - Samsung NEC develops 65,000-color PM OLED mobile phone display.
May - Sony demonstrated a 24.2 inch OLED panel.
June - ERSO and Windell develop 10-inch LTPS TFT technology-based AM OLED display.
June - Sony to invest nine billion yen to build OLED production line.
September - AU Optronics has showcased its 1.93" AMOLED for Mobile Phone.
September - Princeton electrical engineers have invented a technique for making Organic Solar Cells that Could Lead To Widespread Use Of Solar Power.
October - Sanyo Unveils Long-Lasting QVGA Organic EL Panel for Cell Phones.
October - Univision begins OLED production.
November - Tohoku Pioneer Corporation to Be First Manufacturer to Use Universal Display Corporation's PHOLED Material in a Commercial OLED Display.
November - Univision showcases 65,000-color mobile phone OLED sub-display.
December - Univision reaches monthly capacity of 6,000 OLED substrates.
December - Casio Ventures into Organic EL Panels Driven by Amorphous Si TFT.

2004
January - Opto Tech to invest NT$4.5 billion in four new OLED lines in 2004.
February - Philips 639 mobile phone applies PolyLED technology in unique 'Magic Mirror' display.
March - GE Global Research Breaks Two World Records For OLEDs As A Lighting Device. Demo Lighting Panel is Biggest and Most Efficient Ever Created.
March - NEC drops its OLED business.
March - Chi Mei Optoelectronics Corp. (CMO) has announced a fully functional prototype of a 20-inch full-color OLED display - the largest Amorpheous Si TFT.
April - Teco Optronics to invest NT$300 million to build new PM OLED plant.
April - RiT Display ships mobile phone OLED sub-displays to Samsung, says paper.
April - Seiko Epson Reveals 12.5-Inch Organic EL Panel for Large TVs.
April - RiT Display shipping OLED panels to Motorola.
May - Seiko Epson unveils first 40" colour OLED display.
May - Universal Display Corporation Announces Record-Breaking Power Efficiencies for its Phosphorescent White OLED Technology.
May - Taiwan's AU Begins Mass Production of Organic EL Panels.
May - Universal Display Corporation Unveils Ground breaking Flexible OLED Prototype on Metallic Substrate.
June - Toppan to volume produce large-size OLED panels.
June - OLED-Info is on-line, the web's first OLED community site.
September - Sony Starts Mass Production of Organic EL Displays, and released first a new clie PDA with a 3.8 in 480 x 320 OLED screen.
October - LG.Philips develops 20-inch OLED display.
November - OLED displays with 50,000 h operating lifespan from URT.
November - Seiko Epson will commercialize OLED TVs by 2007.
December - CDT IPOs, lists on NASDAQ.

2005

January - Samsung Electronics develops 21-inch OLED for TVs, claims world's largest.
January - Samsung SDI To double the OLED output.
January - OLED Technology Poised to Become Core Business for Daewoo Electronics.
February - MP3-player demand boosts sales of Taiwan OLED makers.
February - LG.Philips LCD launches AM OLED Business.
March - Sony introduces Flash based MP3 players with OLED display.
March - Canon says to start making OLED displays next year.
April - Samsung Licenses OLED Patents from Universal Display.
May - Kodak Licenses OLED Technology to Fuji Electric Holdings.
May - CDT Achieves 100,000 Hour Blue Polymer Lifetime.
May - Samsung Electronics Develops World's First 40-inch a-Si-based OLED.
June - UDC announces fundamental breakthrough in blue PHOLEDs - New sky blue achieves over 15,000 hours of lifetime.
July - Samsung SDI to invest over 850M$ in AMOLED production.
August - LG Electronics Launches Full-Scale OLED Operations.
September - Toppoly develops a 7" AMOLED display.
October - Samsung SDI's Organic LED Display Shipments Top 30 Million units.
November - CDT Prints a 14" P-OLED display.
November - China's first OLED production line set up.
December - Pioneer withdraws from AM-OLED market.

2006

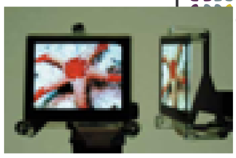
January - BenQ announces a camera and a phone with large (2.0") OLED screens.
January - Kodak Broadens its Participation in OLED Technology, ends OLED joint venture with Sanyo.
March - Univision to invest $40M in OLED line expansion.
March - Epson and CDT shows world's first print head using an OLED light source.
April - Kodak Licenses OLED Technology to Univision Technology.
May - Pioneer Launches Mass Production at White OLED Plant.
June - India's Samtel to produce OLED displays.
August - AUO relocates OLED engineers, focuses on LCD.
September - first 'Nokia' phone with an OLED display.
September - CDT sees rapid progress in Blue and Red lifetime
October - CMEL & CMO develop 25" AMOLED TV panel
October - Samsung showcases 1.7" AMOLED

2007

January - Sony showcases 27" and 11" OLED TVs at CES, Says might start production at 2008.

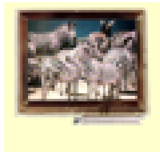
DISPLAYS

Eastman Kodak and Sanyo Electric; Active-matrix, full-color organic 2.4", 852x222 pixel, 1.8 mm thick display for digital still and video cameras and other portable imaging products; a contrast ratio of more than 250:1, and a peak luminance of 200 cd/m².



www.spectrum.ieee.org/publicfeature/aug00/orgsf4.html

www.kodak.com/US/en/corp/display/overview.jhtml



www.kodak.com/US/en/corp/display/activeDisplays.jhtml

DISPLAYS

Why bother with OLEDS?

- Flat panels: thin, light weight, low cost, novel applications
- Compare with competing LCDs: emissive, i.e. no backlighting
- Sales Pitch
  - Flexible
  - Large viewing angle
  - Bright (10^5 Cd/m^2 peak in pulse operation)
  - Long Life? (30000 hours at 100 Cd/m^2)
  - Low voltage (3-8 V)
  - Good luminous efficiency (>20 lm/W)
  - Large colour range

Flexibility

www.universaldisplay.com/concepts.php

www.spectrum.ieee.org/publicfeature/aug00/orgsf1.html

Foldable Displays

Passive-matrix 1.8 mm thick, 5x10 cm 128 x 64 pixel monochrome display; substrate: polyethylene terephthalate (can bend into a diameter less than a cm); operates at conventional video brightness of 100 cd/m².

Viewing Angle

www.kodak.com/US/en/corp/display/viewingAngle.jhtml

Image visible up to 160 degrees. Is that possible with LCDs? Not according to Kodak

Brightness

OLED

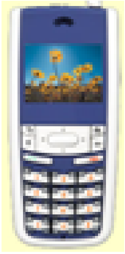
LCD

Brightness, contrast & colour: OLED better than LCD

http://www.kodak.com/US/en/corp/display/brightnessColor.jhtml

Some More Pretty Pictures

www.kodak.com/US/en/corp/display/applications.jhtml



www.kodak.com/US/en/corp/display/intel.jhtml

OLEDs in portable devices such as mobile phones, digital video cameras, DVD players, and PDAs.

Car audio components manufactured by Pioneer and cellular phones marketed by Motorola and Sanyo.

Digital Cameras

2.2" OLED display with 512 x 218 pixels

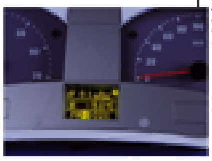
www.dpreview.com/news/0303/03030216kodakls633.asp

March 2003 (Kodak Announcement)

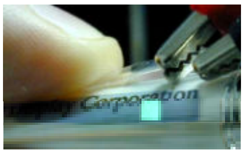
Kodak three megapixel, LS633 Zoom digital camera. The LS633 is world's first digital camera with OLED display. As there is no need for a backlight the LS633 should have good battery life.

Automobile Applications

Automotive, Phillips



Automotive, Siemens



www.universaldisplay.com/toled.php

Transparent substrate for displays on wind shield

Some Products in Market

Samsung YP-K5JQB 2 GB Audio Player with Bui...

Nokia 6215i Phone (Verizon Wireless)

Sony NW-S205F 2 GB Flash Sports Digital Mus...

512MB MP4/MP3 Playing Watch with 1.5-Inch O...

Creative Zen V Plus 4 GB Portable Media Pla...

Cowon iAudio6 4 GB MP3 Player (Black)

3DVisor Digital Display

Sanyo Xacti VPC-HD1 5.1MP MPEG4 High Defin...

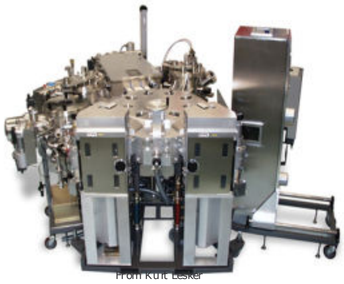
Iriver S10 Post Stamp Sized 2gb Mp3 Player...

Two Flavours: Small Molecules vs. Polymers

Small Molecules	Polymers
Small Molecules currently dominate the OLED display market	PLEDs not yet have substantial market
The materials are inherently more stable and robust than PLEDs	PLED materials suffer from shorter lifetimes, but improvement is occurring
Phosphorescent dopants for small molecules make OLEDs more efficient	Devices are fluorescent, but movement towards phosphorescent devices also
Layers thermally evaporated in vacuum; extensive opportunity for device engineering (DETAILS)	Spin coating limits the number of layers in device
The vacuum evaporation process limits the size of the substrate • Difficult to upgrade for Television and Monitors • Currently machines being developed for large glass sizes	PLEDs offer lower cost manufacturing possibilities with ink jet printing, over large substrates • Suitable for Televisions and monitors
	Printing is yet to develop into a production tool. Currently, PLED manufacturing is confined to monochrome displays, which do not require printing

NEXT

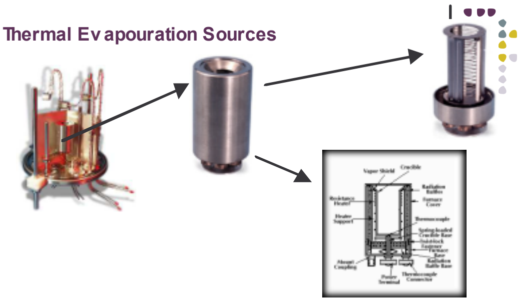
Deposition Cluster Tool



From Kurt Lesker

- Multiple chamber OLED cluster tool separated by Gate Valves
  - Ultra High Vacuum cryo pump based system
  - Substrate transfer to and from chambers within vacuum
  - 5 micron alignment accuracy in UHV
- Multilayer deposition of Organic layers
  - Low temperature evaporation
  - Film thickness < 500 A^0
  - Energy level compatibility between layers for device efficiency

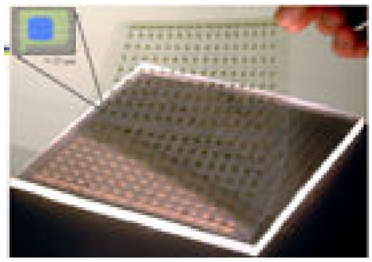
Organic Thermal Evapouration Sources



- Films only few tens of nanometers
- Thickness control is critical
- Temperature control within 0.1 to 1 °C
- Design to enable minimal use of organic materials

Back

All polymer device on plastic substrates...



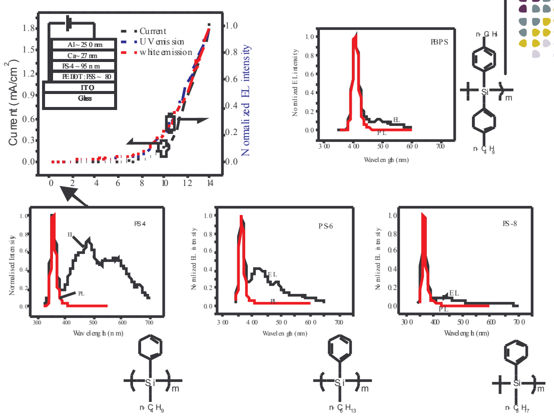
Back

Our Research on OLEDs

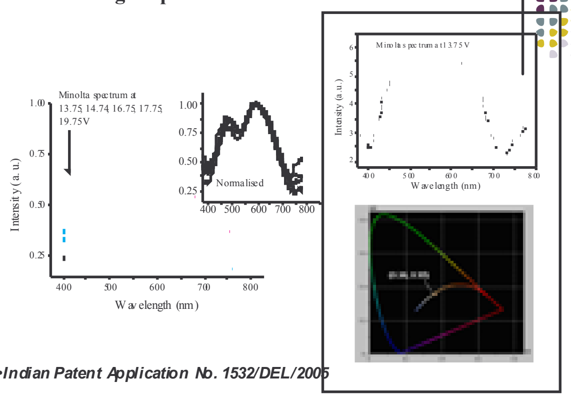
- Development of full colour display prototype
- Polysilane based OLED

Organic	Polysilanes
1. π^*-π Transition	σ^*-σ Transition
2. Large Spectral Width	Narrow Spectral Width
3. Visible Emission	UV or NUV (difficult with p conjugated polymers as gap is < 3eV and requirement of small energy loss before radiative deactivation)

Luminance-Voltage (L-V) characteristics

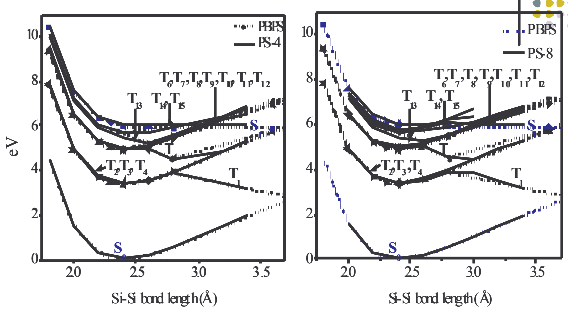


Voltage dependence of the UV and white emission



•Indian Patent Application No. 1532/DEL/2005

Potential energy curves for new polymers (6-31g*)



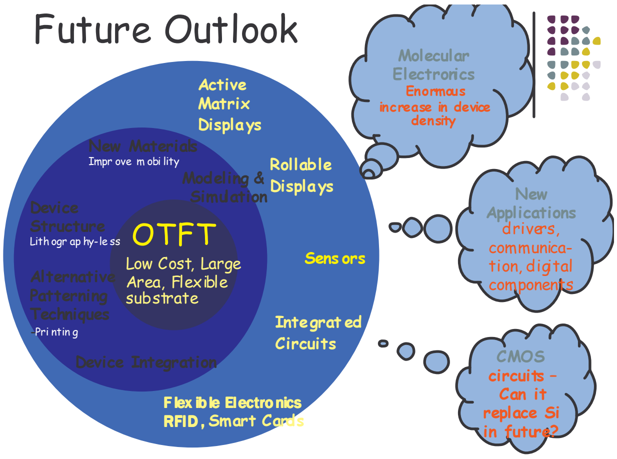
Organics Semiconductors: Beyond OLED & Lighting

- OTFT
- Solar Cells
- Printable RFID tags

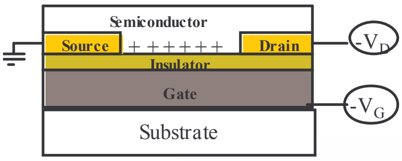
Samtel Center for Display Technologies

1. S. S. K Iyer: Solar cells, OTFTs
2. Baquer Mazhari: Driver design, Solar Cells, OTFTs
3. Monica Katiyar: OLED, OTFTs
4. Y. N. Mohapatra: OLED, Lighting
5. Satyendra Kumar: OLED, Solar Cells
6. A. R. Harish: RFID tags

Future Outlook



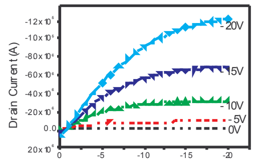
Typical FET structure

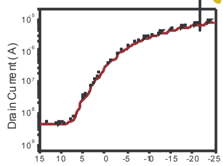


Substrate: Glass, Plastic
Source, Drain, Gate: Metal (Al, Au)
Insulator: PMMA, SiO_2

Pentacene
Poly(3-hexylthiophene) P3HT

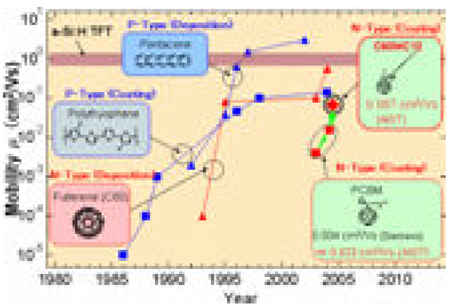
Pentacene FET (Top Contact)





Mobility=0.22cm^2/V.s
Threshold Voltage=-0.5V
On/Off Ratio=10^4
Subthreshold Swing=3.5V/decade
Pentacene Thickness=35 nm

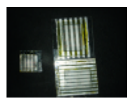
Mobility



Organic Solar Cells

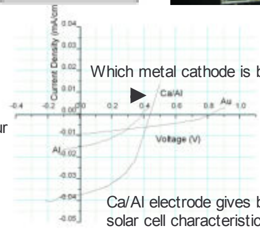
Goal

- Higher efficiency (~10 %), reliable and low cost /economical organic solar cells



Approach

- Understanding the Physics
- Device Modelling
- Experimenting with new Material
  - New organic material from IIT Kanpur
  - Carbon Nanotubes, C_{60} & PCBM
- New Device Structures



Which metal cathode is better?

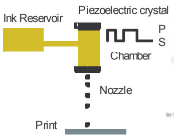
Ca/Al electrode gives better solar cell characteristics!

(Contributed by Prof. S. S. K Iyer)

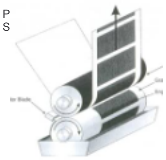
Printable Electronics

Goal

- Develop Printable Electronic Technologies
  - Inkjet printing
  - Gravure printing
  - Screen printing



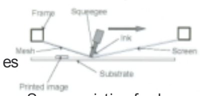
Inkjet printing for customised circuit



Gravure printing for high throughput

Approach

- Ink preparation
- Characterise printed devices
- Design/fabricate circuits

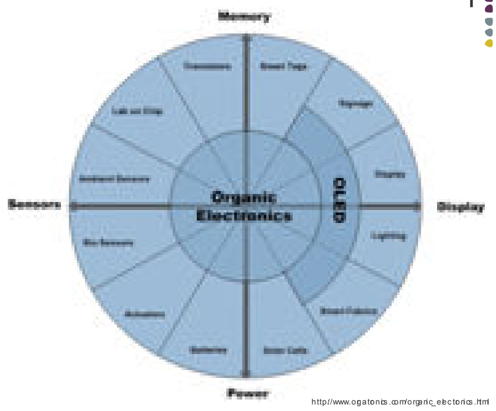


Screen printing for low resolution & cost ckts

RFID tags as prototypical product for demonstration

(Contributed by Prof. S. S. K Iyer)

The Future of Organic Electronics



http://www.orgatronics.com/organic_electronics.html

Opportunities Ahead

1. Blue OLED life time
2. Saturated colours in displays, stable with voltage
3. Materials and devices with high efficiency in high current regime
4. Doping: p-doping deposition, search for n-doping material
5. TFT for active matrix addressing
6. Flexible substrates and thin film encapsulation
7. Polymer OLEDS, printing inks
8. Molecular transistors for high mobility
9. Conversion into numerous possible applications