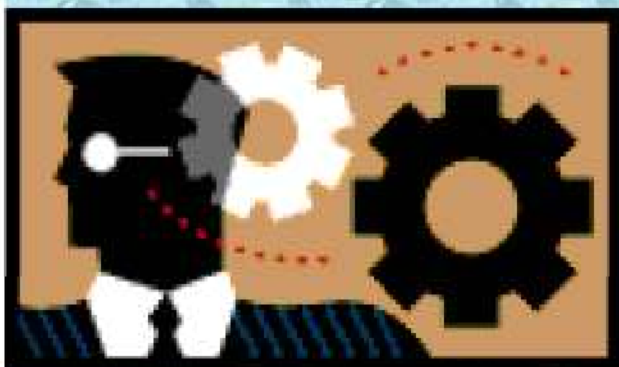
Role of Nanotechnology in Solid State Lighting



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THANKS TO THE TEAM

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DR. M.N. KAMALASANAN

FROM AINT

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- MR. ANIL KUMAR – JRF
- MR. SHASHANK MATHUR- I.M. TECH 10^{TH} SEM

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- DST, NEW DELHI FOR FINANCIAL SUPPORT

Plan of the Talk

- Nanotechnology – An Overview
- Solid State Lighting
  - » LED
  - » OLED
    - Introduction
      - Birth of OLEDs
      - Current OLEDs
      - Different types of OLEDs
      - Advancements
    - Results and Discussion (ZnO & TiO_2)
    - Future of OLEDs

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Nanotechnology: An Overview

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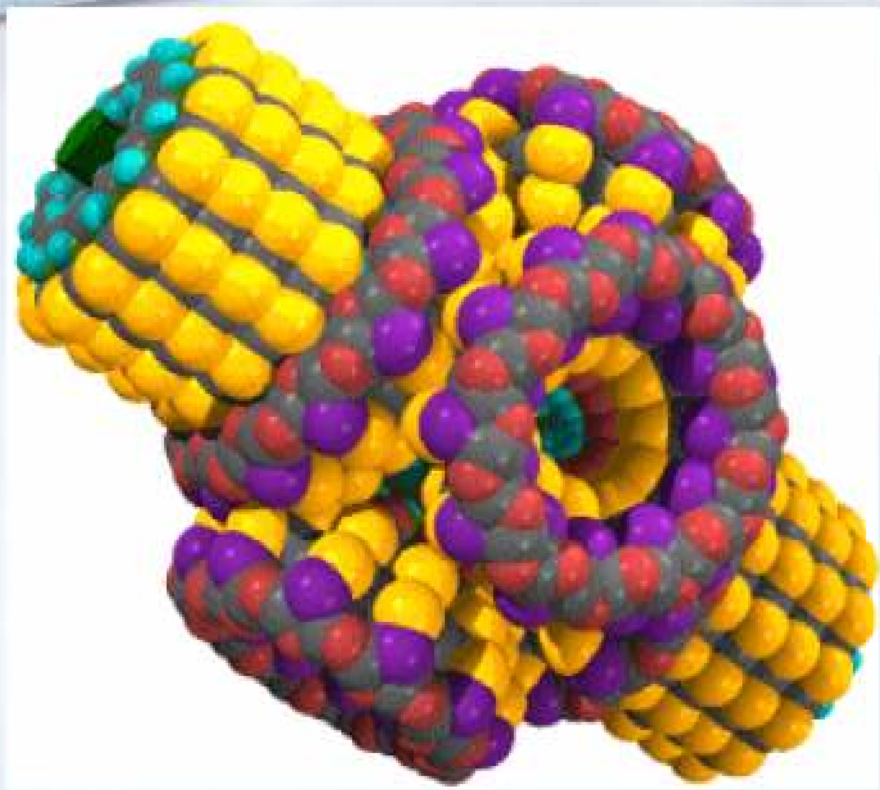
Sir RICHARD FEYNMANN

- In his lecture called "There's plenty of Room at the Bottom" talked about developing the ability to manipulate individual atoms and molecules to develop precise tools at the needed scale, thus giving rise to conceptual underpinnings of Nanotechnology in 1959.
- "The whole idea behind this is I want people to understand a little bit more about nanotechnology," Orfescu said. "I'm trying to make a parallel with the macro world --- the one we see with the naked eye."

K. ERIC DREXLER

In 1986, *K. Eric Drexler* wrote "Engines of Creation" and introduced the term nanotechnology as design, characterization, production and application of structures, devices and systems by controlling shape and size at nanometer scale.

DEFINITION



Nano technology is the hybrid science combining engineering and science that have application in the real world. Nanotechnology is the creation of functional materials, devices and systems, through the understanding and control of matter at dimensions in the nanometer scale length (1-100 nm), where new functionalities and properties of matter are observed and harnessed for a broad range of applications.

(1 Nano meter = billionth of a meter) i.e., 1/80,000 of the diameter of human hair or 10times diameter of hydrogen atom.

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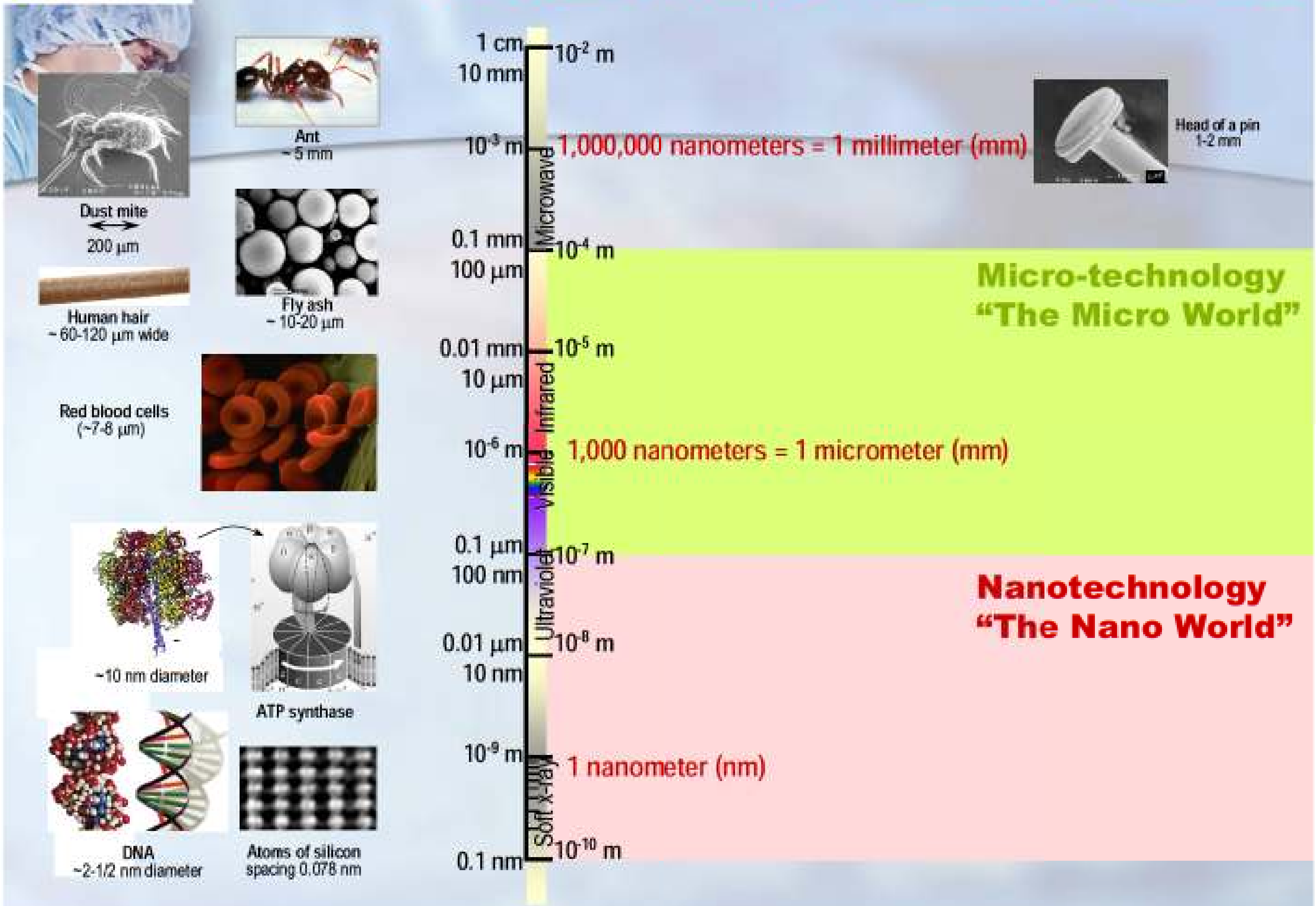
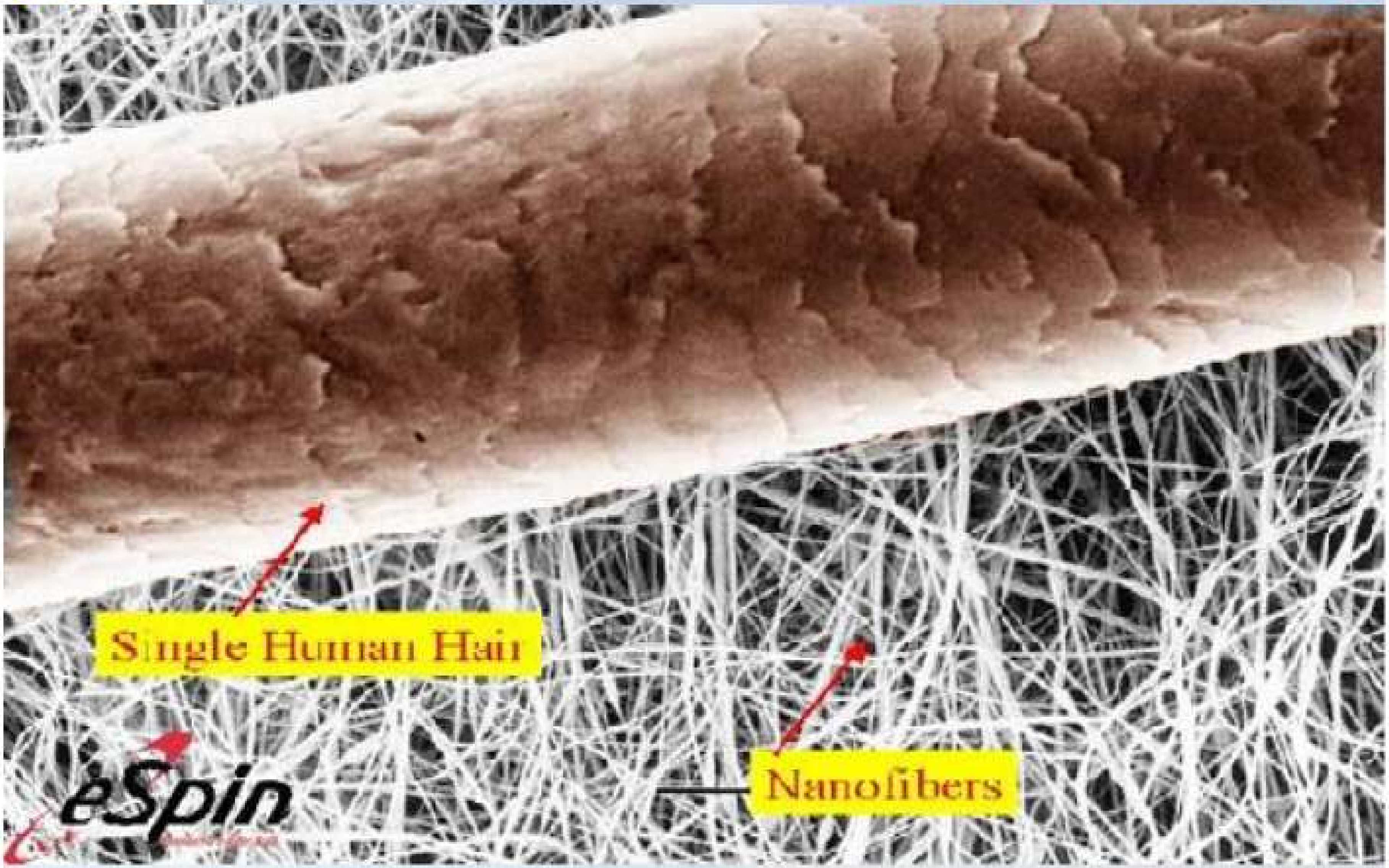
The Scale of Things – Nanometers and More



Compared to Human Hair



A Human Hair is about 100,000µm wide

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NANO TECHNOLOGY IN NATURE

- In nature, Nano particles have existed for billons of years ago. It often comes as a surprise to learn that the Romans and Indians were using Nano particles thousands of years ago.
- Of course they were not aware that they were using nanotechnology, and as they had no control over particle size, or even any knowledge of the nanoscale they were not using nanotechnology as currently defined.

EXAMPLES

- Salt crystals in ocean breezes.
- Hydrocarbons in essential oils.
- Resins of trees (turpentine).

Nanoscale Size Effect

- Realization of miniaturized devices and systems while providing more functionality
- Attainment of high surface area to volume ratio
- Manifestation of novel phenomena and properties, including changes in:
  - Physical Properties (e.g. melting point)
  - Chemical Properties (e.g. reactivity)
  - Electrical Properties (e.g. conductivity)
  - Mechanical Properties (e.g. strength)
  - Optical Properties (e.g. light emission)

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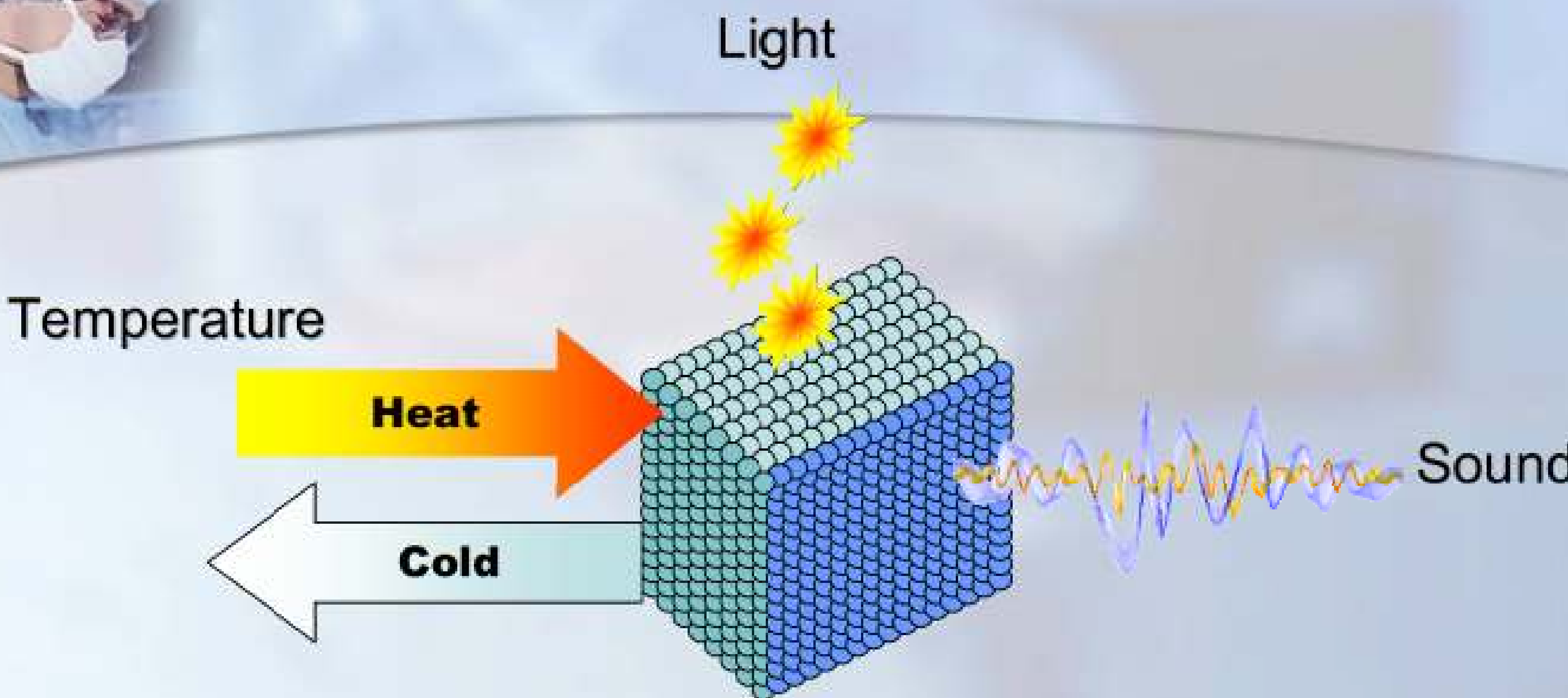
Surface Atoms Interact more with the Environment



The forms of energy that affect us in the environment can affect molecules.

Energy comes from the environment to affect molecular nature. Since more molecules are on the surface, the affect is more pronounced.

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Nanotechnology Applications

Information Technology

- Smaller, faster, more energy efficient and powerful computing and other IT-based systems

Energy

- More efficient and cost effective technologies for energy production
  - Solar cells
  - Fuel cells
  - Batteries
  - Bio fuels

Medicine

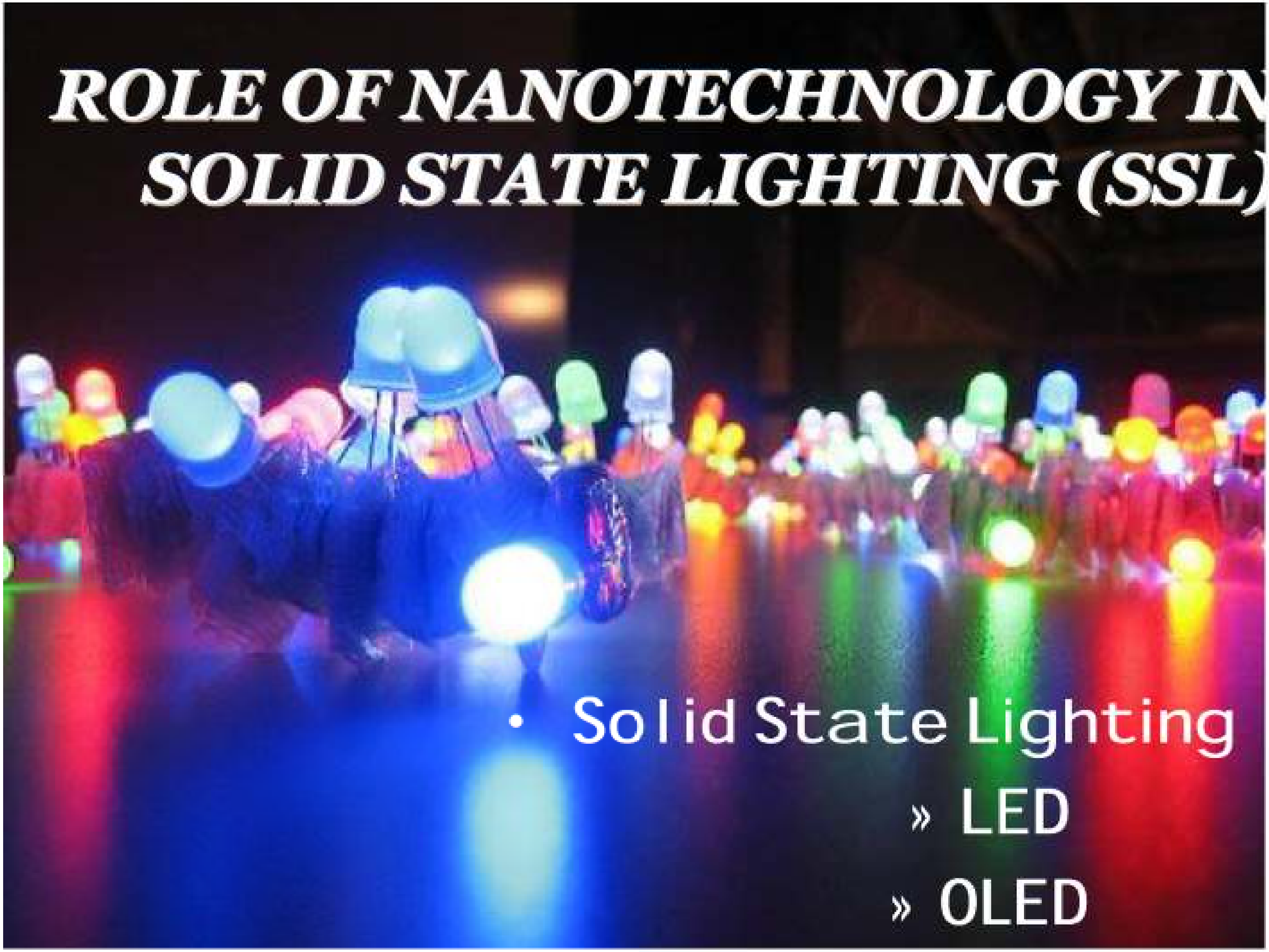
- Cancer treatment
- Bone treatment
- Drug delivery
- Appetite control
- Drug development
- Medical tools
- Diagnostic tests
- Imaging

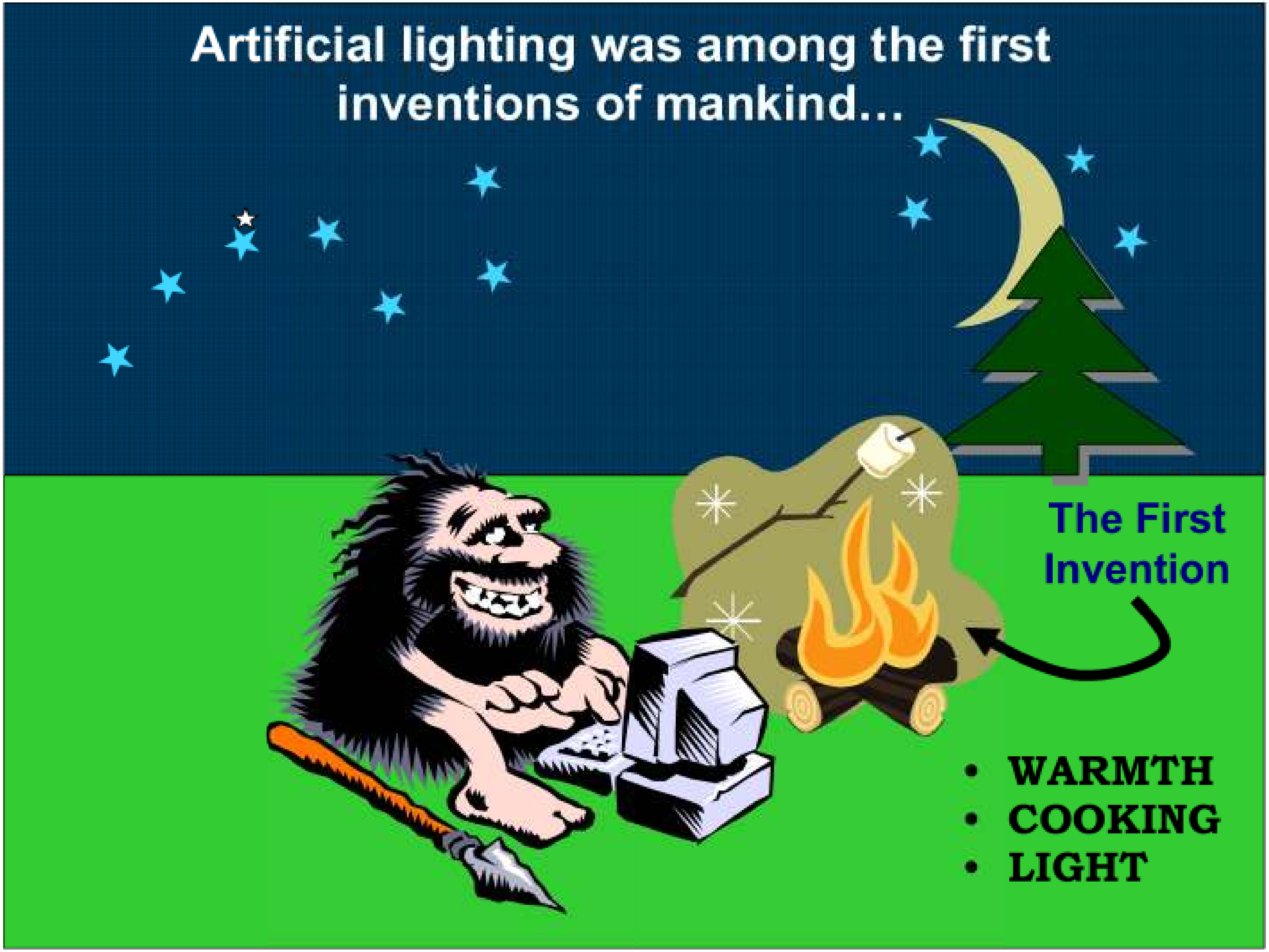
Consumer Goods

- Foods and beverages
  - Advanced packaging materials, sensors, and lab-on-chips for food quality testing
- Appliances and textiles
  - Stain proof, water proof and wrinkle free textiles
- Household and cosmetics
  - Self-cleaning and scratch free products, paints, and better cosmetics

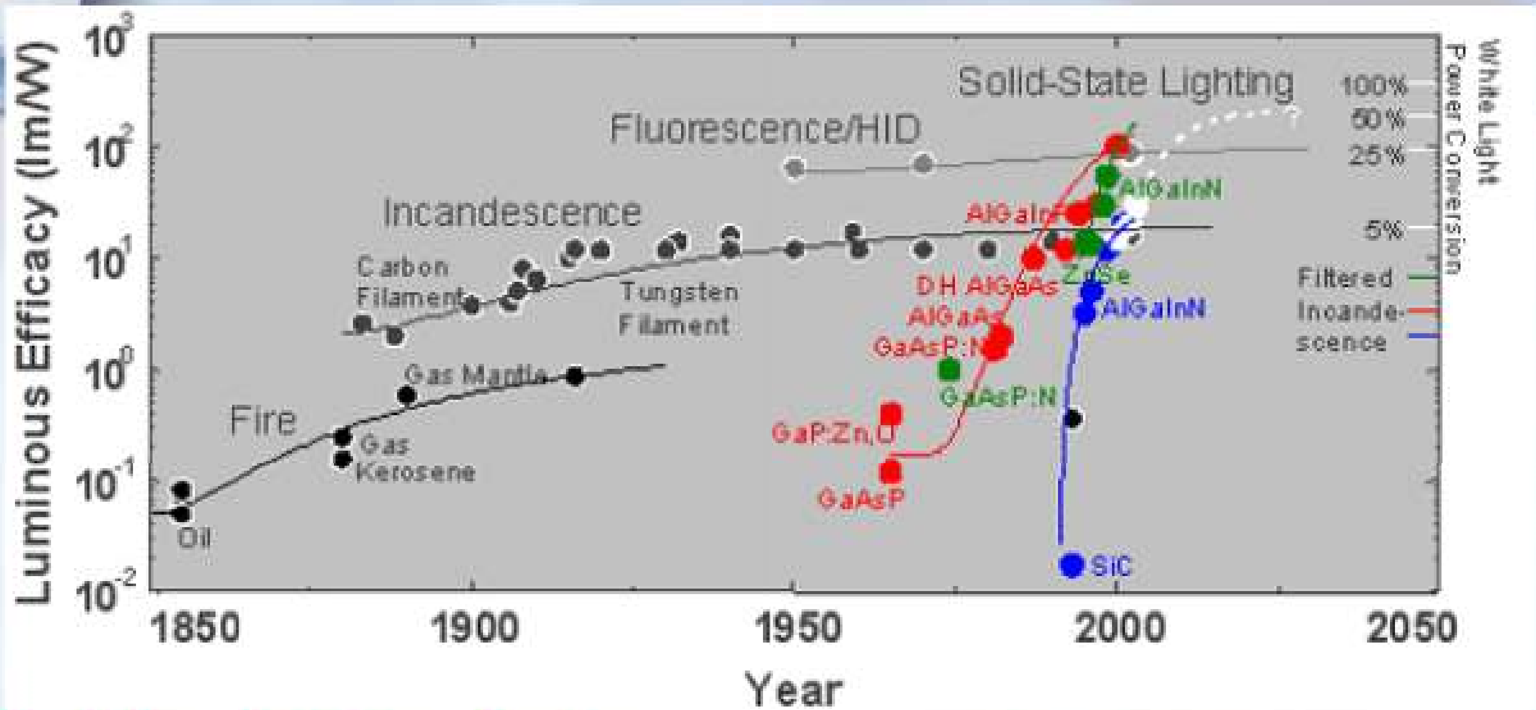
Nano – Tree

: essential is invisible to the eye" A. de Saint-Exupery, "La Petit Prince"


ROLE OF NANOTECHNOLOGY IN
SOLID STATE LIGHTING (SSL)
• Solid State Lighting
» LED
» OLED


Artificial lighting was among the first inventions of mankind...
The First Invention
• WARMTH
• COOKING
• LIGHT

History of Lighting



3 traditional Technologies:

- **Fire**

Oil lamp

- **Incandescence**

Incandescent bulbs

- **Fluorescence & High Intensity discharge**

Fluorescent bulbs

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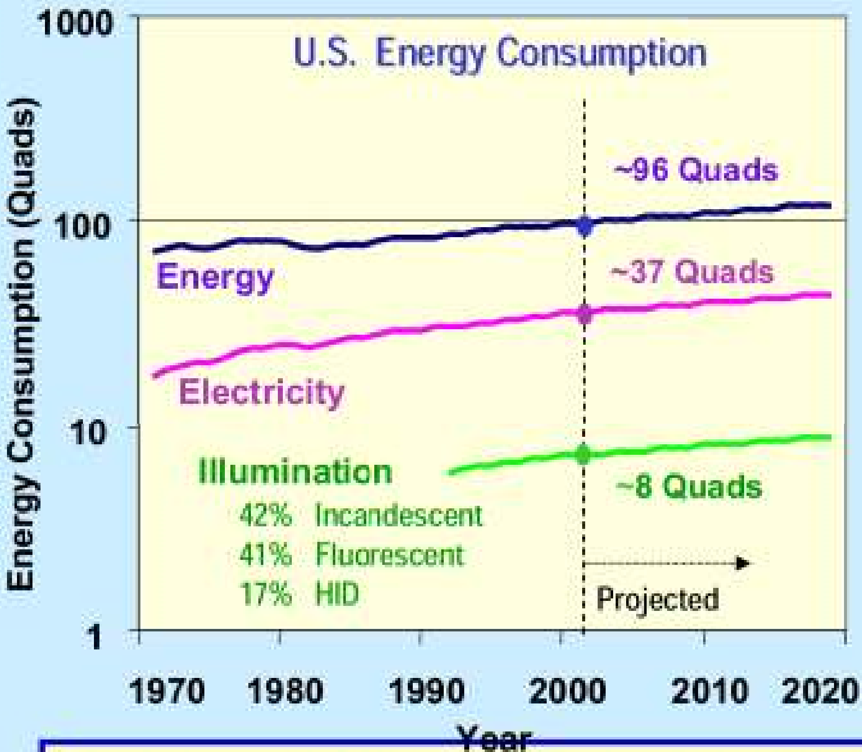
Each subsequent improvement in lighting led to major lifestyle improvements and improvements in the energy efficiency of the light

Candle: 0.05 lumens per watt

Gas lamp: 0.5 lumens per watt

“Incandescent” Light bulb
15 lumens per watt
(5% efficient)

Lighting is a Large Fraction of Energy Consumption



Efficiencies of Energy Technologies in Buildings

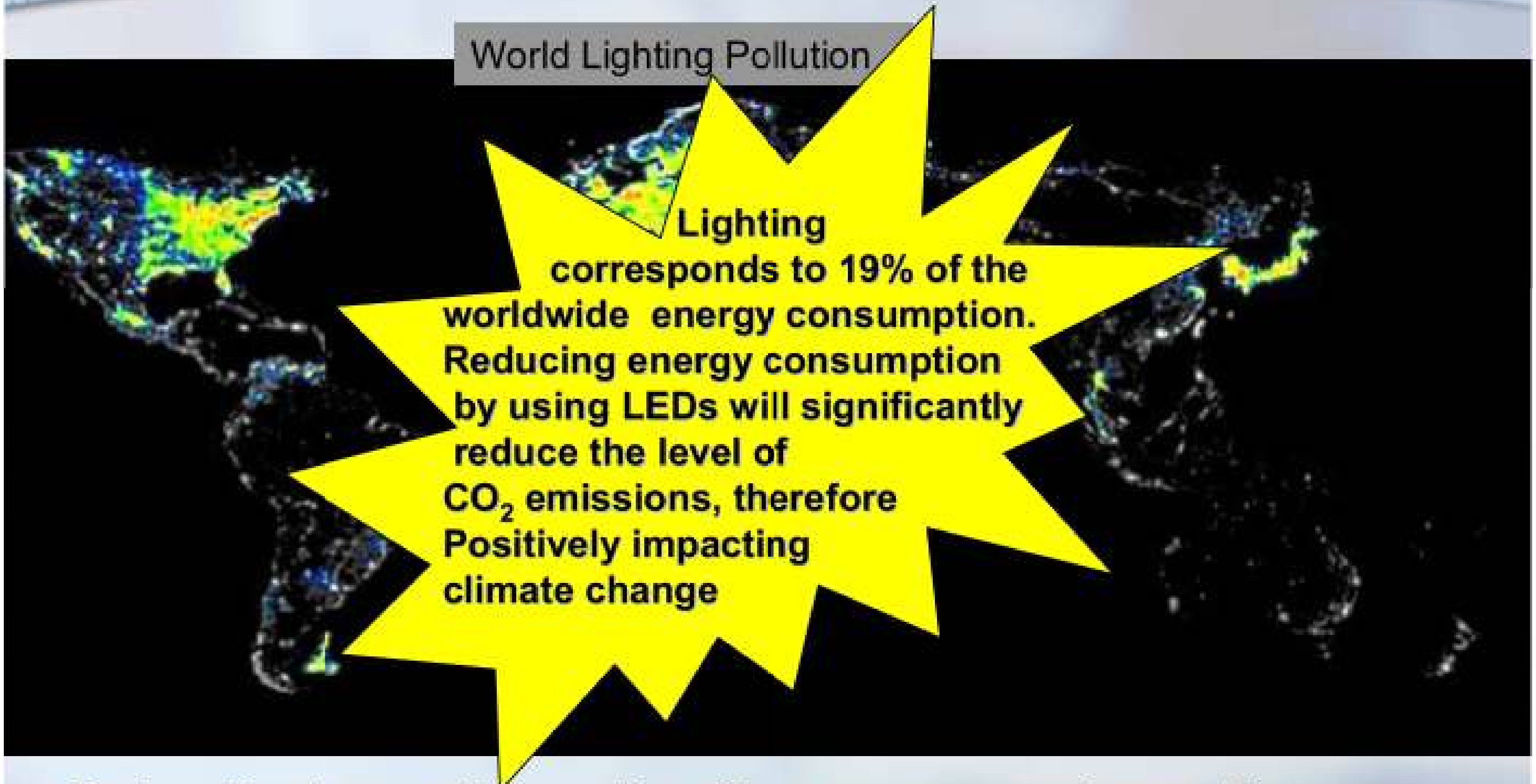
Heating:	70-80%
Electrical Motors:	85-95%
Incandescent Lighting:	~5%
Fluorescent Lighting:	~25%
Metal Halide Lighting:	~30%

Lighting consumes ~20% of U.S electricity and yet has very low efficiency

- **Lighting is a highly attractive target for reducing energy consumption!**

We should be able to do better

SSL: a new alternative to other lighting technologies?



- Reduced heat generation
- Use of less power
- Longer life span

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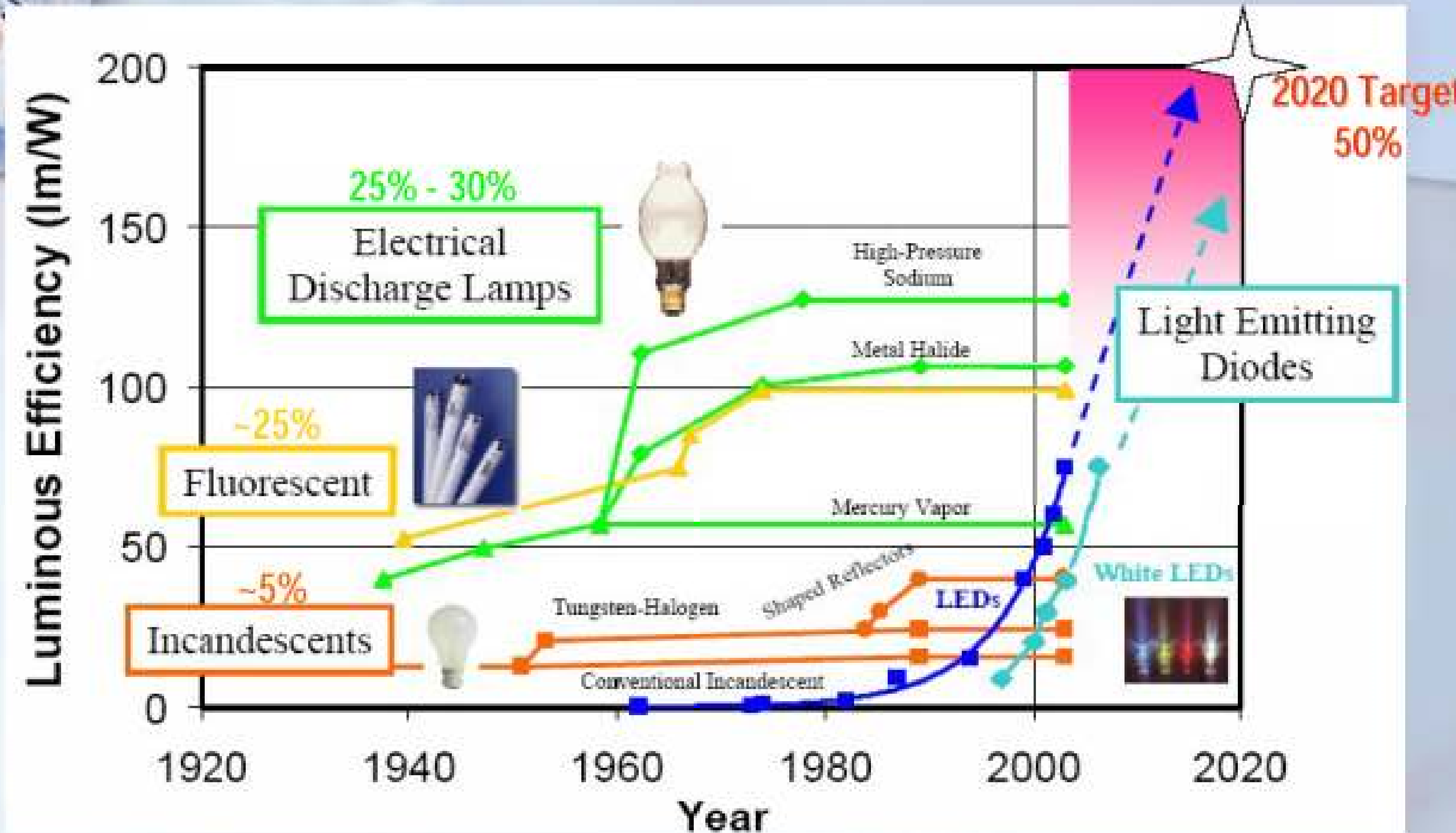
Solid State Lighting Offers Great Potential for Energy Savings



50% conversion efficiency (200 lm/W) in SSL in 2025 could lead to:

- Reduced Electricity Consumption (525 TW-hr/Yr) and Cost ($35 B/Yr)
- Decreases in New Power Plant Needs (75 GW) and CO_2 Emission (87 Mtons)

Ref: J.Y. Tsao, Laser Focus World, May 2003 and references therein

- **The fourth lighting technology**

SSL: Creation of first light emitting diodes (LED)

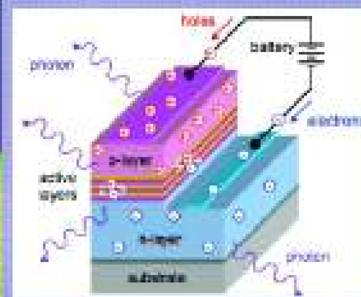
<u>Solid</u>: Light emitted by a solid: a piece of semiconductor

At that time, LEDs were used for showing the time in an alarm clock or as a battery indicator

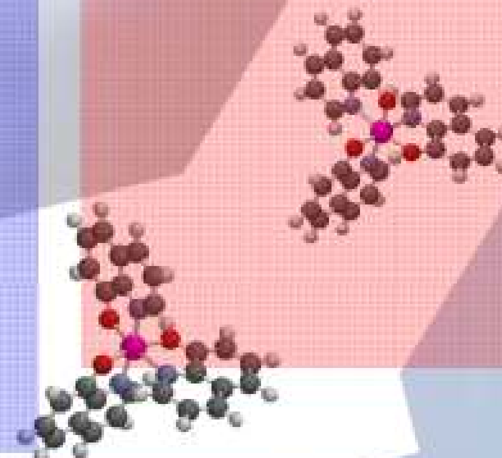
Solid State Lighting

www.sc.doe.gov/bes/reports/list.html

LED Science



OLED Science

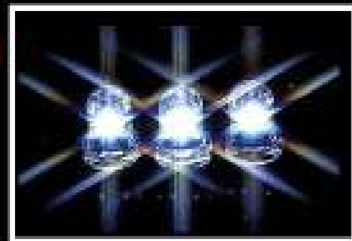


Cross-cutting Science

Solid State Lighting: Semiconductor-Based Lighting Technology

Inorganic Light Emitting Diodes (LEDs)

- III-V semiconductors-based device
- High brightness point sources
- Potential high efficiency & long lifetime



Organic Light Emitting Diodes (OLEDs)

- Organic semiconductors-based device
- Large area diffuse sources
- Thin and flexible
- Ease of fabrication

Current LEDs are predominantly in mono-chrome or niche applications.

High brightness, broad-band white light is needed for general illumination applications.

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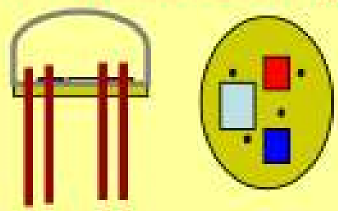
White Light Solid State Lighting

Multi-LED

Multi-chip LED (with control circuitry)

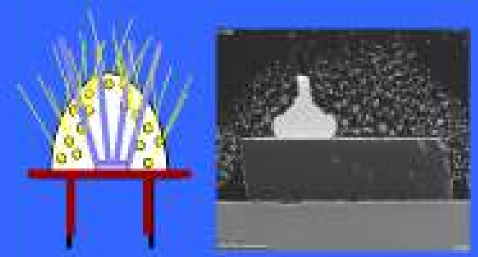


Mix light from multiple LEDs of different color

- ✓Potential High Efficiency
- ✓Precise Control of Color and Power Output
- Color Likely Sensitive to Temperature
- Higher Materials and Processing Costs

LED + Phosphors

Blue or UV LED + Phosphors



Use blue or near-UV LED to pump a mixture of phosphors

- ✓ Good Temperature Stability
- ✓ Lower Cost
- Limited Control of Color and Power Output
- Lower Energy Conversion Efficiency

Current Market Status & Technology Gaps

	Efficiency (lm/W)	Price ($/klm)
Incandescent (75 W)	13	~$0.60
Fluorescent (T8)	83	~$0.73
HID (Metal Halide)	100	~$1.27
SSL (White Light)	~50 ➡ (200*)	~$150 ➡ (less than $2*)

* 2020 Milestones in a SSL Technology Roadmaps developed by SSL Community http://lighting.sandia.gov

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Nanoscale Research Opportunities in OLEDs

1. Organic Semiconductors

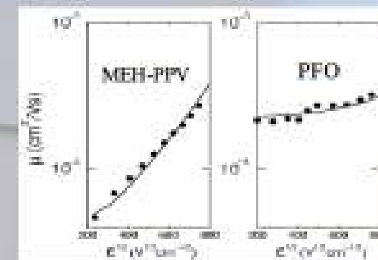
Defect Tolerant

The Wonders of Chemistry-

Guided by Quantum Chemistry and Intuition

Widely Tunable Properties

Semiconducting and metallic polymer "inks" A. Heeger, UCSB

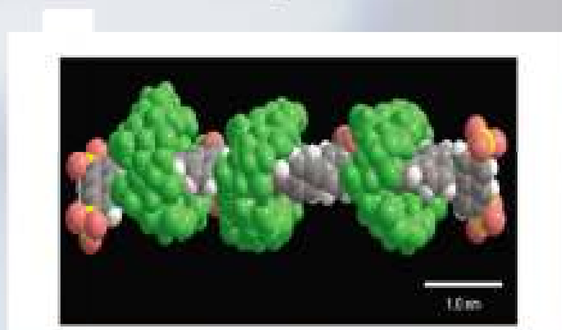


Mobilities Modeling
D. Smith, LANL

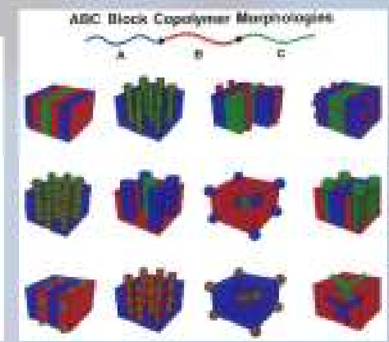
2. Synthesis and Processing

Solution and Vacuum Processing

Self Assembly at the Molecular Level



Chemical structures of the polyrotaxanes
Cacialli et al, Nature Materials



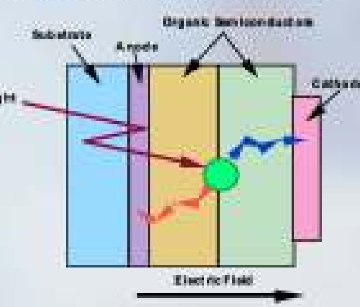
Block Copolymer Morphologies

3. Nanoscale Manipulation

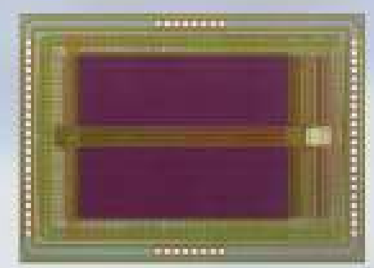
Charge Injection

Tailored Transport & Optical Process

Will Benefit Other Organic Electronics



Organic PVs
Bradley, Imperial College London



1MB prototype chip
shown by Motorola in June 2002

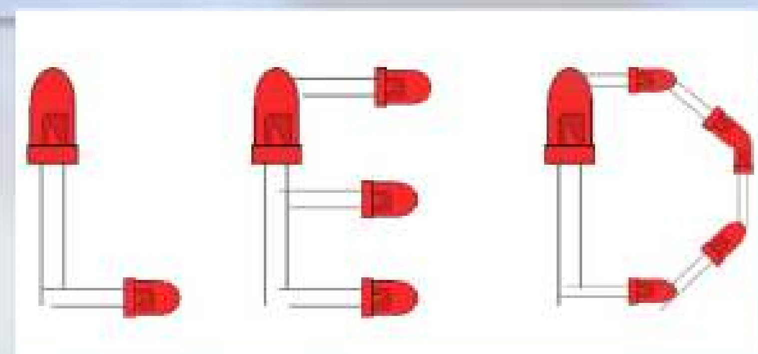
Light Emitting Diodes

- Introduction
  - Birth of OLEDs
  - Current OLEDs
  - Different types of OLEDs
  - Advancements

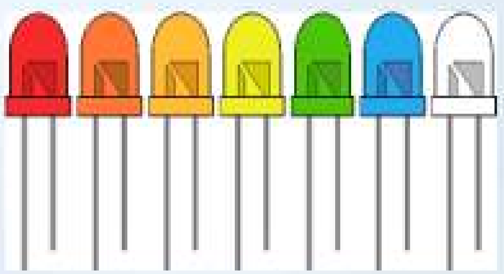
- Results and Discussion
- Future of OLEDs

Light Emitting Diodes

- Long Life
- Small size and
- Temperature Stability
- Fast switching Time
- Emits Cold Light
- Work at low Voltages
- Good Quantum Efficiency



Problems with Inorganic LEDs



- Single Crystalline- Limitation of area
- Epitaxial films - Lattice Matching Problems
- Large Processing and Material Cost
- Non Flexible
- High refractive index-Difficult to extract Light Out of the Devices

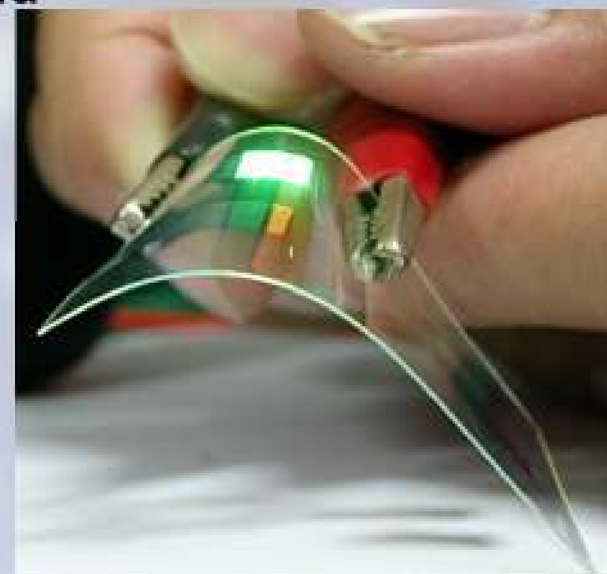
What is an OLED?

OLED - **<u>O</u>rganic <u>L</u>ight <u>E</u>mitting <u>D</u>iode**

An OLED is any light emitting diode (LED) in which emissive electroluminescent layer is composed of a film of organic compounds.

Birth of OLEDs

- First successfully created by Ching Tang and Steve Van Slyke in 1987 at Kodak Labs.
- First tests – very efficient, simple to make
- Showed potential for displays



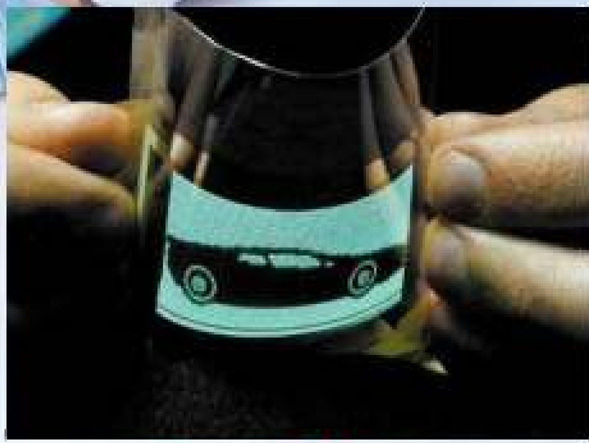
Current OLEDs

- OLEDs Becoming Popular
  - Slim – UDC developed an 18mm thick display
  - Use less power – 6W when all pixels on
  - Easy to *manufacture* – No back light or heavy drivers.
  - Inexpensive – Small screens comparable to LCDs and components are cheap.
  - True Color – Using a stacked approach
  - Durable – No liquid crystals, some use plastic substrate.

Different Types of OLEDs

- Conventional (OLED)
- Inverted (OILED)
- Transparent (TOLED)
- Metal-Free (MF-TOLED)
- Stacked (SOLED)
- Foldable (FOLED)

OLED's



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IBM's OLED PDA Watch

Viewing area diagonal	1.08 inch
Format	VGA (640 x 480)
Pixel pitch	34.3 microns
Resolution	741 dots per inch
Structure	1 SRAM cell per pixel with a memory bus interface
OLED forward voltage	~6.75 V
OLED color	yellow; CIE(x=0.473, y=0.508)
OLED efficiency	~2 lumens/watt
Aperture ratio	90%
Luminance range	0 to 500 cd/m^2 in 4 cd/m^2 increments

LCD vs. SOLED

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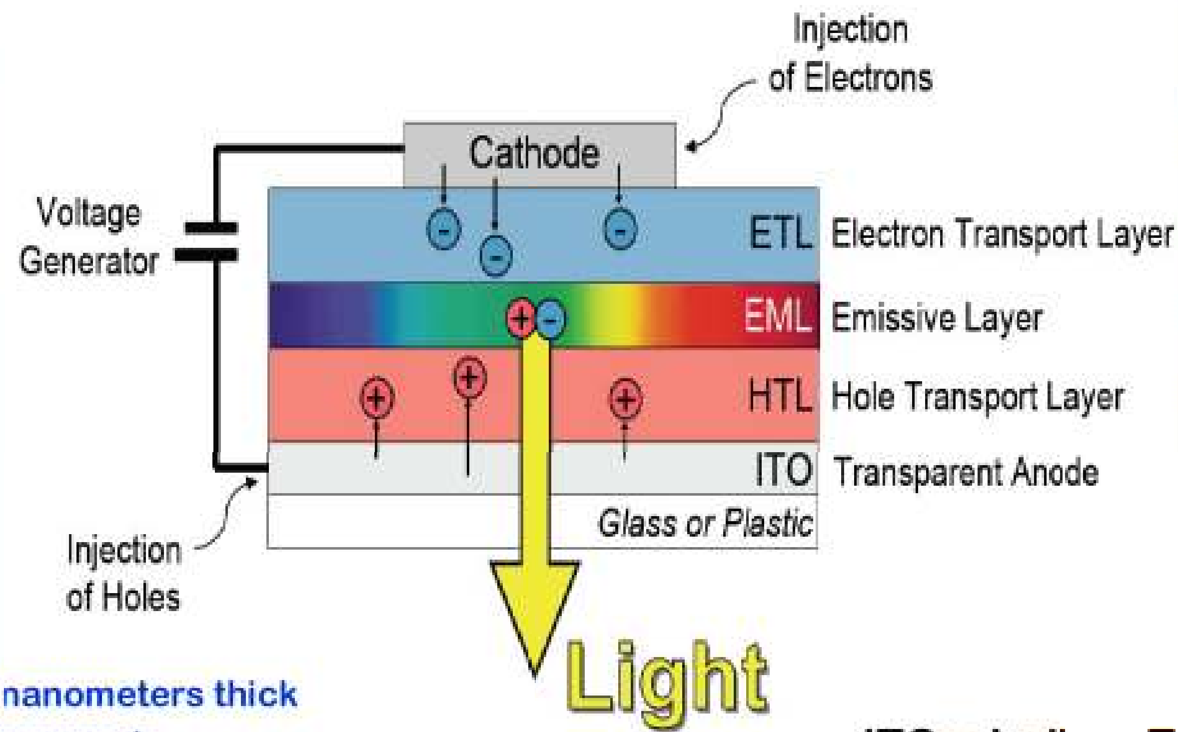
OLED'S TECHNOLOGY

- Technology based on electroluminescence
  - Light is emitted when current flows through organic material
- Luminescent materials have great potential
  - Fireflies utilize process with nearly 100% efficiency

OLED Device Structure

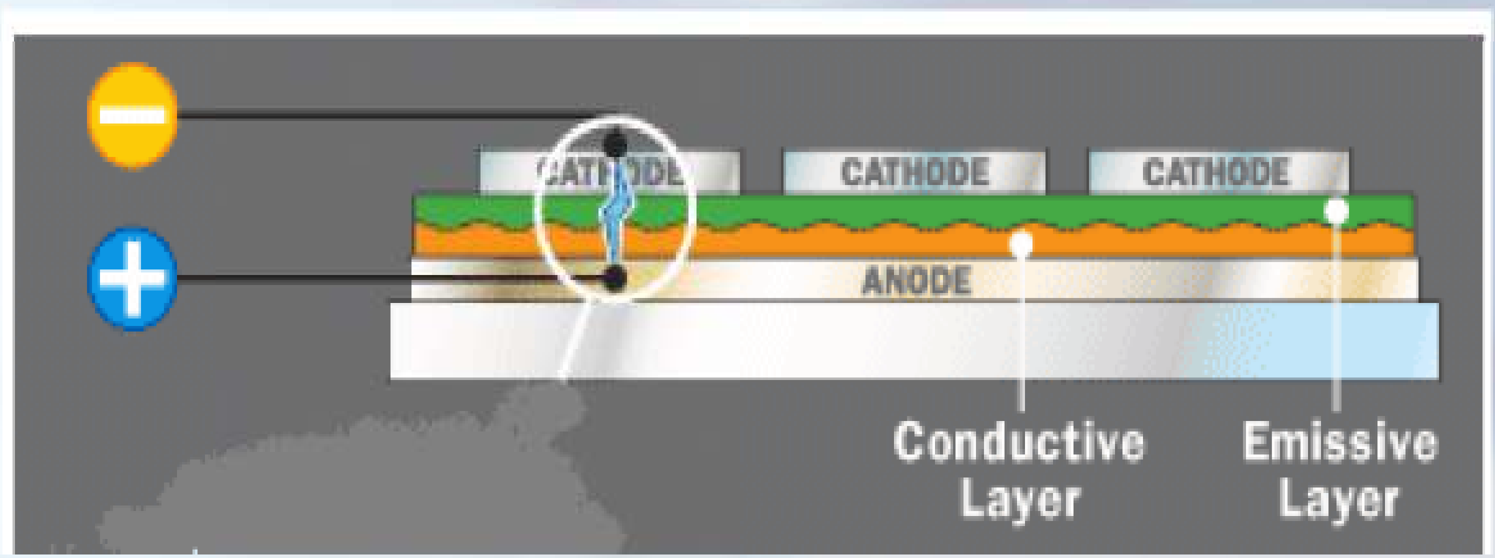


- 100 – 500 nanometers thick
- 3 main components
  - Substrate
  - Electrodes
  - Organic Layer

ITO = Indium Tin Oxide

Basic operation

- Battery or power supply of the device containing OLED applies a voltage across OLED



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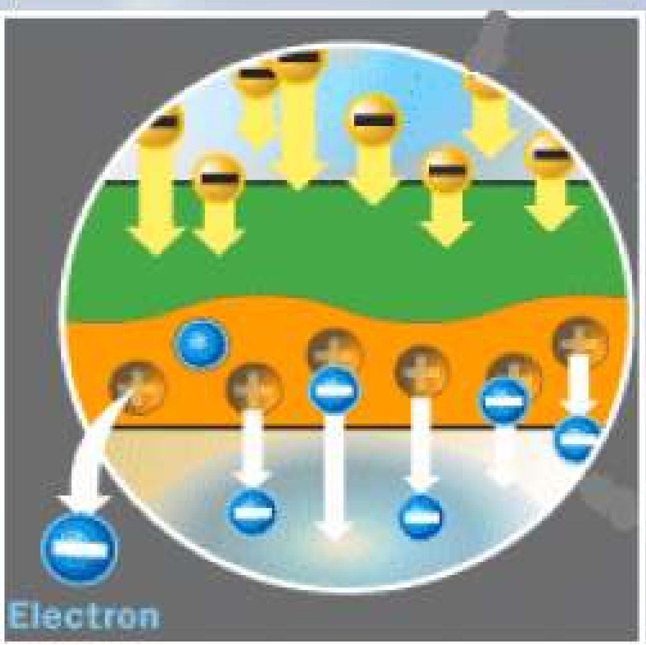
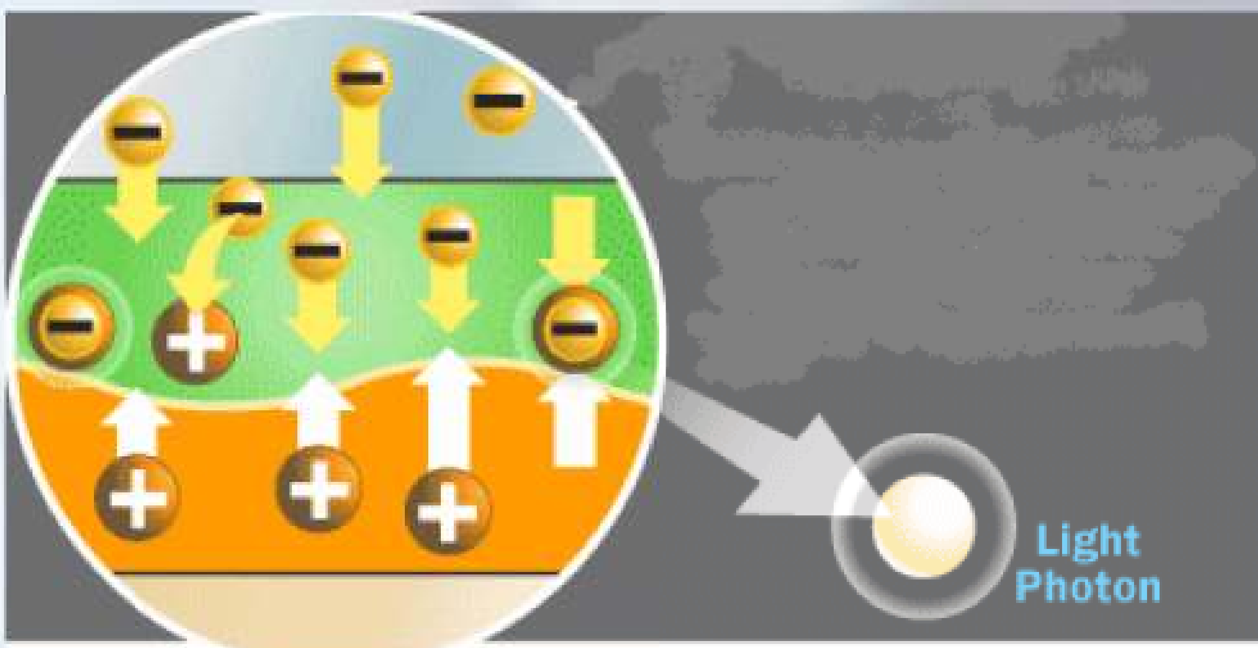
- Electric current flows from cathode to anode through organic layer
- Cathode gives electrons to emissive layer of organic molecules
- Anode removes electron from the conductive layer

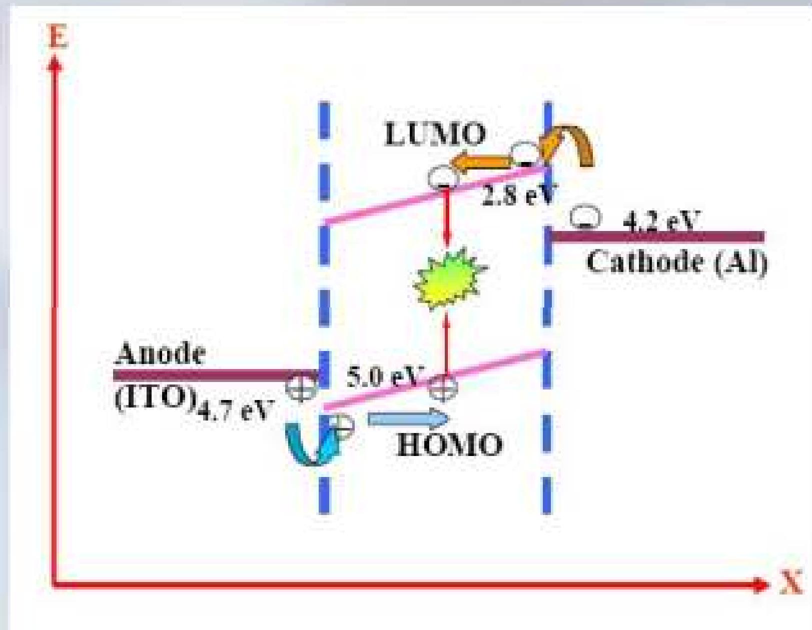


- **Electrons recombine with holes at the boundary between emissive and conductive layer**
- **Gives up energy in the form of a photon of light**



OLED Device Operation

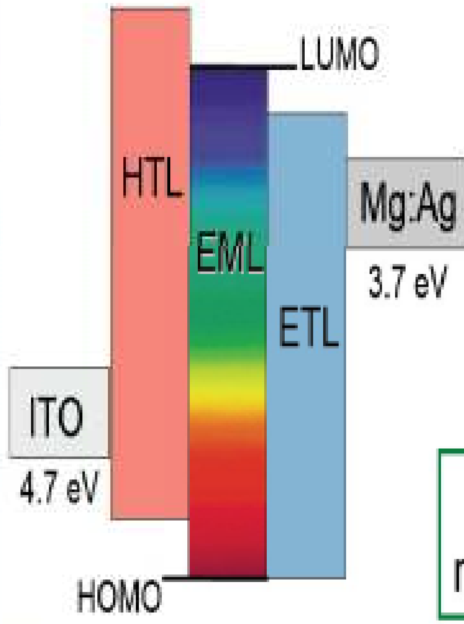
- Electrons injected into the lowest unoccupied molecular orbital - LUMO at the cathode
- Holes are injected into the highest occupied molecular orbital - HOMO at the anode
- charge carriers migrate throughout the emissive layer
- Charges recombine to form excited state
- excited state relaxes and emits light

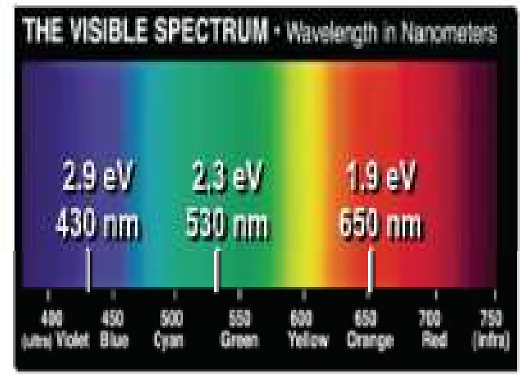


Light Emission in OLED

HOMO-LUMO energy gap determines wavelength of emitted radiation

- **Colour – depends on the type of organic molecule in the emissive layer**
- **Dopants added for different colours**
- **Intensity or brightness – depends on the amount of electric current applied**
- **More the current ,brighter the light**





Ensure electron-hole recombination occurs in the EML

OLED Roadblocks

- Materials
  - Small molecule lifetimes still not OK for TV applications, although robust for mobile phones
  - Polymers struggling with material stability
- Manufacturing
  - UHV process not easily scalable to larger Mother Glass.
  - Printing (Polymers) still in R&D stage
- Active Matrix Back plane
  - Incompatible with the existing a:Si technology
  - LTPS technology (considered suitable for current driven devices) suffers from uniformity problems and restricted to displays < 8”

What we are doing?

RESULTS: TiO_2

Materials Chemistry and Physics 133 (2012) 317–323

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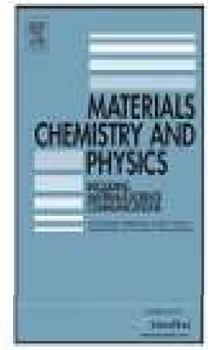
Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys



Studies on morphological and optoelectronic properties of MEH-CN-PPV:TiO_2 nanocomposites

Punita Singh[a], O.P. Sinha[b], Ritu Srivastava[a,*], A.K. Srivastava[a], J. Kaur Bindra[b], R.P. Singh[b], M.N. Kamalasanan[a]

[a] National Physical Laboratory, New Delhi 110012, India
[b] Amity Institute of Nanotechnology, Amity University, U.P., Noida, India

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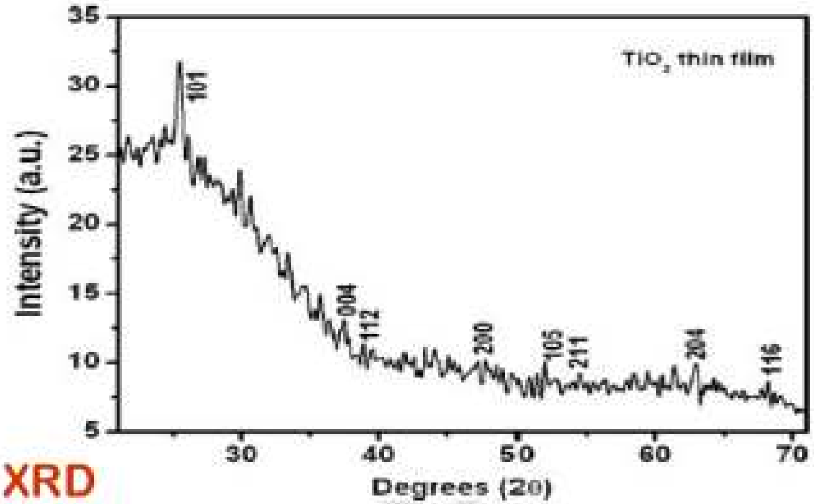
Characterization of nanoparticles

Materials Chemistry and Physics 133 (2012) 317–323

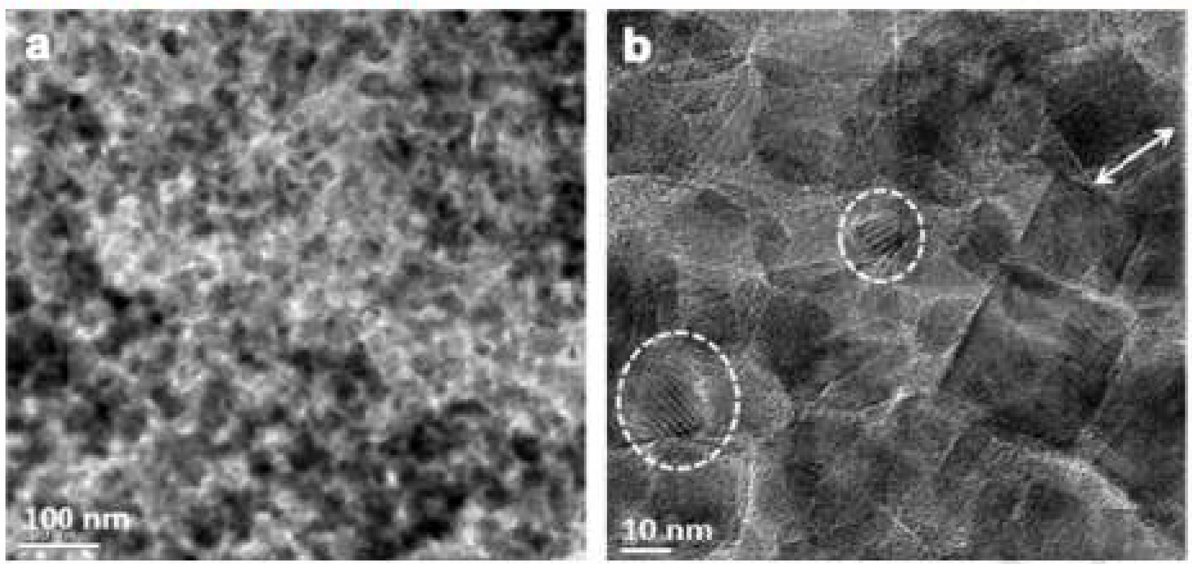


XRD

Fig. 1. XRD pattern of virgin TiO_2 thin films (drop cast).

The peaks at d = 0.35, 0.24, 0.19, 0.17, 0.16, 0.15 and 0.14 nm (Fig. 1) match well with the d-values of tetragonal structure of TiO_2 in accordance to the (1 0 1), (0 0 4), (2 0 0), (1 0 5), (2 1 1), (2 0 4) and (1 1 6) reflections of Anatase phase.

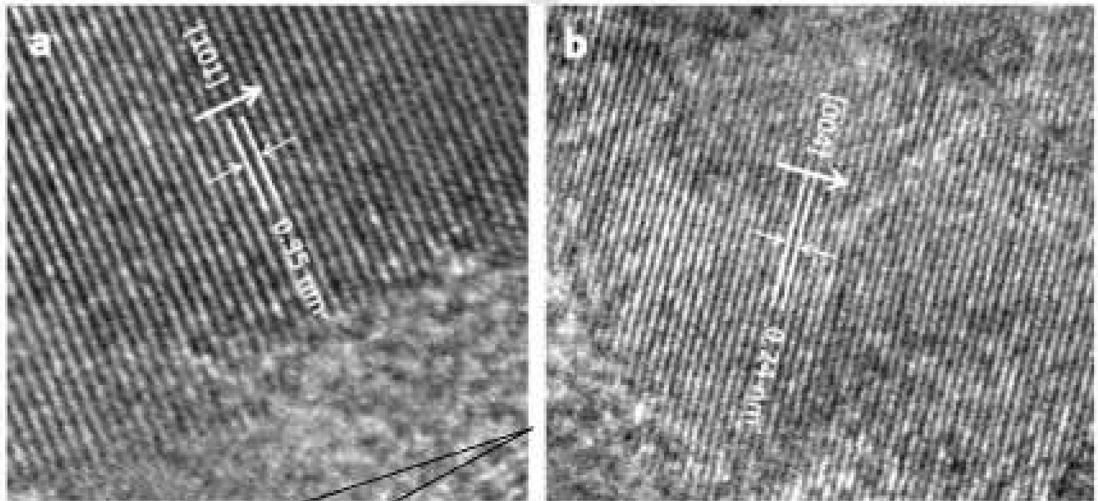
(a) Uniform ultra-fine nanoparticles (about 5–15 nm) (b) Cuboid shape or thin sheet facetted with sharp edges and vertices. Thin sheets with an edge length of ~15 nm



TEM

Fig. 2. Transmission electron micrographs of virgin TiO_2 showing (a) uniform distribution and a high magnification image (b) showing cuboid shape or thin sheets of TiO_2.

Single Crystalline



HR-TEM

Fig. 3. Transmission electron micrographs showing lattice scale images of few nanocrystallites of TiO_2 with interplanar spacing of (a) 0.35 and (b) 0.24 confirming single crystalline nature of facetted nanoparticles.

An inter planar spacing of 0.35 and 0.24 nm corresponds to h k l : 1 0 1 and 0 0 4 respectively of anatase phase (body centred tetragonal and space group $I4_1/amd$, lattice constants a = 0.38 nm and c = 0.95 nm)

Region A in the micrograph shows the thickness of about 2.8 nm, constituted with the stacking of planes, h k l: 2 0 0 with the inter planar spacing of 0.19 nm (magnified image of A is shown in the inset of Fig. 4). The corresponding surface planes stacking to this nanocrystal were along h k l: 1 0 1 with the interplanar spacing of 0.35 nm.

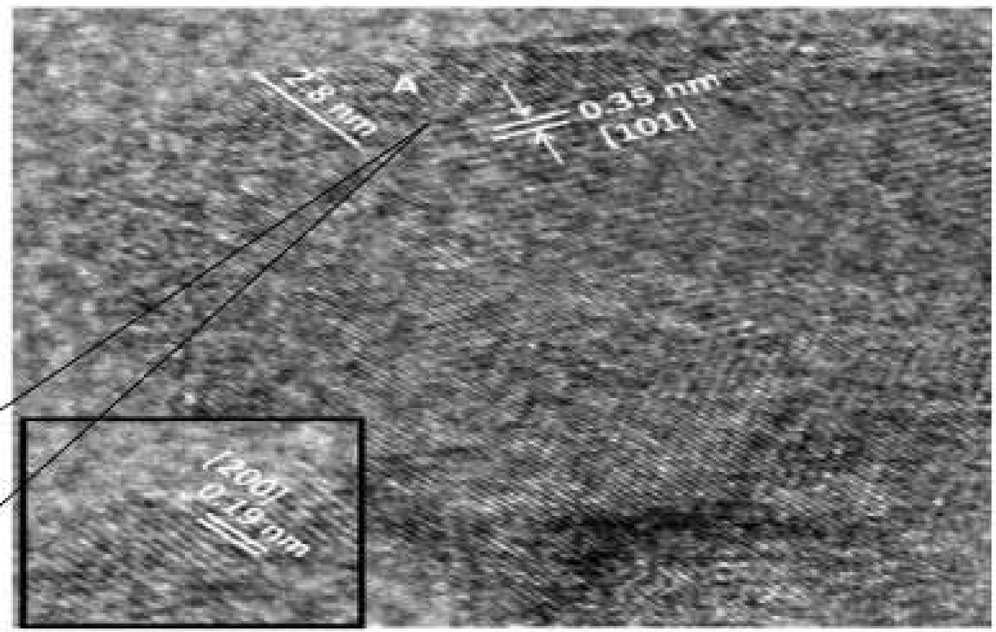


Fig. 4. Transmission electron micrograph showing an individual TiO_2 nanosheet. 'Region A' showing the thickness of TiO_2 nanosheet; inset shows magnified image of 'A'.

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UV-Visible Absorption & Photoluminance

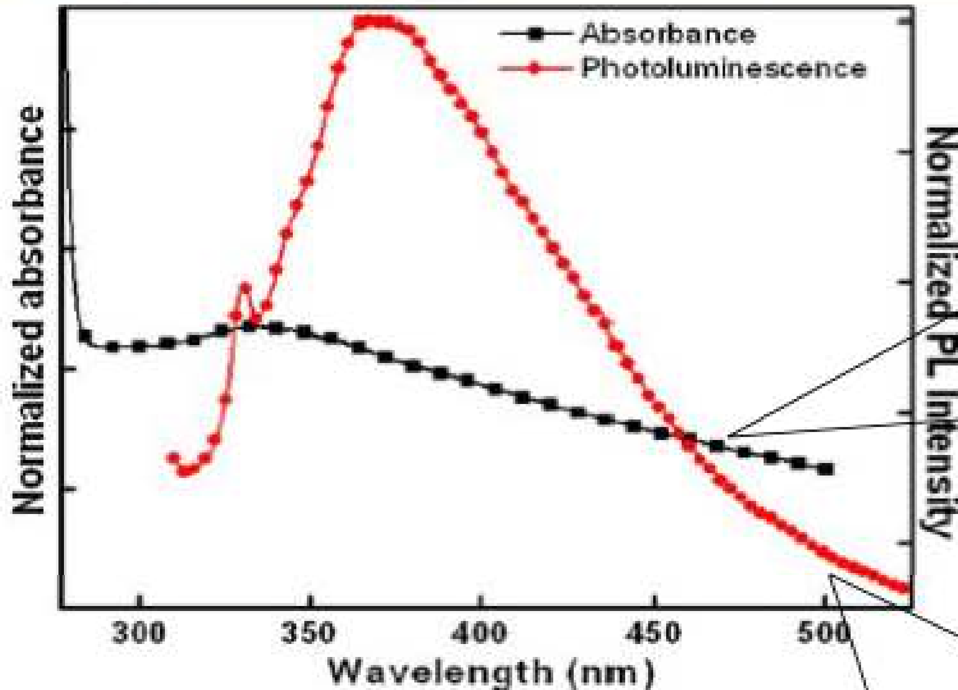

Fig. 5. Normalized UV vis absorption and photoluminescence (PL) spectra of virgin TiO_2 nanoparticles dispersed in a blend of chloroform and chlorobenzene (1:1).

- Optical absorption at 336 nm is associated with electronic transition from valence to conduction band which show blue shift in the excitonic features from the value of bulk.

- The spectrum of the TiO_2 nanoparticles displays an outstanding peak at 370 nm.
- Emission near the green band is almost negligible implying low oxygen defect concentration
- The PL peak is observed at 3.35 178 eV (370 nm), in contrast to that of the bulk anatase TiO_2 band gap at 3.18 eV, indicating a blue shift phenomenon in the synthesized nanoparticle. This is attributable to size effect.

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Characterization of nanocomposites

ITO/PEDOT: PSS/Pristine MEH-CN-PPV/Al
ITO/PEDOT: PSS/MEH-CN-PPV:5% TiO_2/Al
ITO/PEDOT: PSS/MEH-CN-PPV:10% TiO_2/Al

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AFM

The rms roughness shows increasing pattern for MEH-CN-PPV and its nanocomposite (a) 2.13nm (b) 10.45nm (c) 14.76nm

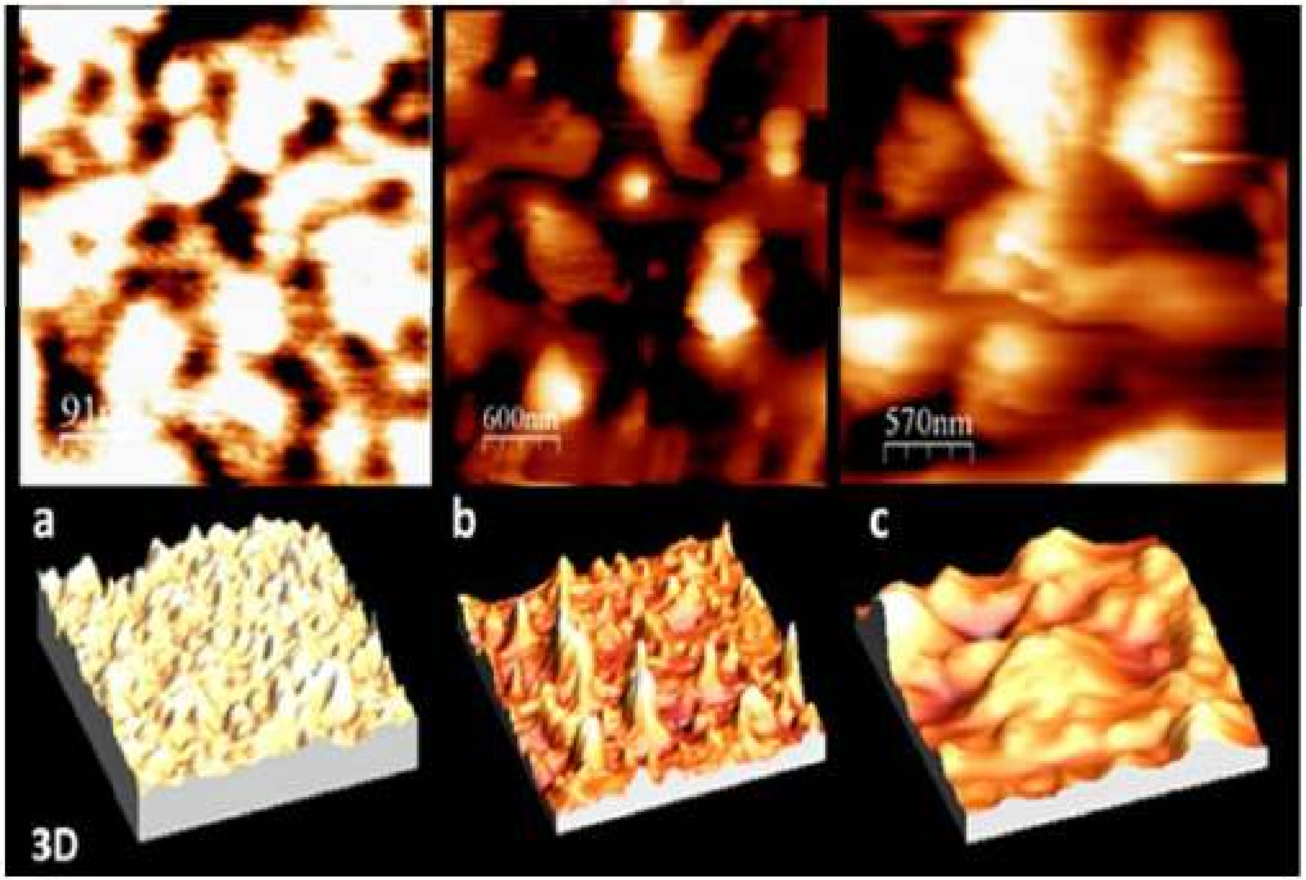

Fig. 6. AFM images (surface plots) of (a) pristine MEH-CN-PPV (b) MEH-CN-PPV:5% TiO_2 (c) MEH-CN-PPV:10% TiO_2; corresponding three-dimensional images shown on the right side.

HR-TEM

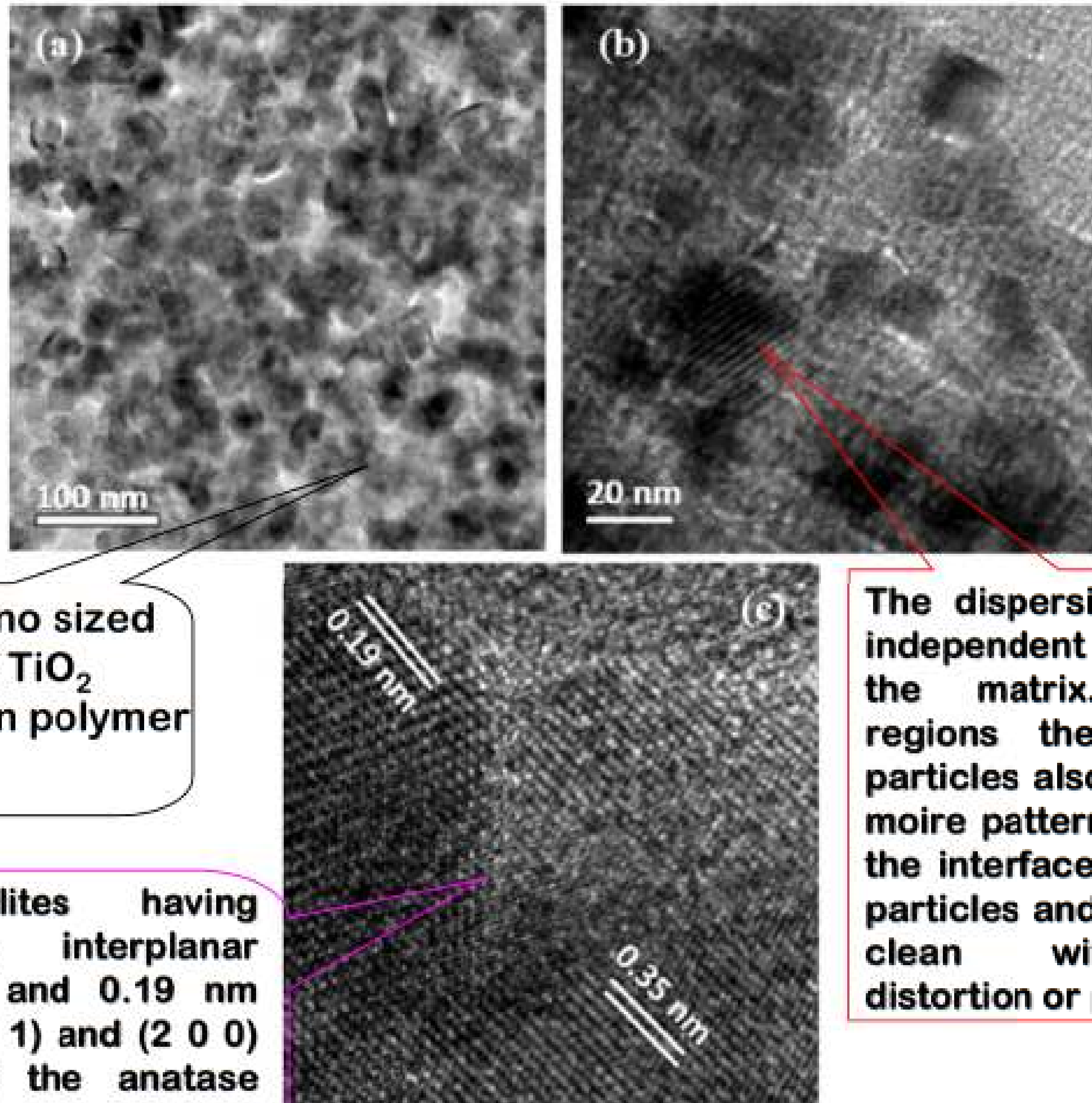

Fig. 7. Transmission electron micrograph showing (a) TiO_2 dispersed in polymer matrix MEH-CN-PPV, (b) a high magnification image showing dispersion of independent particles in the matrix without any distortion or porosity and (c) lattice scale image showing two crystallites of TiO_2 in the matrix.

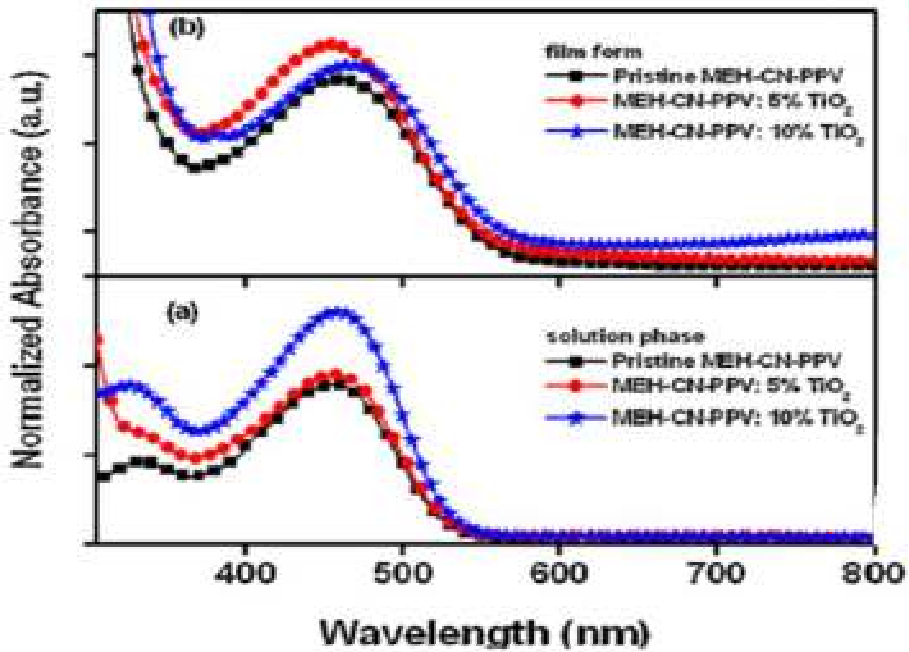

Fig. 8. UV-vis absorption of the nanocomposites in (a) solution phase and (b) thin film forms.

UV-Visible Absorption

•The absorbance (max) (Fig. 8a) in solution phase in pristine MEH-CN-PPV is at 455 nm along with a weak peak in high energy region at 335 nm. Addition of 5% and 10% TiO_2 does not show any shift in the absorption maxima of MEH-CN-PPV. The absorption spectrum reveals large red shift on moving from solution phase to thin film forms.

• **Thin film spectrum (Fig. 8b) is broader in comparison to its solution phase and also the variation in the intensity according to the concentration of TiO_2 is not so pronounced.**

• Intensity of absorption for MEH-CN-PPV with 10% TiO_2 is observed to decline below 5% and is red shifted whereas for 5% it is enhanced and blue shifted.

•**The high energy peak at about 335 nm observed in solution phase for all concentrations is found to be almost absent or in consequential in thin film form.**

Photoluminance

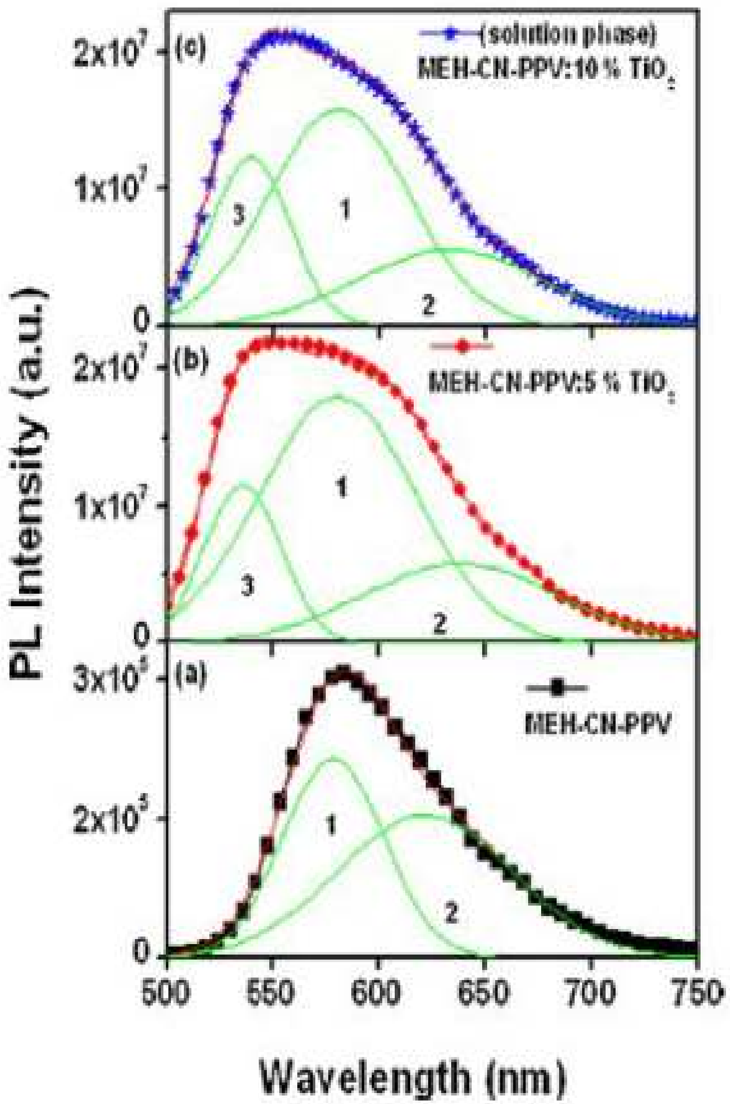

Fig. 9. Photoluminescence spectra of the nanocomposites in solution phase (a) pristine MEH-CN-PPV, (b) MEH-CN-PPV:5% TiO_2 and (c) MEH-CN-PPV:10% TiO_2 deconvolution of each spectrum shown by peaks 1–3. (For interpretation of the references to color in text, the reader is referred to the web version of the article.)

- **PL emission for pristine MEH-CN-PPV (in solution phase) is observed at 580 nm (Fig. 9a), for MEH-CNPPV : 5% TiO_2 hybrid it intensifies and shifts to 545 nm along with a shoulder in the red region (Fig. 9b). Similar spectral emission is observed in MEH-CN-PPV:10% TiO_2 hybrids peaking at 550 nm (Fig. 9c)**

- **The Gaussian line shapes for pristine MEH-CN-PPV show two peaks, at 578 nm (peak 1) of high amplitude attributed to intra- chain exciton dynamics and the lower energy peak at 622 nm (peak 2) is related to interchain interactions. Generally, interchain interactions are weaker in solution phase.**

- **Addition of TiO_2 by 5 % and 10% shows one additional PL peak (peak 3) in high energy region at 535 nm which is probably related to energy transfer from nanoparticles to the polymer.**

Photoluminance

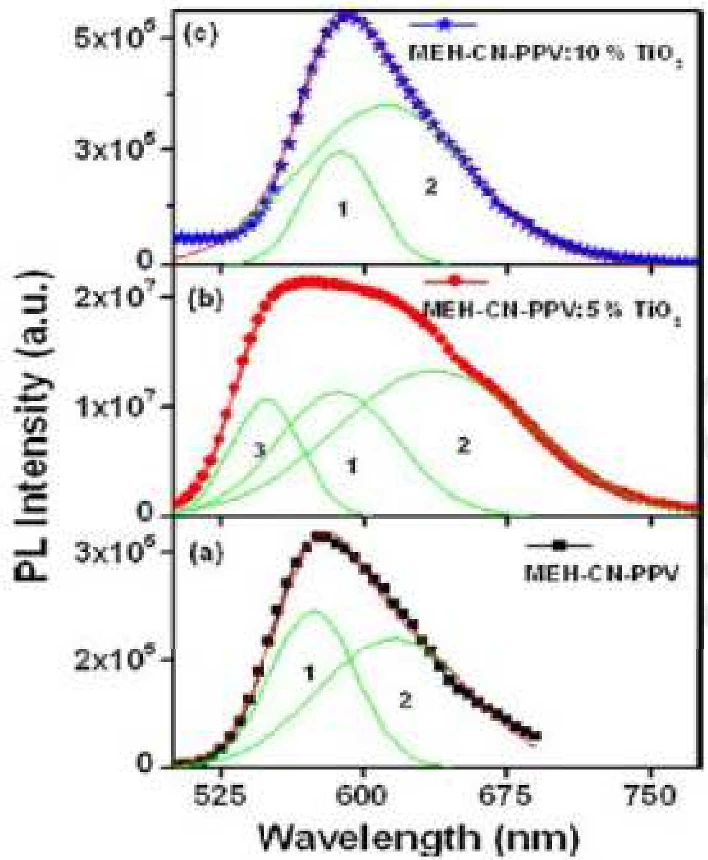

Fig. 10. Photoluminescence spectra of the nanocomposites in thin film forms (a) pristine MEH-CN-PPV, (b) MEH-CN-PPV:5% TiO_2 and (c) MEH-CN-PPV:10% TiO_2; deconvolution of each spectrum shown by peaks 1–3.

The PL emission for pristine MEH-CN-PPV shifts to 575 nm (Fig. 10a).

MEH-CN-PPV with 5% TiO_2 (Fig. 10b) shows blue shifted PL emission at 570 nmand 10% TiO_2 hybrid shows red shift to 590 nm (Fig. 10c).

The PL emission for hybrids with 5% TiO_2 shows asymmetry in the red region whereas the 10% TiO_2 hybrid seems to be uniform throughout the spectrum.

The Gaussian line shapes for pristine and hybrid MEH-CN-PPV (in thin film form) shows that ampli tude of both the peaks (1 and 2) in all cases increases in comparison to its solution counterpart demonstrating increased chain packing in the organic thin film resulting from agglomeration of the polymer during solvent evaporation and annealing.

In 5% nanocomposite film additionally a peak in high energy region (peak 3) is also present analogous to its solution phase PL indicating increasing contribution from intrachain recombination

Characterization of Devices :

ITO/PEDOT: PSS/Pristine MEH-CN-PPV/Al
ITO/PEDOT: PSS/MEH-CN-PPV:5% TiO_2/Al
ITO/PEDOT: PSS/MEH-CN-PPV:10% TiO_2/Al

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J-V Characteristics

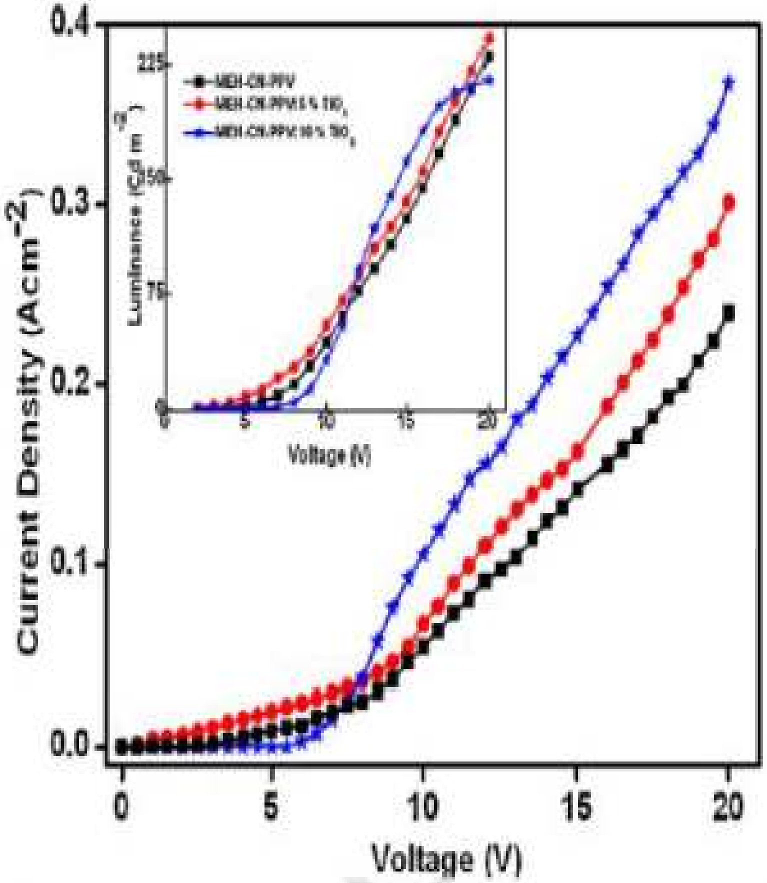

Fig. 11. Current density vs. voltage curve (J–V) of the fabricated device using MEH-CN-PPV:TiO_2 nanocomposites; inset shows luminance vs. voltage plot (L–V) of the fabricated devices.

Inset in Fig. 11 demonstrates luminance vs. voltage curves for all the three devices.

Here the driving voltage is defined as the bias voltage at which the current density (J) rises and achieves a value of 10 mA cm−2.

The driving voltage for the device with pristine MEH-CN-PPV is 5 V.

The device with MEH-CN-PPV:5% TiO_2 shows decrease in the driving voltage to about 3 V and with MEH-CN-PPV:10% TiO_2 device it increases to about 6.5 V.

The characteristic curves show nonlinear nature with ohmic conduction at low voltages and trap limited conduction at high voltages.

The J–V curve specifies that the current passing through 5% device is higher than the pure device indicating better illumination or charge injection.

In case of 10% device, current propagation is higher than the other two devices.

As consequence high current in 10% is expected to affect the device lifetime.

J-V Characteristics

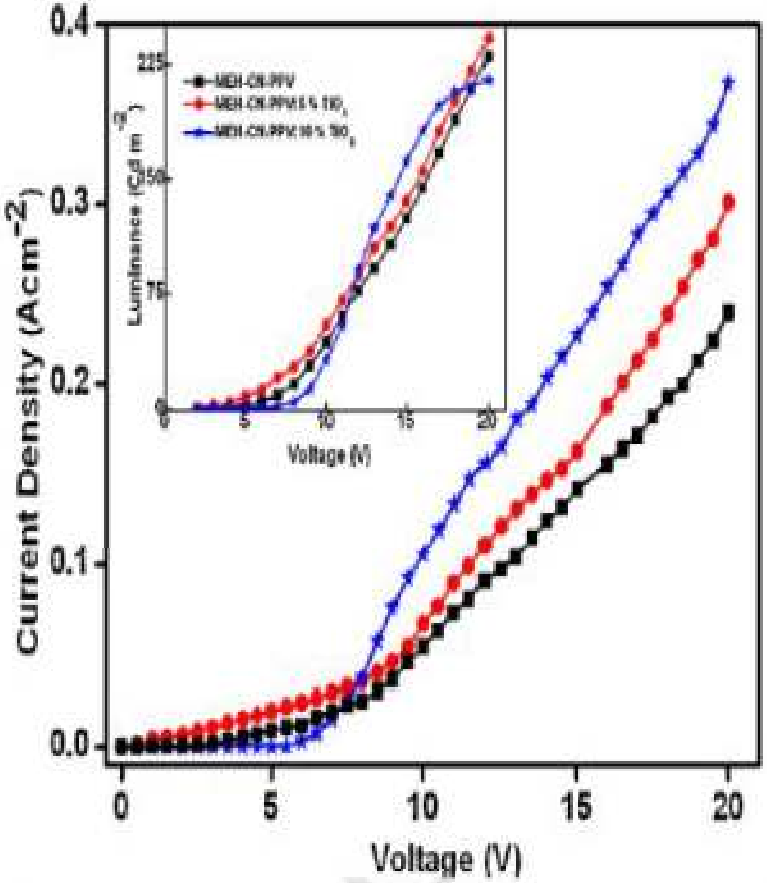

Fig. 11. Current density vs. voltage curve (J-V) of the fabricated device using MEH-CN-PPV:TiO_2 nanocomposites; inset shows luminance vs. voltage plot (L-V) of the fabricated devices.

Inset in Fig. 11 demonstrates luminance vs. voltage curves for all the three devices.

- **The luminance of the device with pristine MEH-CN-PPV as achieved is 43.4 Cd m^{-2} at 10 V.**
- **A luminance intensity of 55.5 and 33.0 Cd m^{-2} is achieved (at 10 V) for the devices with 5% and 10% TiO_2 respectively.**
- **It can be seen that incorporation of 5% TiO_2 shows substantial increase in the luminance and decrease in the turn-on voltage of the device.**
- **Conversely, incorporation of 10% TiO_2 decreases the luminance and increases the turn-on voltage probably due to clustering of the nanoparticles and trap limited conduction**

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Electroluminescence

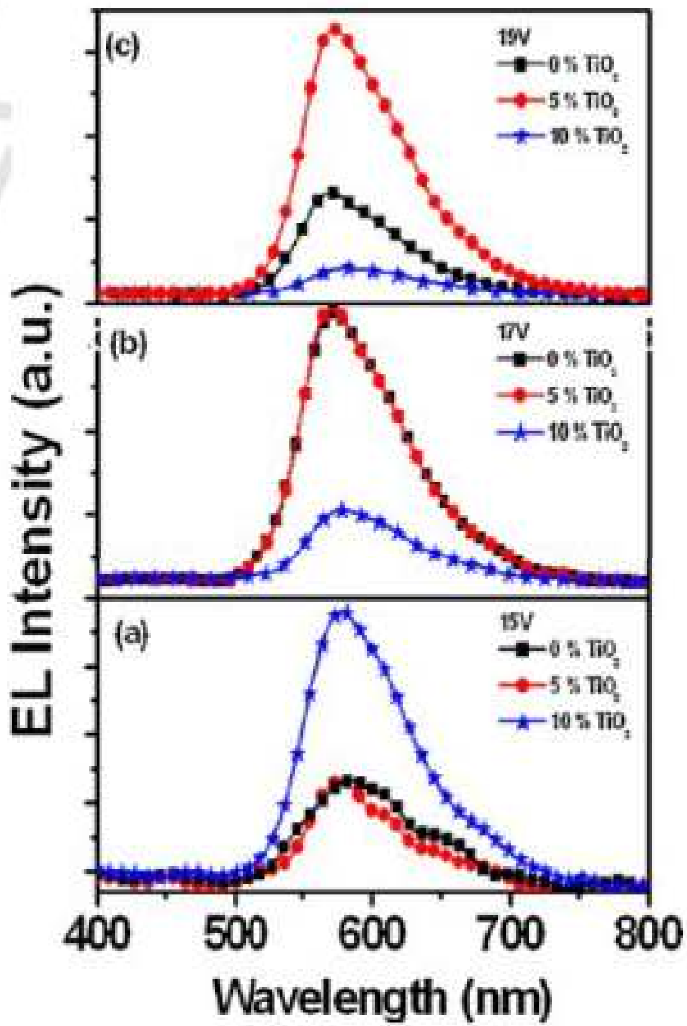

Fig. 12. Electroluminescence spectra of the fabricated device recorded at room temperature at (a) 15 V, (b) 17 V and (c) 19 V.

At three different voltages 15, 17 and 19 V.

For the device with pristine MEH-CN-PPV electroluminescence (EL) emission peak (at 15 V) (Fig. 12a) is observed at 570 nm and remain almost constant, i.e. is not varying with increased voltage.

Device with MEH-CN-PPV:5% TiO_2 show narrow emission with intensity and emission range identical to pristine polymer.

The EL intensity for 10% hybrid device seems to be far better than the other two fabricated devices at this voltage. It has a narrower more intense peak, slightly shifted indicating modification in the device interfacial morphology facilitates electron injection and improvement in the EL efficiency.

But as the voltage increases (17 V) (Fig. 12b) the EL emission for 10% hybrid device declines in intensity whereas in pristine and 5% hybrid device it is 305 observed to be of almost equivalent intensity

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Electroluminescence

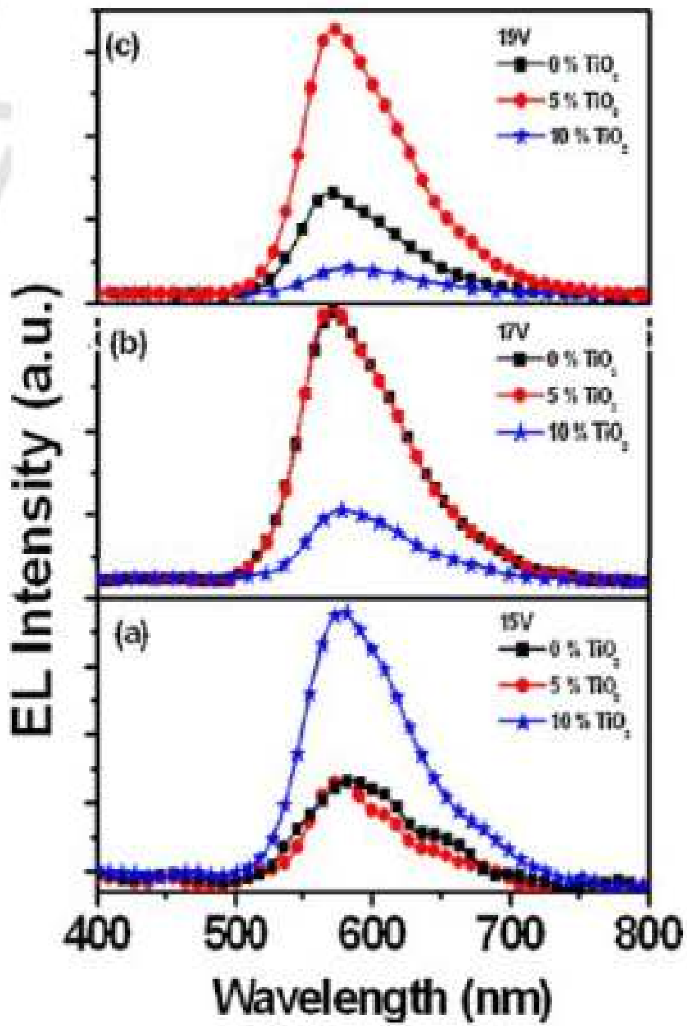

Fig. 12. Electroluminescence spectra of the fabricated device recorded at room temperature at (a) 15 V, (b) 17 V and (c) 19 V.

At 19 V (Fig. 12c) EL emission intensity shows dramatic variation.

The peaks are more symmetric and narrow besides 5% device shows the most intense EL whereas 10% device shows reduced intensity of emission indicating decay/quenching in EL by excess current drain, also shown by J–V curves.

The morphological conversions as indicated by AFM and PL are possibly responsible for decay of EL in 10% hybrid device.

Table 1. Performance of the three devices

Device	Driving Voltage (V) (For 10mA cm^{-2})	Max. Light at 10 V (cd/m^2)
MEH-CN-PPV	5V	43.4
MEH-CN-PPV- 5% TiO_2	3V	55.5
MEH-CN-PPV- 10% TiO_2	6.5V	33.0

ITO/PEDOT: PSS/Pristine MEH-CN-PPV/Al
ITO/PEDOT: PSS/MEH-CN-PPV:5% TiO_2/Al
ITO/PEDOT: PSS/MEH-CN-PPV:10% TiO_2/Al

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Summary :

- Nano-scaled TiO_2 were synthesized by non-hydrolytic solvothermal method.

- Structural and morphological investigations using X-ray diffraction and electron microscopy studies ascertained that the synthesized nanoparticles are single crystalline and are in anatase phase with a cuboid shape or thin sheets.

- The morphologies are facetted with sharp edges and vertices.

- The optical absorption of TiO_2 shows blue shift while PL emission indicates emission due to band gap transitions.

- Hybrids of MEH-CN-PPV with nanosized TiO_2 were prepared in different concentrations and investigated with respect to its structural and optical properties.

- Variation in the absorption and PL emission features were correlated to the formation of interchain and intrachain exciton species.

- Current-density curves in 5% hybrid device illustrate high current values at low voltages in comparison to pristine device owing to better illumination or charge injection.

- Concomitantly, fabricated device shows improved EL in 5% hybrid device at elevated voltages which is a direct consequence of the modified surface morphology

Future of OLEDs

- New organic materials will lead to even higher efficiency
- New production processes will reduce overall cost of devices and allow for larger devices to be made
- Stability will increase
- Future is "bright" for OLEDs.

Change a Light, Change the World

- **The century old, low conversion efficiency technologies still dominate world lighting application.**
- **Semiconductor based Light Emitting Diodes offer significant savings in energy consumption.**
- **Nanoscale basic research presents new opportunities to advance solid-state lighting technologies.**

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OLED's could soon be the light of the world
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