GREEN CHEMICAL PROCESSING FOR HIGH-TECH INDUSTRIES

Professor Jan B. Talbot

Chemical Engineering Program
Department of NanoEngineering
University of California, San Diego
jtalbot@ucsd.edu

UCSD

What is GREEN Chemistry?

U.S. Environmental Protection Agency

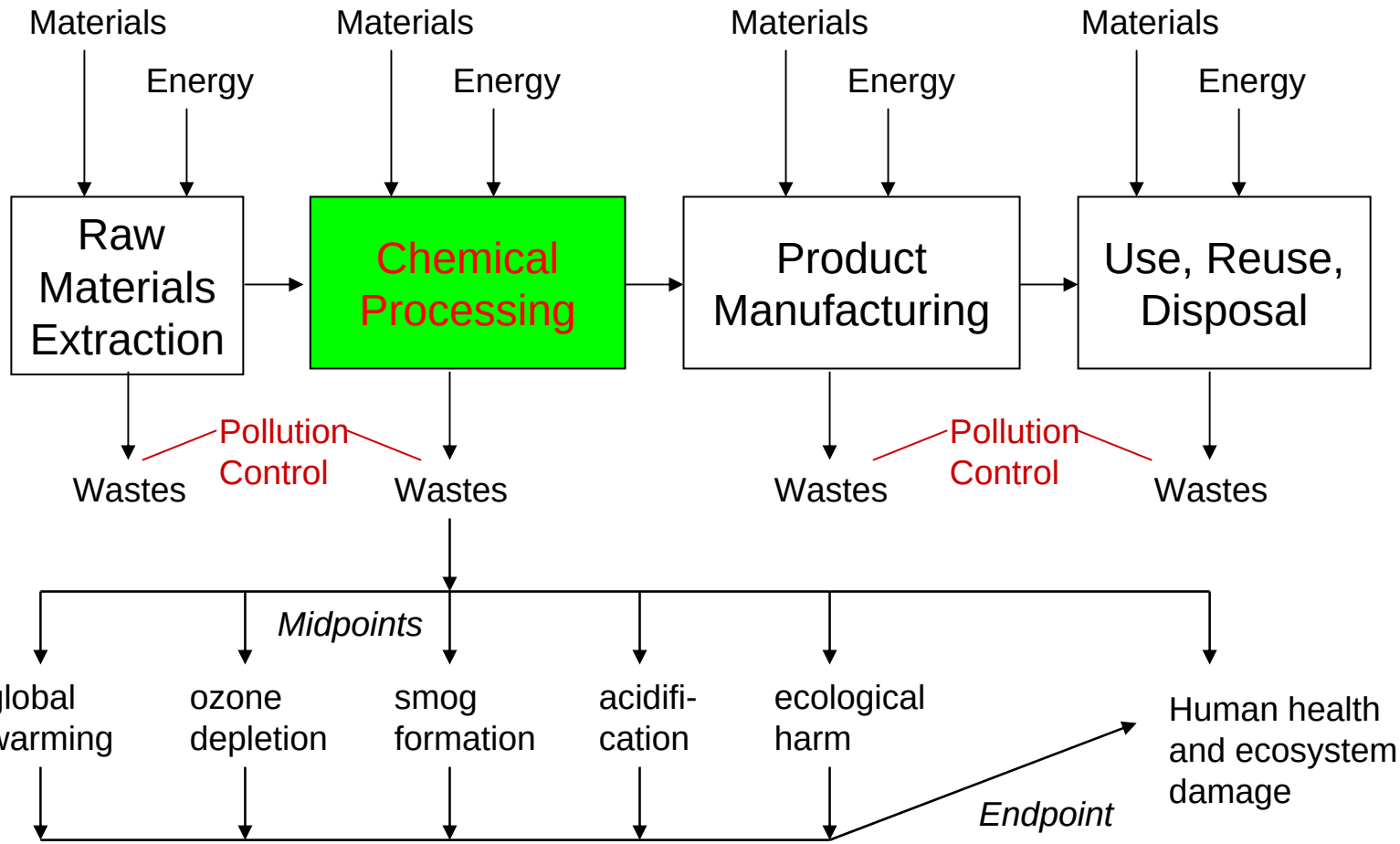
"Green Chemistry is the use of chemistry for pollution prevention. More specifically, green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. offering environmentally benign alternatives to the more hazardous chem and processes that are often used in consumer and industrial applicatior green chemistry is promoting pollution prevention at the molecular level."

http://www.epa.gov/greenchemistry/

UCSD

Scope of Environmental Impacts

Life-Cycle Stages



Ref: David Shonnard, Michigan Technological University

UCSD

Research Projects

1) **Discovery of materials for efficient white solid state lighting** (LEDs) (with OSRAM-Sylvania - DOE)
   Jonathan Tao - PhD MSE

2) **Development of environmentally-benign process & Remediation of wastes -** Patterning using Tacky Dot® (polymer by Dupont)
   a) dry screening method for emissive displays;
   b) supported photocatalyst - Dr. Michielle Hurt - ChemE PhD (2006)

UCSD

PROJECT 1: Solid State Lighting

- **Need for developing energy-saving lighting technology**
  - ~20% of the nation's electricity is used in artificial lighting
  - Equivalent to $50 billion per year or $2000 per year per person
  - Equivalent to 130 million tons of carbon emitted into atmosphere
- **Current technology**
  - Incandescent light bulb: ~5% energy conversion efficiency (15 LPW)
  - Fluorescent light: ~20% energy conversion efficiency (70-100 LPW)
  - If ~50% efficient technology is used to replace current lighting (200 LPW):
    - Can achieve energy savings of 1000 TWh of electricity (or 93 1.35 GW power plants worldwide).
- **Environmental benefits**
  - Hg emission reduction
  - National carbon savings (with 200 LPW, 220 million metric tons)

Basic Research Needs for Solid-State Lighting: Report of the Basic Sciences Workshop on Solid State Lighting, May 22-24, 2006. <http://www.sc.doe.gov/bes/reports/files/SSL_rpt.pdf>

UCSD

Solid State Lighting

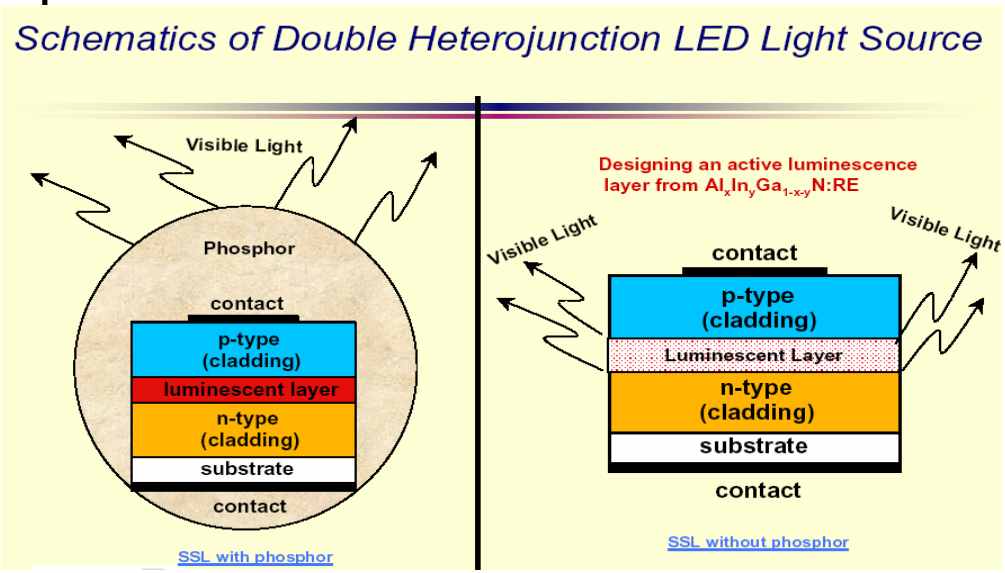
- Solid-state lighting: using semi-conducting materials to convert electricity to light
- Compounds of GaN, AlN, InN as tunable emitters across the visible spectrum
- Potential for white-light generation
- Economical materials discovery for powders for thin film processes

http://mrsec.wisc.edu/Edetc/SlideShow/slides/LED_applications/applications2.html

UCSD

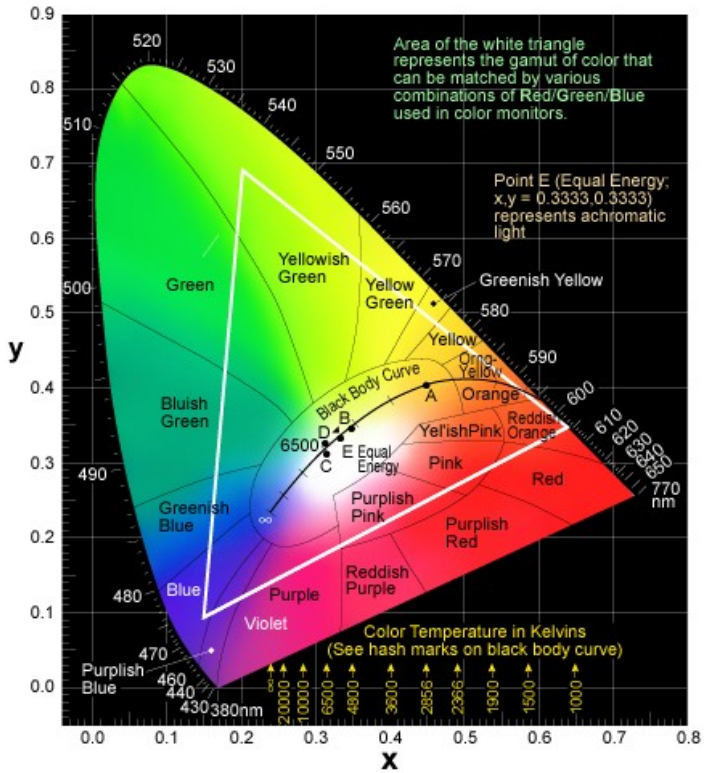
Project Goals

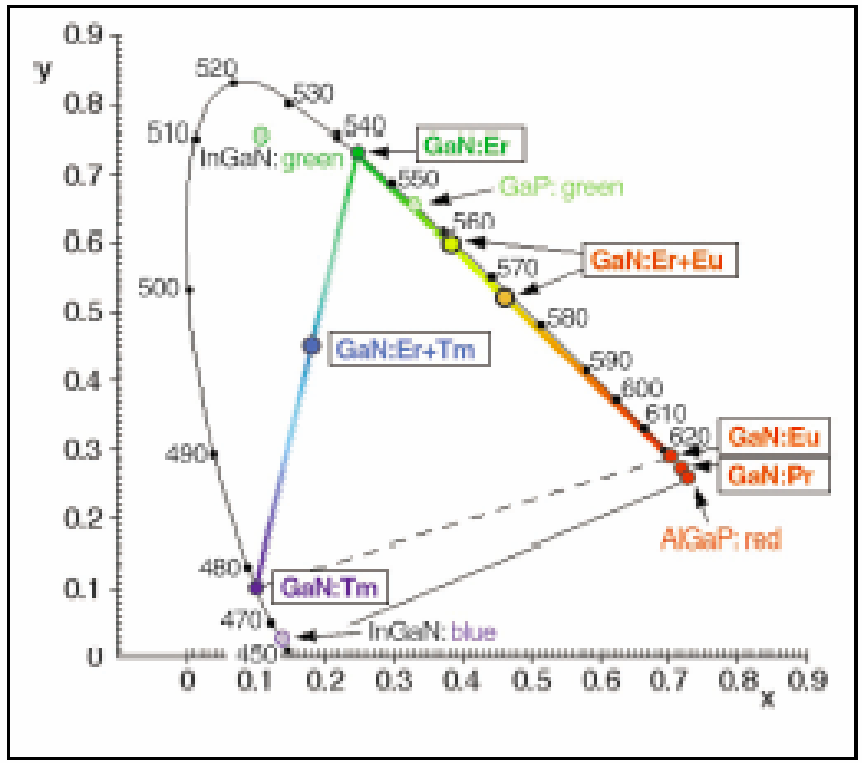
- Develop a nitride-based material activated by rare earth / transition metal ions
  - for producing white light efficaciously within an LED
  - optimize its composition for high efficacy (LPW) and color rendering index (CRI)
  - Projected: GaN:Eu, Tb (~280 LPW, ~81 CRI)
- Develop a new LED architecture



UCSD

GaN:RE Color Emission





- Pure color emission from GaN doped with:
  - Tm (blue)
  - Er (green)
  - Eu or Pr (red)
- Mixed color emission using:
  - GaN:Er+Tm (cyan)
  - GaN:Er+Eu (yellow/orange)

UCSD

Research Project Approach

- Synthesis of rare earth or transition metal activated nitride powders (AlN, GaN and alloys)
- Analysis of chemical composition, crystal structure, purity, morphology and size
- Luminescence characterization
- Fabrication of targets of the activated powders for thin film deposition
- Characterization of the structure, composition and luminescence behavior of the thin films.

UCSD

Research Team

- Dr. Kailash Mishra, Dr. Madis Raukas, Keith Kleindinst (Osram-Sylvania, Beverly, MA)
- Jonathan Tao, Dr. Joanna McKittrick, Jennifer Asis, Sarah Chowdhury(UCSD)
- Dr. Gustavo Hirata, Dr. Nestor Perea (Center for Condensed Materials Science, Ensenada, Mexico)
- Funded by DOE, UC Mexus, San Diego Foundation

UCSD

Nitride Powder Synthesis

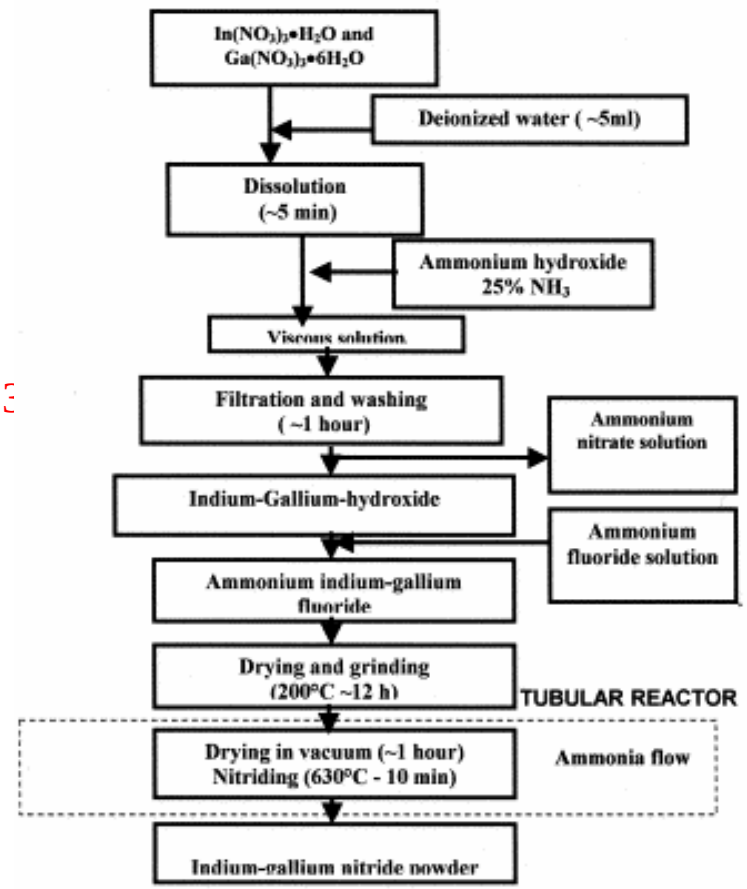
Hydroxide-to-fluoride-to-nitride:

Step 0: RE_2O_3 (s) + 6 HNO_3 (l)
→ $2RE(NO_3)_3$ (l) + 3 H_2O (l)

Step 1: $M(NO_3)_3 + NH_4OH \rightarrow M(OH)_3 + NH_4NO_3$

Step 2: $M(OH)_3 + 6NH_4F \rightarrow (NH_4)_3MF_6 + 3H_2O + 3NH_3$

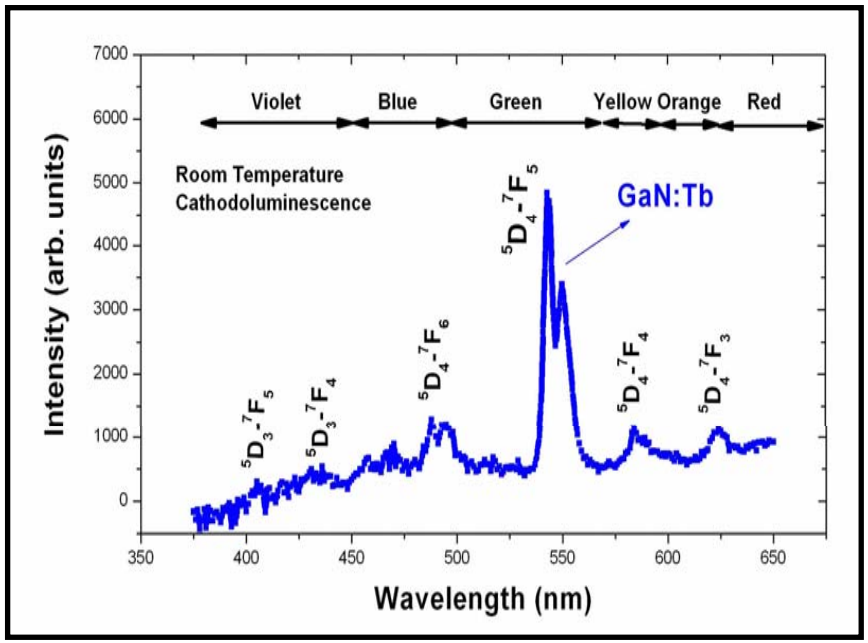
Step 3: $(NH_4)_3MF_6 + 4NH_3 \rightarrow MN + 6NH_4F$

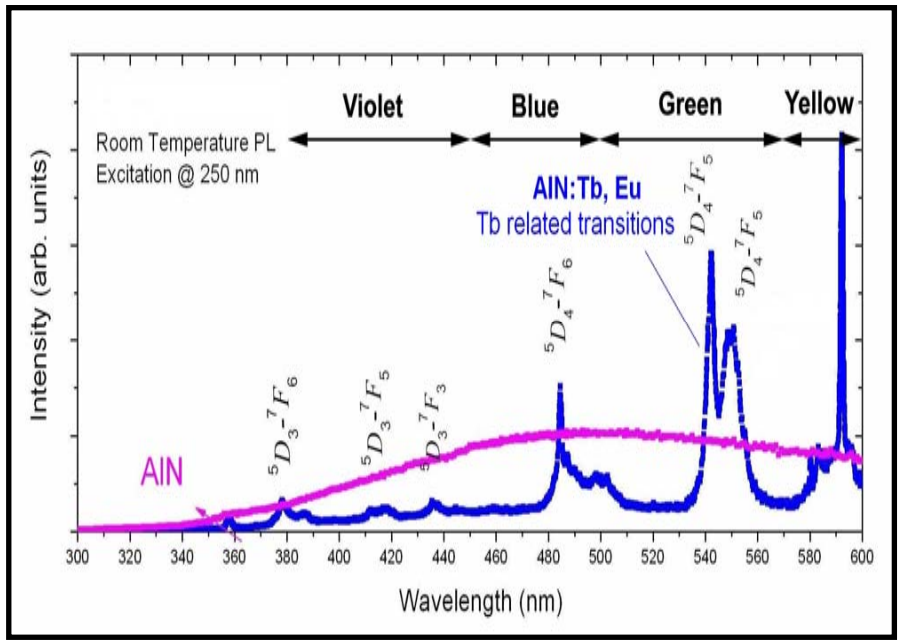


Garcia, R., et al., *Mater. Sci. Eng. B*, 90, 7-12 (2002).

UCSD

Photoluminescence Measurements





Han, B., K. Mishra, M. Raukas, K. Klinedinst, J. Tao, and J.B. Talbot, "Investigation of Luminescence from Dy^{3+} in AlN," *J. Electrochem. Soc.*, **154** (1), J44 (2007).

UCSD

Solid State Lighting Project Conclusions

- Synthesis of small quantities (50 mg and 0.5 grams) of doped AlN and GaN with very low oxygen content (~3 at%)
- Single phase nitride formation confirmed via X-ray diffraction
- Luminescence from doped GaN and co-doped AlN powders clearly observed
- Successfully synthesized powders:
  - AlN, AlN:Eu, Tb, Dy, Nd, Tm, Er, and Cr; (Eu, Tb), (Eu,Dy), (Dy, Tm)
  - GaN, GaN:Tb, Eu, Tm, Dy
  - GaAlN

UCSD

Future Work

- Nitride with RE^{3+} for white light generation -a promising concept for higher efficacy but needs further in-depth basic research

- Application of GaN:RE^{3+} as a monochromatic light source in an integrated device
- Dy^{3+} ---Yellow, Eu^{3+} ---Red, Tb^{3+} ---Green

UCSD

Papers & Disclosure

Papers:

1. A study of luminescence from Tm^{3+}, Tb^{3+} and Eu^{3+} in AlN powder, B. Han, K. C. Mishra, M. Raukas, K. Klinedinst, J. Tao and J. B. Talbot, *J. Electrochem. Soc.*, **154**, J262 (2007).
2. Investigation of luminescence from Dy^{3+} in AlN, B. Han, K. C. Mishra, M. Raukas, K. Klinedinst, J. Tao and J. B. Talbot, *J. Electrochem. Soc.*, **154**, J44 (2007).
3. A study of oxygen content in GaN, AlN, and GaAlN powders, J. B. Talbot, J. Tao, N. Perea-Lopez, J. McKittrick, B. Han, M. Raukas, K. Klinedinst, and K. C. Mishra (accepted to *J. Electrochem. Soc.*)

Invention Disclosure:

1. Rare earth activated nitrides for solid state lighting applications, B. Han, J. Tao, K. Klinedinst, M. Raukas, J. Talbot and K. C. Mishra, Patent Application filed (2007).

UCSD

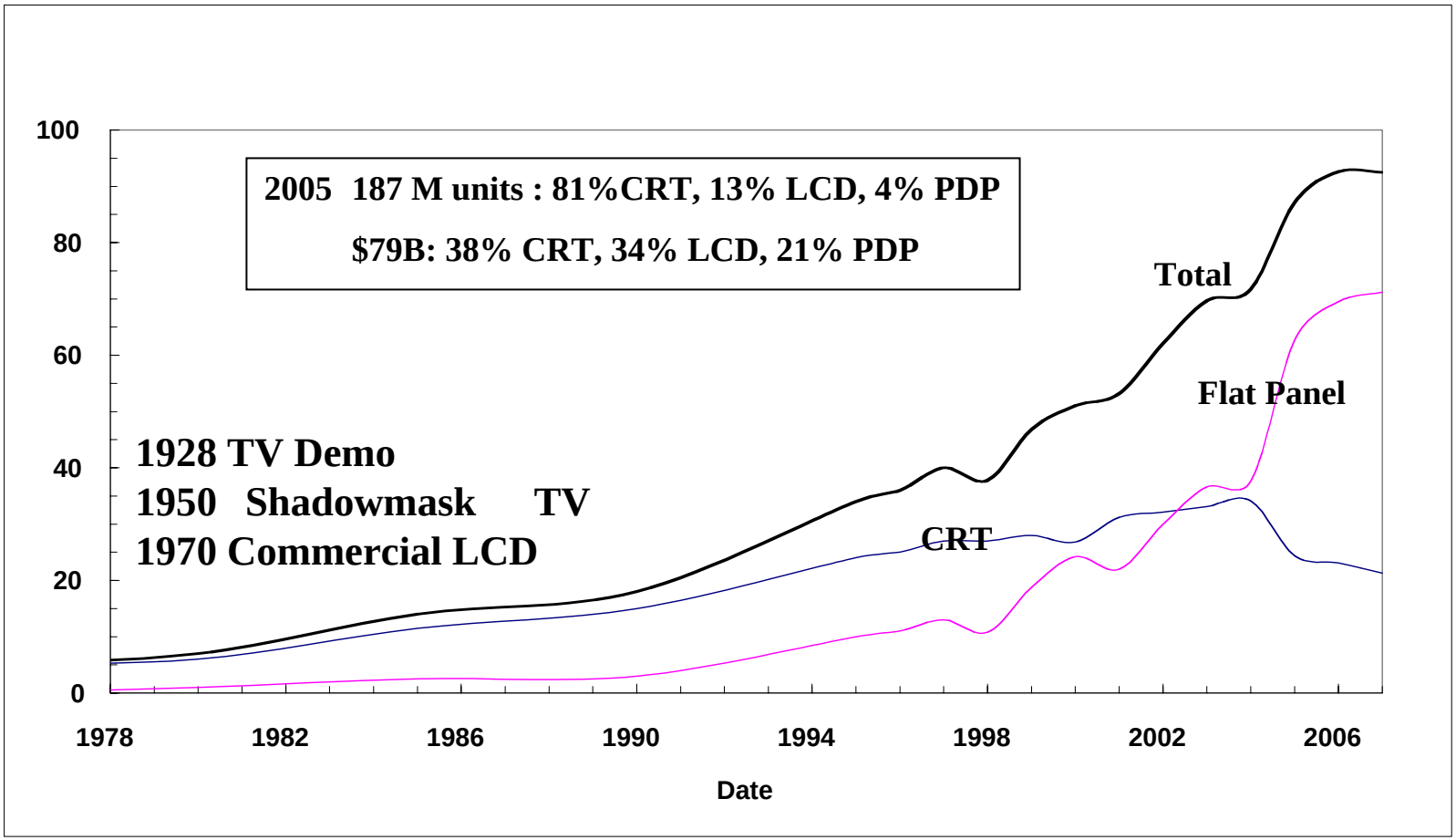
PROJECT 2:
Development of environmentally-benign process & Remediation of wastes

Patterning using Tacky Dot® (polymer by Dupont) - Michielle Hurt PhD (2006) & Andrei Petrov MS

1) Dry screening process to pattern phosphors for information display screens
2) Producing a monolayer of photocatalyst for use in hazardous waste treatment
3) Deposition and patterning of nanoparticles
4) Patterning of proteins
5) Patterning of metal by electroless deposition

UCSD

World Wide Displays Market



ref: Ross Young, President DisplaySearch

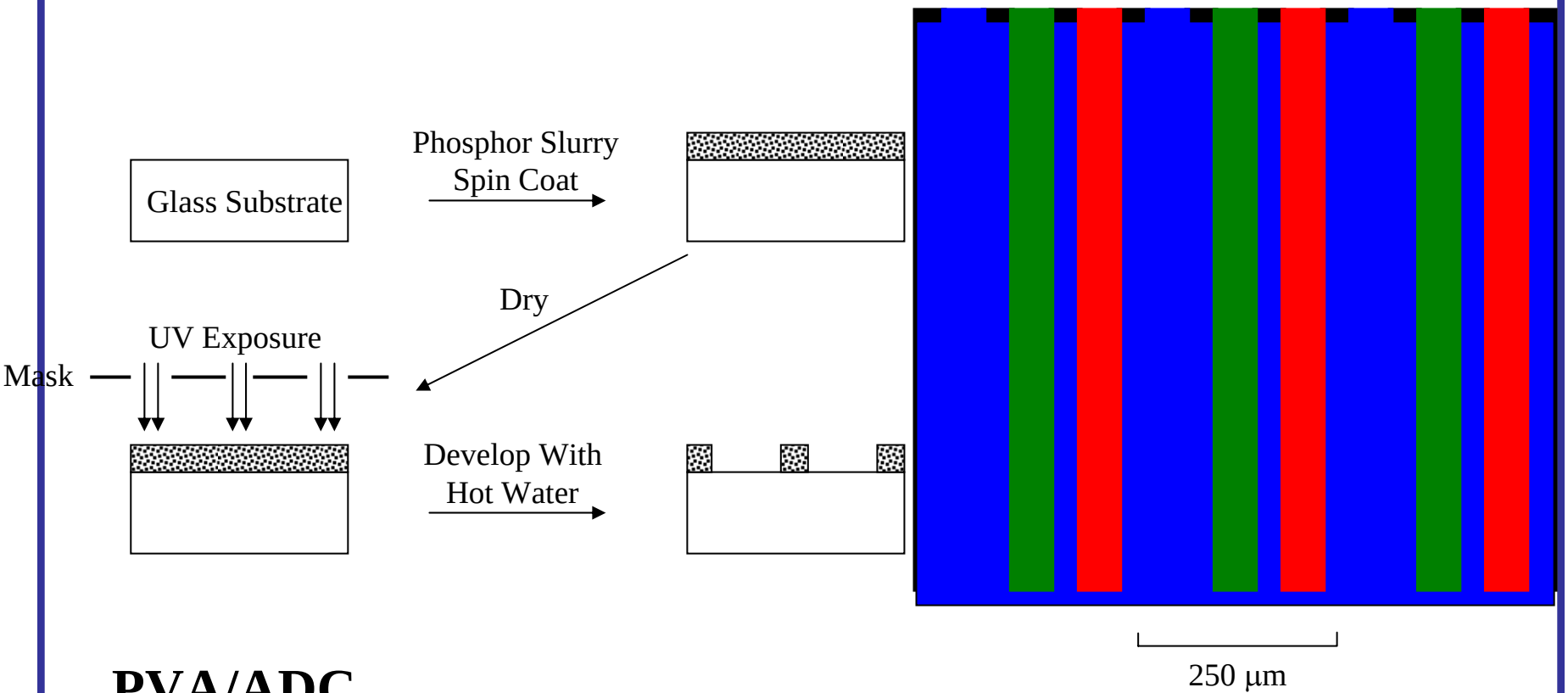
UCSD

Electronic waste represents 2% of US's trash in landfills, but equals 70% of overall toxic waste (Pb, Cr, etc). From 2004 California introduced an Electronic Waste Recycling Fee on all new monitors and televisions sold to cover the costs of recycling.

At E-World Recyclers in Vista, Luis Ramirez prepared cathode-ray tubes for the process that separates the leaded glass from lead-free, or "clean," glass.

UCSD

Phosphor Deposition



PVA/ADC

Polyvinylalcohol /Ammonium Dichromate

$(NH_4)_2Cr_20_7$

UCSD

Tacky Dot®

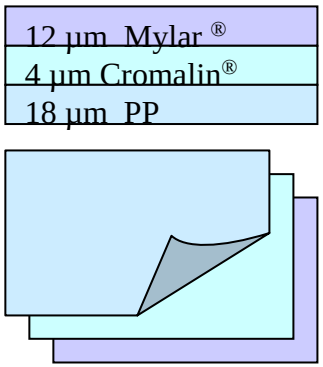
- Tacky Dot® - composed of acrylic monomers, polymer binders and free radical initiators, can be patterned with features as small as 4 µm
- Tacky and through polymerization becomes non-tacky (positive) or visa-versa (negative).
- DuPont created this technology for solder bumping of input/output pads to fabricate integrated circuits

Image/Population Prototype Apparatus that images a sheet of photosensitive material (in roll form) and populates with solder bumps.

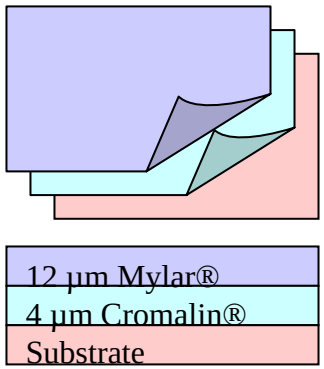
- DuPont donated Tacky Dot® IP with funding for use in new applications

UCSD

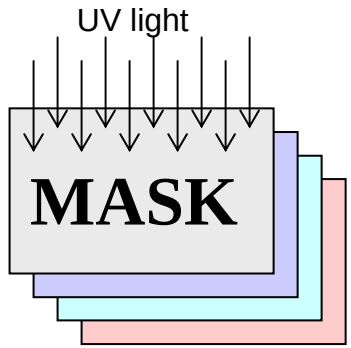
Tacky Dot Patterning Procedure



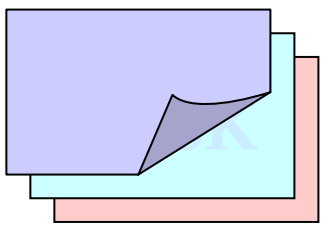
Cromalin® is made up of three layers: Mylar® cover sheet, the tacky photo-polymer and PP cover sheet



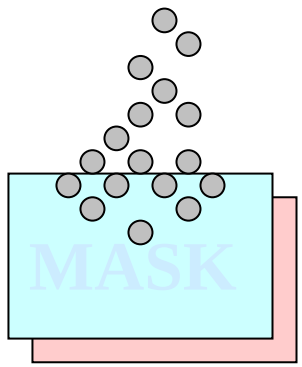
The polypropylene cover sheet is removed, allowing the Cromalin® to be laminated onto another substrate



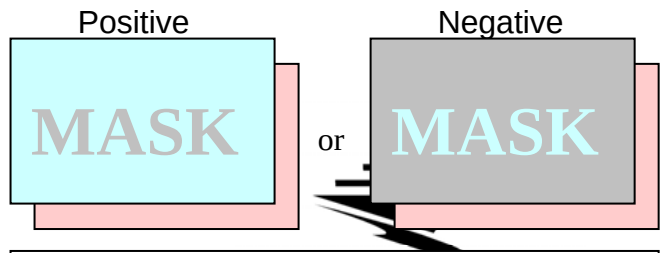
A Mask is placed over the Cromalin® which is patterned using UV light



Removing the Mylar® cover sheet exposes the tacky photo-polymer

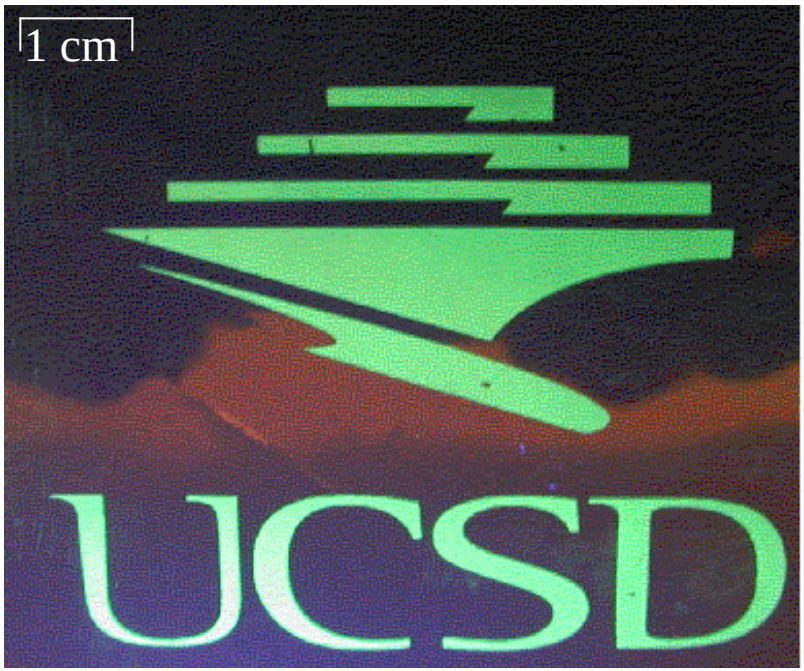


Particles may then be loaded onto the tacky surface



Creating an either Positive or Negative image depending on the type of Cromalin®

Patterns on Positive Cromalin®

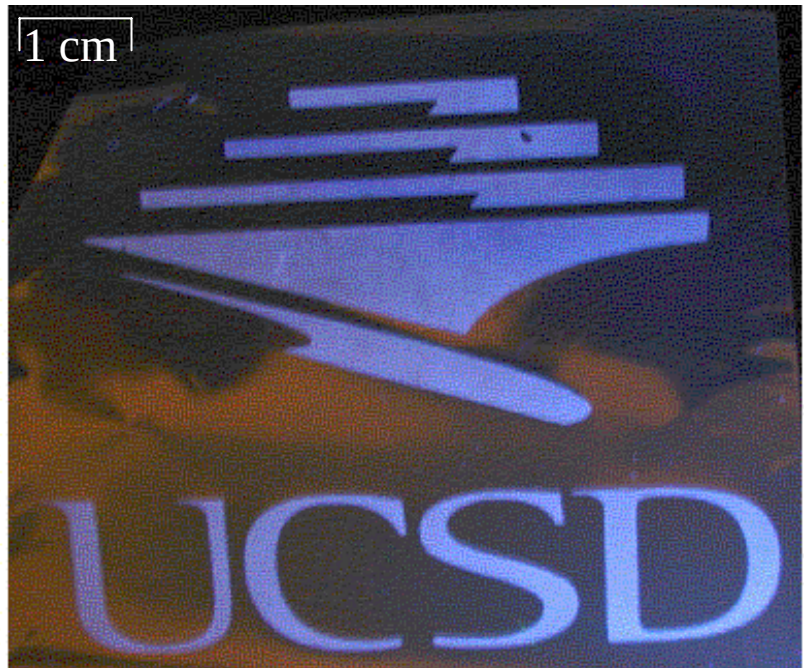


Nichia Green Phosphor

(ZnS:Cu ~6µm)

Exposure time: 25 sec

15 Watt UV lamp: 3.42 cd/m^2



Nichia Blue Phosphor

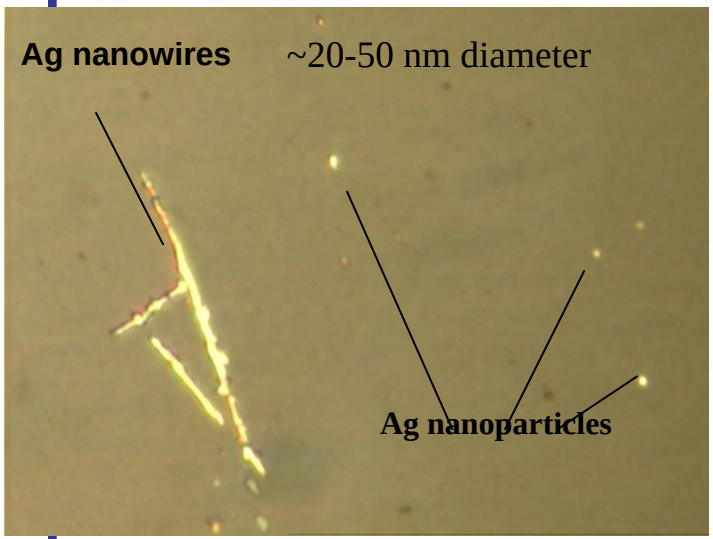
(ZnS:Ag,Cl ~5µm)

Exposure time: 25 sec

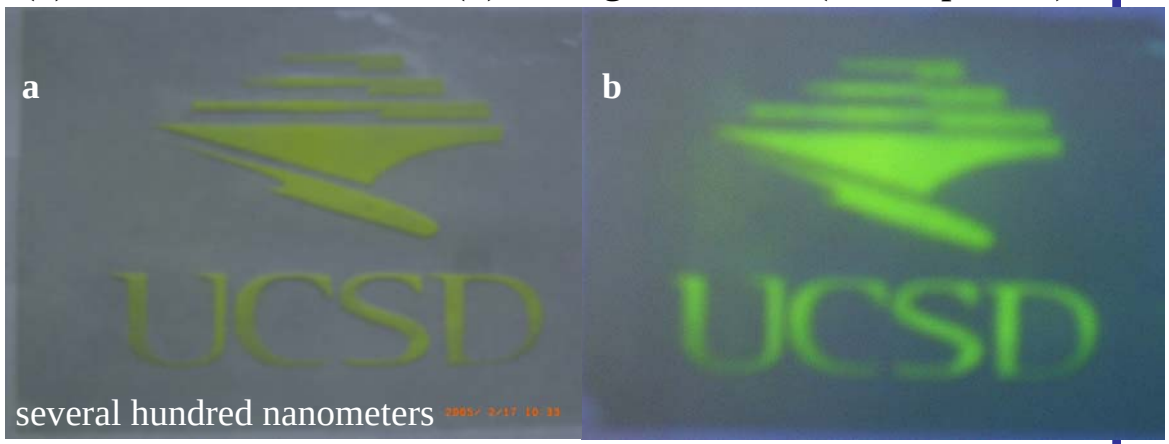
15 Watt UV lamp: 3.42 cd/m^2

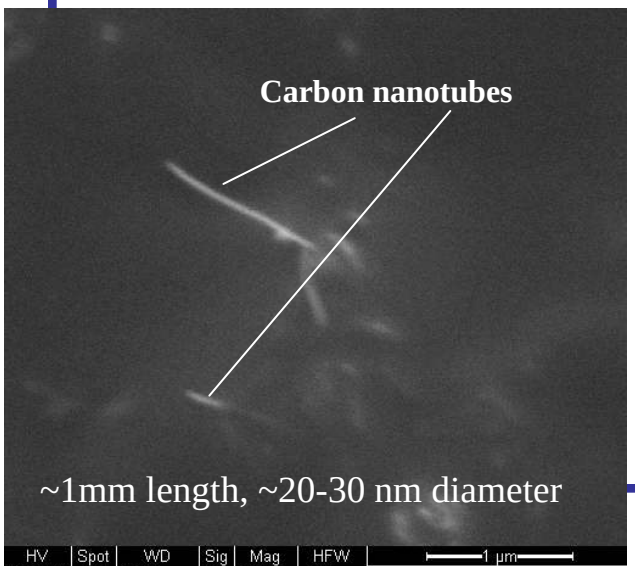
UCSD

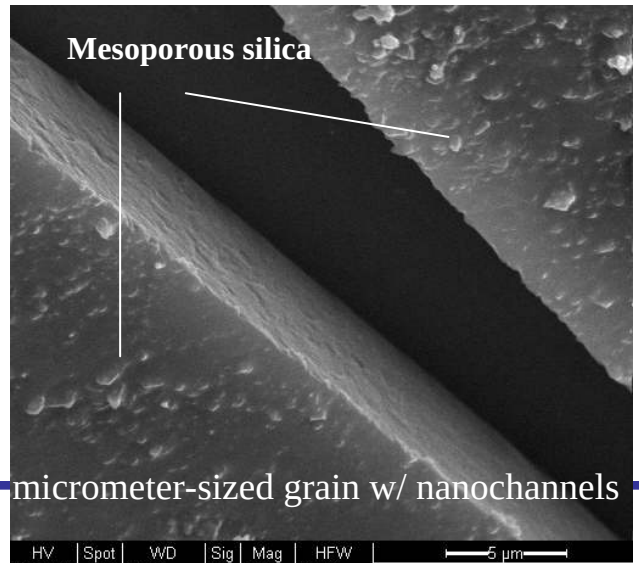
Application: Nanometer-Sized Particles

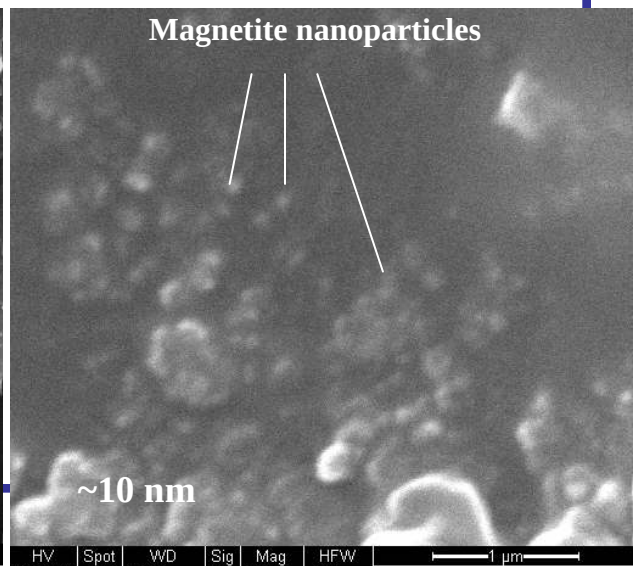


Fluorescent zinc 8-hydroxy-quinoline nanoparticles:
(a) before excitation and (b) during excitation (UV exposure)

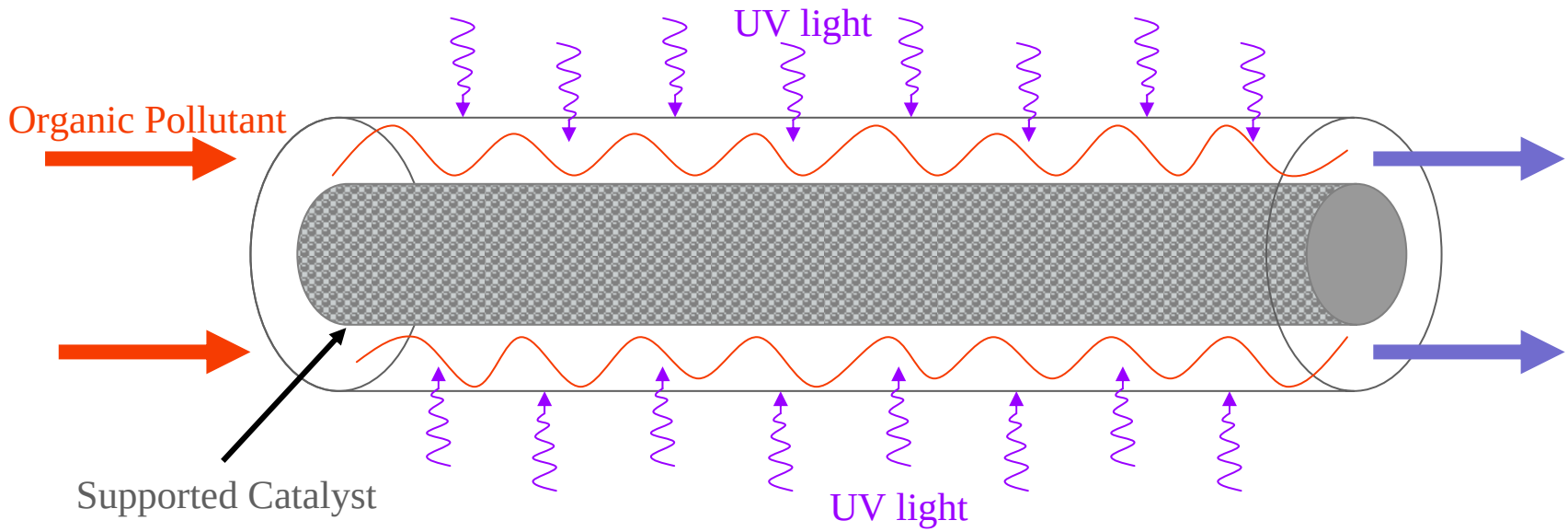








II. Photocatalytic Degradation



Pollutant oxidized by peroxyl radicals produced through UV light, catalyst (TiO_2) and water interaction

UCSD

Paper & Disclosures

- Paper: Hurt, M., and J. B. Talbot, "A Dry Phosphor Screening Method for Emissive Displays Using a Tacky Photopolymer," *Journal of The Electrochemical Society*, **152** (11) H178-H182 (2005).
- Invention Disclosures:
  - Tacky Dot Technologies (SD2002-092)
  - Electrostatic Methods and Apparatus for Mounting and Demounting Particles from a Surface Having an Array of Tacky and Non-Tacky Areas (SD2002-091)
  - Improved Method and Apparatus for Adhering and Centering Particles to the Tacky areas on a Surface Containing an Array of Tacky and Non-Tacky Areas (SD2002-090)
  - Method and Product for Particle Mounting (SD2002-089)
  - Photodetackafiable Film for Dry-Screen Phosphor Display Manufacture (SD2004-241)
  - Dry Adhesion and Patterning of Nanomaterials on Tacky Photopolymer (SD2005-190)

UCSD

Conclusions

Invention disclosures available for:

Solid state lighting technology

Tacky Dot® applications

For more information:

invent.ucsd.edu

UCSD