Sensing and Other Functionalities in Smart Coatings

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Smart Coatings

• Conventional Coatings are “passive”, they provide corrosion protection & aesthetics

• Active or Smart Coatings:
  • Sense
  • Self-heal
  • Monitor Structural Health
  • Change Color
  • Generate Energy
SWNT-Composites

• Key SWNT Processing Technology:
  • Purification
  • Chemical Functionalization
  • Dispersion in solvent
  • Dispersion in polymers
Nanotube Purification

- Metal removal close to 90+%
- No functionalization
- Disordered carbon removal 90+%
Synthesis of highly water soluble SWNTs

(A) 0.05mg/ml, (B) 0.1 mg/ml, (C) 0.2 mg/ml, (D) 0.3 mg/ml, (E) 0.5 mg/ml and (F) 10mg/ml. All the SWNTs were from three minutes microwave reaction. *JACS* (2006).

**Solubility** - 10-20mg/ml in DI water

**DLS** - Original 100-600nm, max 300

**Stable** – Months

**Ionic Conductivity** – 215.8 uS compared to 1.5 for DI water
Electroactive Thin-film for Scratch, Damage and Corrosion Sensing

Active Coating with embedded sensor.

A Sensor Cell Acting as a Transducer for Surface Damage.

Overcoat

Electroactive Film on a Decal

Electroactive membrane

Undercoat

Surface

Pat. Pending (2006)
Real-World Applications

(a) The tail of a proto-type helicopter with a scratch sensor built in. (b) Real-time sensing,

Automobile with a Scratch sensor

LED array to locate coating damage
The structure of poly(styrenesulfonate)/poly-(2,3-dihydrothieno-[3,4-b]-1,4-dioxin) - PEDOT/PSS

Incorporating microwave-soluble carbon nanotubes into the conducting polymer matrix can significantly increase the compound’s conductivity and applicability. The thermal resistivity of the CNT-conducting polymer composite is expected to decrease.
Wireless Network

• Sensor units are battery of solar operated

Electroactive Sensing Elements
Important Features

- Optimizing electroactive films
- Developing real-world applications
- Wireless network and interface
Permanently-polarized materials produce an electric field when the material changes dimensions as a result of imposed mechanical forces, which effects charge asymmetry.

Conversely, an applied electric field can cause a piezoelectric field to change dimensions.
Piezo-Sensor for Impact Detection

Wireless data transmission

Protective coating
Conductive polymer film
Piezoelectric thin film
Metal surface
Using data on time delay and signal intensity from the sensors, the magnitude and location of the impact will be computed. This information can be wirelessly transmitted.
Response as a Function of Distance

Distance to the impact point, cm

Signal, V

A

B
The emissive layer (EML) is sandwiched between two electrodes.

- The ITO (indium tin oxide) anode is transparent.
- The color of the emitted light is controlled by the energy gap of the chromophoric polymer.

Under applied voltage, opposite charge carriers are injected into the polymer coating and their recombination leads to electroluminescence (light emission). The color of the emitted light is controlled by the energy gap of the chromophoric polymer.
EL for Color Change and Camouflage

- Material selection
- Using Dyes to alter color
- EL device on flexible substrate
EL for Color Change and Camouflage

Materials for EML

![Graph showing emission spectrum](image)

**PVK: poly(9-vinyl carbazole)**

**PBD: 2-(4-biphenylyl)-5-(4-tert-butylphenyl)-1,3,4-oxadiazole**

**Host polymer matrix**

- Polymer PVK - good film forming property, hole transporting
- PBD molecules: electron transporting
- Proper PVK:PBD ratio to ensure balanced hole/electron injection into EML
Different light colors can be emitted from fluorescent or phosphorescent dyes doped in the host material.

**Ir(mppy)$_3$:** Iridium (III) tris(2-(4-totyl)pyridinato-N,C$^2$

**Ir(ppy)$_3$:** Tris(2-phenylpyridine) iridium (III)

**Rubrene:** (5,6,11,12-tetraphenylnaphthacene)

**(btp)$_2$Ir(acac):** Iridium (III) bis(2-(2′-benzothienyl) pyridinato-N,C$^{3′}$)(acetyl-acetonate).
EL Smart Coatings for Color Change and Camouflage

Light emission from EL devices under applied voltage

Ir(ppy)$_3$ doped: 1600 cd/cm$^2$ at 9 V
rubrene doped: 400 cd/cm$^2$ at 9 V
EL for Color Change and Camouflage

- EL devices based on dye-doped polymer coatings
- Color tuning via co-doping of different dyes
- EL devices on flexible substrate
SWNT-C60 Composite for Bulk-heterojunction Photovoltaic Cells

P3HT: poly(3-hexylthiophene)
PCBM: [6,6]-phenyl-C61-butyric acid methyl ester

- P3HT and P3OT are more stable in air.
- P3HT has higher hole mobility and higher degree of structural ordering than P3OT.
Functionalized Carbon Nanotubes in Photovoltaic Coatings

- Limited electron transport property and high cost of PCBM (usually 50 wt% or more is needed in the active coating).
- Excellent electrical conductivity of single walled carbon nanotubes (SWNTs).
- Low cost of fullerene C60.

Strategy: combination of strong electron accepting ability of C60 (or PCBM) molecules and superior electron transport property of SWNTs.

- SWNTs decorated with C_{60} molecules via microwave processing.
- C_{60} molecules serves as electron acceptor
- Efficient electron transport through nanotubes
- SWNTs may also be involved in dissociation of photo-generated excitons.