OLED display
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Outline

- OLED basics
- OLED display
- A novel method of fabrication of flexible OLED display
Potentials of OLED

- Suitable for thin, lightweight, printable displays
- Broad color range
- Good contrast
- High resolution (<5 μm pixel size)
- Fast switching (1-10 μs)
- Wide viewing angle
- Low cost of materials
Energy level diagram of OLED

• Electrons injected from the cathode (Ca, Al, Ba, etc.)
• Holes injected from the anode (Indium/tin oxide, PANi, PEDOT)
• Transport and radiative recombination of electron hole pairs at the emissive polymer
A threshold voltage must be achieved to overcome the barriers to inject charges into the organic materials.

N₂ molecules doped during the evaporation of Alq₃ cause the expansion of the traps states below the LUMO thus lowering the injection barrier for electrons.

The J-V curves of bi-layer OLEDs with Alq₃ evaporated under different N₂ ambient pressure. The insert presents schematic structure diagram of OLEDs. [2]
OLED types

- **Small-molecular OLED**
  - Made by vacuum evaporating small molecules to the substrate similar to that used in semiconductor manufacturing
  - Well proven on fabrication of up to about 15 inches in diameter (shadow mask)
  - Crystallization due to low glass transition temperature shortens lifetime and reliability

- **Polymer OLED**
  - Made by depositing the polymer materials on substrates through an inkjet printing process or other solution processing methods under ambient conditions
  - Fabrication of large screen sizes
  - Oxidation of carbon-carbon bonds between the aromatic rings reduce the conjugation length of the polymer
Inkjet printing

- Advantage: high-resolution, low cost, materials saving
- Selectively deposit many layers in a display simultaneously
- Surface properties of the substrate affect the uniformity of the film thickness
- Problems: layer shift and dimensional changes from the PLED drying and evaporation process

Ref. 3
First active-matrix full-color display by Sanyo in 1999
Challenges and shortcomings I

- **Addressing schemes**
  - Huge driving currents are needed to achieve adequate average brightness in Passive Matrix addressing displays. Such large currents cause problems such as large drive voltages leading to increased power dissipation, excess flicker, and shortened lifetimes.
  - Active Matrix addressing can be used to overcome such problems.
Challenges and shortcomings II

- **Brightness and Lifetime Requirements**
  - State of art OLED brightness and lifetime: 100 nits and 40,000 hours (50% initial luminance)
  - High brightness level require the display driving voltage levels to be increased which trades off expected lifetime. For most OLED materials, the relationship between driving voltage level and lifetime is nearly linear.

- **Moisture sensitivity**
  - Over time, moisture can react with the organic layers and cause degradation and defects in an OLED display
  - Sealing techniques
  - Inserting desiccants
Applications

- **Current main commercial applications**
  - Mobile phone screen (Samsung/NEC, Motorola, LG)
  - Car radio
  - Digital camera (Kodak)
  - Car stereo (Pioneer, TDK, Kenwood)
  - Razor (Philips)

- **Future**
  - Flexible displays
  - Replacing incandescent and fluorescent light bulbs
    - Currently power efficiency equivalent to incandescent light bulb while a factor of five less than that of fluorescent lighting
Flexible display

- Flexible substrate requirements
  - Transparent
  - Robustness
  - Low cost
  - Stability
    - Low coefficient of thermal expansion
    - Low moisture absorption
    - Resistant to chemicals & solvents

- Processing temperatures limited by:
  - Deformation temperature of material layers
    - For common plastic materials, <300 °C
Top-gate TFT process flow

1. deposit barrier oxide
2. deposit a-Si
3. crystallize a-Si (laser)
4. deposit gate oxide
5. deposit gate electrode
6. pattern gate (2μm min. features)
7. dope source/drain (laser)
8. pattern Si device regions
9. deposit contact isolation oxide
10. pattern and etch contact holes
11. deposit and pattern metal

- 4-inch PET (Polyester), PEN (Polyethylenenapthalate) substrates
- Poly-Si formation by pulsed laser crystallization
- Low temperature (<100 °C) gate oxide (~100 nm) formation
- Dopant activation by pulsed laser annealing the dopant layer
• Pulsed Laser Crystallization (PLC)
  • PLC converts a-Si film (90 nm) to poly-Si via ultrafast melting and solidification.
  • SiO$_2$ buffer layer prevents the heat from being transferred to the substrate.
  • Plastic kept below 250 ºC, cools rapidly.
TFT results [4]

NMOS

Mobility ~250 cm²/V-s
Threshold voltage ~ 5 V

PMOS

Mobility ~65 cm²/V-s
Threshold voltage ~ -4.8 V
OLED integration [4]
Fabrication challenges

- Evaluate damage to plastic & thin films
- Defects generation during thin film deposition
References