# Recent Trends in Flexible Electronics

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1. The beginnings
2. The drivers
3. A multi-disciplinary field

# Materials

- Key parameters:
  - Electrical Performance
  - Resolution and Registration
  - Environmental Stability
  - Mechanics and Optics

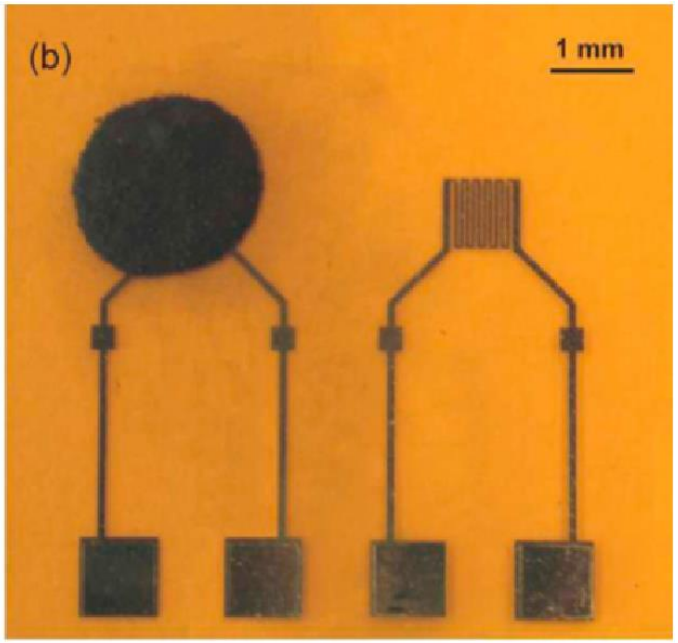
# Materials

- Key parameters (continued):
  - Process Parameters
  - Cost and Yield
  - Bio-compatibility
  - Biodegradability

# Materials
## Flexible substrates

Polyimide (PI):

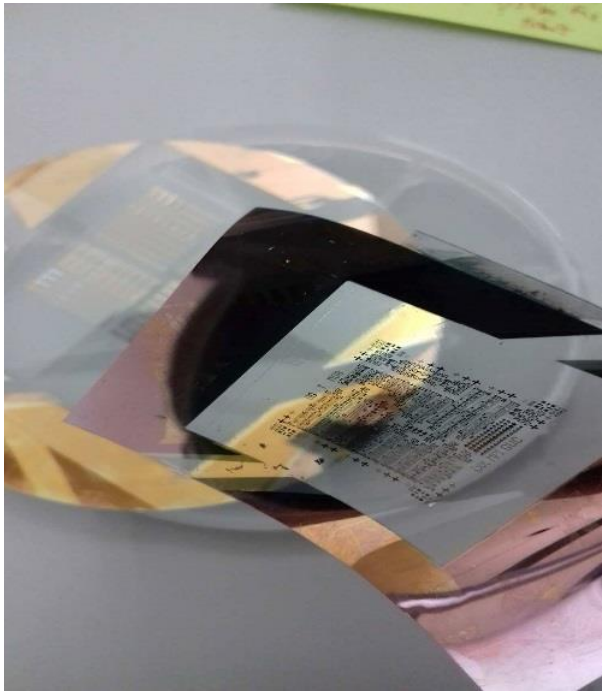
- Thermal stability
- Chemical stability
- Good adhesion
- Humidity sensitivity



# Materials
## Flexible substrates

Poly(ethylene terephthalate) (PET) and poly(ethylene 2,6-naphthalate) (PEN):

- Transparent
- Lower operating temp.



# Materials
## Flexible substrates

Paper:


- Ubiquitous
- Wide variety
- Surface roughness
- Low melting Temp.

# Materials
## **Flexible substrates**

polydimethylsiloxane (PDMS):

- Stretchable
- Thermal stability
- Transparent
- Biocompatable

# Materials
## Flexible substrates

Cellulose nanofibril (CNF):

- Eco-friendly
- Highly transparent
- Vulnerable to water→
- Surface modifications

# Materials
## Semiconductors

1. Metal oxides
2. Carbon allotropes and nanotubes
3. Thinned monocrystalline silicon circuits
4. Organic Semiconductors

# Materials
## **Semiconductors**

1. Metal oxides

- Valence compounds
- Effective electron mass < effective hole mass
- Normally N-type (e.g. $In_2O_3$, ZnO, IGZO)
- P-type: NiO, $Cu_2O$

# Materials
## **Semiconductors**

2. Carbon allotropes and nanotubes
   - Can exhibit semiconducting properties
   - Successful demonstration of sheets
   - Forming transistors still challenging
   - Saturation mobilities reaching 100000 $cm^2/Vs$ for CNT, 200000 $cm^2/Vs$ for graphene.

# Materials
## **Semiconductors**

3. Thinned monocrystalline silicon circuits
   - Thinned down to few tens of micrometers
   - Transferred to plastic film
   - Handling and packaging difficulties

# Materials
# **Semiconductors**

4. Organic semiconductors
   - Classified as small molecules or polymers
   - Polymers: high solulability→ solution processing
   - Small molecules: vacum sublimation, higher mobility
   - Normally undoped
   - Normally P-type

# Materials
# **Dielectrics**

- Used in passive and active devices
- Quality, physical properties and chemical nature c insulator-semiconductor interface
- Several kinds: Inorganic, Organic, Electrolytes
- Electrolytes: EDL (electrical double layer) (nanocapacitors→ high capacitance)

# Materials
## **Electrodes**

1. Inorganic conductors
   - Transperant variant: ITO
2. Organic:
   - Transperant vatiant: PEDOT:PSS

# Materials
## **Passivation**

- Protects the devices against environmental influences
- Examples: Parylene C, PDMS

# Fabrication Processes

- Wafer level technology
- Hybrid technologies
- Fully printed technology

# Fabrication Processes

Key Technology Parameters:

- Mobility/electrical performance
- Resolution/registration
- Barrier properties/environmental stability

# Fabrication Processes

Key Technology Parameters (continued):

- Flexibility/bending radius
- Compatibility of process parameters
- Yield

# Fabrication Processes

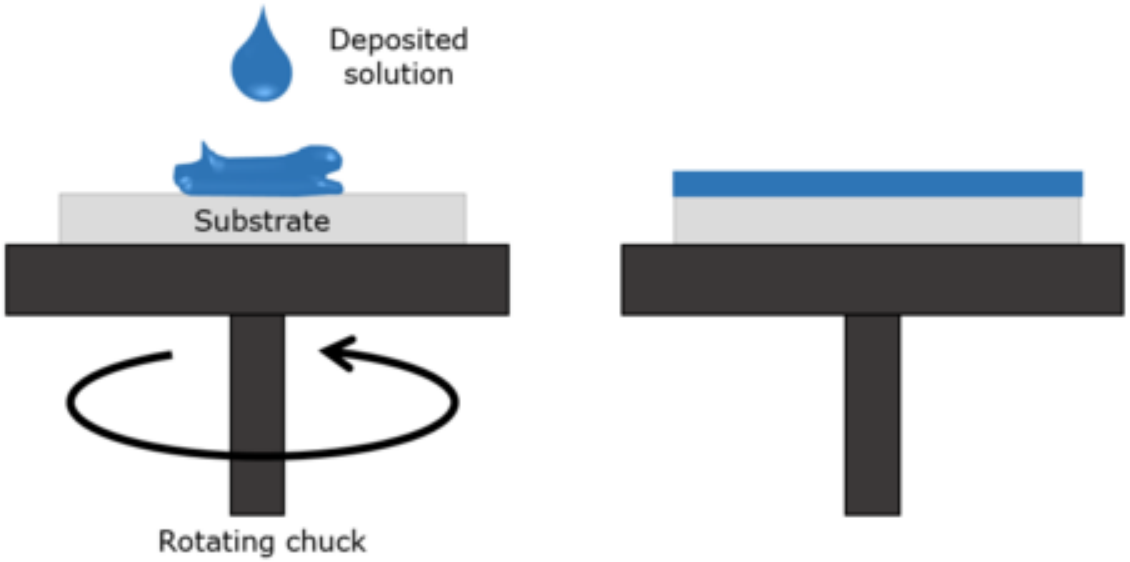
## Solution processing

- Enable roll-to-roll
- Mass printing
- Cheaper, low energy
- Build on currently existing technologies
- Ink formulation a major aspect

# Fabrication Processes

## Solution processing

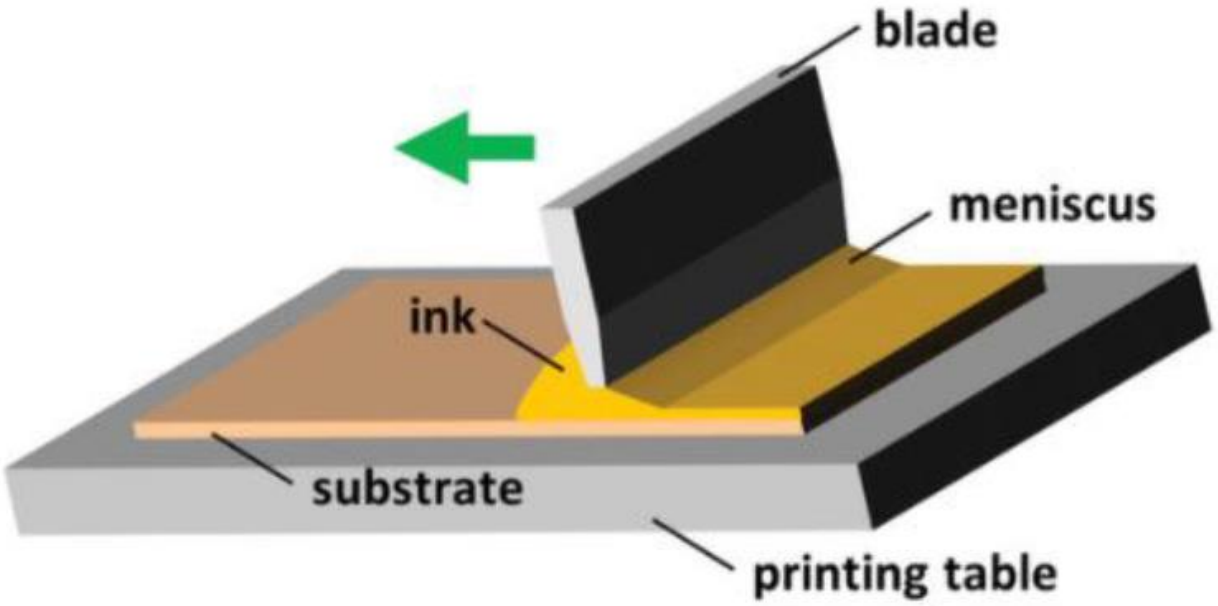
1. Spin coating



# Fabrication Processes

Solution processing

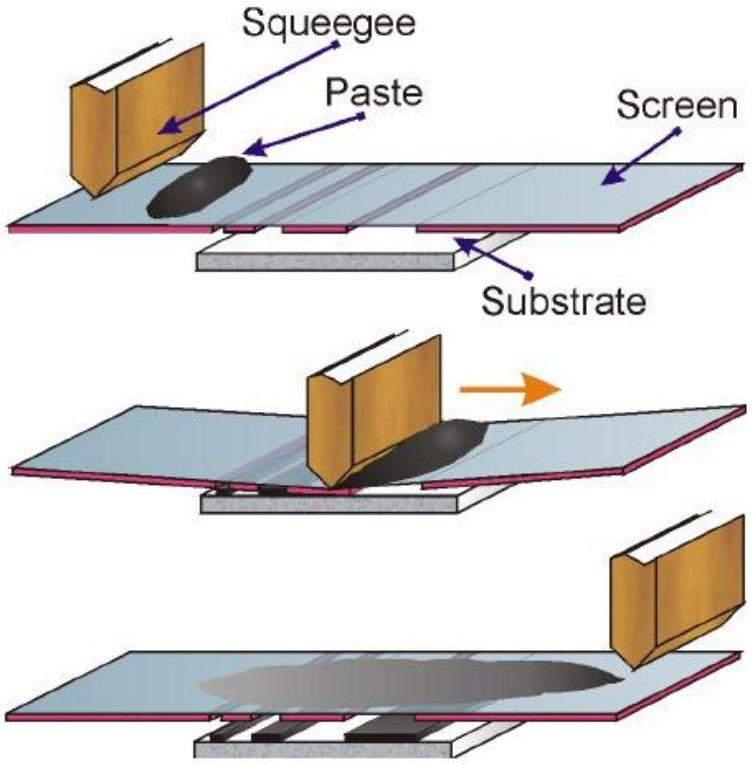
2. Doctor blading



# Fabrication Processes

Solution processing

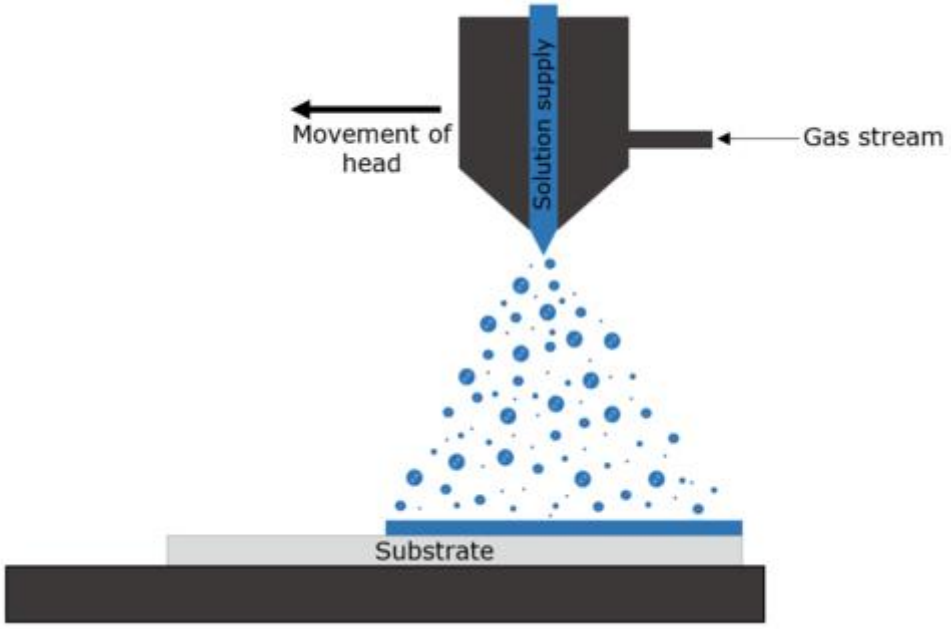
3. Screen printing



# Fabrication Processes

## Solution processing

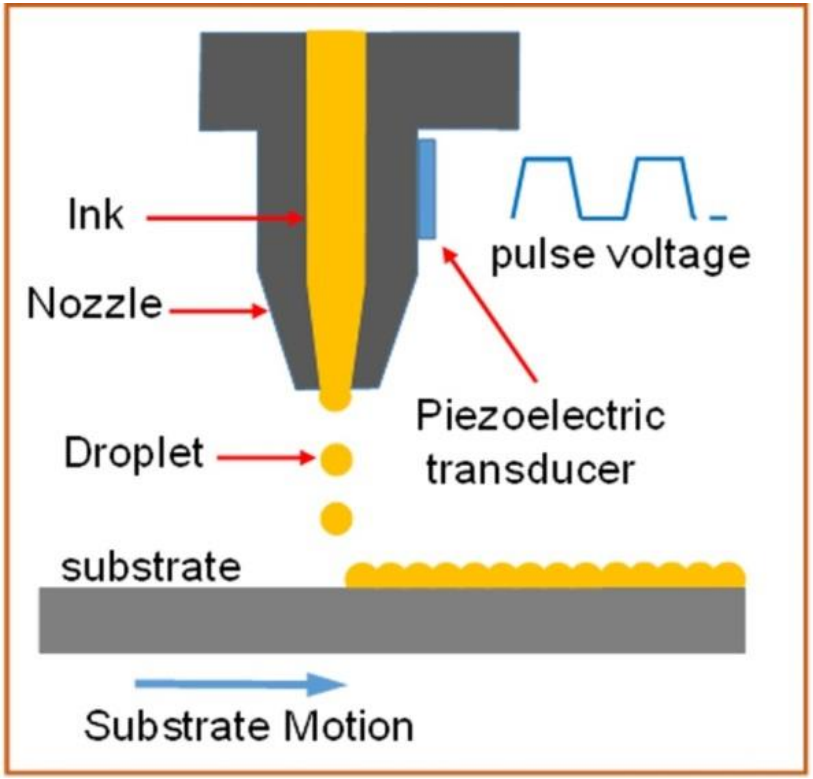
4. Spray coating



# Fabrication Processes

## Solution processing

5. Inkjet printing

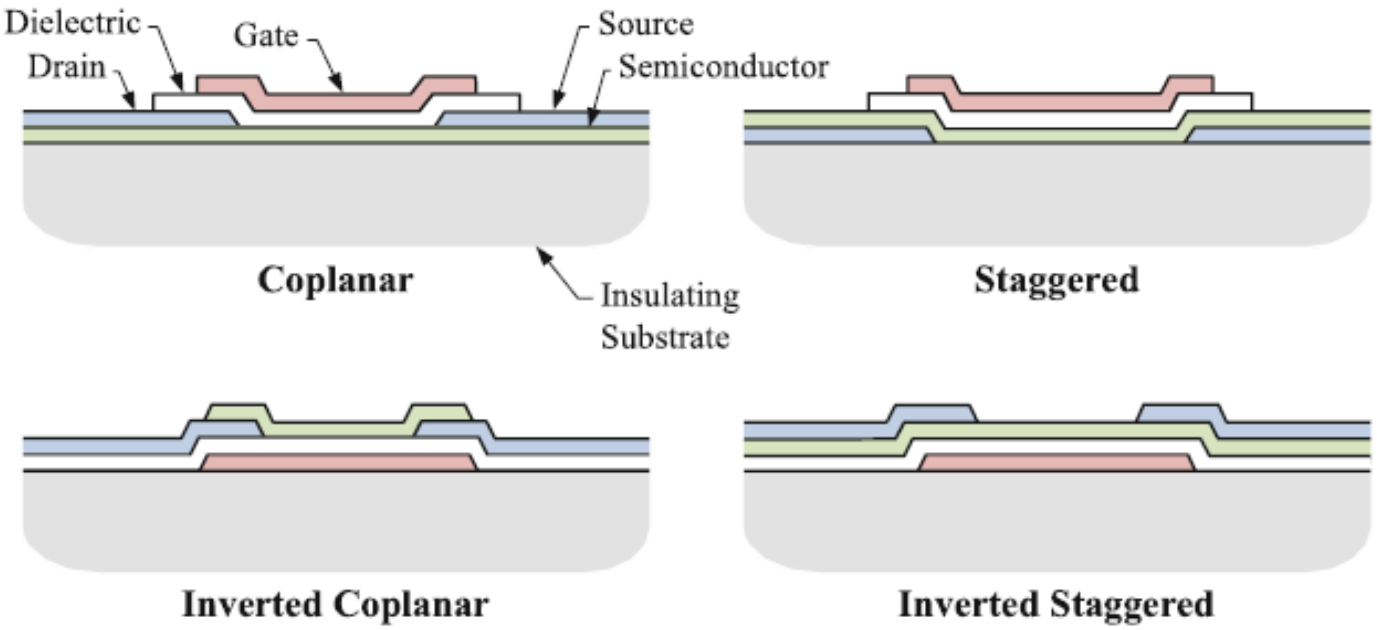


# Devices

- Evolution of Thin Film Transistors (TFT): a-Si:H
- Accumulation rather than depletion devices

# Devices

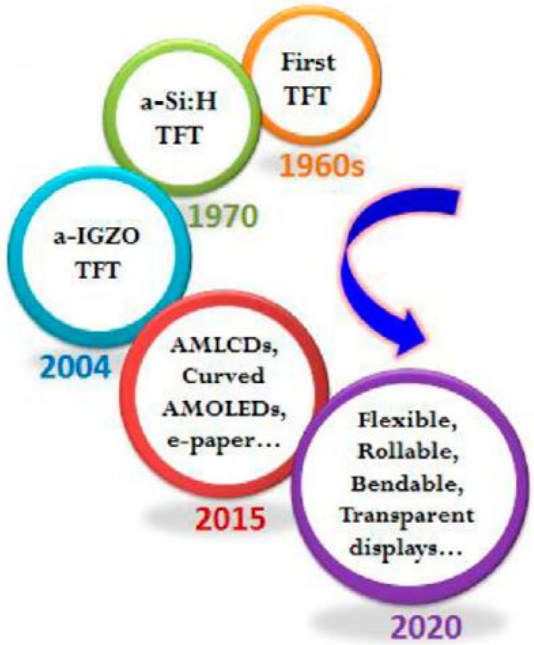
## Thin Film Transistors



# Devices

## Thin Film Transistors:

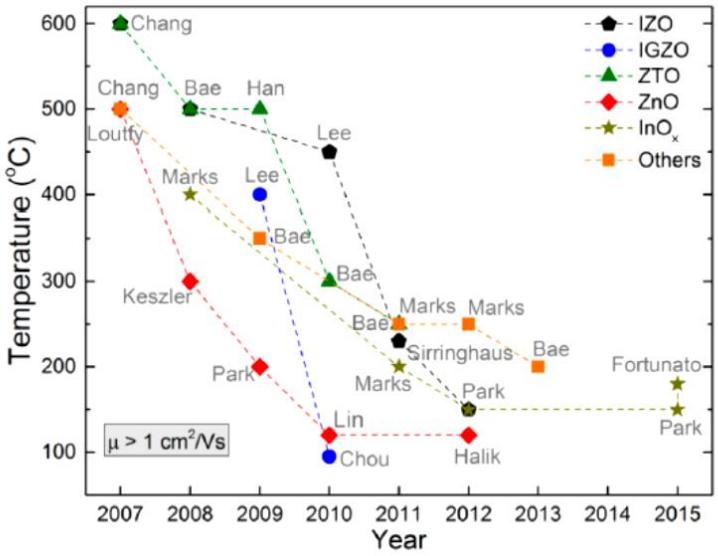
### Metal oxide TFTs:

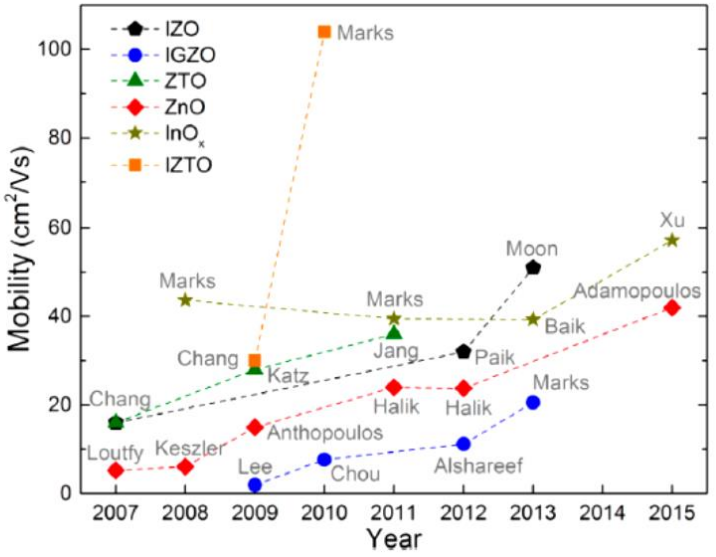


# Devices

## Thin Film Transistors:

### Metal oxide TFTs:

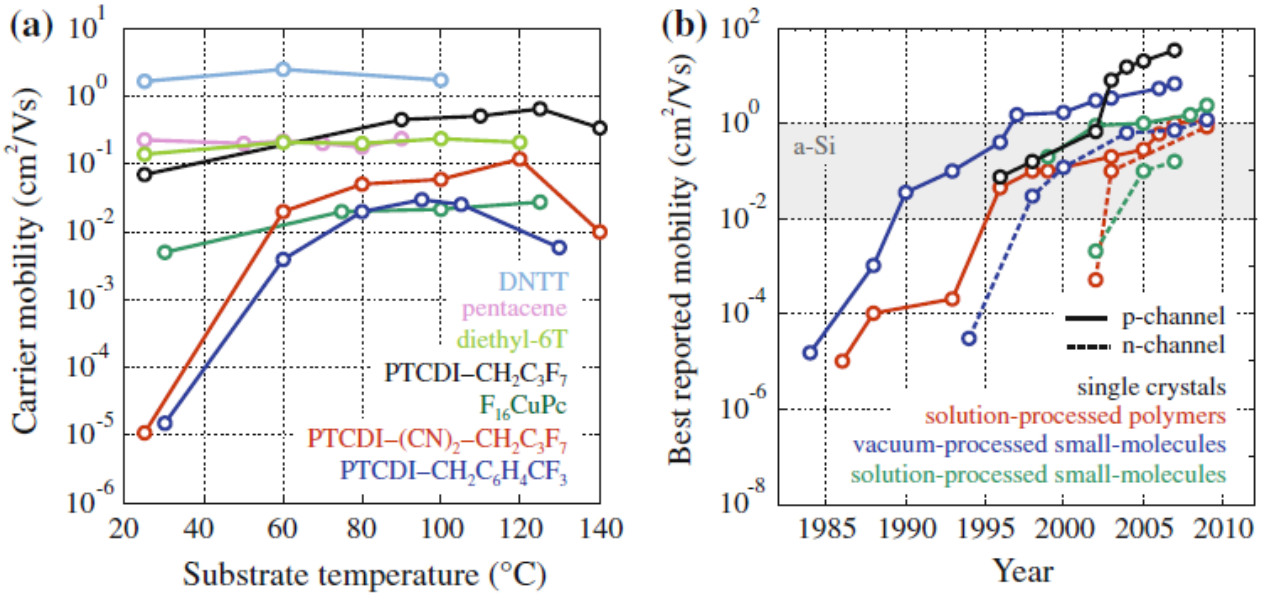


# Devices

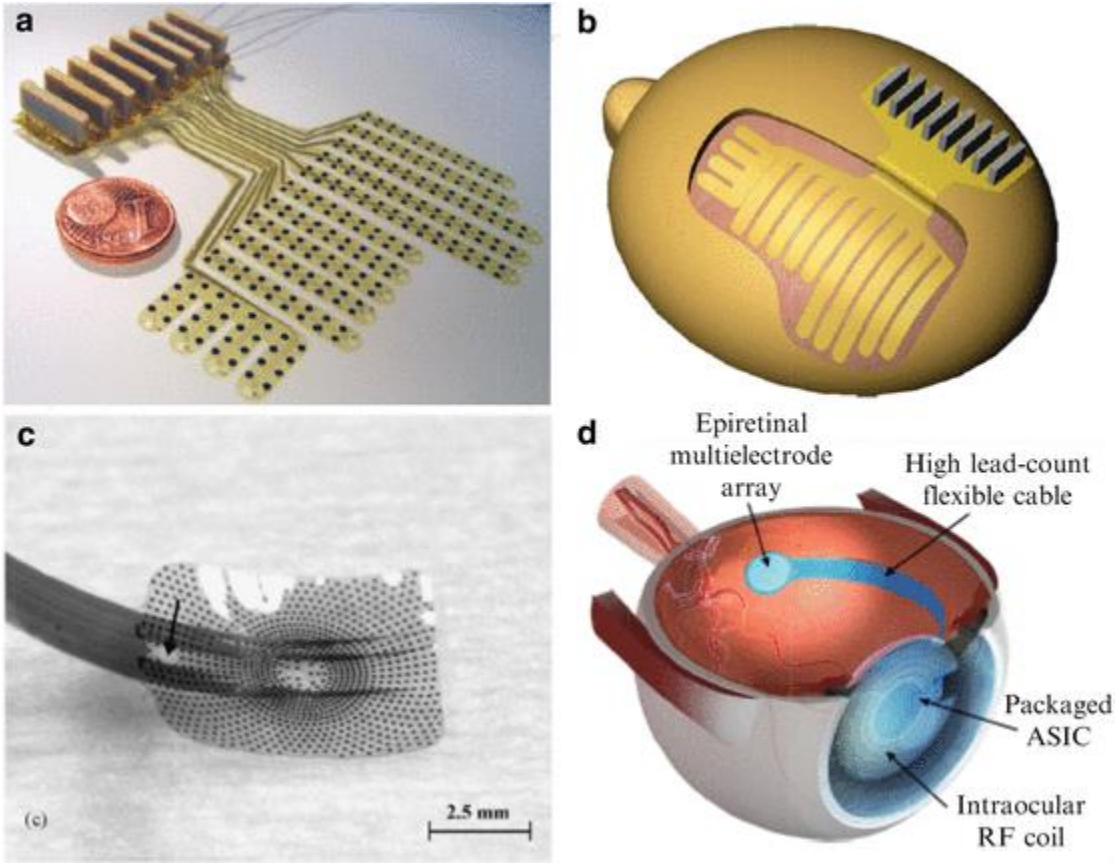
## Thin Film Transistors:

### Organic TFTs:



# Applications

## Flexible Neural Electrodes




Source: https://link.springer.com/chapter/10.1007/978-1-4614-8151-5_6

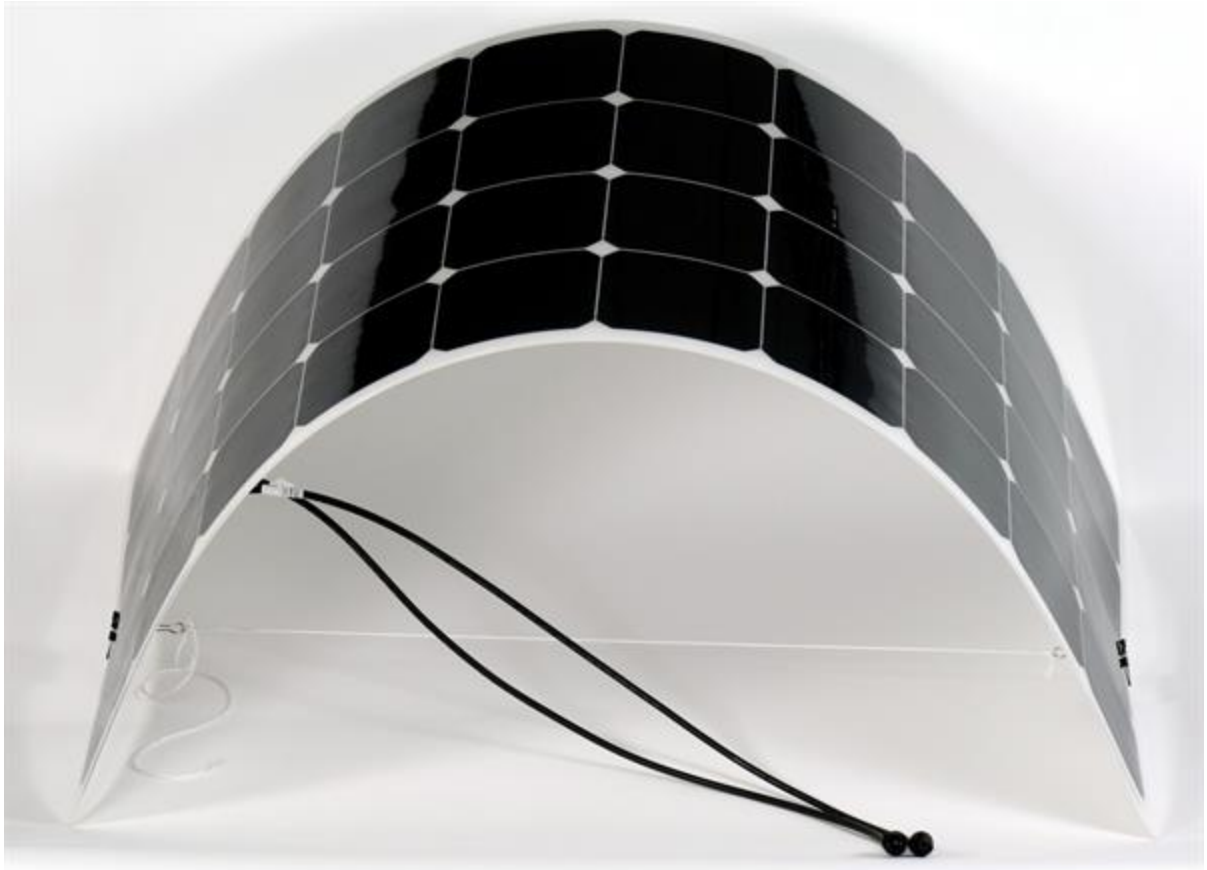
# Applications

## Flexible Displays


Source: https://www.oled-info.com/lg-display-supply-flexible-oleds-german-car-makers

# Applications

## Flexible Solar Panels



Source: https://www.todoensolar.com/Flexible-solar-panel-de-60W-12V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Grazie
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Ngiyabonga
Dank U
Thank
You
Merci
Ngiyabonga
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Demo