# Flexible, Transparent thin-film transistors for display technology

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Summary

- Thin film transistors (TFTs) using solution-processed metal-oxides as active material;

- Applications on active-matrix displays (AMD);

- Current demand on AMDs;

- Conclusions and Perspectives;

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100 km
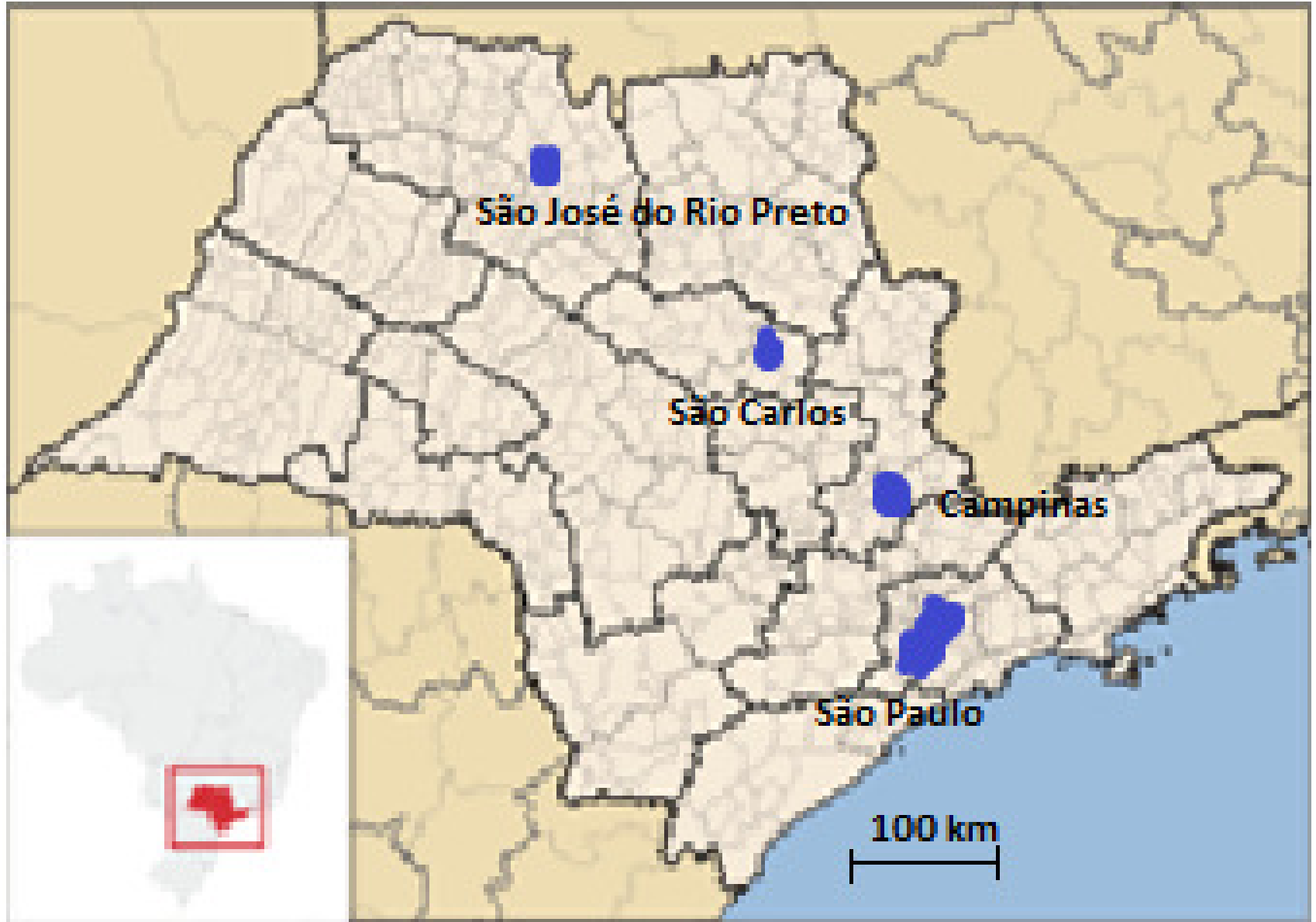
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Topics of interest

Electronic transport in Organic Semiconductors

- Sandwich structures: OLEDs and OPVs;

- Planar structures: OFETs and biosensors;

- a.c. and d.c. electrical characterization (impedance spectroscopy, IxV, electroluminescence, electroabsorption, etc.);

Thin-film transistors comprising solution-processed amorphous metal oxides (AMOs):

- Transparent devices for applications on active-matrix displays;

- Solution-processed. Precursor route. Nanoparticles;

- Electrical transport properties on AMOs;

Motivation: Transparent active-matrix display

SMD
30"A

Motivation: Transparent active-matrix display

- Requirements for flexible transparent displays:
    - High transmittance of the materials in the visible spectrum range (for the materials that composes the pixel and the drive circuit);
    - Compactibility with flexible substrates (low-temperature deposition);
    - Coverage of large areas, low-cost and processability;
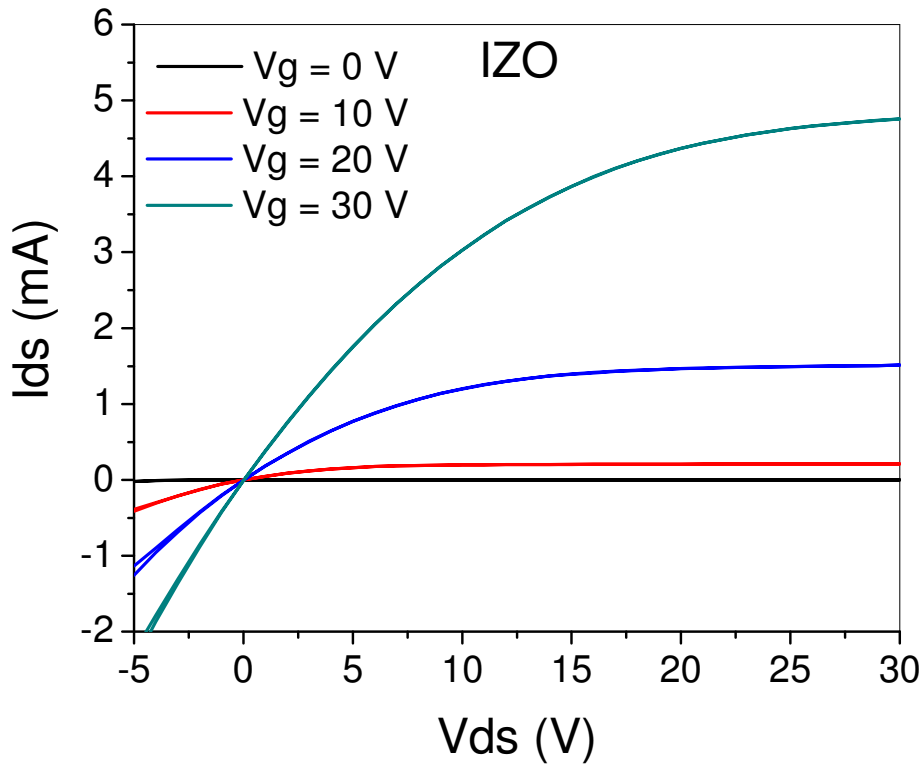
Thin-film Transistors (TFTs)

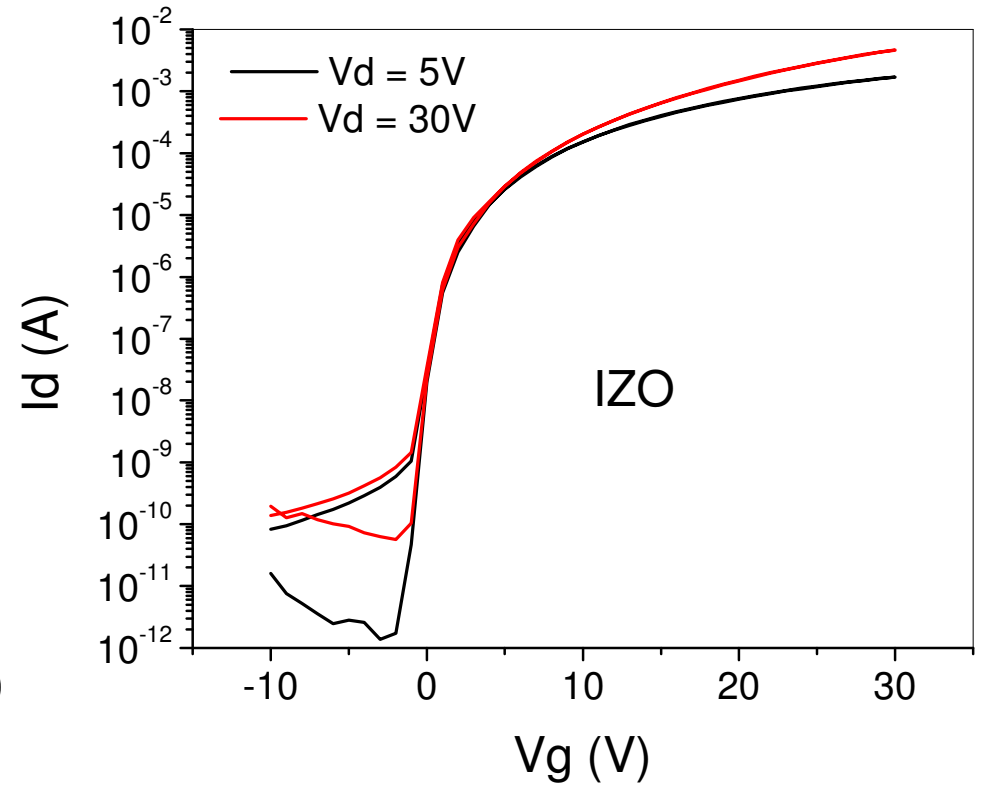Enhancement type TFT
(accumulation)

Conducting channel

Source

Semiconductor tipo p

drain

Insulator

I_D

gate

V_G

V_D
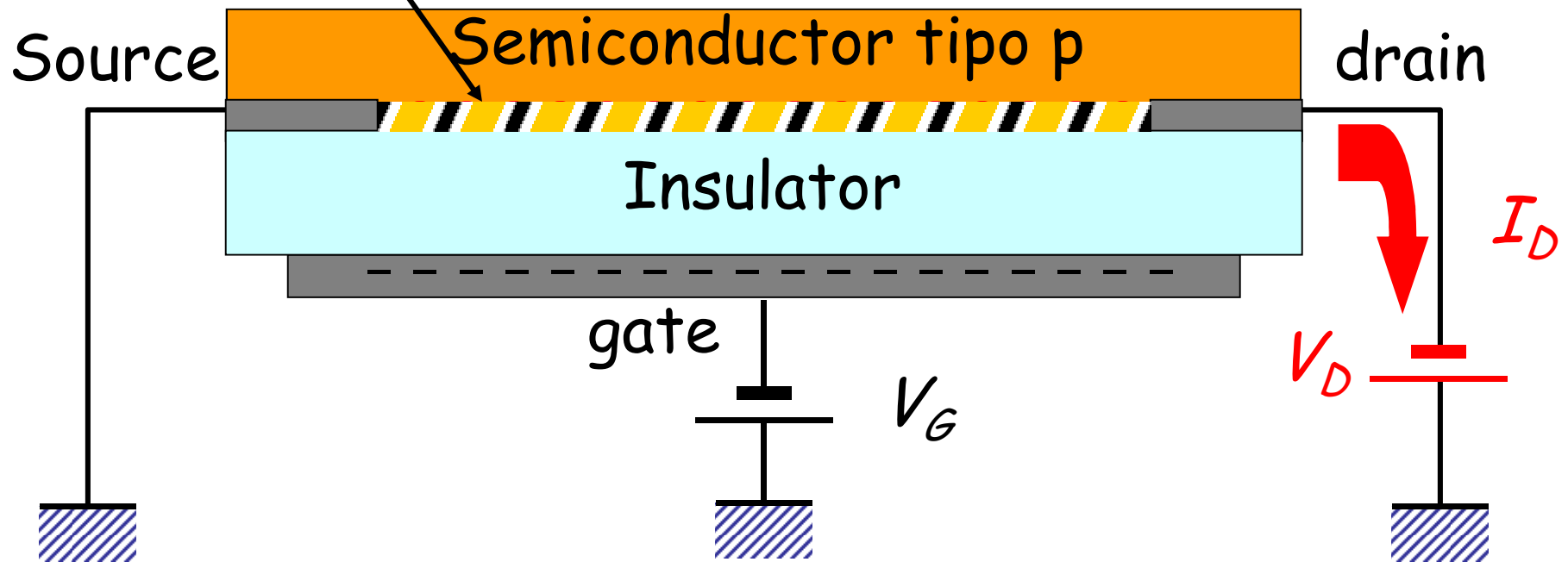
Thin-film Transistors (TFTs)

Output curve

Transfer curve

FETs: Modo de Operação e Princípios Básicos

Substituindo e integrando em x :

$$I_D = \frac{LC_i\mu}{W}\left[(V_G - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$ Shockley equation for a TFT

I_D: corrente no dreno (canal)

V_G: Tensão no *gate*

V_{DS}: Tensão dreno-fonte

W: largura do canal

L: comprimento do canal

C_i: Capacitância por unidade de área do dielétrico
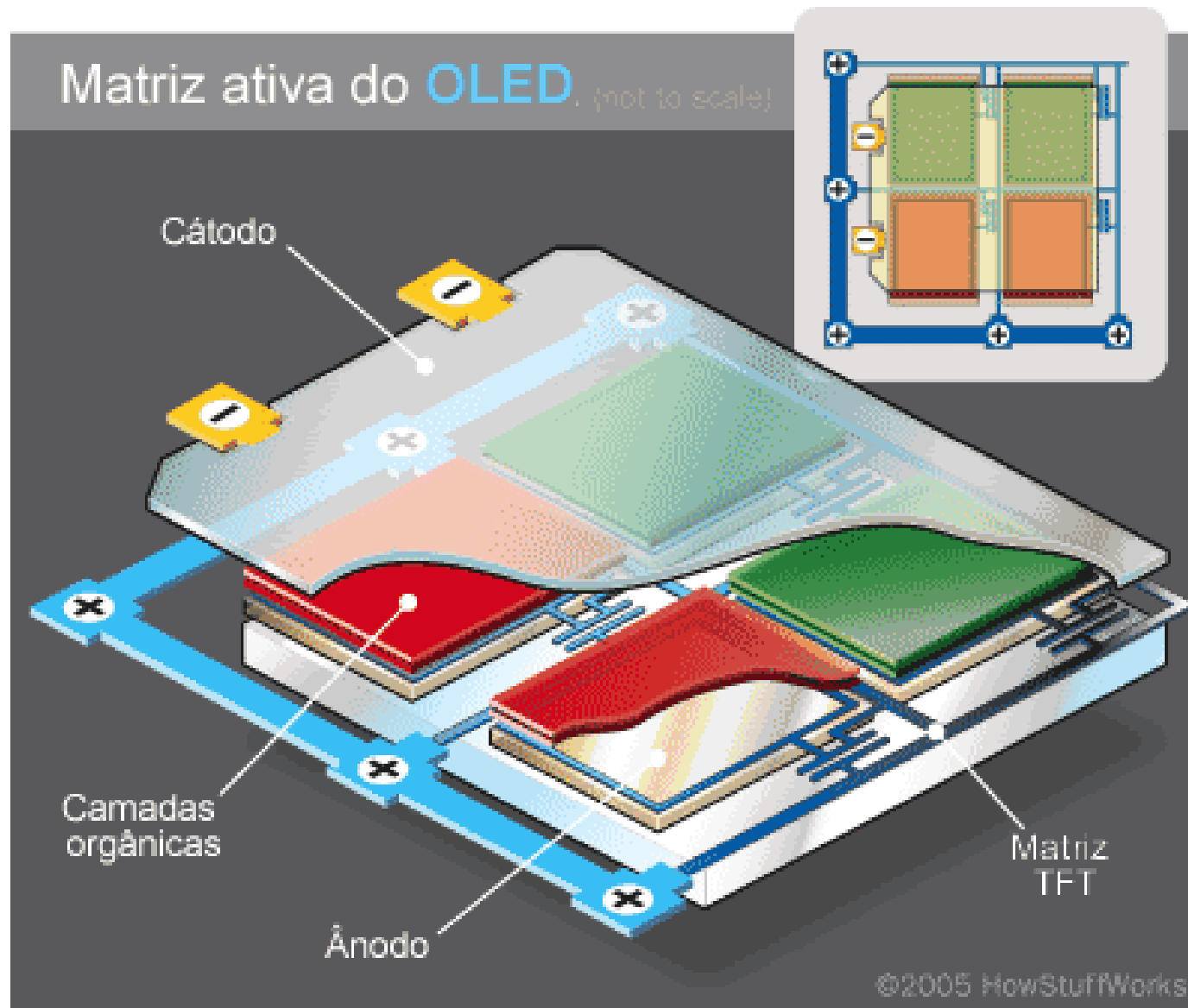
μ: mobilidade dos portadores no canal

Válida para: $0 \leq V_{DS} \leq (V_G - V_T)$ Até o "joelho" da curva de saída

Transistores de Efeito de campo (FETs)

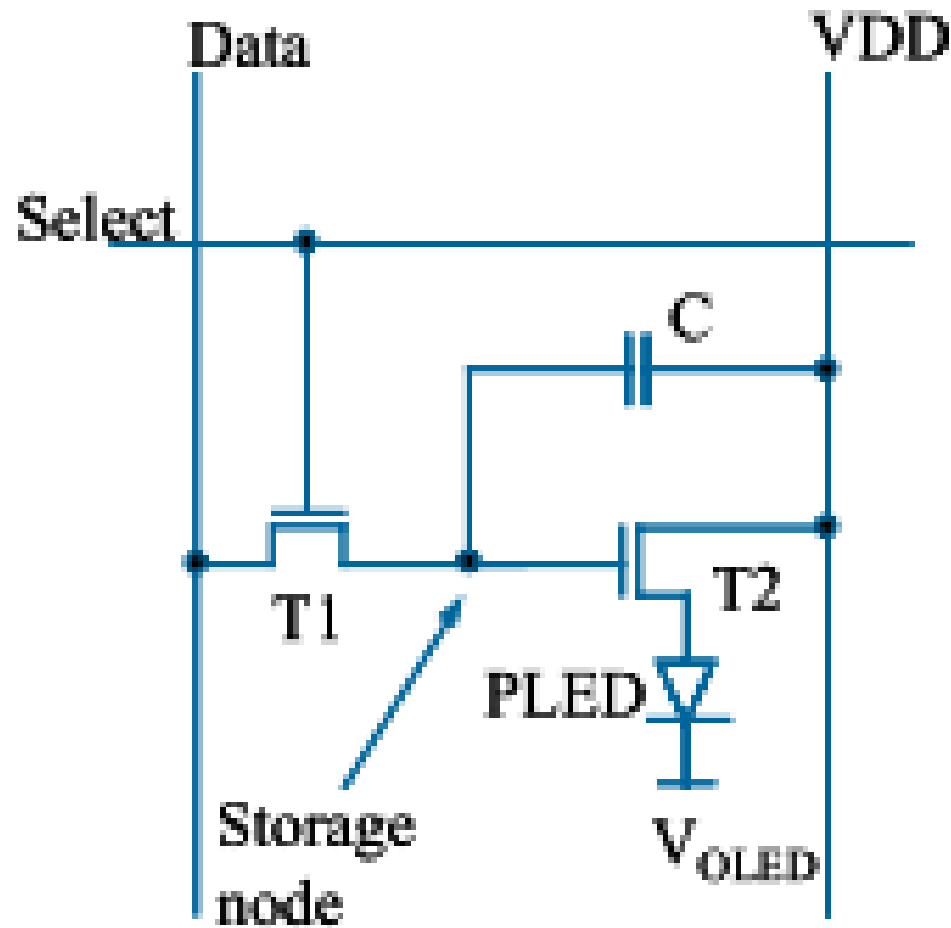**Parâmetros importantes obtidos a partir das curvas de saída e de transferência:**

- Fator de modulação de corrente (relação *on/off*);

- Tensão de inversão (*Threshold voltage*);

- Mobilidade dos portadores majoritários;

- *Off current* (*leakage + intrinsic conduction*);
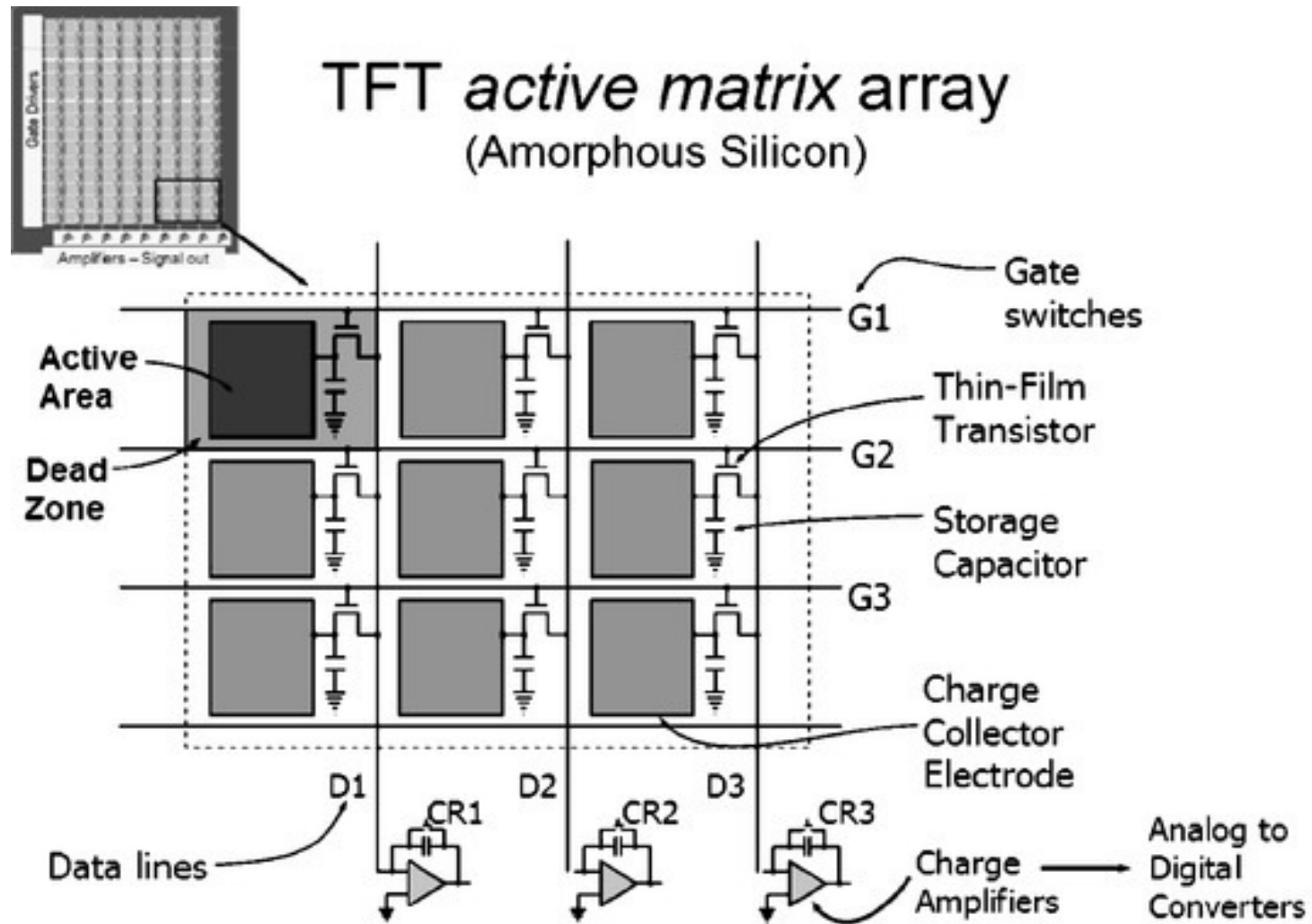
TFTs in active-matrix display circuits

Matriz ativa do OLED (not to scale)

Cátodo

Camadas orgânicas

Ânodo

Matriz TFT

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TFTs em circuitos de matriz ativa

TFTs em circuitos de matriz ativa

TFT *active matrix* array
(Amorphous Silicon)

Gate Drivers

Amplifiers – Signal out

Active Area

Dead Zone

Gate switches

Thin-Film Transistor

Storage Capacitor

Charge Collector Electrode

Charge Amplifiers

Analog to Digital Converters

Data lines

G1

G2

G3

D1

D2

D3

CR1

CR2

CR3

TFTs in active-matrix display circuits
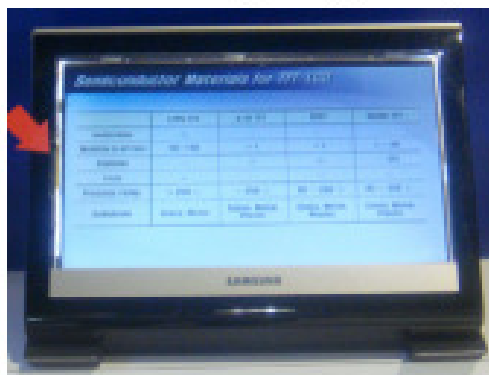
Flexible BW E-paper
5.35",VGA,150ppi
(Toppan, 2009)

Flexible BW E-paper
2",VGA,400ppi
(Toppan, 2009)

Scan-driver-integrated
AM-OLED
(LGE&ETRI,2009)
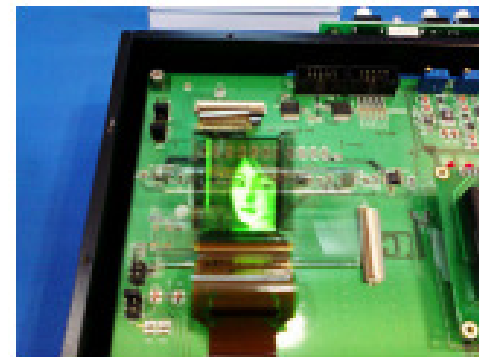
Gate-driver-integrated
15" WXGA AM-LCD
1280×720 (SEC, 2008)

19" QFHD AM-OLED
960×540 (SMD, 2009)

37" FHD AM-LCD
1920×1080
(AUO, 2010)

TFTs in active-matrix display circuits

Hi-Res LCD Smart Phones (2010-)

Hi-Res LCD & OLED Tablets (2012-)

iPhone 4 & 5   New iPad   Samsung Galaxy OLED
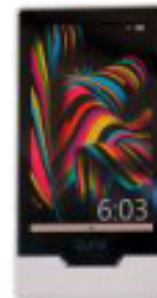
OLED Smart Phones (2010-)

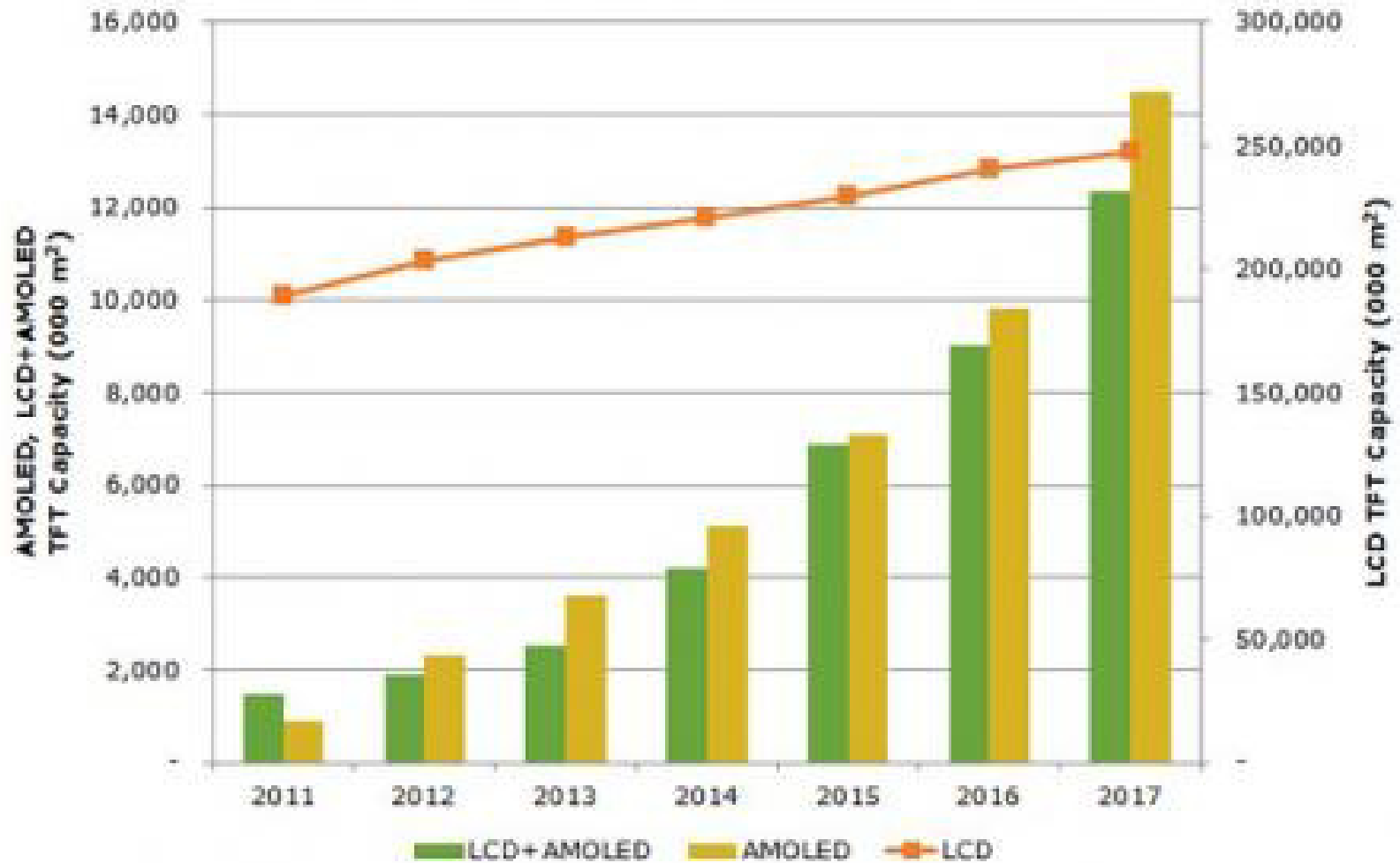Google Nexus One   Samsung Galaxy SII   Microsoft Zune

TFTs in active-matrix display circuits
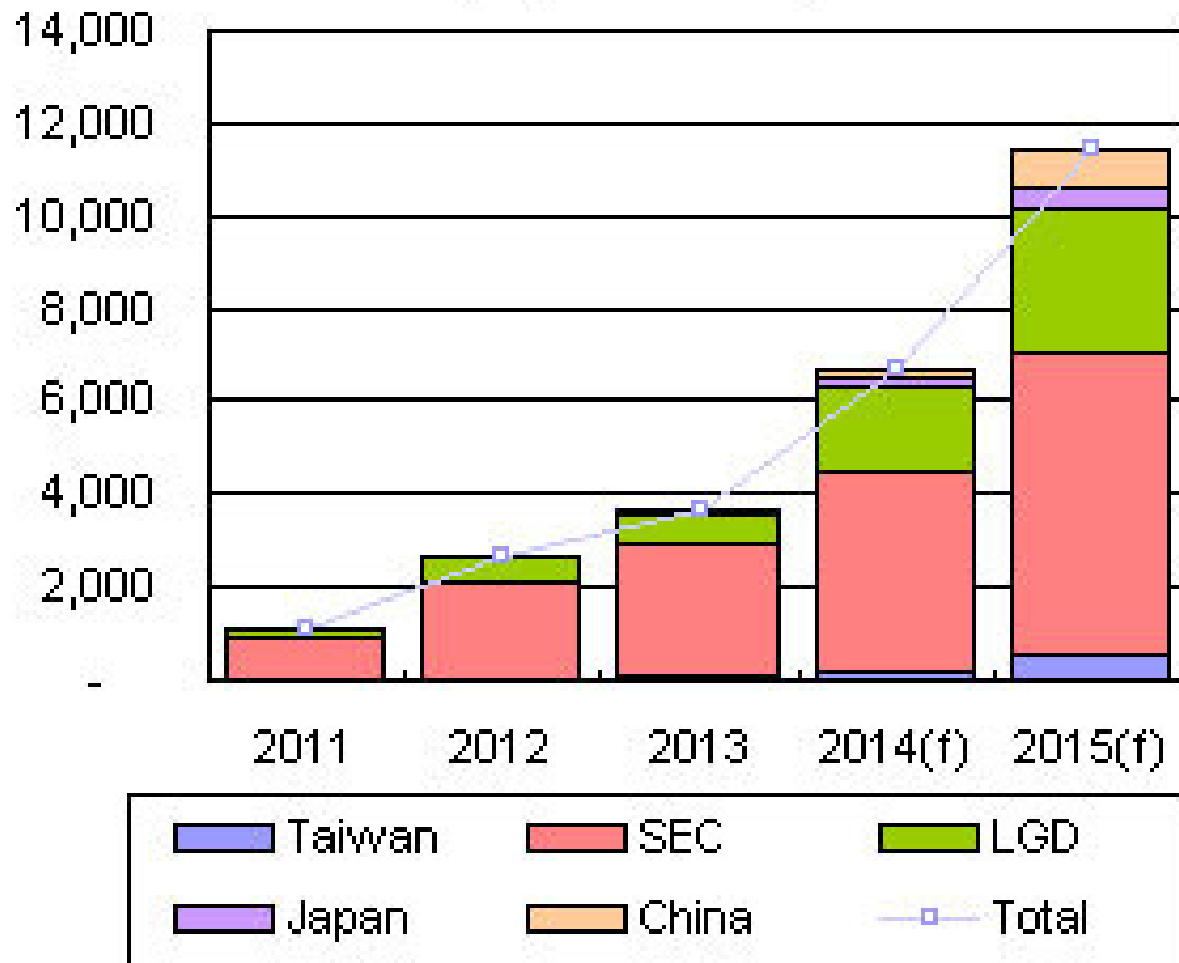
TFTs in active-matrix display circuits

- Current demand:

  - high mobility (higher scan rates);
  - transparency;
  - flexibility;
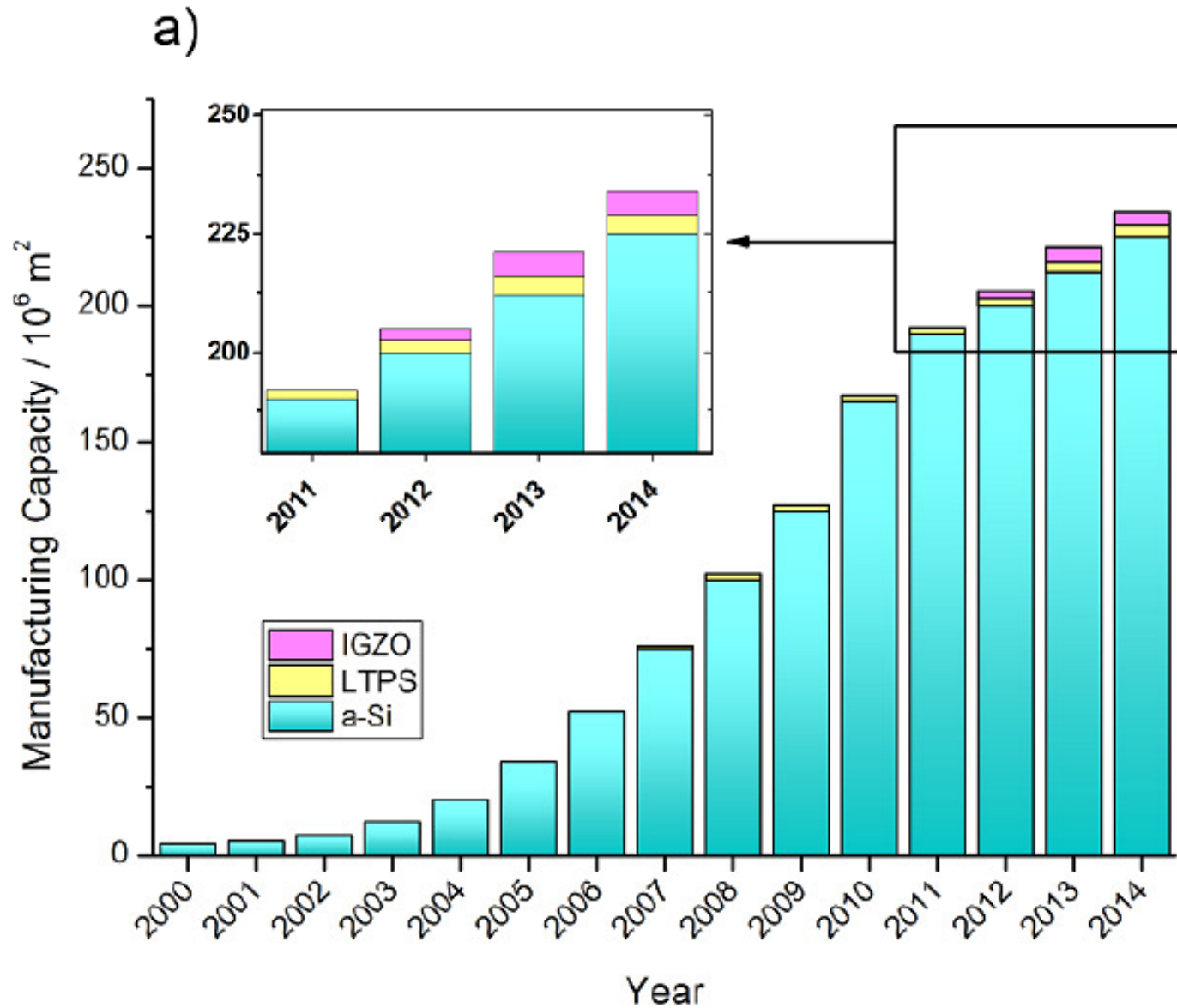 - low production cost;
  - large areas;

Production of AM-displays
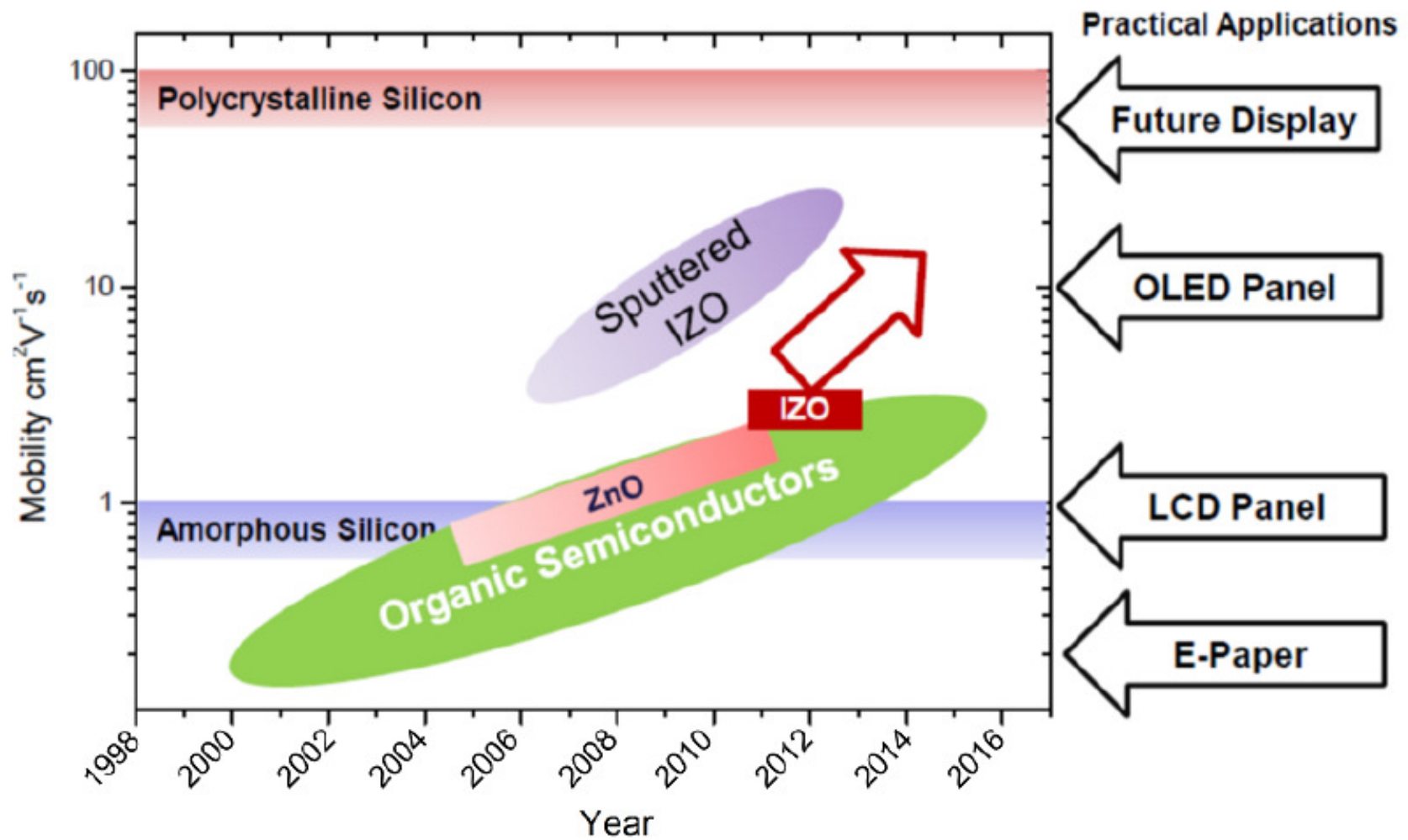
Capacidade de produção de AM-displays

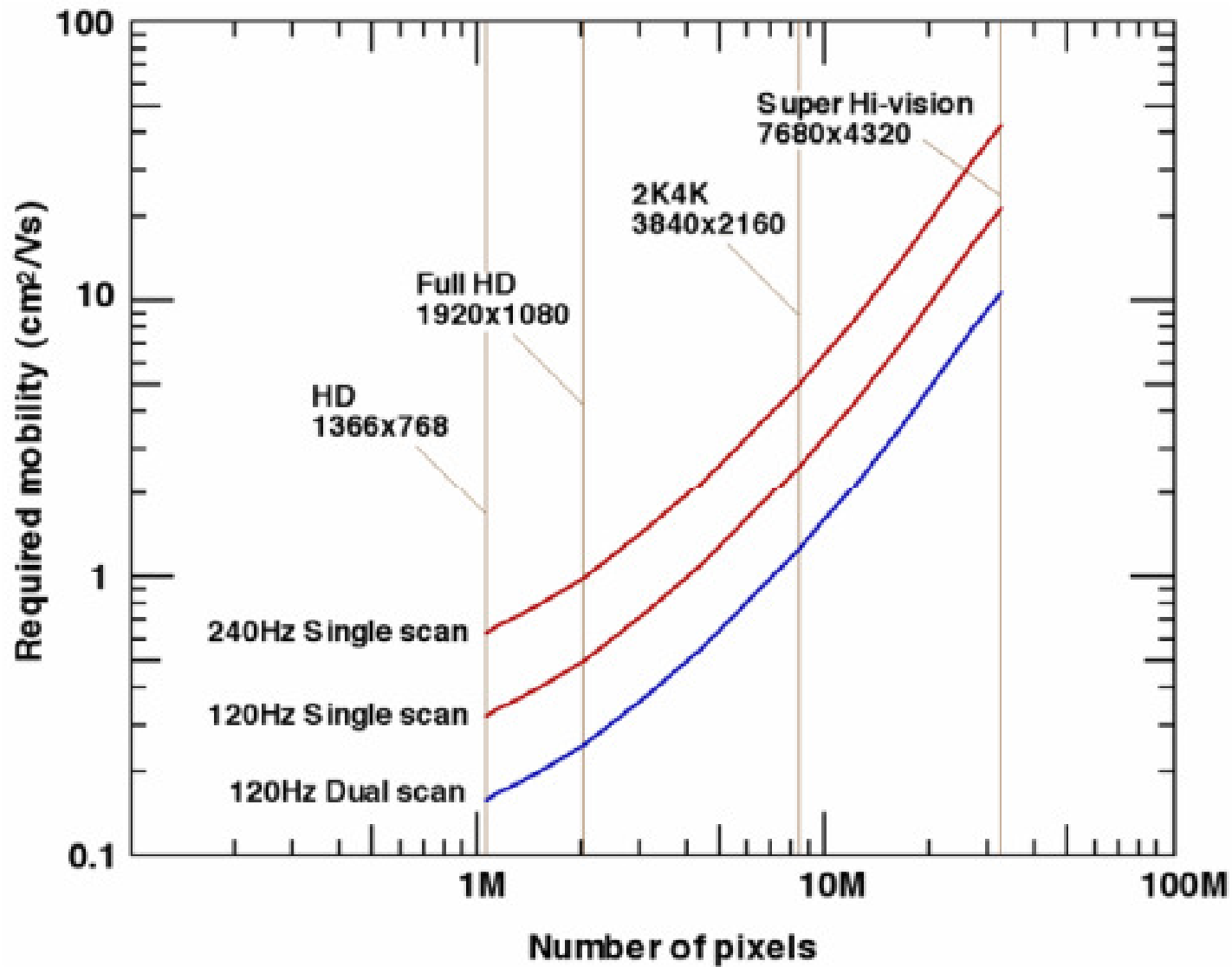Global AMOLED panel capacity, 2011-2015
(k square meters)

Legend: Taiwan, SEC, LGD, Japan, China, Total

Production of AM-displays

# Production of AM-displays

Demand for higher mobilities

Comparison among different technologies

- Low-temperature polycrystalline silicon (LTPS):

  - Liquid-phase chemical vapour deposition (LPCVD), plasma-enhanced chemical vapour deposition (PECVD), or solid-phase crystallization (SPC). Temperatures usually higher than 500°C; High mobility; Non-uniform films; Not suitable for large areas;

- Amorphous Metal-Oxide semiconductors (AMOS):

  - Deposited by RF-sputtering, pulsed-laser deposition (PLD) or solution processed organic precursor pyrolysis; Suitable for large areas; Suitable for transparent applications; Suitable for flexible applications;

- Amorphous Silicon (a-Si):

  - Deposited by Chemical-vapour deposition (CVD), Physical-vapour deposition (PVD); Suitable for flexible applications;

- Organic Semiconductors (OS):

  - Deposited by spin-coating, physical vapour deposition, ink-jet printing; Suitable for flexible applications;
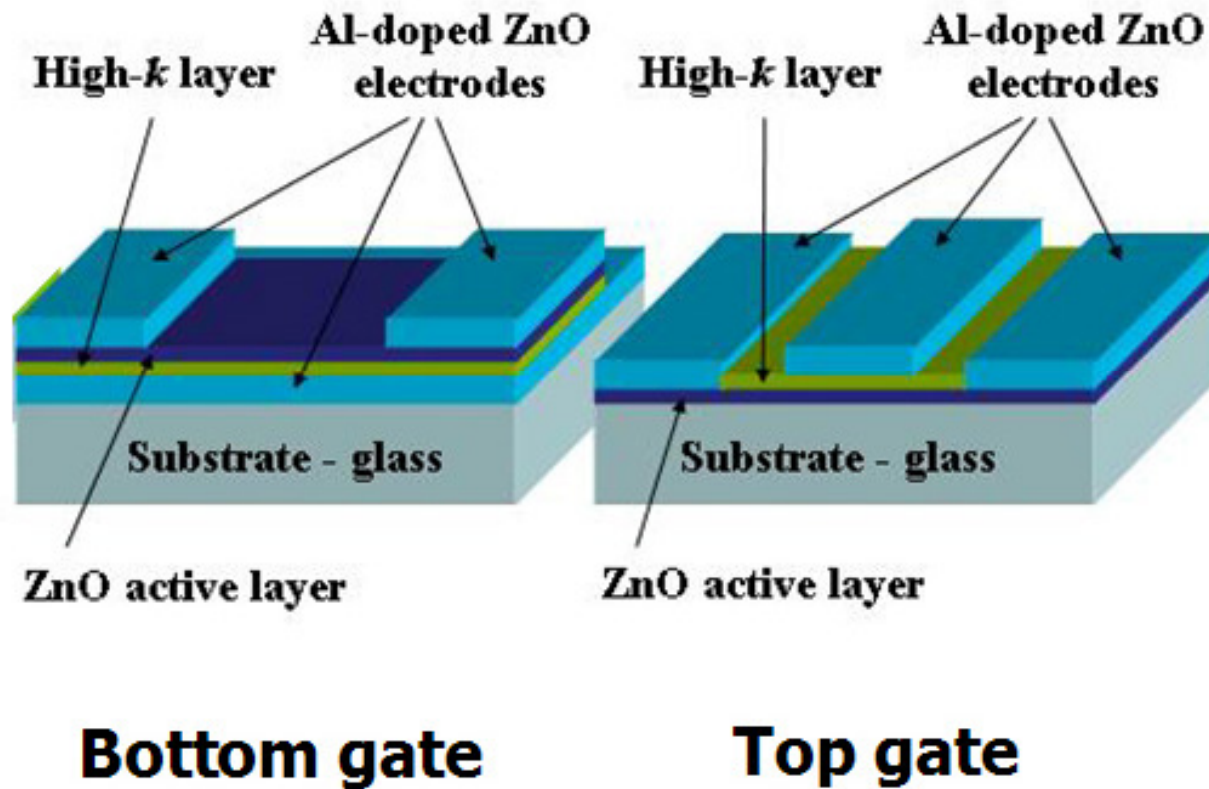
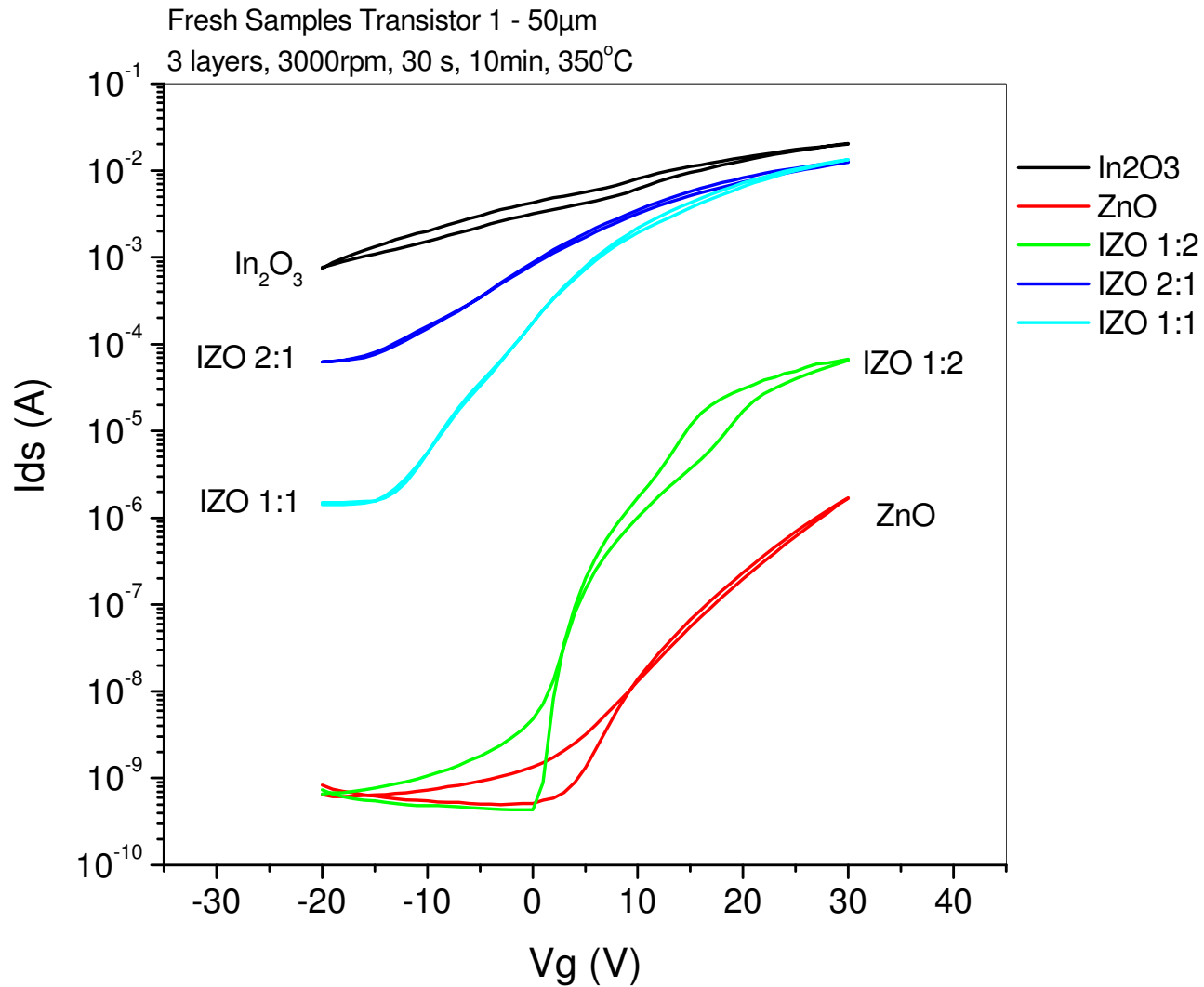# Comparison among different technologies
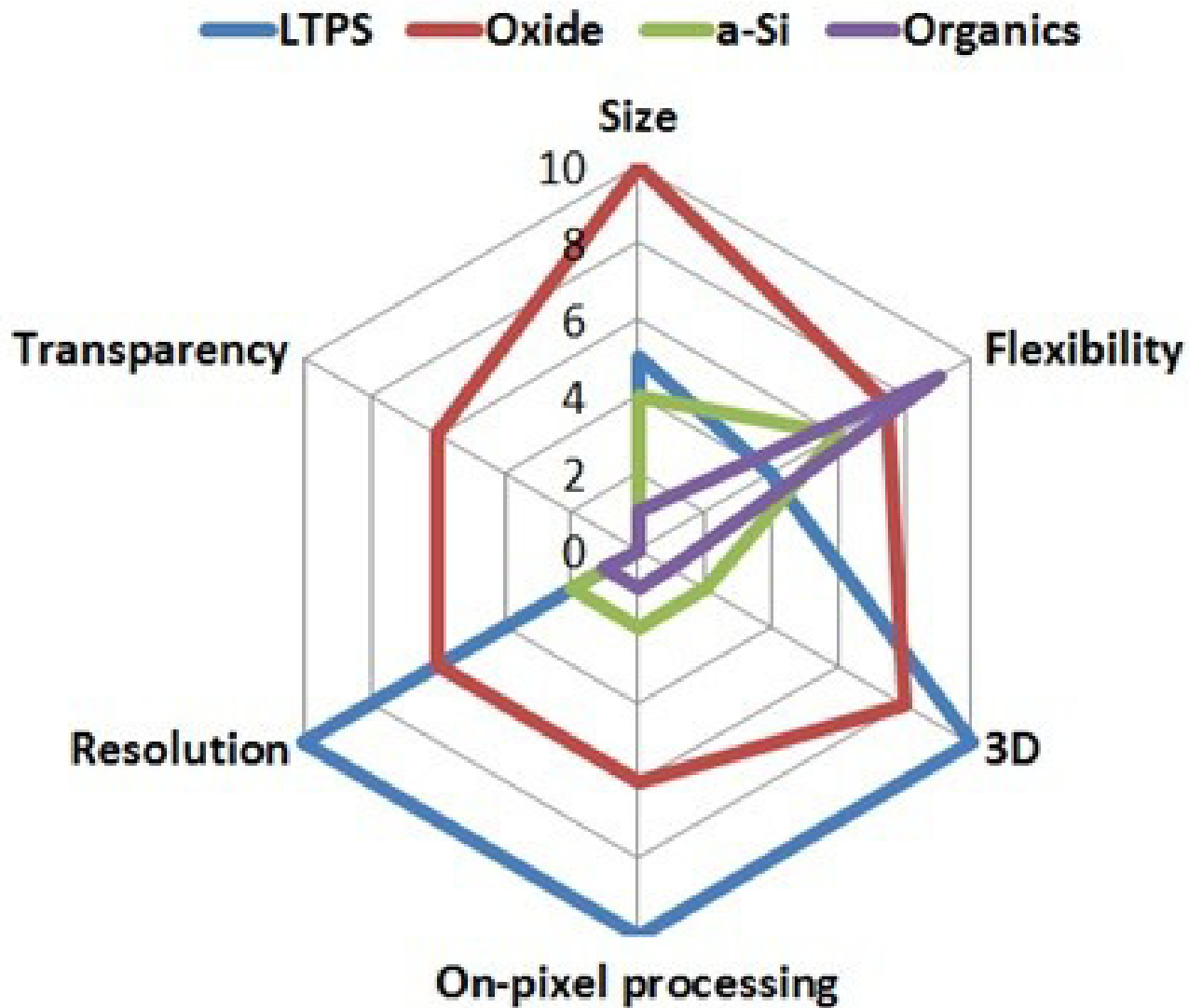
Amorphous metal-oxide TFTs

- Why using AMO TFTs ?

- Advantages:

    - Low-cost and easy processing;

    - higher mobilities (1-20cm^2.$V^{-1}s^{-1}$) compared to a-Si and more uniform films than poly-Si;

    - Highly transparent in the whole visible spectrum;

    - Can be solution-processed (spin-coating, dip-coating, ink-jet printing, spray deposition);

- Disadvantages :

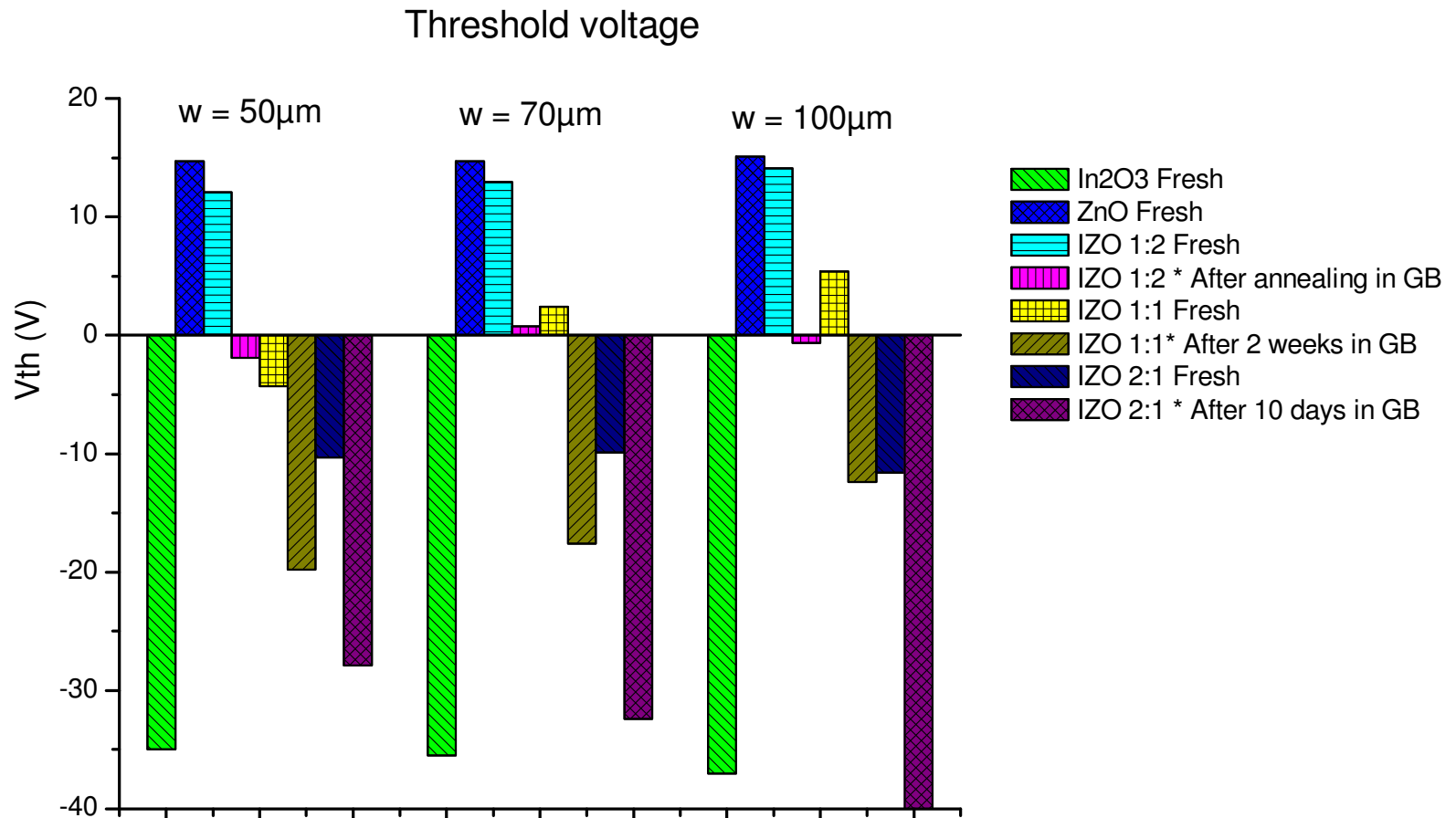   - Processing temperatures are still relatively high (~350°C) to enable flexible substrate deposition.
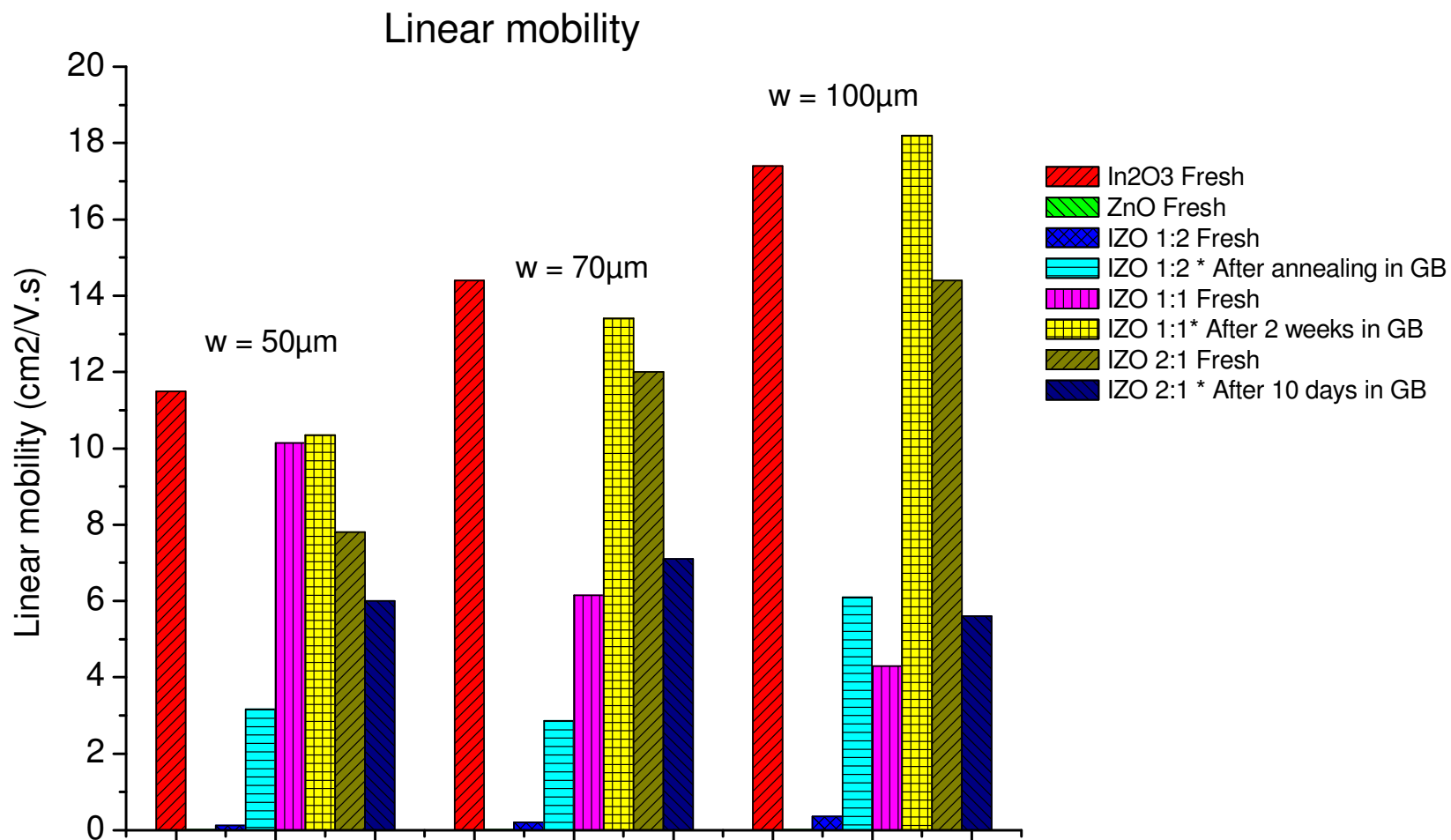
Transistores de Óxidos metálicos amorfos (AMOs)

Amorphous metal-oxide TFTs

Fresh Samples Transistor 1 - 50µm
3 layers, 3000rpm, 30 s, 10min, 350°C

Solution-processed AMO-TFTs

Threshold voltage

w = 50µm   w = 70µm   w = 100µm

Vth (V)

Legend:
- In2O3 Fresh
- ZnO Fresh
- IZO 1:2 Fresh
- IZO 1:2 * After annealing in GB
- IZO 1:1 Fresh
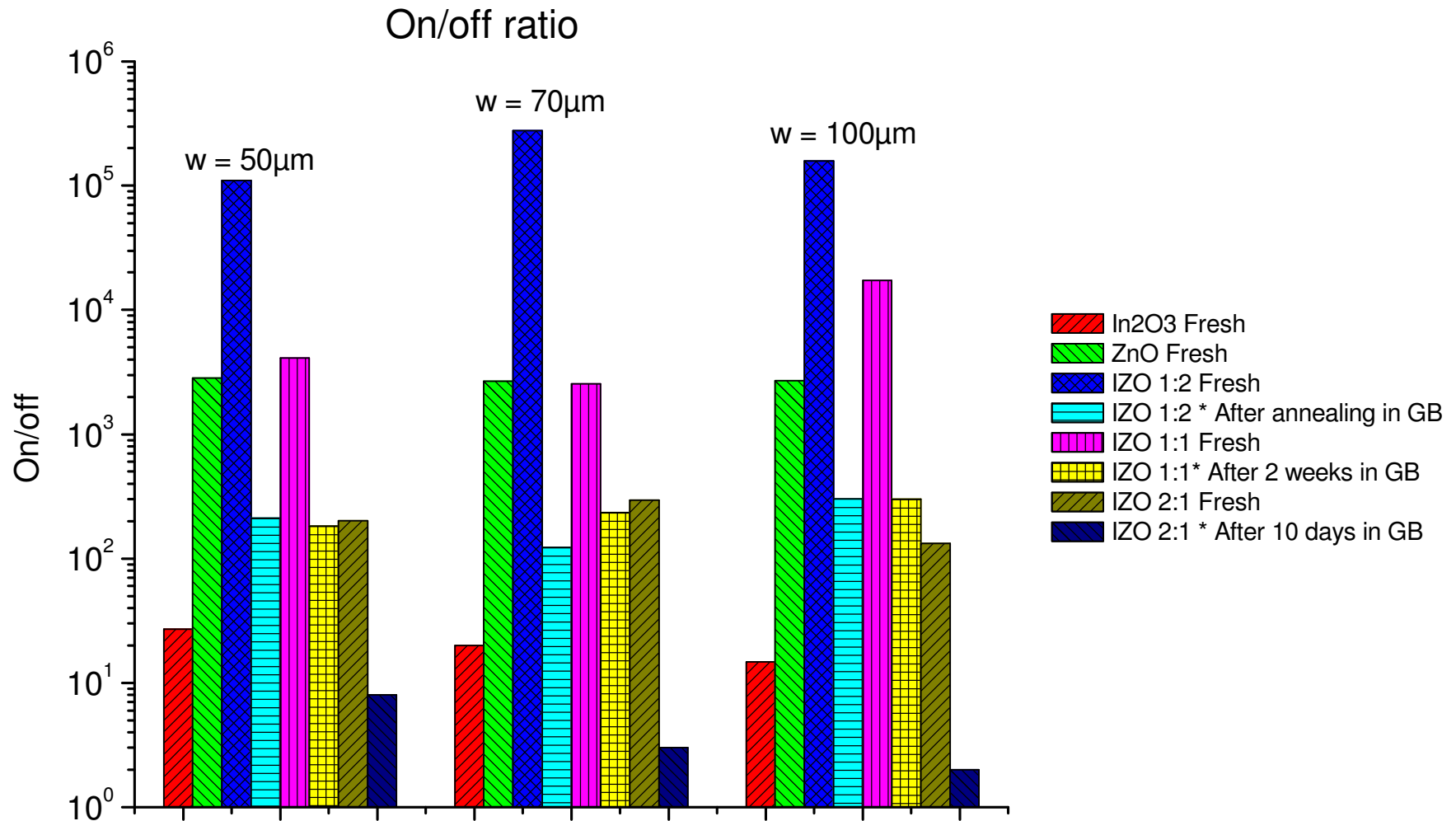- IZO 1:1* After 2 weeks in GB
- IZO 2:1 Fresh
- IZO 2:1 * After 10 days in GB

Solution-processed AMO-TFTs

Linear mobility

Solution-processed AMO-TFTs

Conclusions and Perspectives

• Solution-processed AMOs can achieve high enough mobilities for application in drive circuits of high-resolution active-matrix displays;

• There are still lots of open questions concerning device stability and the role of oxygen on the electrical properties of TFTs active layers;

• Morphology and growth dynamic can affect the device performance. Better control of deposition parameters;

• Processing temperature has to be lowered to enable flexible applications;

Grupo de Optoeletrônica Orgânica - UNESP

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Thank you for your attention!