UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Campus de São José do Rio Preto

Flexible, Transparent thin-film transistors for display technology

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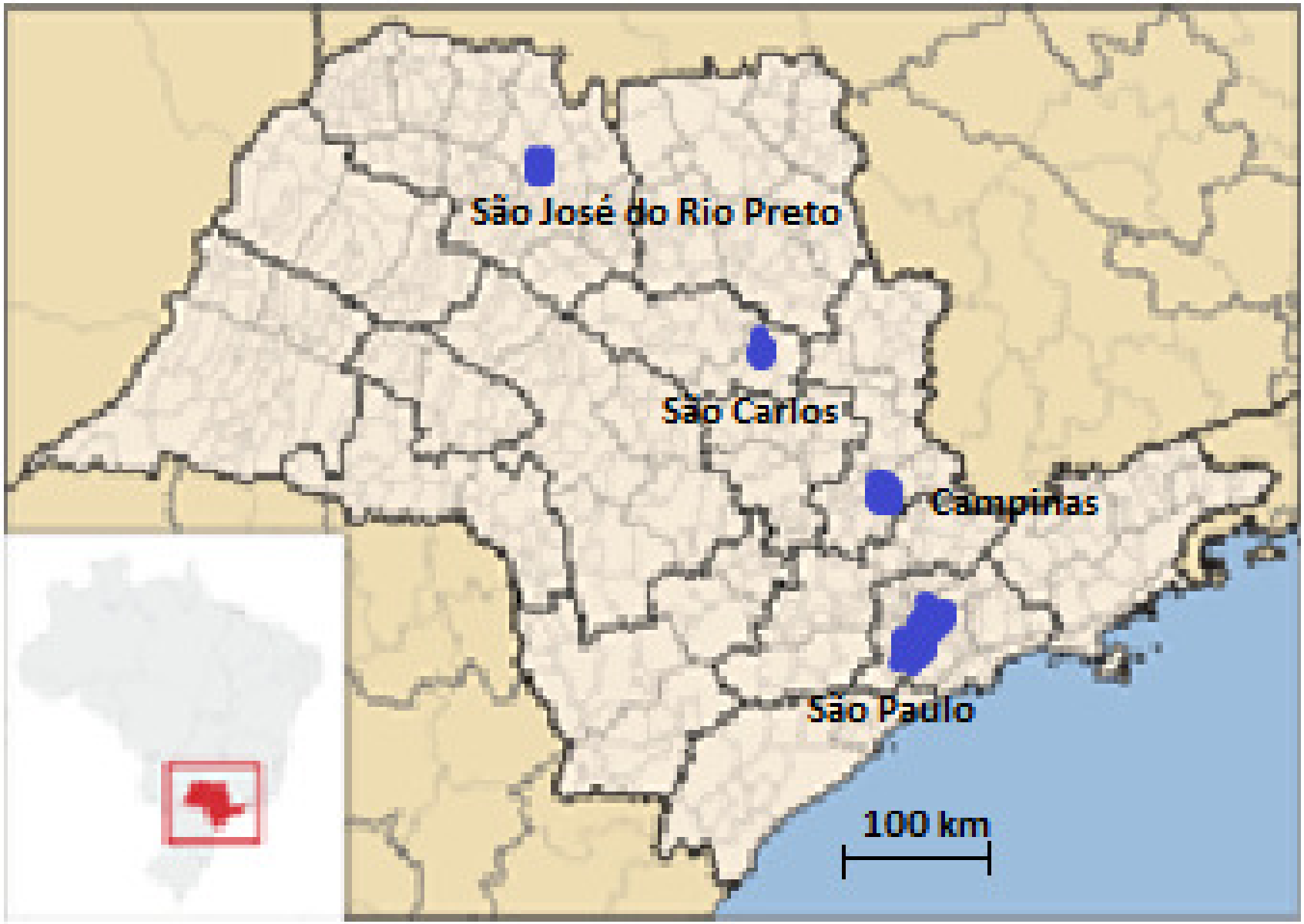
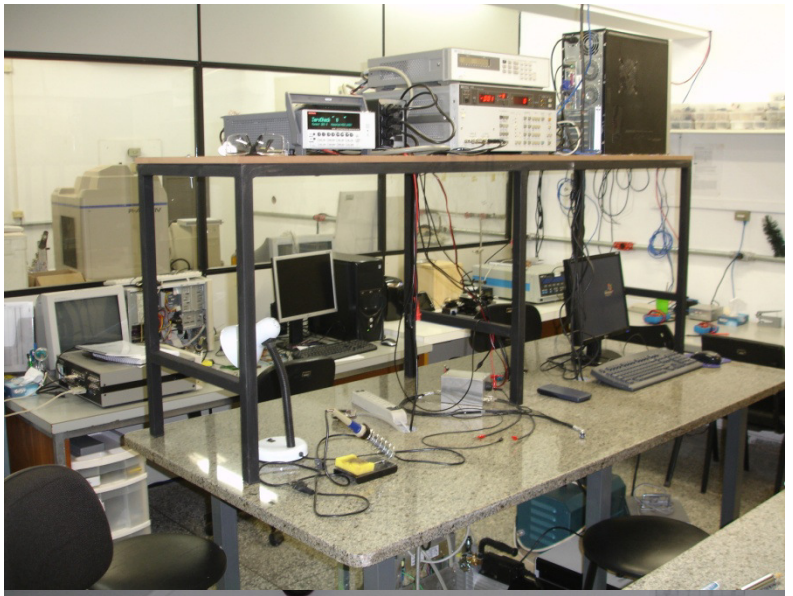
Summary

- 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;


São José do Rio Preto
São Carlos
Campinas
São Paulo
100 km

Laboratório de Optoeletrônica Orgânica – DF/IBILCE/UNESP



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

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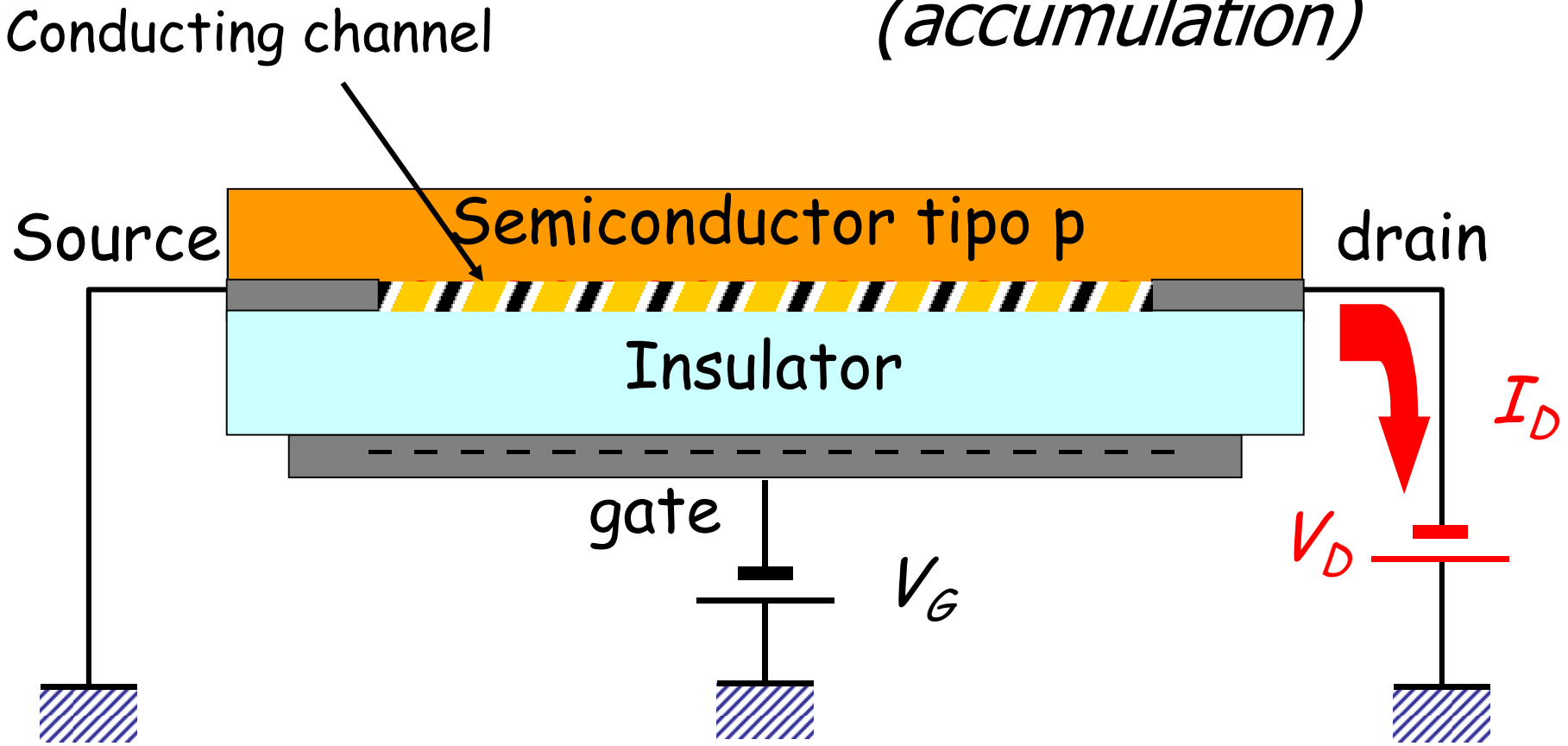
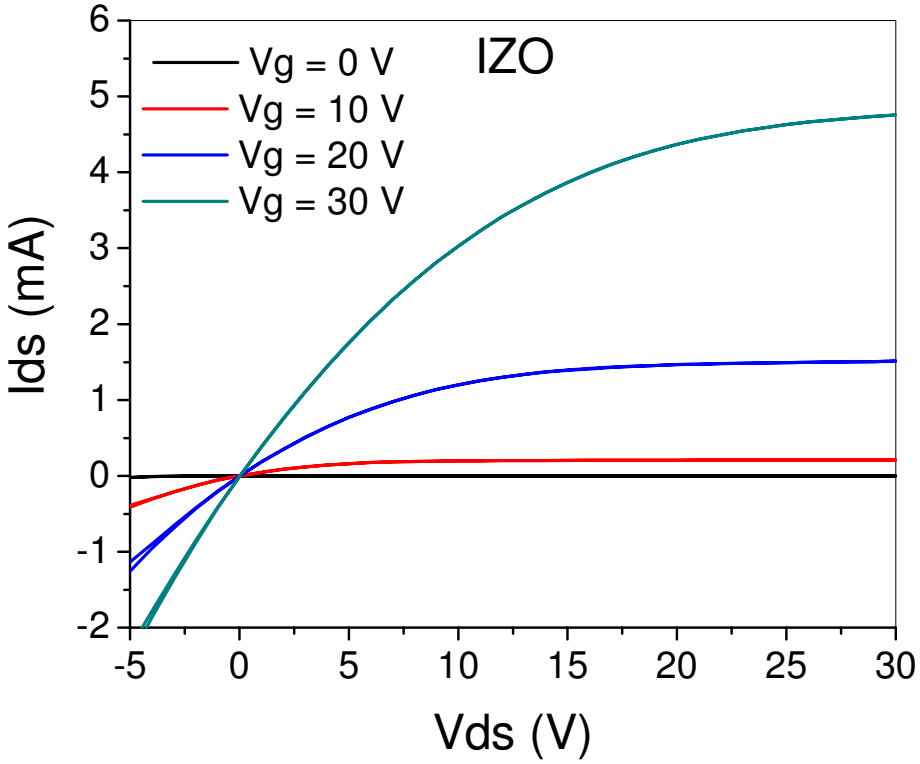
- Requirements for flexible transparent displays:
  - High transmittance of the materials in the visible spectrum range (for the materials that composes the pixel and the drive circuit);
  - Compactibility with flexible substrates (low-temperature deposition);
  - Coverage of large areas, low-cost and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

Thin-film Transistors (TFTs)

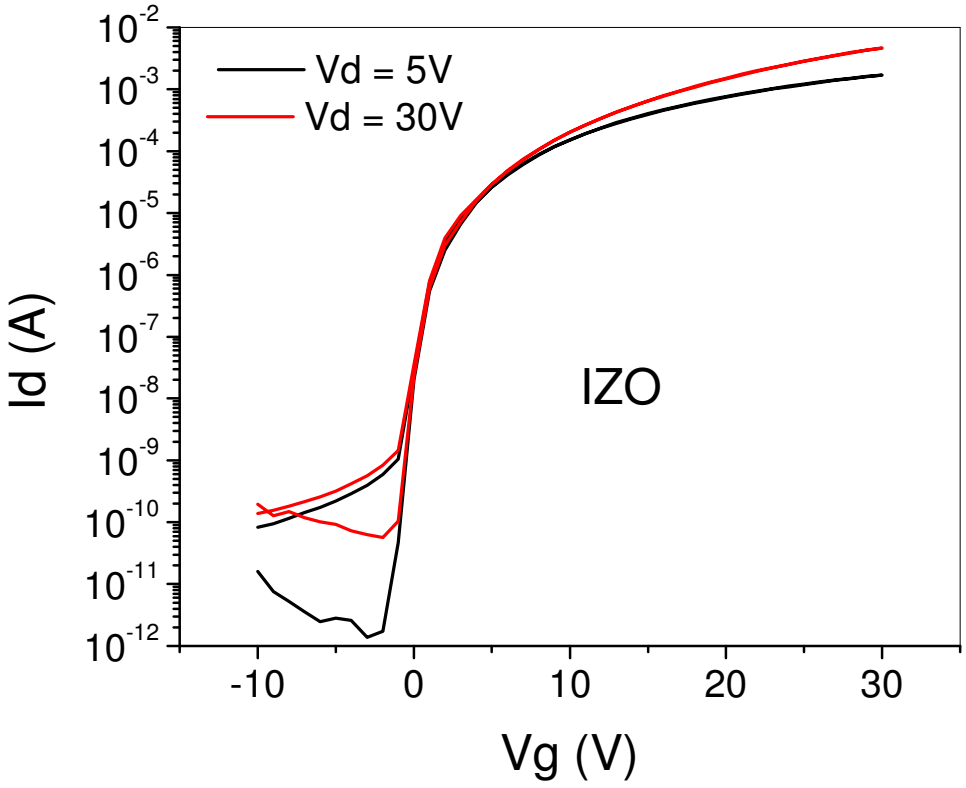
Enhancement type TFT
(accumulation)



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

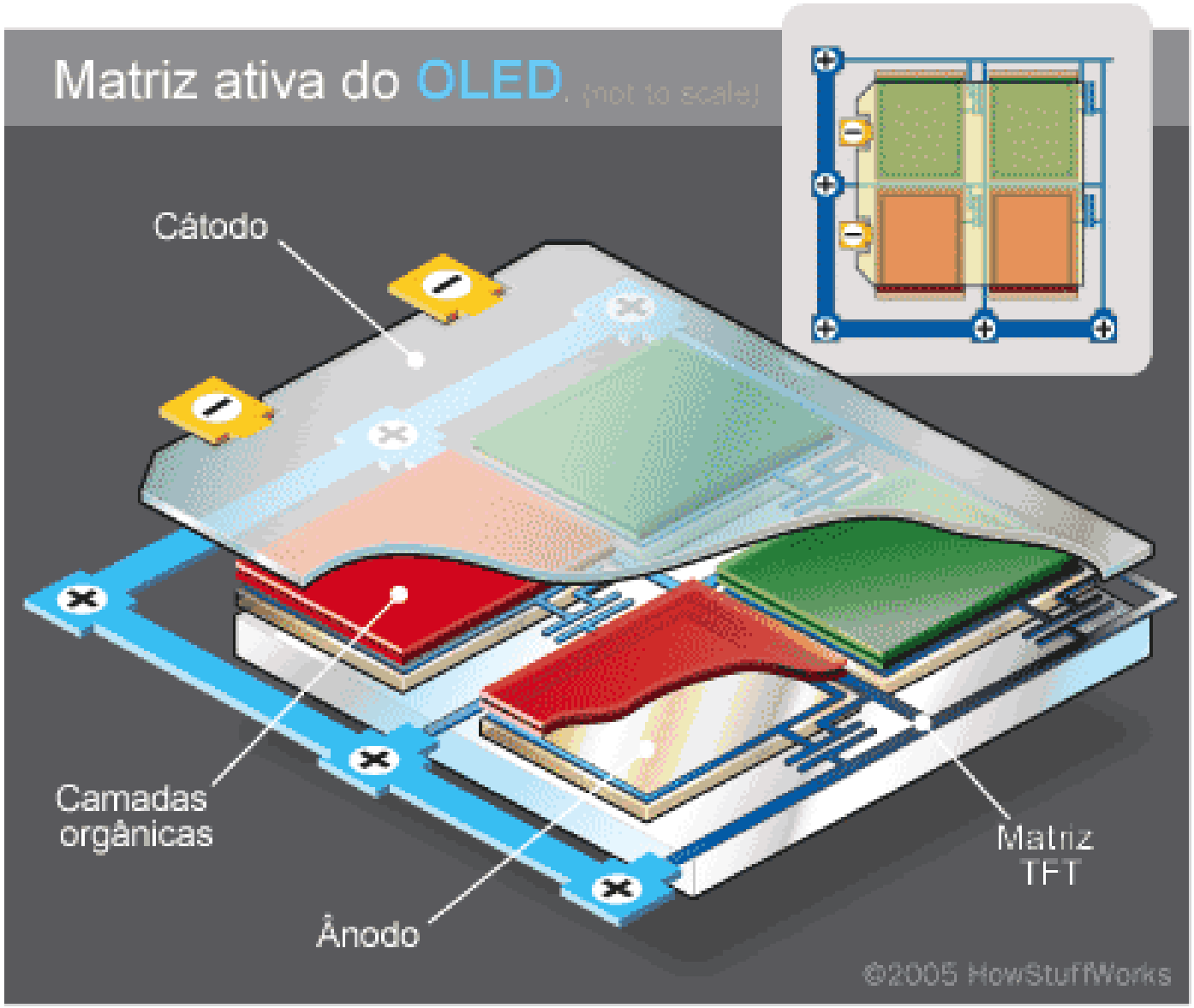
Válida para: $0 \le V_{DS} \le (V_G - V_T)$ Até o "joelho" da curva de saída

Transistores de Efeito de campo (FETs)

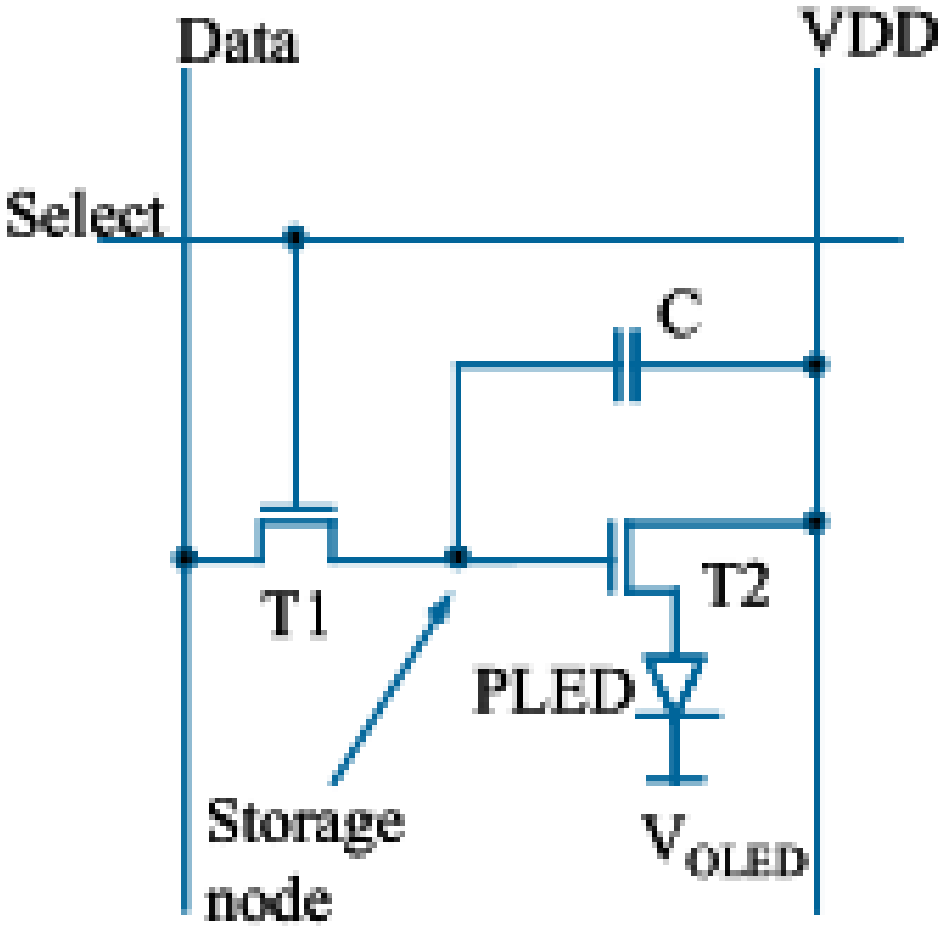
Parâmetros importantes obtidos a partir das curvas de saída e de transferência:

- Fator de modulação de corrente (relação *on/off*);
- Tensão de inversão (*Threshold voltage*);
- Mobilidade dos portadores majoritários;
- *Off current* (*leakage + intrinsic conduction*);

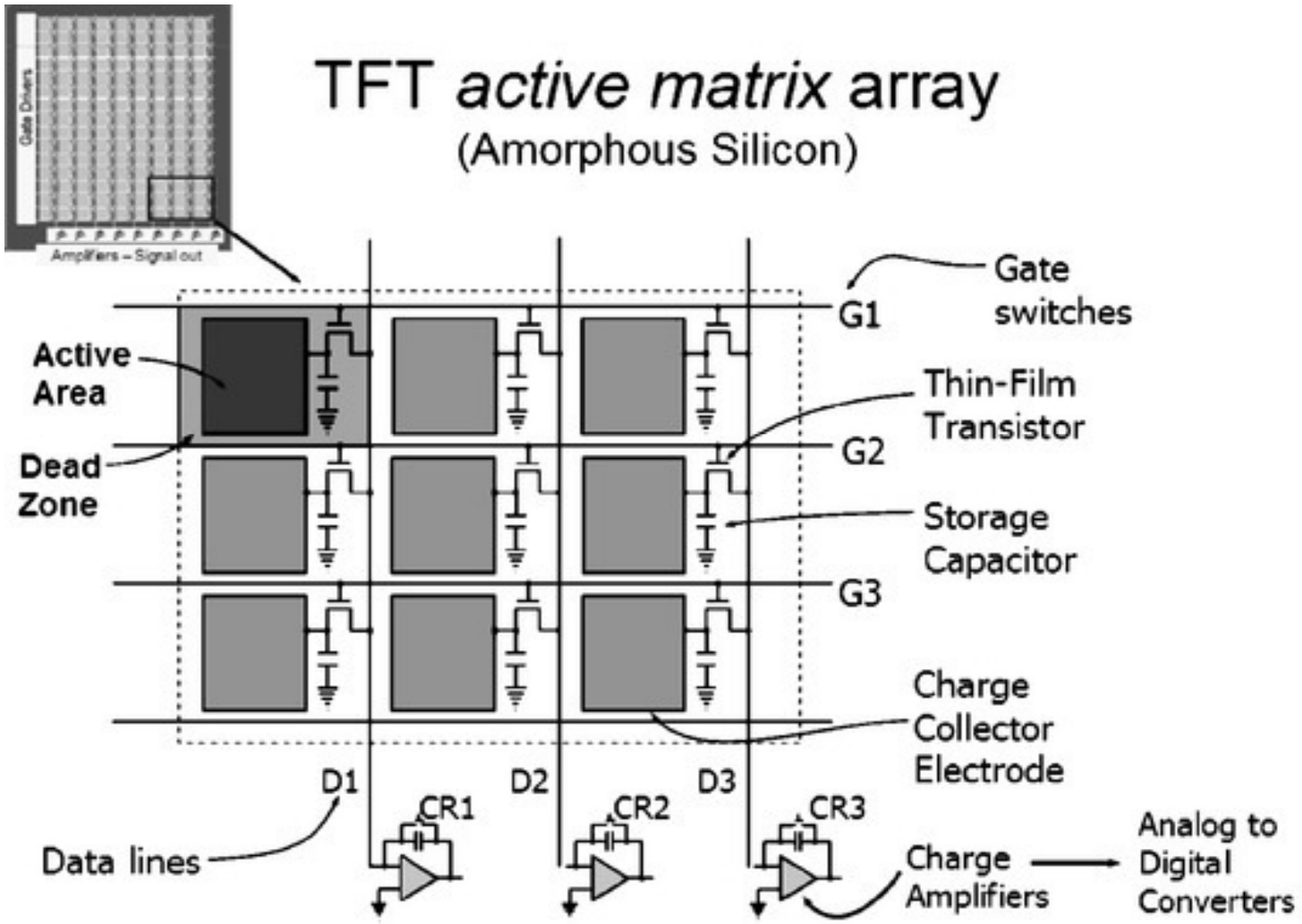
TFTs in active-matrix display circuits



TFTs em circuitos de matriz ativa

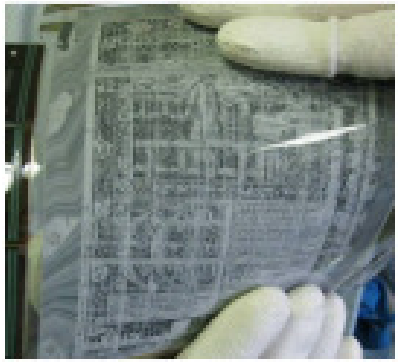


TFTs em circuitos de matriz ativa



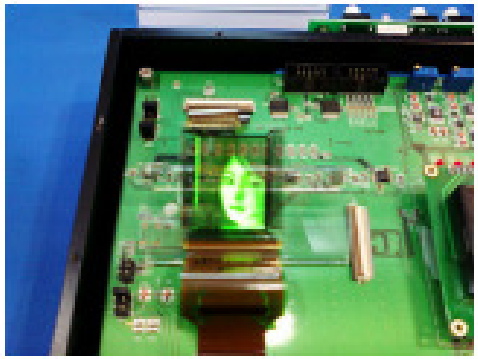
TFTs in active-matrix display circuits

Flexible BW E-paper
5.35",VGA,150ppi
(Toppan, 2009)

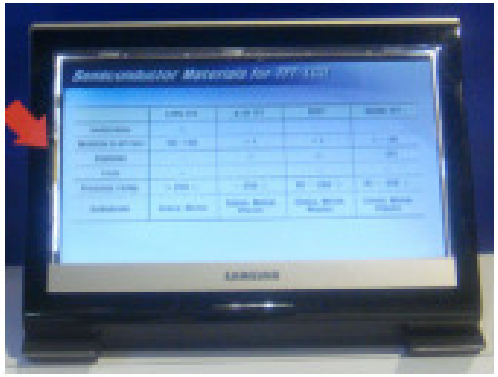


Flexible BW E-paper
2",VGA,400ppi
(Toppan, 2009)

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-)

iPhone 4 & 5

Hi-Res LCD & OLED Tablets (2012-)

New iPad

Samsung Galaxy OLED

OLED Smart Phones (2010-)

Google Nexus One

Samsung Galaxy SII

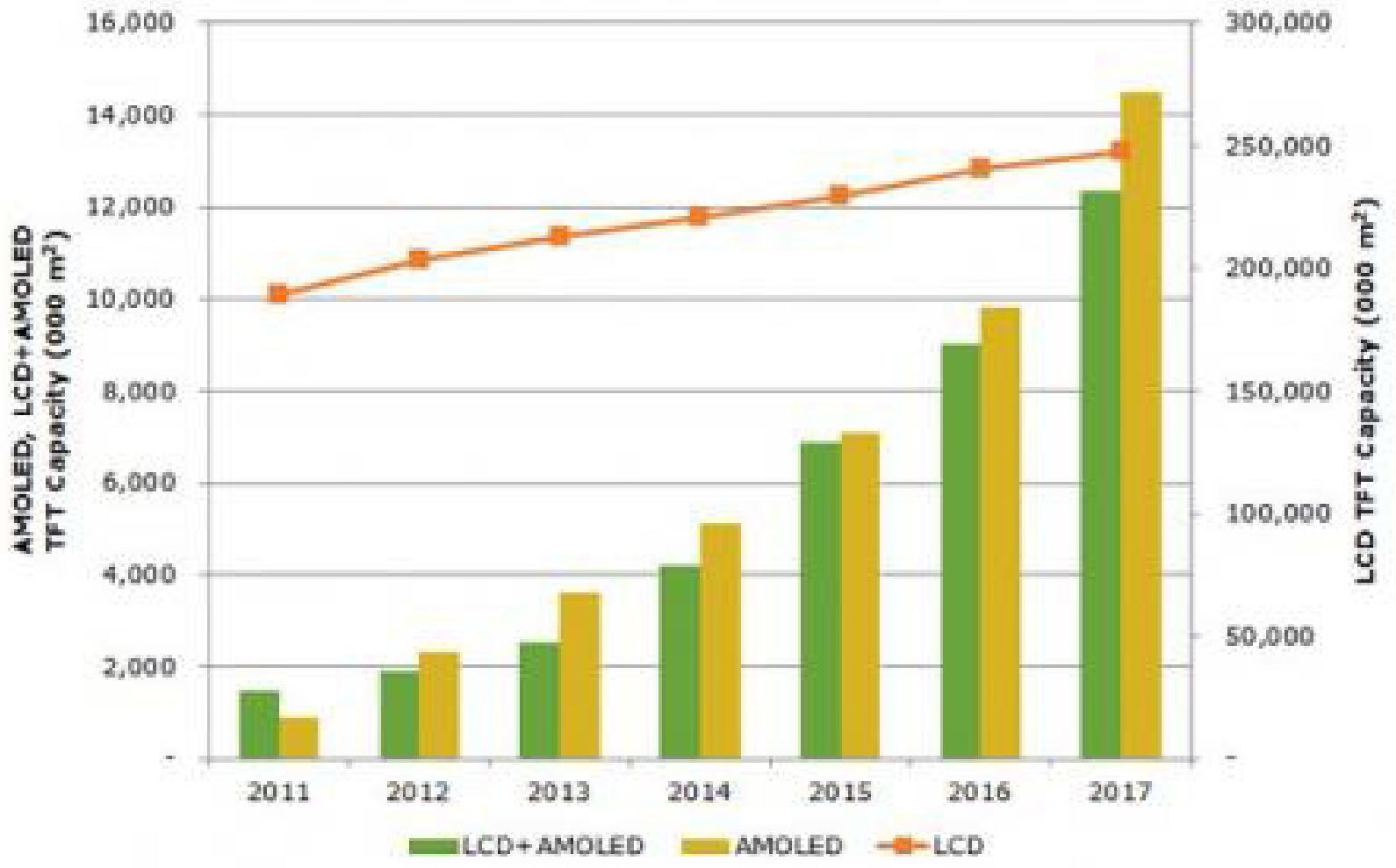
Microsoft Zune

TFTs in active-matrix display circuits

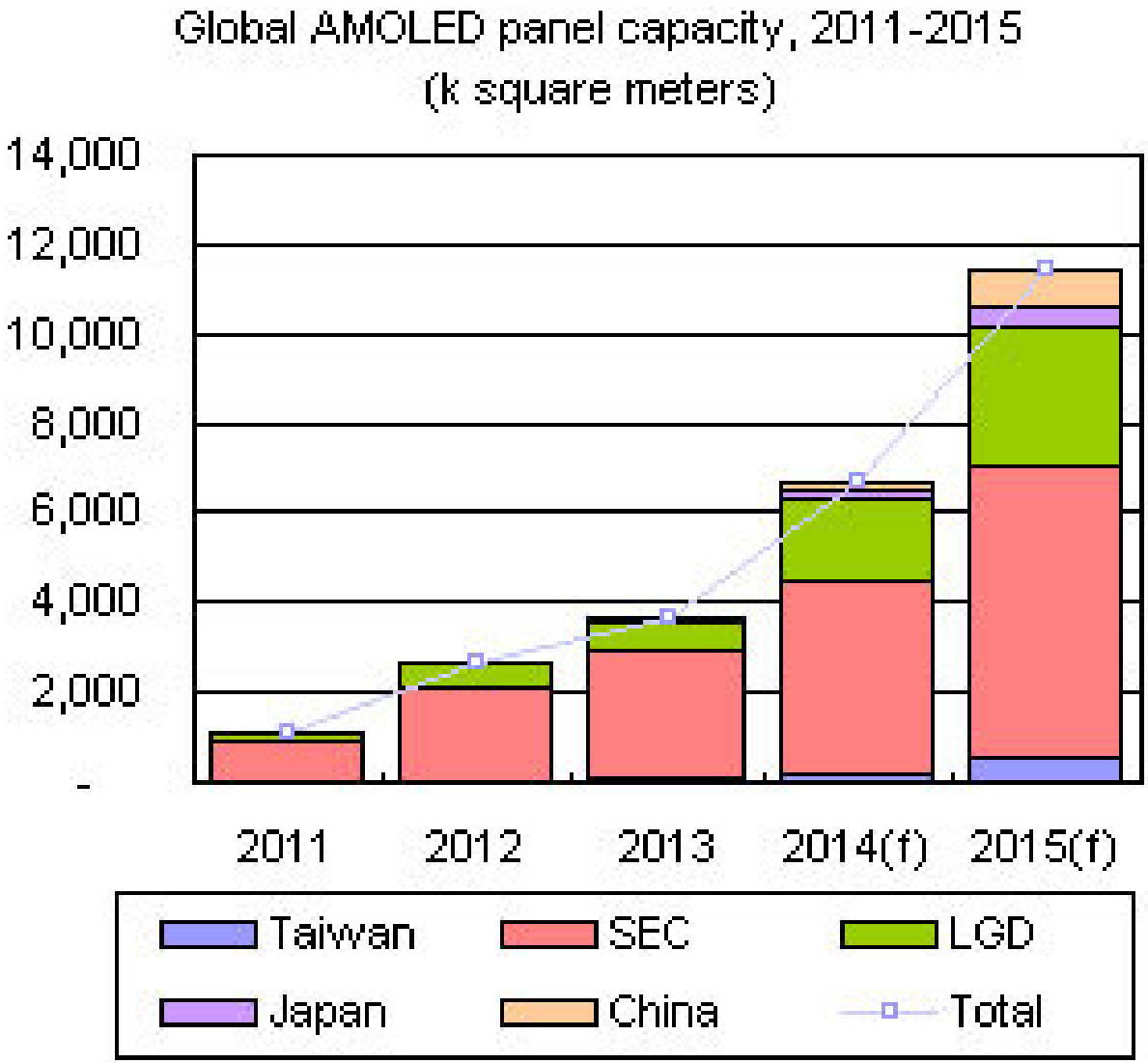
TFTs in active-matrix display circuits

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

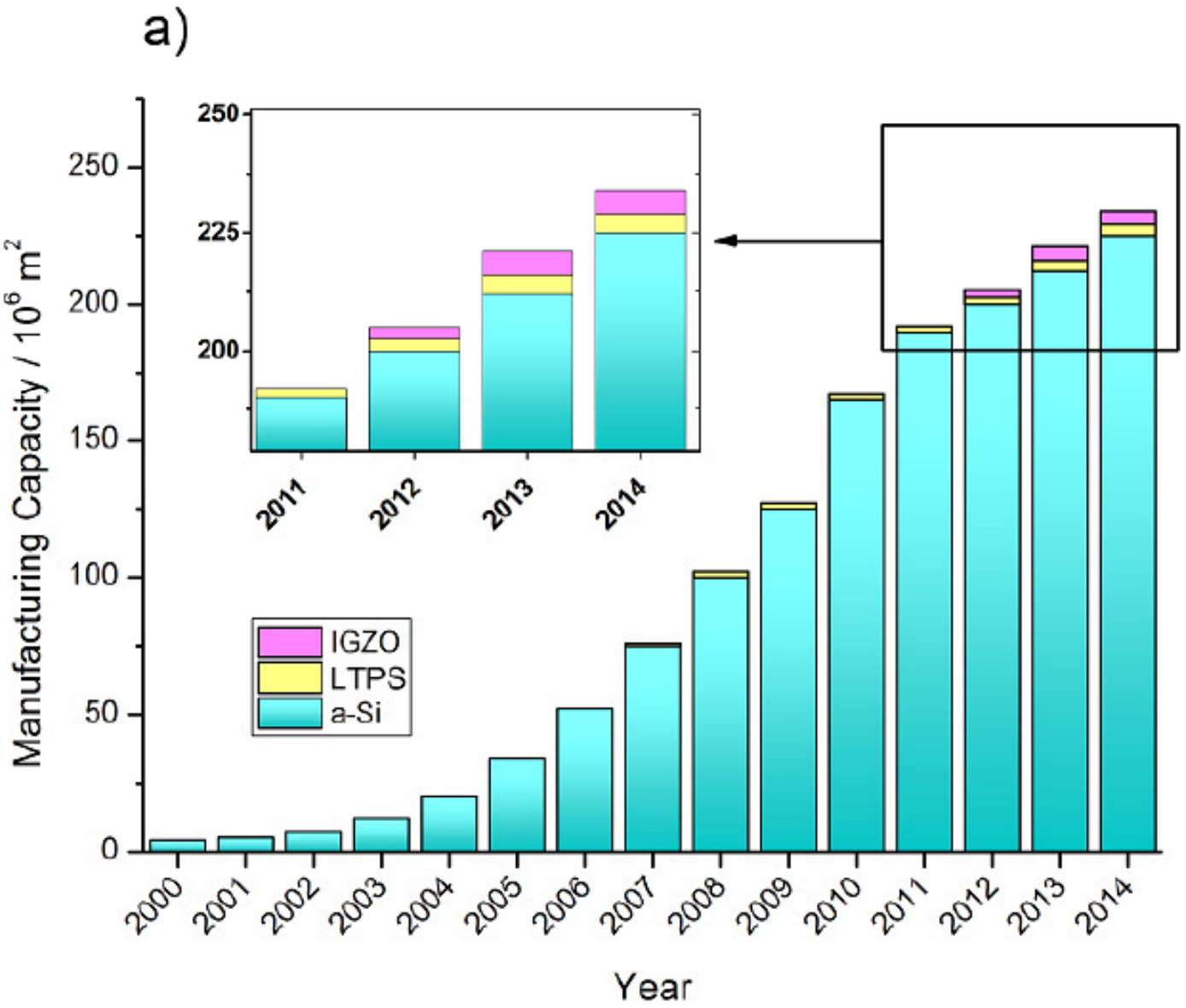
Production of AM-displays



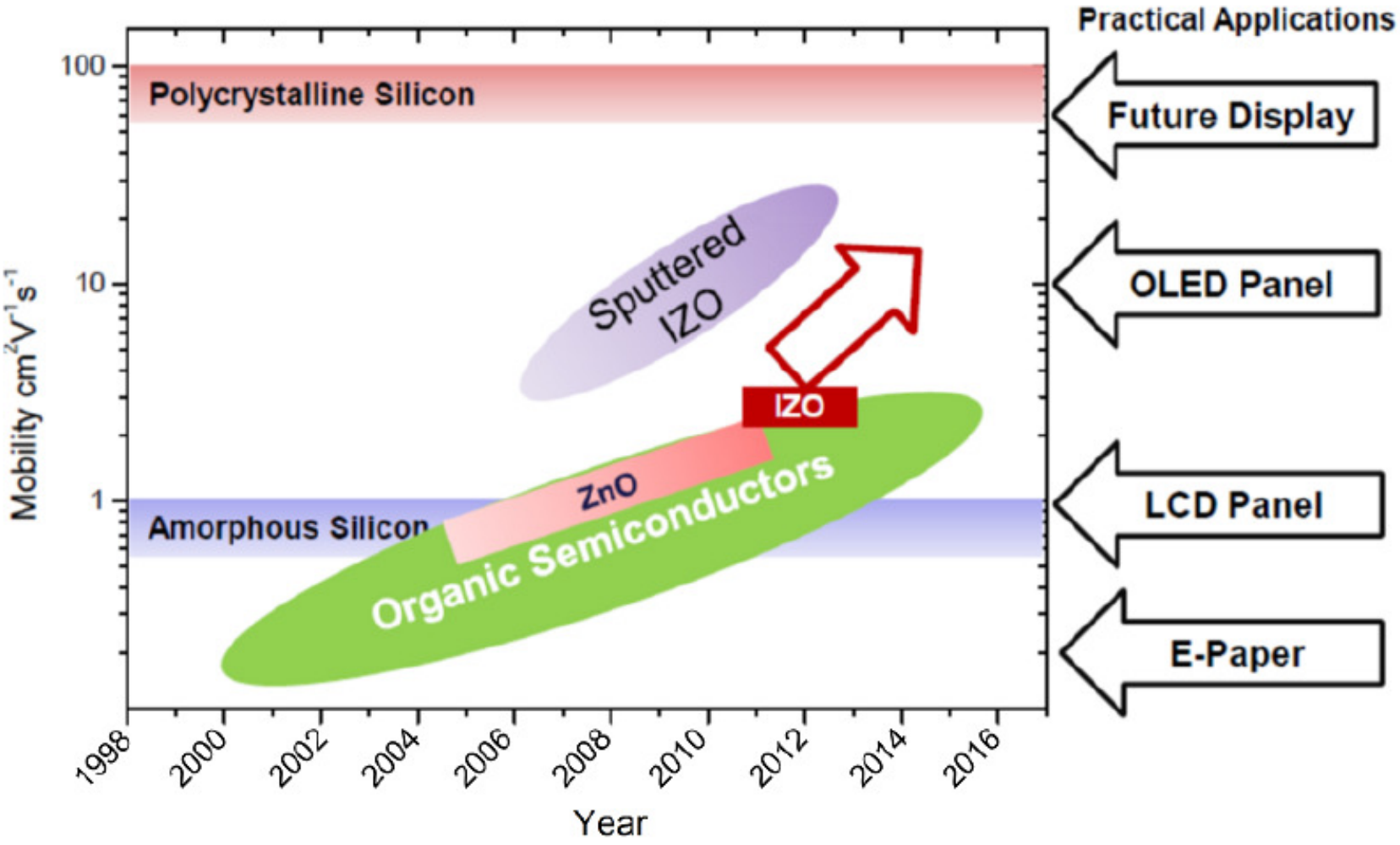
Capacidade de produção de AM-displays



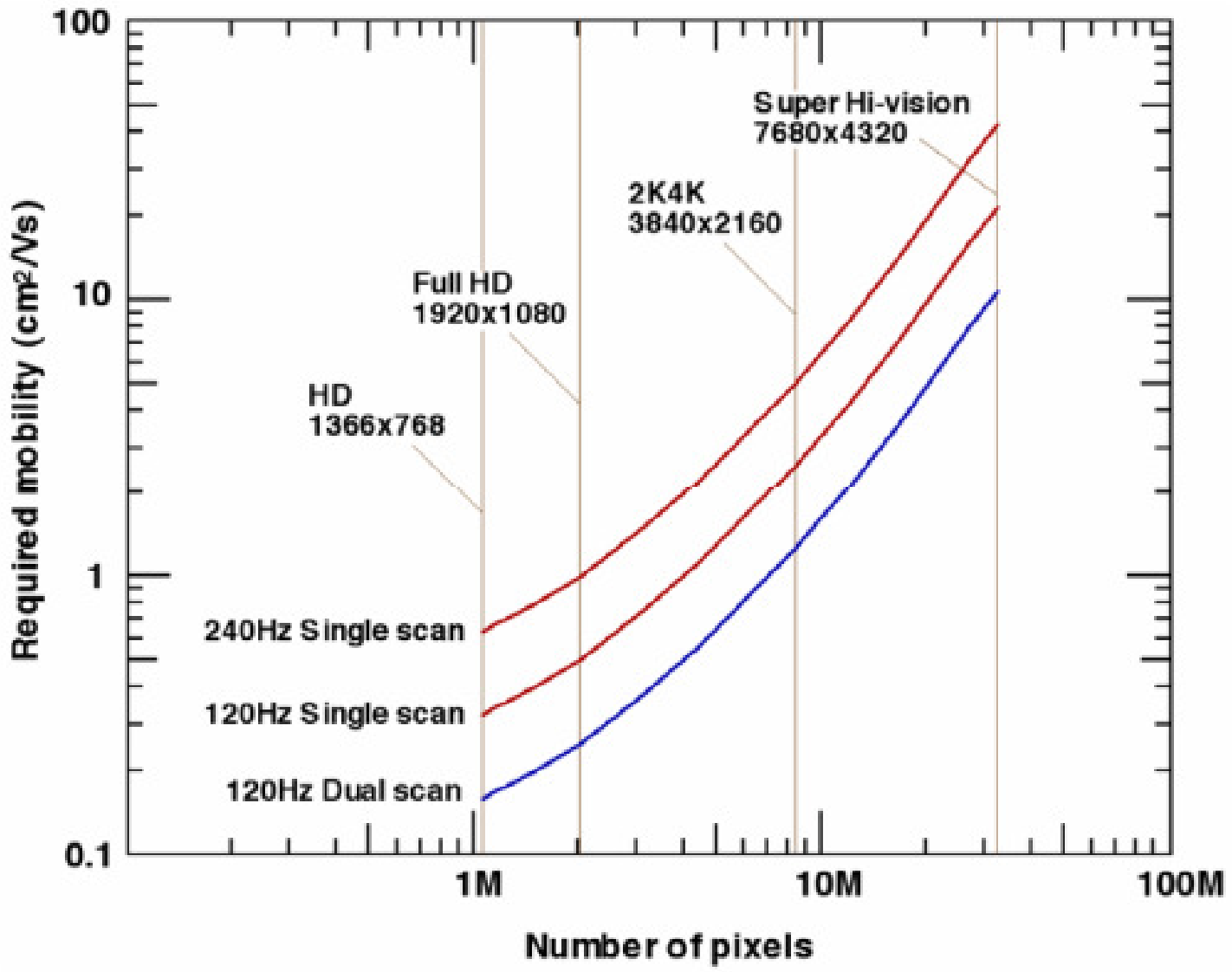
Production of AM-displays



Production of AM-displays



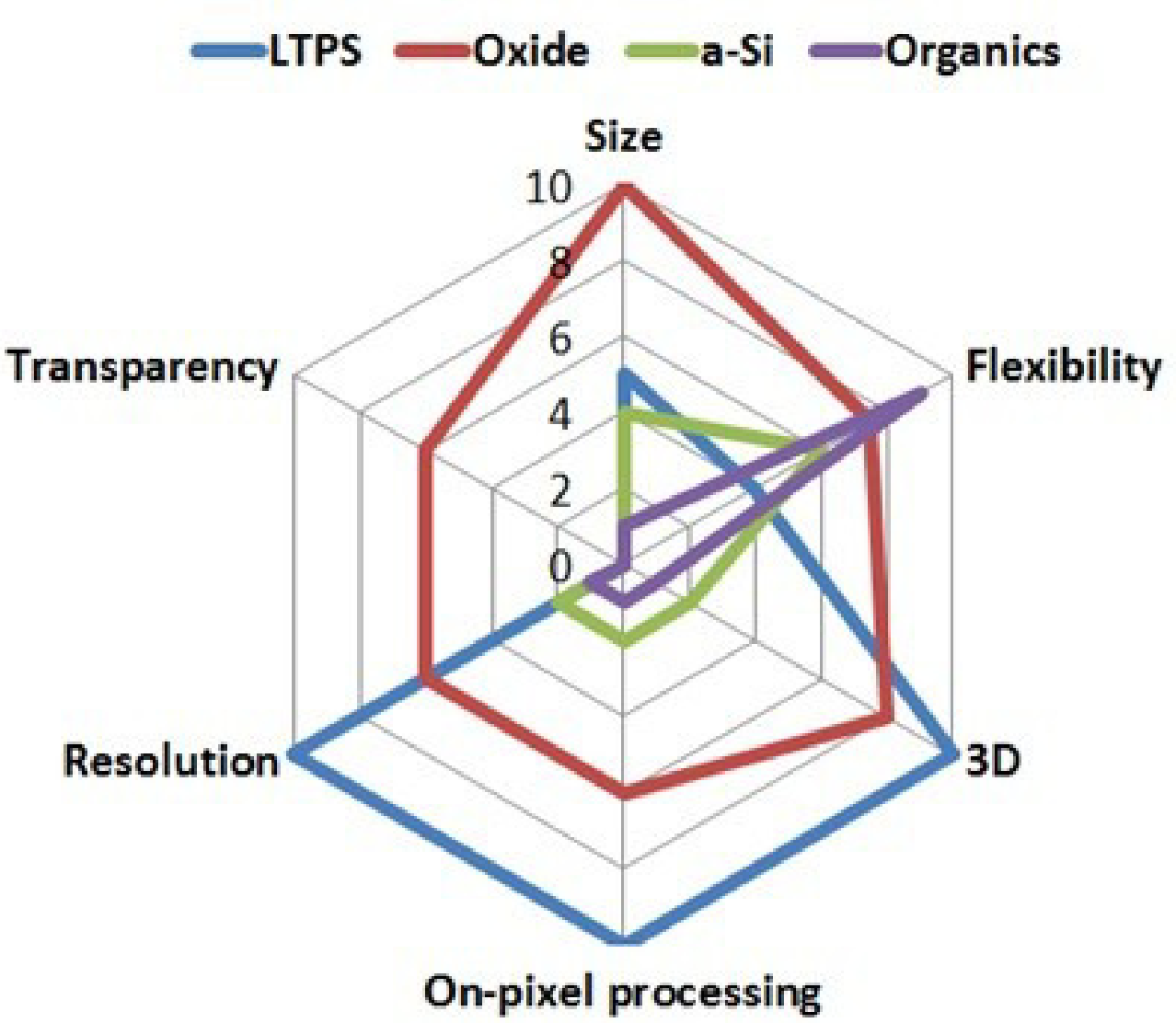
Demand for higher mobilities



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^{o}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

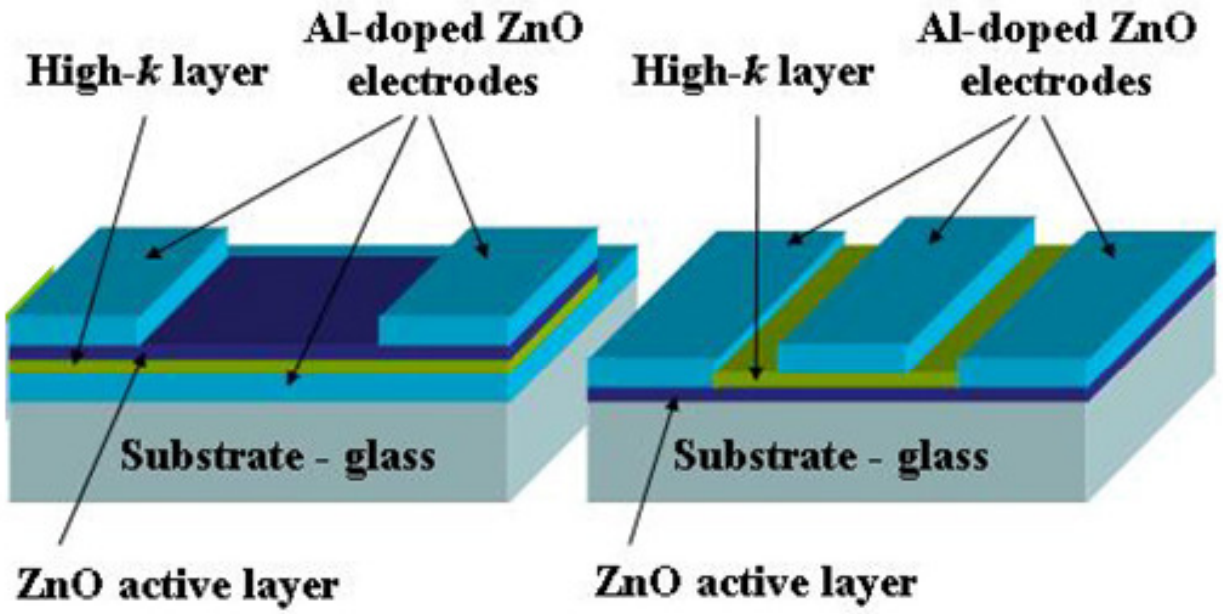


Amorphous metal-oxide TFTs

- Why using AMO TFTs ?

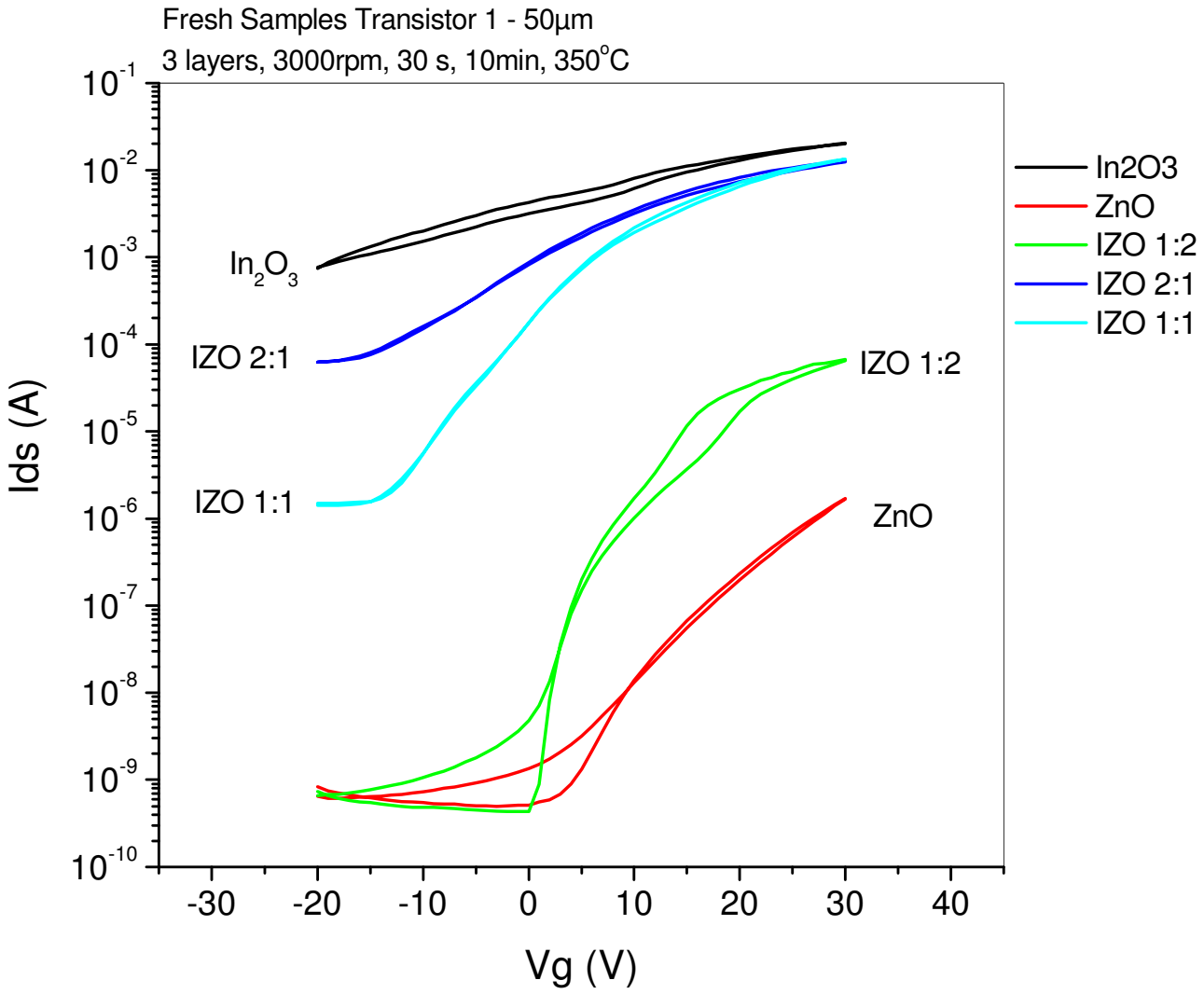
- Advantages:
  - Low-cost and easy processing;
  - higher mobilities (1-20$cm^2.V^{-1}s^{-1}$) compared to a-Si and more uniform films than poly-Si;
  - Highly transparent in the whole visible spectrum;
  - Can be solution-processed (spin-coating, dip-coating, ink-jet printing, spray deposition);
- Disadvantages :
  - Processing temperatures are still relatively high (~350^oC) to enable flexible substrate deposition.

Transistores de Óxidos metálicos amorfos (AMOs)

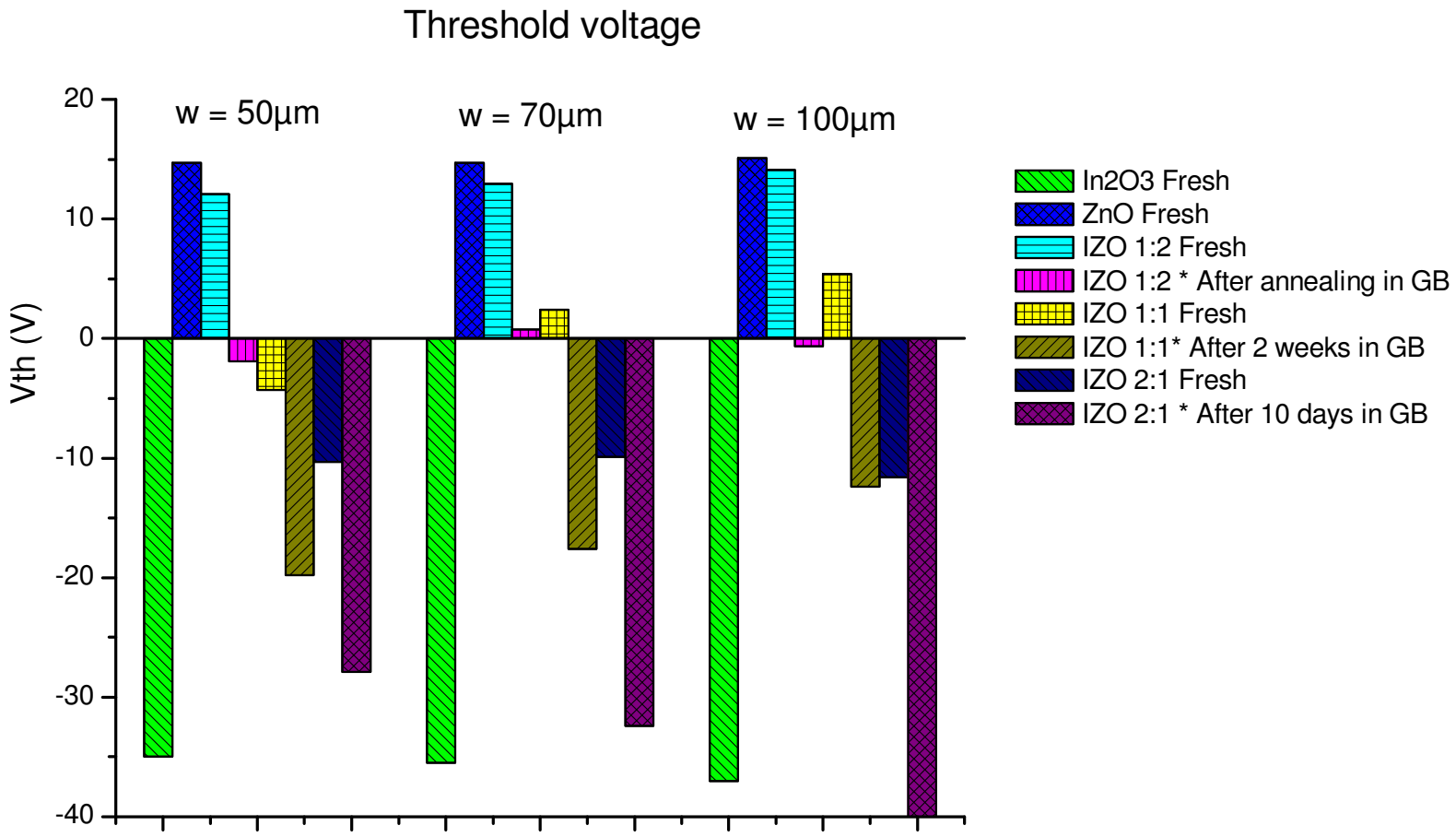


Bottom gate **Top gate**

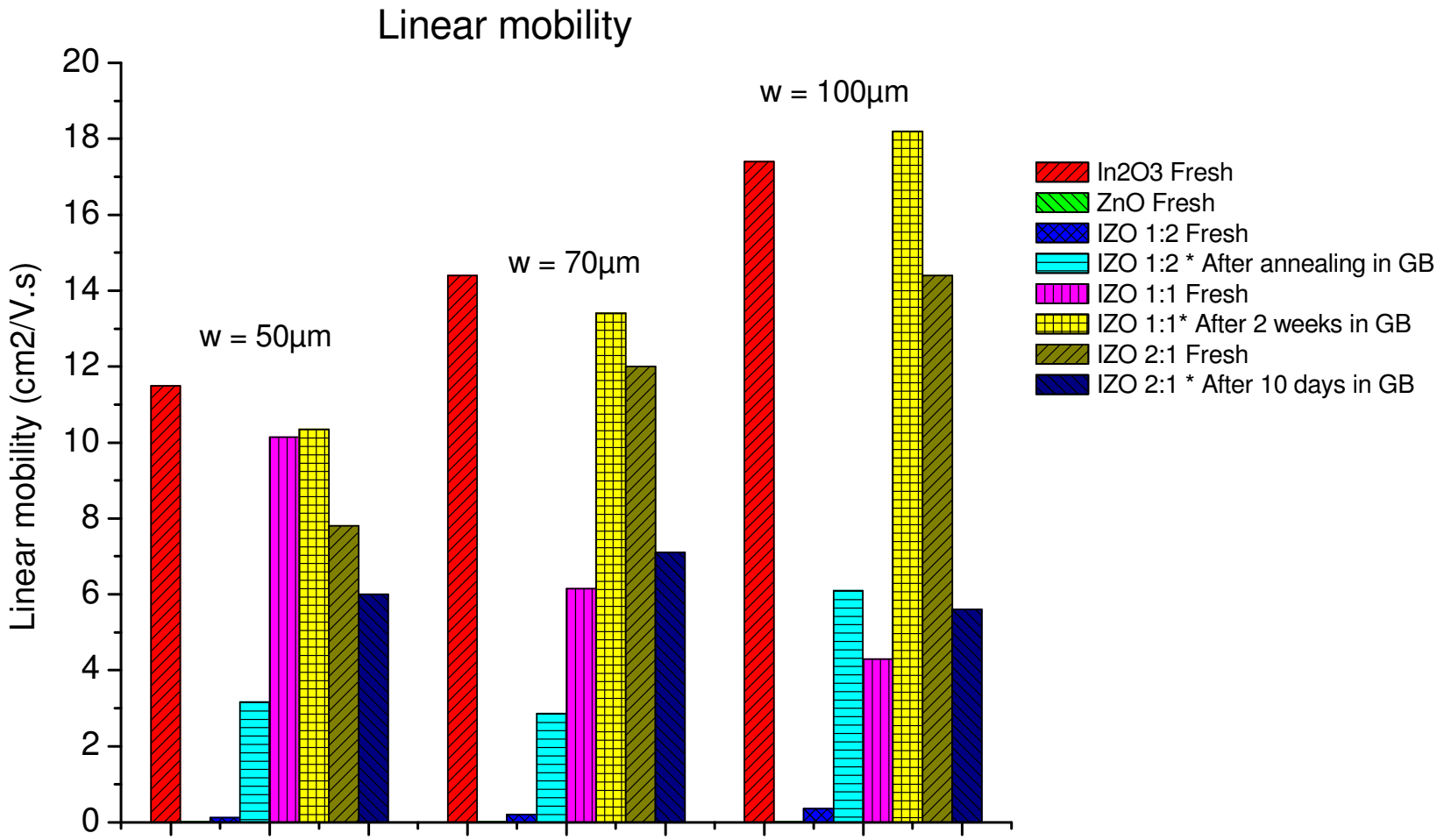
Amorphous metal-oxide TFTs



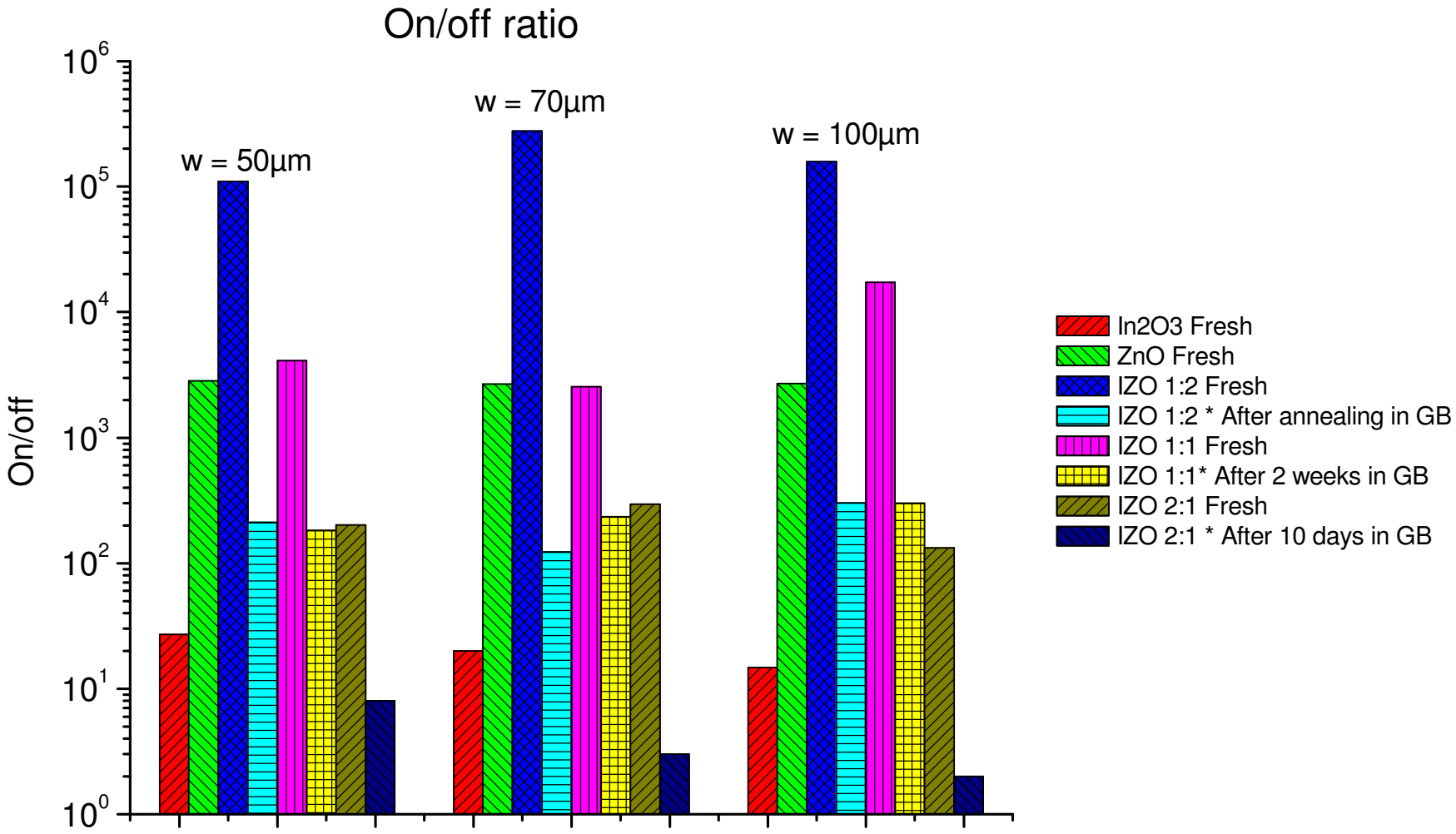
Solution-processed AMO-TFTs



Solution-processed AMO-TFTs



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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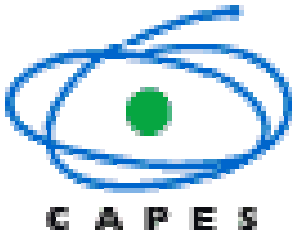
- Grupo de Polímeros, Instituto de Física de São Carlos, USP, Brasil;
- E-MAT Group (Prof. Von Seggern), TU Darmstadt, Alemanha;



Thank you for your attention!