



Activating surfaces with conformable and shapeable plastic LCD's

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FlexEnable at a glance

- Headquarters – Cambridge, UK
- **World's most experienced team** of plastic electronics engineers with collective experience of over 700 engineering years, >650 patents
- **Lowest cost and most flexible platform** for bringing surfaces to life
- **Focused on mainstream applications** – LCD, OLED and sensor arrays for IoT
- **Proven volume-production technology** and experienced tech-transfer team



Industrially-proven technology platform

- The **lowest cost** flexible electronics platform based on **high performance** organic thin-film transistor (OTFT)
- Enables **ultrathin, ultra-lightweight, shatterproof** and **flexible** displays and sensors
- **Fully industrialised** and **easily transferred** for mass production in existing facilities



Low-temperature OTFT backplane is combined with various frontplanes to create **truly flexible electronics over small and large surfaces.**

Benefits of FlexEnable's organic electronics technology

Mechanical



0.25mm
Transistor bend radius
Wraps around a matchstick



25µm
Substrate thickness
As thin as a human hair



100gsm
Weight per area
As light as a sheet of paper

Electrical



1.5cm²/Vs
Better mobility than a-Si



Long Lifetime
Better stability than a-Si



Low-leakage
Better leakage currents than a-Si

Manufacturing



< 100°C
Lowest transistor manufacturing temperature



High Yield



Low Cost
Lowest cost flexible for all areas and surfaces

Activating surfaces with flexible displays and sensors

Displays



Automotive



Consumer electronics



Wearables



Digital Signage

Sensors



Banking and PoS



Border control

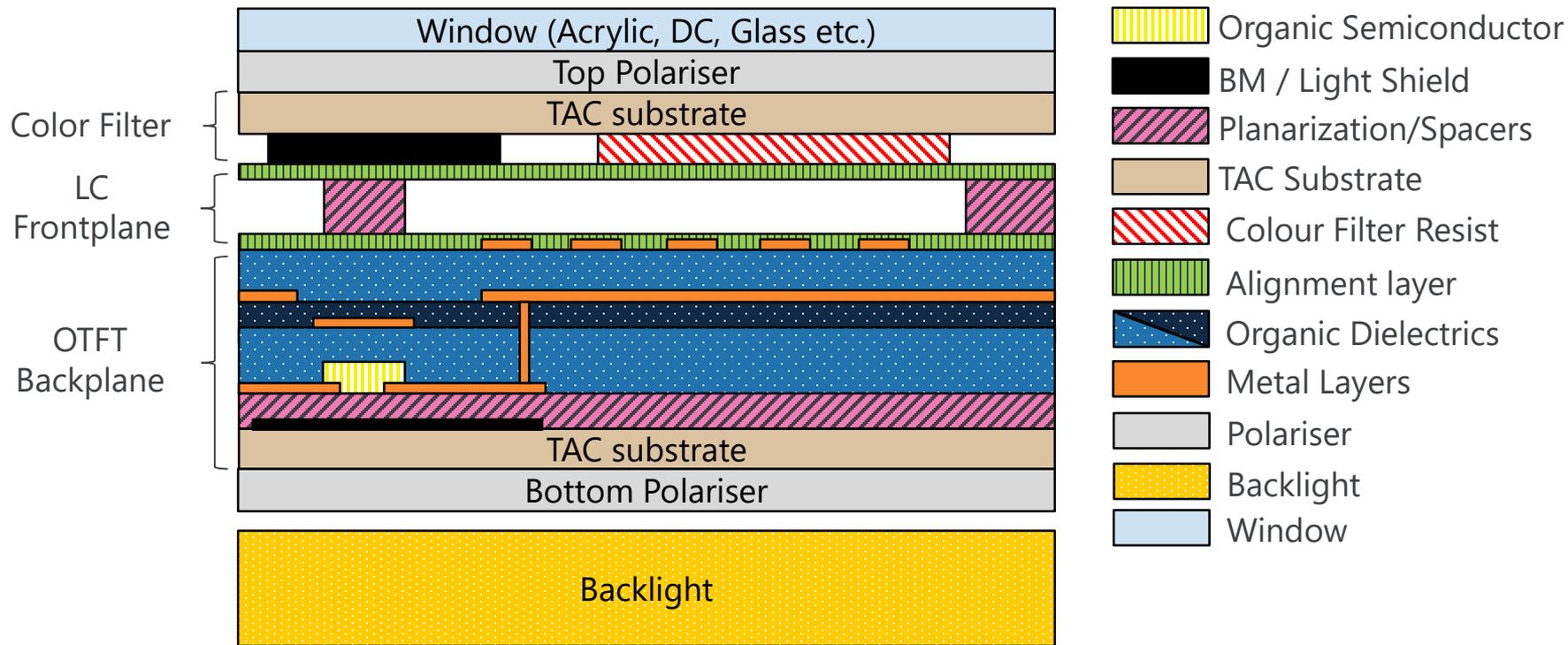


Healthcare



NDT

Plastic OLCD can achieve same performance as colour a-Si/glass LCD displays with all the benefits of glass-free



Flexible Display means AMOLED, Right?

- For super-flexible, foldable displays, AMOLED will eventually be the answer
- Most consumer electronics, automotive, industrial and digital signage applications need conformed displays, with radius of curvature down to 1cm
- OLCD has significant advantages over AMOLED for conformed applications

Display Requirement	Flex OLED	OLCD
Reliability	Still far away from required reliability in a flexible, high-brightness application	OTFT has proven reliability, LCD is dominant in high-rel automotive displays
Brightness	Reliability gets 4 times worse with 2X brightness (e.g. for automotive specs and other applications subject to sunlight)	Backlight solutions with automotive brightness specs available – no reliability impact
Supply chain	Few suppliers	Can run on any a:Si line with minimum modifications
Cost	Very high	Close to glass LCD
Scalability	Yield a major issue for large displays, other flex backplanes cannot scale to large Gen fabs	OTFT has excellent uniformity and low-temp demount enables nearly 100% demount yield at any size

OLCD is a complementary technology to OLED



OLCD is enabled by a uniquely low temperature process



Samsung LCD on FRP (**220°C**), 2011*



AUO LCD on Colourless PI (**220°C**)



JDI LCD on Colourless PI (270°C**)

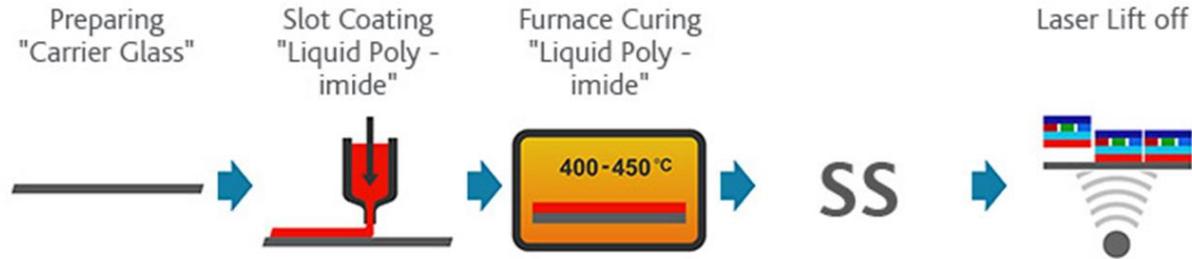
- Plastic LCD is not new ...
- What is new with OLCD is the ability to make them high performance, in high yield and therefore at affordable price.
- Low temperature processing for OLCD is the key enabler



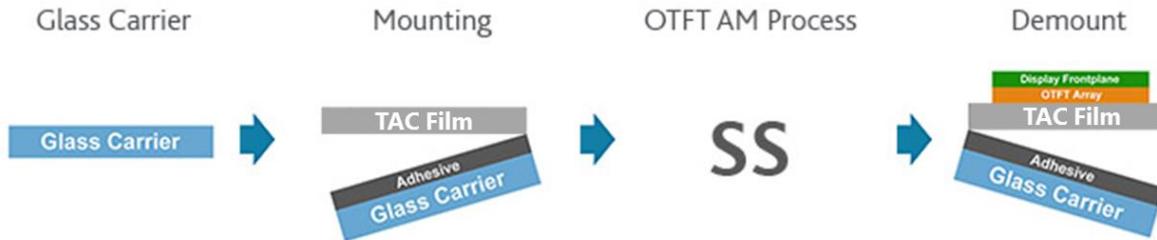
***FlexEnable OLCD on TAC (**100°C**), 2015

Coat-debond, versus mount-demount

Typical low yield (De) bond process required for high temperature AM

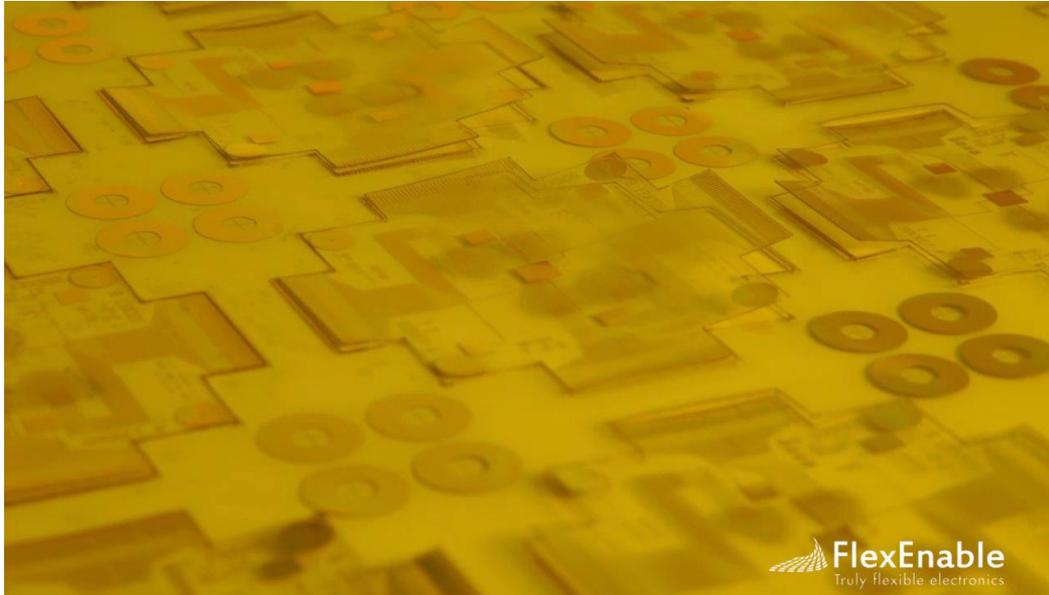


FlexEnable high yield (De) mount process used for low temperature OTFT



FlexEnable process enables maximum yield at the most critical release stage

Low T enables low cost, high yield mount/demount



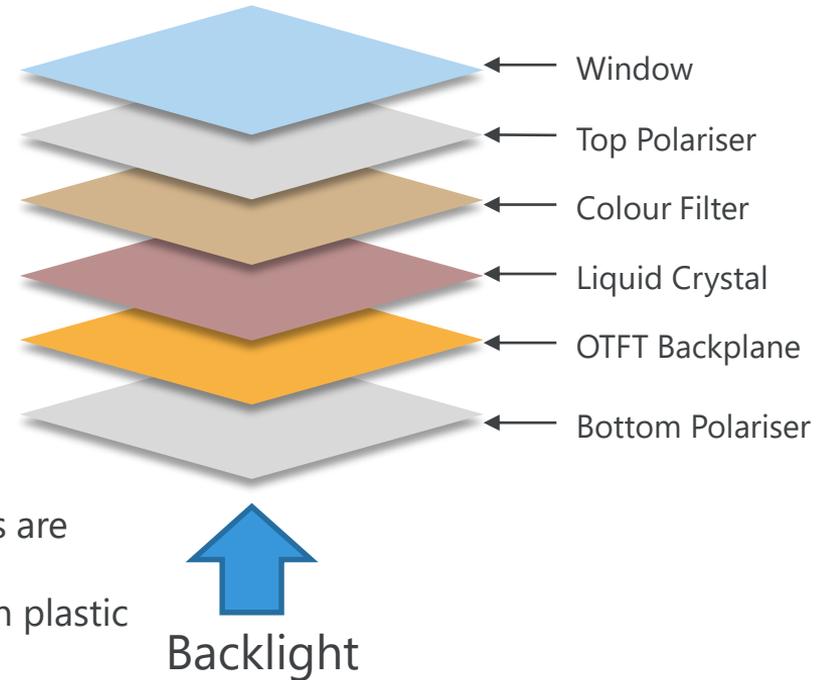
- Enables unique (non-rectangular) display shapes to be easily cut
- High yield process for flex based OLCD and AMOLED displays
- Only possible with low-temperature OTFT processing

Substrate materials

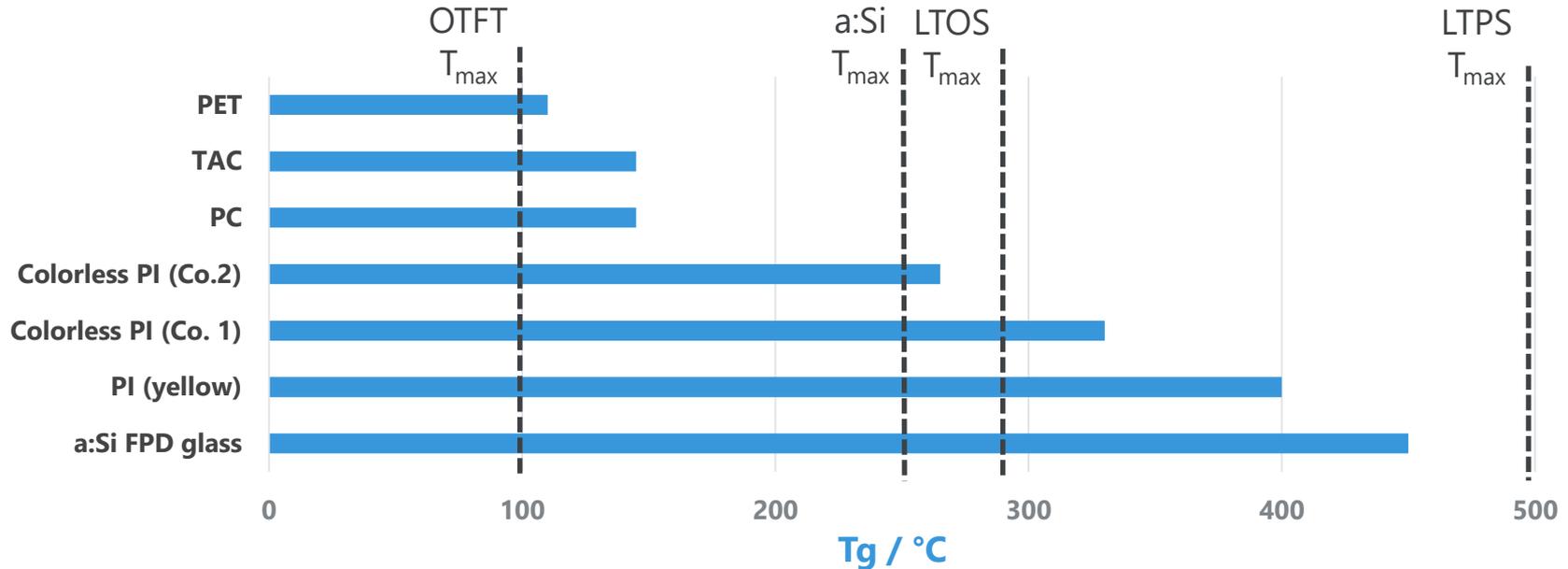
LCD has particularly demanding substrate requirements, because the polarized light must pass through the substrate materials

Key requirements for the substrate are:

- For manufacturing:
 - **Process Temp compatible**
 - **Chemically compatible**
 - **Low cost**
- For display performance
 - **High optical transmission**
 - **Colourless**
 - **Low haze**
 - **Low / zero birefringence**
- Glass meets these requirements well
- More difficult for plastics if high process temperatures are required.
- Goal is to meet the same performance as glass, but on plastic
- TAC film has near ideal optical properties



Thermal Properties of plastic substrates



- T_g must be sufficiently higher than the TFT processing temperature.
- 'Conventional' PI (for flex OLED) has high T_g , but optically not suitable for LCD
- Colourless PI materials have lower T_g – though will likely improve over time.

Re-defining "Display Module"

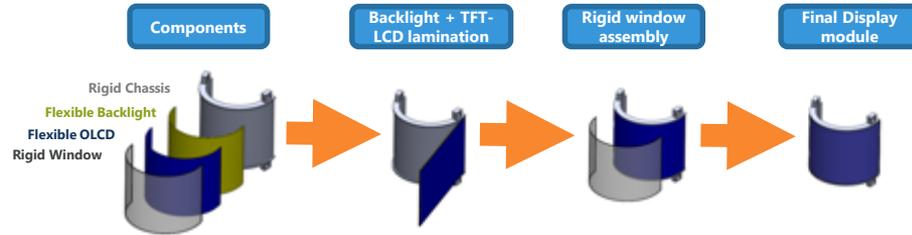
One flexible OLED panel format

Flexible OLED panels are manufactured in a flat state using conventional FPD techniques



One assembly process

Flexible OLED panels are assembled into a rigid display module using a unique lamination process which conforms the OLED to a curved shape



Many unique module shapes

The same 'standard' flexible OLED panel supports many different module shapes achieving low customization cost and aggregated volumes for standard OLED panel designs



FabEnable: Transforming the economics of unutilised FPD capacity

- Today there are **37 million m²** of unutilised capacity in the global FPD industry – across all Gen sizes
- Overcapacity higher at older, earlier generation lines (Gen 6 and below)
- FlexEnable process brings improved economics through product differentiation and diversity (sensors) using today's Sheet-2-Sheet equipment

FlexEnable
qualified
materials set
from established
global suppliers



Existing FPD assets
+
FabEnable License

Truly Differentiated
Displays and
Products

Truly and FlexEnable sign License Agreement to bring low-cost, scalable flexible display production to China



Chuck Milligan, CEO of FlexEnable (left) and Dr James Wong, Chief Operation Officer (COO) and Group Executive Director of Truly (right)

- Truly and FlexEnable signed a technology transfer and license agreement in July 2017
- Truly Semiconductors is the first display maker to adopt OLCD
- Truly will implement the process into its existing production lines in Shanwei, China
- Already sampling key customers with volume production expected by end of 2019

“FlexEnable's OLCD technology is a breakthrough in the TFT-LCD industry and with its characteristics of thinness, lightweight, and more durability it is going to create lots of possibilities for innovative product design. We have been receiving many enquiries for flexible display from the market, specifically, wearable devices, smart home appliances, electric cars and self-driving cars etc. This is a pretty exciting display technology and we do believe there is a considerable potential market size.”

KK Ho, General Manager, R&D center, Truly Semiconductors Ltd

Technology transfer for plastic, OTFT-based OLCD

FE work closely with factory production teams to provide complimentary solutions:

- Plastic substrate (TAC / PEN / PET) mounting onto glass carrier
- Materials sourcing and testing (OSC / Polymer Dielectrics / Low Cure Temp layers)
- OTFT pixel, OTFT AM, and photolithograph mask designs
- Plastic based OTFT process flow and production equipment mapping
- Plastic based Colour Filter Array
- LC Cell Assembly

Optimised process and material selection for plastic substrates

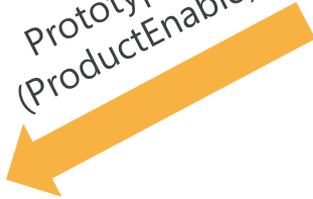
4.68" OLCD made at Truly Semiconductors using FlexEnable's high performance OTFT technology



Partnering to bring OTFT technology to displays and sensors



Prototyping
(ProductEnable)



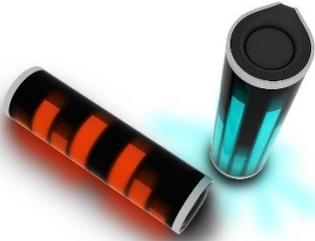
Technology transfer
and license
(FabEnable)



Production



Displays: Smart Speakers & Smart Home



OLCD enables 'wrap-around' displays



Why FlexEnable Technology?

- Smart Speakers are the fastest growing connected device category with 2018 sales of nearly 100M units and \$4.3Bn*. High-end models increasingly integrate displays (e.g. Echo Show, Facebook Portal).
- Audio features are 360 degrees but flat glass displays are unidirectional.
- FlexEnable OLCD enables 'wrap-around' displays enabling 360 degree audio visual use cases such as video conferencing while walking around.
- Advantages over plastic OLED include:
 - half to a third of the cost
 - 24 hour display without risk of burn-in (e.g. time, weather, song details etc.)
- Other Smart Home includes white goods and robotics

*[Deloitte](#) (2018)

Displays: Notebooks and Tablets



OLCD provides a route to bezel-free large area displays

- Key areas of display innovation for Notebooks and Tablets are: Thinness, Bezel size and Power
- Glass-free screens allow thinner, lighter notebooks, but today's flexible OLED technology is too costly for mass market large area displays
- OLCD is uniquely enabling for notebooks and tablets because:
 - The lowest cost flexible display
 - The world's thinnest LCD - replaces 400-800 μ m of glass with 80 μ m of TAC film
 - Provides a route to bezel-free displays through curved edges or folded borders

Displays - Automotive



Image source: Yanfeng Automotive Interiors

- Displays are the last remaining flat surface in most vehicles today – all car makers want to remove this design constraint.
- Flexible, surface-conformable displays not only bring design freedom, but also unlock new use cases in vehicles (e.g. invisible A-Pillar), and allow more display surface area in a car
- IHS forecast the Auto display market will grow to over \$22Bn by 2022.
- OLCD is the only flexible (colour, video rate) display technology suitable for automotive use because:
 - It can be high brightness without affecting lifetime (unlike flexible OLED)
 - It can be made into large sizes (unlike flexible OLED)
 - OLCD manufacturing costs are the lowest of any flexible displays technology
 - It uses a frontplane technology already used in cars (LCD), and the OTFT backplane is higher performance than a:Si

Displays: Digital Signage



- Many surfaces in the built environment and on street furniture are curved. Plastic screens will bring value to these surfaces for advertising and information display.
- Existing LCD signage market (\$8Bn* / 2021) will be significantly expanded with conformability.
- There is also demand for smaller plastic displays for POS, for example to create a video “glorifiers” (that curve behind a high-value item like a watch) or shelf-edge labels that are curved.
- FlexEnable OLCD is ideal for this range of applications because:
 - It is thin, light, robust and able to meet reliability and lifetime requirements for industrial applications
 - It can achieve the high brightness required for outside applications without compromising lifetime.

*IHS Markit Digital Signage

Summary

- Plastic OLCD is needed for many applications that require:
 - Large area and/or
 - High Brightness & long lifetime
- It makes use of existing supply chains for the frontplane and much of the backplane
- OLCD is well suited for “activating surfaces” with one-time conformed uses
- FlexEnable and Truly will be demonstrating ‘consumer spec’ displays by end of 2019 and plan availability of automotive qualified mass production units in Q4 2020



Thank you

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