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FlexiDis Newsletter

INTRODUCTION

By Eliav Haskal, Philips, FlexiDis project coordinator

Welcome to the third and final Newsletter of the Integrated Project FlexiDis, or "Flexible Displays". After more than three years of research, the results of the project are in!

In the last year, the consortium has mostly focussed on industrializable technological results, with pressure on completing demonstrators and on determining how far certain research efforts could be made more practical. This plan for seeking the exploitation routes for the final work in the project has been revelatory, resulting in significant publications, research advances, and business opportunities, as is described later.

Originally, the purpose of the project was to research, develop and compare technologies suitable for cost-competitive manufacturing of flexible active-matrix displays and test prototypes in both traditional and novel display applications. This translated to work in the FlexiDis project on examining different forms of thin-film transistor (TFT) backplanes, including low-temperature poly-Si (LTPS) on metal and polyimide, a-Si:H on polyimide, organic TFTs (inkjet printed, vacuum-evaporated and spincoated) on plastics, and microcrystalline-Si on plastic. Different display effects were used, such as electrophoretic materials and vacuum-evaporated organic light-emitting devices (OLED), with flexible interconnects and driver IC's for flexible display applications such as mobile devices, wearable applications (sportswear), electronic books, automotive, and other novel applications where flexible displays could be the solution to an otherwise impossible idea.

Research was also done in other domains to support the demonstrators, including mechanical modelling of thin films (cracking, creep, …), industrialization scenarios and cost modelling, and handling procedures of flexible foils. This serves to ensure that there will be a long-term impact from the project.

Some highlights of this work are described in the articles in the newsletter, and we would like to thank you for your interest.

As a summary of the highlights of the project, here is a brief and nonexhaustive list list:

The world's first production-ready flexible display manufacturing method was developed, in the form of the EPLaR technology, which has now been transferred and is running in two display production facilities (including the last remaining European display fab, Thales Avionics LCD in Grenoble, France).

A spinoff company was created named Polymer Vision (www.polymervision.com), with a focus on rollable organic TFT active-matrix display devices. Polymer Vision has recently opened up a new manufacturing facility in the south of England, and will have its first product (the Readius) on the market early in 2008, with a major European customer. This will be the first flexible active matrix display product, and first organic TFT based display product.

As an extension of the EPLaR work with electrophoretic displays, the first flexible OLED on active-matrix substrates made in a display production facility was presented at the Eurodisplay 2007 in Moscow. This display is now being integrated into sports clothing, as discussed in Newsletter 2.

The first simulation model for understanding and predicting mechanical properties of patterned display devices and materials has been developed at EPFL,

A study comparing TFTs on different flexible substrates (metal, glass and plastic) for device fabrication, electrical characteristics, device reliability and mechanical properties has lent insight into the overall advantages and disadvatanges of each substrate.

Novel prototypes have been developed, including a ski jacket, snowboard, flexible e-book and more, making use of the many product designers in the project.

Finally, with these results, we would claim that Europe clearly has a leading position in the world in flexible displays and electronics. Hence, our partners welcome any new research proposals, development ideas, application partners or customers – please contact the coordinator for further assistance!

The FlexiDis Newsletter is part of the dissemination activities of the EU funded Integrated Research Project FlexiDis – Flexible Displays.

For more information please visit our website:
www.flexidis-project.org

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Nokia Research Centre	FIN
IPM, Institute of Polymer Mechanics, University of Latvia	LV
Novaled	D
Thales Avionics LCD	F
Applied Materials GmbH & Co. KG	D
Pulsium	F
iRex Technologies	NL
ProTec Process Systems	D
Deutsche Thomson OHG	D
Polymer Vision	NL

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Information Society Technologies
SIXTH FRAMEWORK PROGRAMME

Multi-scale simulation tool for failure analysis of TFT structures on EPLaR™

By Roy Engelen, Olaf van der Sluis, Peter Timmermans, Philips Applied Technologies

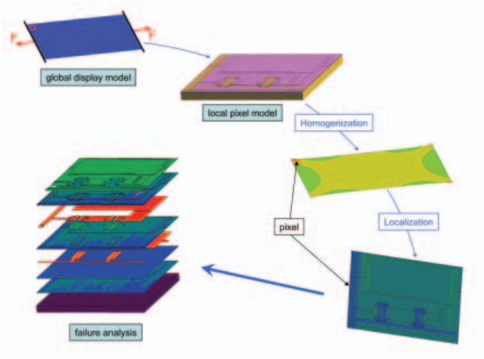
Within the FlexiDis project current research is aimed at further extending the developed failure analyses methods to realistic multi-layered TFT display structures. For this purpose a multi-scale finite element simulation tool has been developed that accurately represents the 3D layout of a 256 by 512 pixel EPLaR™ a-Si TFT demonstrator (Isla) as fabricated at the Thales-LCD factory near Grenoble.

Due to the large scale difference between the geometric features at the display and pixel level, typically five orders of magnitude, two separate models are constructed. The first covers the entire display without the exact pixel details. The second covers a single pixel including the multi-layered TFT patterning.

A numerical homogenization procedure is used to calculate the anisotropic material behavior of the TFT structures (both stiffness and thermal expansion) from the local pixel model. This anisotropic behavior is input for the display model that is subjected to a tensile loading. During the localization step the resulting (global) deformation is prescribed on the local pixel model. The end result is a detailed failure analysis at the pixel level that allows for an inspection in each TFT layer using the failure criteria that already have been developed within the FlexiDis project.

Initially, the framework has been developed for global loading conditions that are uniform over the thickness of the display. Ongoing work considers an extension to incorporate the (non-uniform) bending behavior of the display as well. Furthermore, the result of the failure analysis will be compared to the experimental observations of the mechanical integrity analysis of the 4-level EPLaR™ TFTs that have been performed at EPFL.

Figure 1: Schematic representation of the multi-scale simulation tool for multi-layered TFT structures



Electro-mechanical analysis of flexible displays

By Yves Leterrier, Albert Pinyol, Damien Gilliéron, Aurélie Mottet, EPFL

Flexible electronic devices such as thin film solar cells and displays present a challenging problem in terms of mechanical integrity. This mainly comes from the considerable contrast between the inorganic, brittle device layers and the compliant polymer substrates with limited hygro-thermo-mechanical stability. Scientists at the EPFL have developed a novel automatic method to investigate the fatigue behaviour of this class of layered composites, which is greatly complicated due to the nanometric dimension of the thin film structures. The key concept is to explore the development of damage with simultaneous observation in-situ in a microscope and monitoring of the electrical properties. A miniature fatigue apparatus was designed including special clamps to enable real-time electrical measurements. An ultra thin graphite coating is used as a conductive probe layer in case of dielectric films such as SiO_2 and SiN_x passivation and diffusion barriers. A careful optimization of the conductive probe layer was carried out to avoid artefacts resulting for instance from a change of the residual stress state of the investigated coating. Figure 1 depicts the change of electrical resistance during cyclic loading at different strain levels of a transparent conducting oxide film on PET. Detailed analysis of the onset of tensile damage reveals the existence of very long stable cracks in the brittle coating as shown in Figure 2, and a progressive transition towards unstable failure. The consequence of this process is that sub-critical cracks may grow under fatigue loading until catastrophic failure, the details of which being essential for proper theoretical analysis. This method enables to simulate a broad range of thermo-mechanical scenarios, and is therefore well suited for accurate insight into critical processes that control the lifetime stability of flexible electronic devices, as was discussed in a FlexiDis workshop held at the Philips High Tech Campus in Eindhoven in July 2007.

Figure 1: Normalized electrical resistance increase of a 100 μm thick transparent conductive oxide film on PET under cyclic loading at different tensile strain levels e ('COS' corresponds to the onset of unstable crack propagation).

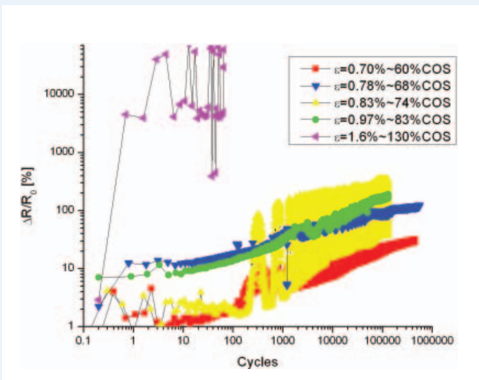
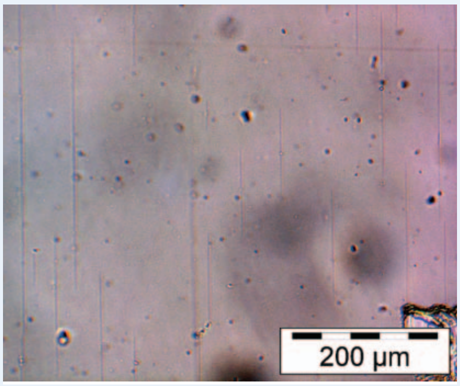


Figure 2: Damage state (cracks of finite length) in a 100 nm thick transparent conductive oxide film on PET after 1700 cycles to 0.97% tensile strain (the loading was parallel to the fiducial mark).



Enhanced flexibility through UTCP technology: the Ultra-Thin Chip Package

By Jonathan Govaerts, IMEC

For the user to be able to fully benefit from the flexibility, it is crucial to make sure the driving electronics, necessary for a working display, are as flexible as the flexible displays themselves. To this end, new types of packaging technology, currently under development at IMEC in another European project, namely FP6-IP-SHIFT, are transferred and enhanced within FlexiDis, so that external driver chips might even one day be fully integrated inside the display substrates.

The updated process flow is shown schematically and basically consists of embedding chips, thinned down to approximately 20 micron, in cavities made in photodefinable polyimide (PI). The chips are so thin that they become truly flexible, but also very brittle. This is why the photodefinable layer with the chip is sandwiched in between two very thin (5 micron) layers of PI. To contact the chips' pads, via holes are drilled through the top PI layer and metallisation for the interconnection is patterned on top.

The result is a bendable chip, so thin it even becomes slightly transparent, as illustrated in the pictures. Although the whole process is in principle quite straightforward and looks simple enough, there are quite some tricky steps involved, and all are to be considered and optimised very carefully. Within FlexiDis, this so-called UTCP (Ultra-Thin Chip Package) technology, is mainly developed as a method for realizing flexible packages starting from rigid bare dies, but in the future the same techniques may be applied to embed several chips in a display substrate. Combining this with, for example, EPLaR technologies, it might be possible to integrate the driving electronics directly inside the displays themselves, minimizing the number of connections from the display to the outside world.

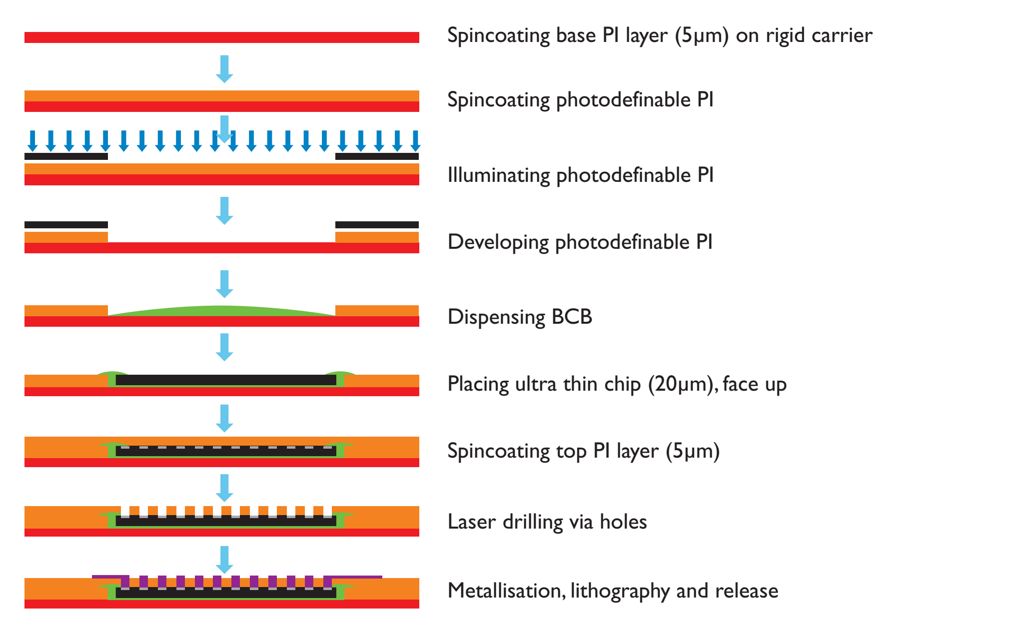


Figure 2: layers

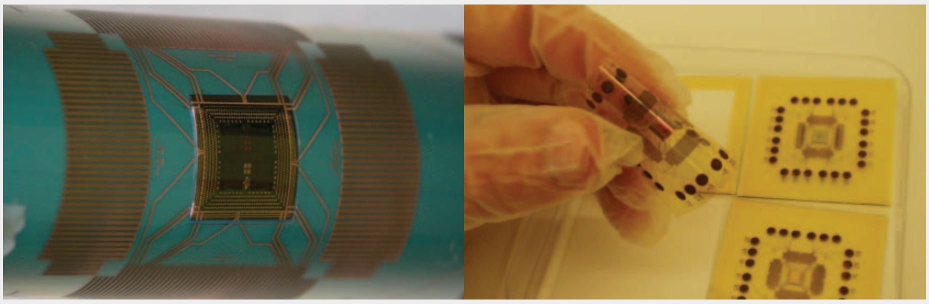


Figure 3: 0.5 cm bend radius

Figure 1: A functional chip before and after thinning down.

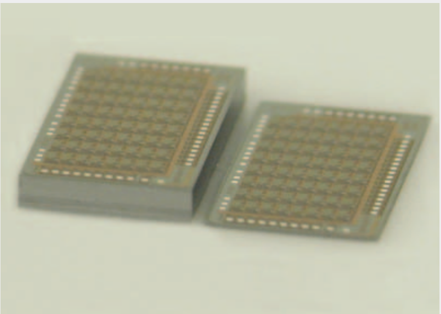
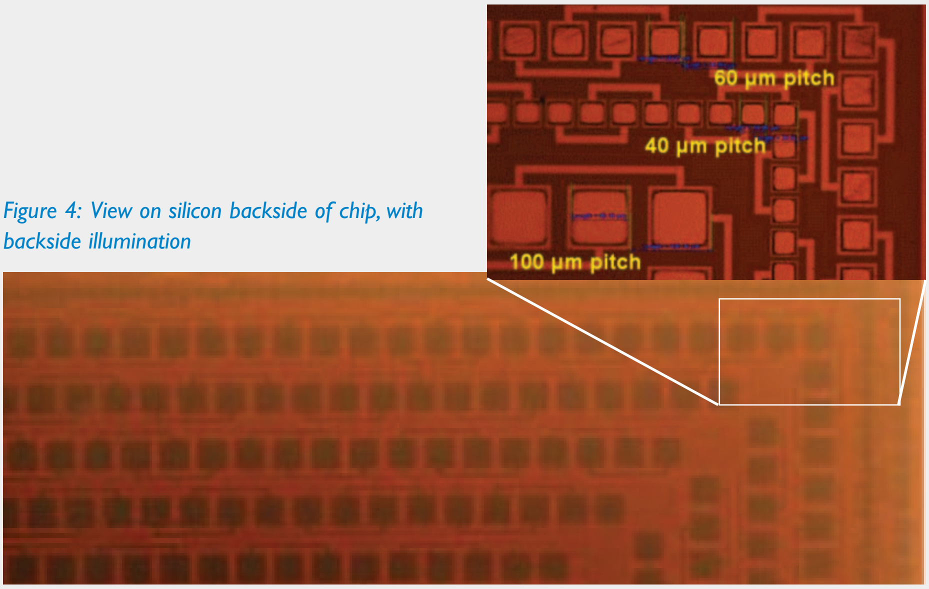
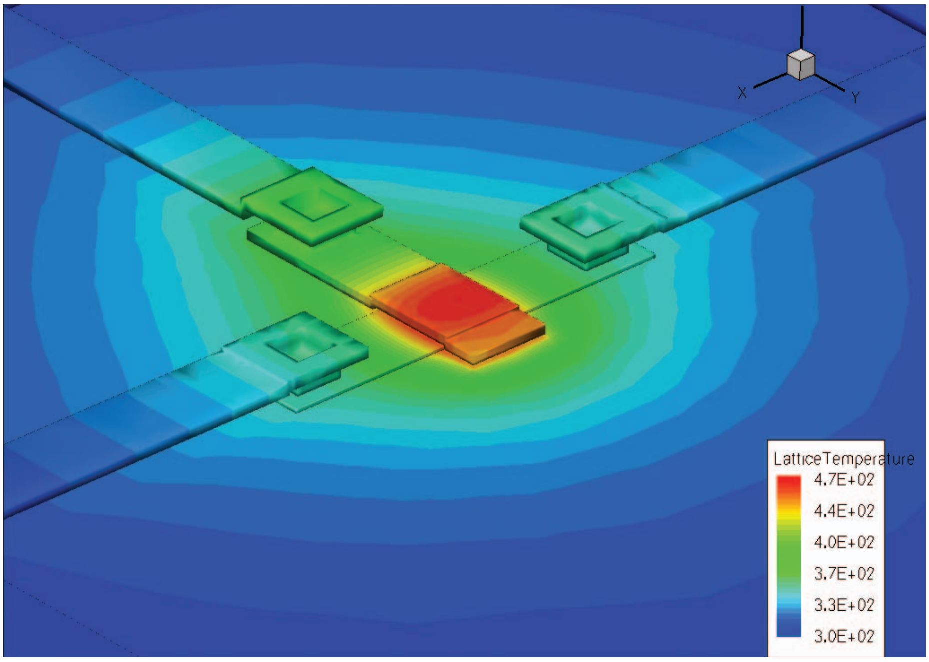


Figure 4: View on silicon backside of chip, with backside illumination



Modeling self-heating effects in Polycrystalline silicon TFTs

By Guglielmo Fortunato, CNR Roma



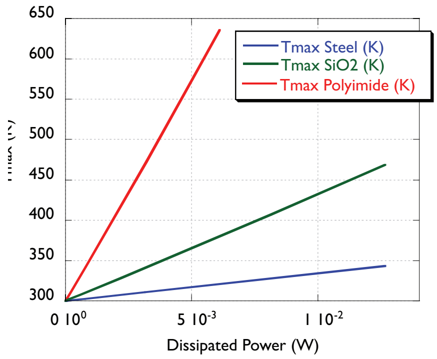


Figure 2: Maximum channel temperature as a function of the overall dissipated power for L = W = 10 μm devices fabricated on different substrate materials.

Self-heating in polycrystalline silicon TFTs is a critical issue, as it can sensibly influence the electrical characteristics of the devices. Moreover there are evidences that these effects can trigger device instabilities like, for example, the de-passivation of dangling bonds. Therefore, a precise understanding and modeling of such phenomena is required to optimize circuit design.

In order to get some insight on the self-heating in polysilicon TFTs, simulations with a coupled drift-diffusion and thermodynamic model have been performed by CNR Roma. Since the self-heating effects are strongly dependent from the specific device geometry and the thermal properties of the materials surrounding the devices, these simulations have been performed in three dimensions (see Figure 1), taking into account the heat fluxes inside the metal interconnects and the heat dissipation provided by the substrate and the environment. Three different substrates have been taken in account: glass (100 μm of SiO_2), stainless steel (500 nm of buffer oxide over 100 μm of AISI 304 stainless steel) and polyimide (250 nm of buffer oxide over 8 μm of Polyimide).

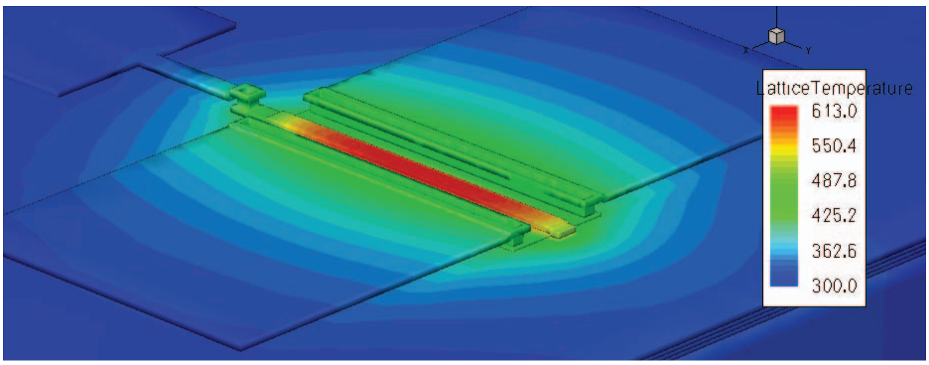
As shown in Figure 2, the maximum temperature reached for a given dissipated power in the device is strongly dependent upon the substrate used, since the thermal conductivities associated with these materials are very

Figure 1: Temperature distribution in a L = W = 10 μm device made on a SiO_2 substrate, with a dissipated power of 1.2 mW for each micron of channel width. The maximum channel temperature reached is 470 K. (For clarity, the passivation oxide and the gate oxide are not shown).

different: the stainless steel substrate strongly reduces the self-heating effects while the thermal insulation provided by the polyimide is the cause of the very high maximum temperature reached with this substrate. Three dimensional simulations also evidenced, as shown in Figure 3, an higher maximum temperature, even at lower dissipated power, as the device channel width (W) is increased. Moreover, large W devices show a lower temperature in correspondence of the channel edges. This is due to the lateral heat dissipation at the channel edges, that has an higher impact in short W devices.

These studies have clarified the different behavior found in the electrical characteristics of the devices fabricated on different substrates and with different geometries, providing quantitative indications on the device channel temperature, and can be used as guidelines for circuit design.

Figure 3: Temperature distribution in a L = 10 μm, W = 150 μm device made on a SiO_2 substrate, with an overall dissipated power of 0.6 mW for each micron of channel width. The maximum temperature reached in the channel is 613 K.



Realistic demonstrator for flexible AMOLED

By Jürgen Bühler, Deutsche Thomson OHG (DTO)

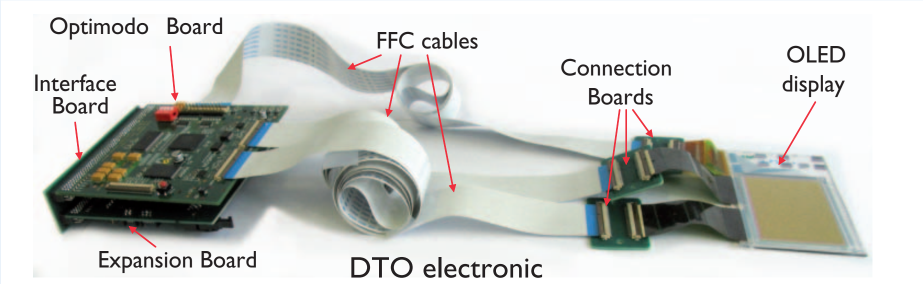
In order to better illustrate future possible usages of flexible AMOLED, the FlexiDis consortium decided to realize a demonstrator based on an application scenario defined by the company Pulsium specialized in conceptual studies for advanced sport equipment: a ski jacket integrating a shock-resistant flexible display in the sleeve, several sensors (temperature, altitude…) and a camera supporting the filming both during day and night. The Deutsche Thomson OHG (DTO) was realizing the overall electronic both for testing the displays and for realizing the prototype equipment. This very specific electronic has two major items:

- Driving and testing FlexiDis AMOLED displays
- Improving picture quality by appropriate signal processing

In order to be fast but flexible, DTO developed several electronic platforms, all based on **FPGA** (**F**ield **P**rogramming **G**ate **A**rrays). The platform used for the prototypes was built out of two boards: one (Optimodo) for display driving and a second (Expansion) for the handling of inputs like video, sensors functions and bendable keyboards.

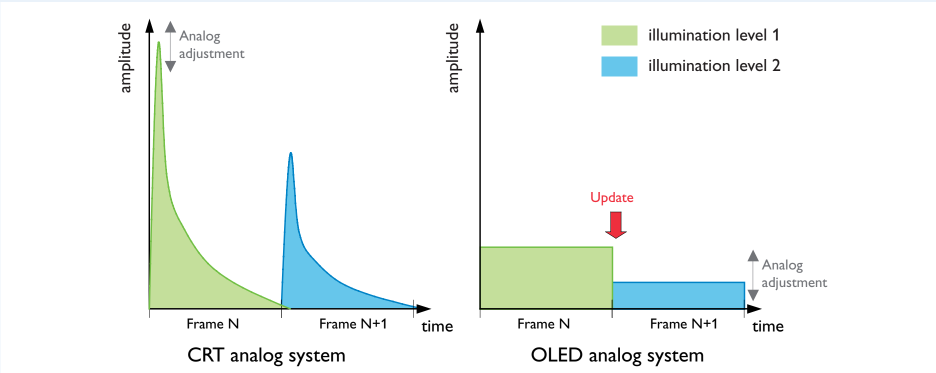
Since OLED and LCD displays have similarities in their driving signals, customized row and column LCD drivers have been selected for the first generation of FlexiDis display prototypes. In the second generation, the external row-driver will be exchanged by integrated row drivers, thus enabling a gain in terms of form-factor and flexibility. In this case, the line selection will be done by transistors integrated in the display itself whereas the pixel value is still controlled externally through column drivers, connected directly to the heart of the electronic: the Signal-Processing Unit (SPU).

The SPU is a key element since AMOLED technology, among strengths, shows also weaknesses that must be overcame to provide better picture quality. The following list will give a non-exhaustive overview of such weaknesses that can be compensated by appropriate algorithms, a key competency of DTO:



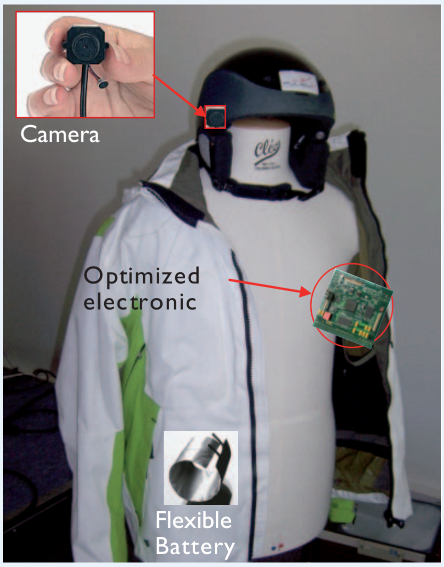
- The active TFT matrix for FlexiDis OLED prototypes is based on amorphous silicon like LCD. However, in AMOLED technology, the brightness is produced on the backplane itself and not through a separate backlight. This increased usage of the TFT introduces ageing issues: the more a pixel is used, the less efficient the driving pixel transistor will be. Therefore, to have always a constant brightness, automatic compensation is required.
- The three OLED chemicals producing the colors (Red, Green and Blue) have a different aging and brightness gain. In order to keep the display color unchanged during its whole lifecycle, specific compensation algorithms are required.
- In opposition to CRT that provides sharp moving images, newer technologies like LCD or AMOLED have worse motion rendition. Even if an AMOLED can be seen as a perfect LCD (instant respons time), the fact that such sample and hold driven systems are keeping the image constant during the whole frame duration are introducing motion blur. This is mainly due to the fact that the temporal lighting is not reflecting logical motion as perceived by our brain. Due to an intelligent signal processing, this artifact can reduced to be nearly invisible.
- Usually the dynamic of OLED images represents a maximum of 8 bit linear per color. This is clearly not sufficient due to the non-linear function of the human visual system. Well-adapted algorithms can improve the image rendition quality.

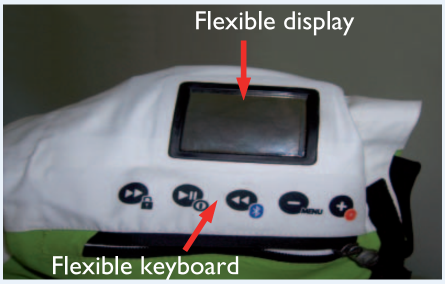
For prototyping and small quantities, such algorithms are usually implemented through FPGAs. FPGAs are programmable digital hardware showing advantages in terms of processing speed compared to processor and enabling integration of several functions like micro-controller, memory, specific interfaces like those requires by AMOLED drivers (e.g. mini-LVDS) in a single low cost device. The component used for FlexiDis demonstrators is a Xilinx Spartan 3E FPGA, which are, compared to the capabilities, cheap and powerful. They can be in-system programmed and therefore always be adapted to the progress of the project, without any modification of the hardware.



CRT analog system

OLED analog system





EPLaR and FlexiDis

By Ian French, Philips Research Redhill

EPLaR, or Electronics on Plastic by Laser Release, is a method of making flexible displays and flexible electronics in existing TFT-LCD factories. This technology has been described further in FlexiDis Newsletter 2. A distinguishing feature is that it allows batches of flexible displays to be made alongside standard glass LCDs on the same equipment, without creating any interference with the standard production processes, yields and results. EPLaR therefore significantly reduces the technology introduction time and cost, and helps the factory to remain fully loaded by being able to choose between making glass LCDs and flexible displays, depending on market demand. The EPLaR technology has been partially developed within the FlexiDis project, and the growth of EPLaR was massively accelerated by being co-developed in an open innovation environment with a range of European partners.

First results were achieved in March, 2005, when the first small displays were made in the Philips Research laboratories in Redhill (UK). At that stage we expected relatively slow progress because of our experience that any new display technology must demonstrate high-yield displays before it is taken seriously by the outside world. This was due to the fact that our access was limited to research-level cleanrooms, where it is known to be notoriously difficult to make high-yield demonstrators in general purpose research facilities that are designed to allow maximum processing flexibility. At this point, however, the FlexiDis project created a possibility to enter the program at its first meeting in April 2005. This probably

Figure 1: 2" EPLaR display at the time of the first FlexiDis progress meeting in 2005.

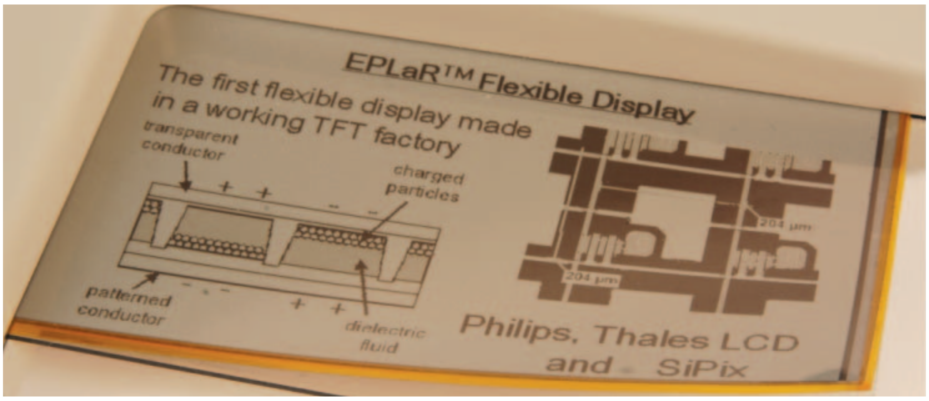


Figure 2: 5" EPLaR display jointly made by Thales-LCD and Philips. The electrophoretic foil was supplied by SiPix.

took considerable faith from the other members of FlexiDis, based on the early stage results that EPLaR was able to demonstrate at that moment in time. Figure 1 shows a photograph of the display that was used to demonstrate what EPLaR could make for a plastic display at that first meeting in 2005.

After joining FlexiDis, the technical progress of EPLaR increased tremendously, also based on the fact that Thales-LCD joined FlexiDis at the same time as Philips Research to help develop EPLaR. Thales-LCD has the only TFT-LCD manufacturing factory outside of Asia and is renowned for its high quality displays for avionics and other specialist applications. By the end of 2006 the partners could demonstrate first displays with no defects, as shown in Figure 2. Also, within FlexiDis a range of other plastic displays and devices were co-developed with partners; such as high quality LTPS TFT circuits and backplanes with CEA LETI and a-Si:H based active matrix OLED devices with CEA LETI, Thales LCD, Applied Materials Germany, Thomson Germany and Philips. It is highly unlikely that this rate of progress would have been possible if development had only been carried out by a single company.

Philips and Thales-LCD will continue to develop EPLaR displays for specialist applications. However, one of the major application areas for plastic displays is E-books, and these can only realistically be commercially developed in a TFT factory that can delivers millions of E-books per year. All of the TFT-LCD factories that have this production capacity are located in Asia, and therefore EPLaR has now been licensed for mass production to Prime View International (PVI) Corporation in Taiwan. Figure 3 shows a 9.7" display in development in PVI. It is expected that mass production will begin in mid-2008.

Other applications which are being pursued within the FlexiDis program in EPLaR include (a) the development of a large-area, flexible e-book applications with IRex Technologies, and (b) displays-in-clothing and sports equipment with Pulsium. In addition, significant research on the mechanical stability of devices on EPLaR foils has been performed (see article by EPFL and Philips Applied Technologies in this Newsletter), and on flexible EPLaR display readability by Nokia Research for mobile applications. These quite different applications, supported by reliability research and human factors studies, as well as fundamental simulations and modelling of the devices for electrical and mechanical stability, could not have been developed without a coherent, multi-partner project such as FlexiDis.

Figure 3: 9.7" EPLaR display under development for mass-production.

World's first flexible active-matrix OLED display fabricated in standard production facilities

By Eliav Haskal, Philips, with Thales Avionics LCD, CEA LETI, Deusche Thomson OHG, Applied Materials, and more.

Flexible displays offer significant advantages due to their light weight, thin form factor, robustness and conformal shape. OLED ("organic light-emitting device") displays can be especially attractive when made flexible, as the single-substrate, emissive display effect has a wide viewing-angle and good video reproduction. In the FlexiDis newsletter 2, the EPLaR ("Electronics on Plastic by Laser Release") process for making flexible displays in standard amorphous Si-TFT based active-matrix display factories was described for electro-phoretic displays. As an extension of that work, the world's-first, flexible active-matrix OLED on plastic made with the EPLaR process was presented recently at the Eurodisplay '07 Conference in Moscow, and is described here.

An optimal display effect for a flexible flat-panel display (FPD) should have an excellent viewing angle, a simple fabrication methodology (such as layer coating) and some degree of robustness to bending. While liquid crystal displays (LCDs) make up the bulk of the FPD market, the need for multiple (thick) compensation films for improvement of the inherently poor viewing angle and the double-substrate solution do not make an optimal choice for flexible displays. Hence, electrophoretic displays with (reflective) monochrome will appear on the market first (see the EPLaR article on page 6 of this newsletter). However, the slow refresh rate and monochromaticity limit the applications to e-book, smart-card and signage types of applications.

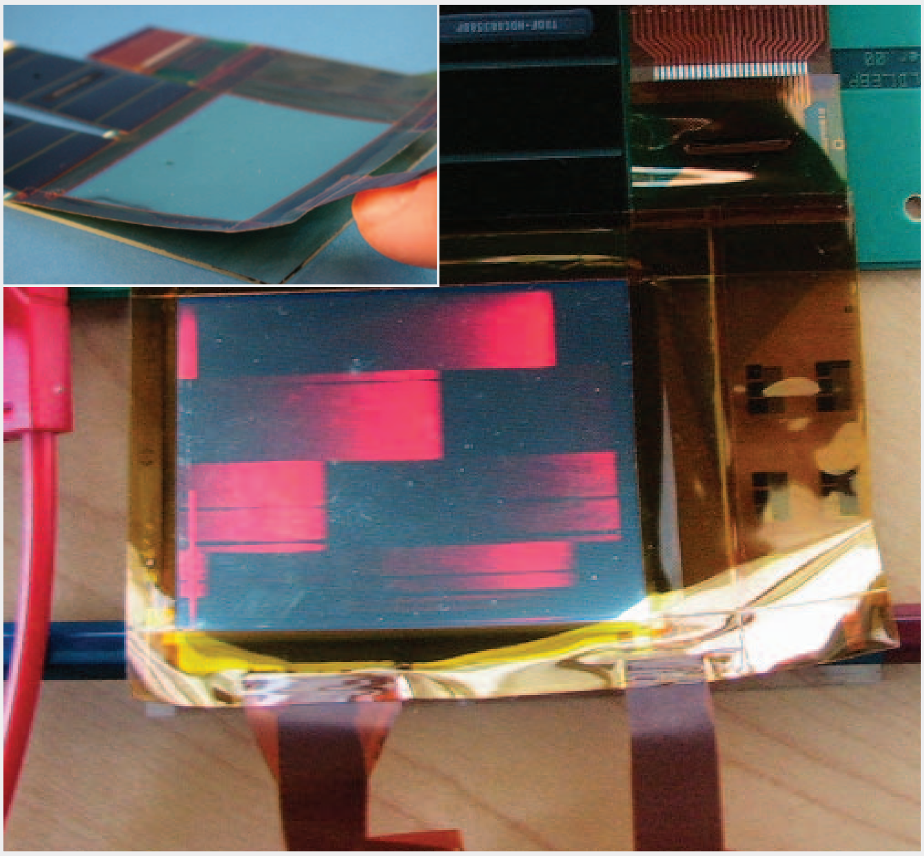
OLEDs have been discussed generally for more than ten years as the next generation of high-quality video displays. Recent intro-duction of the first OLED TV (from Sony) in December, 2007, is showing that this tech-nology is finally reaching the market. Based on emissive light generation from ultrathin organic materials, with a nearly-Lambertian viewing angle and high pixel switching speed coupled with high electricity-to-light conversion efficacy, OLEDs have been touted as the main challenger to LCDs. A typical OLED device stack is less than 1 micron in thickness, which would seem to make it suitable for flexible displays. Therefore the key issue in fabricating flexible OLEDs became how to protect them from moisture and oxygen using a robust and impermeable thin film encapsula-tion coating.

We therefore set out to demonstrate that flexible active-matrix OLEDs could be made in standard production facilities using the EPLaR process. The cooperation scheme for this demonstration turned out to be (a) flexible active-matrix a-Si TFT backplanes from the standard display production facility with EPLaR at Thales Avionics LCD, the technology of (b) flexible single pixel OLED devices with EPLaR from Philips Research, (c) high-performance, long-lifetime OLED devices using PIN structures at CEA LETI , (d) a high-quality thin film OLED encapsula-tion at Applied Materials, and (e) driving electronics developed at Deutsche Thomson OHG. The sum total of the work led to the first demonstration of a factory-produced FLAMOLED, or flexible active-matrix OLED.

The overall thickness of the FLAMOLED was mainly determined by the polyimide substrate (10 µm) and the inorganic/organic multilayer top thin film encapsulation (~75 µm), for an overall thickness of slightly more than 85 µm *in the display region*. Since the thin film encapsulation was not deposited on the display edges, these regions are <15 µm thick, and curl easily. To ensure that the display did not curl into the display region after release or damage the interconnects, the laminated foils were applied. After laser release, the display looked like the inset in the figure below. The display also worked well after laser release, as shown in the image. One can see the polyimide curling up from corners of the glass substrate where no polyimide support foils were laminated.

This demonstration represents a significant step forward for flexible displays, and could only have been achieved with the close cooperation of the many partners in the FlexiDis consortium.

Figure 1: Flexible monochrome AMOLED after laser release, shown in operation. Note the curling of the substrate edges. Inset: Flexible AMOLED after laser release using the EPLaR process.

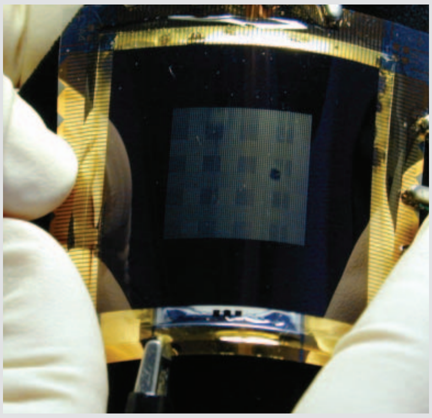


Active matrix PDLC display

By Silke Göttling, Norbert Frühauf, Thomas Bürgstein, Universität Stuttgart

For the first time the Chair of Display Technology at Universität Stuttgart created an active matrix PDLC display on a plastic foil using organic TFTs. The used plastic foil is ordinary PEN or PET material, which makes it extremely interesting from an industrial point of view. The main goal was to establish a process which is compatible to plastic substrates and moreover capable to create homogeneous TFTs all over the substrates. The carrier mobilities of the sublimed organic material are able to drive even larger displays than the one built at the Chair of Display Technology. Roughness of the plastic substrates is an issue, therefore a preprocessing coating with a thick layer is useful to cover detrimental spikes on the substrate. With this additional planarization the OTFT display process originally developed for glass substrates could be applied with minor changes, although the handling of the plastic films is more delicate. Especially the bending during the process makes alignment during the photolithographic steps difficult. Using special preannealing procedures this problem could be solved.

Another challenge for a PDLC display on a flexible substrate is to achieve a homogeneous cell gap which is essential for its optical performance. The cell gap was homogenized by an optimization of the spacer density and a modification of the seal frame application process. The display demonstrator shows the viability of pentacene for flexible display's backplanes.



Bottom Gate Microcrystalline Si TFTs with Low Off-Current and High Reliability.

A new way for AMOLED flexible displays

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Recently, amorphous Si (a-Si:H) based thin-film transistors (TFTs) used as a back-plane for active matrix organic light emitting diodes (AMOLED) have attracted a lot of attention. However, the performance of a-Si:H TFTs still needs to be improved in such areas as off-current, mobility, and reliability. The fact that a-Si TFTs can make only n-channel TFTs is another drawback for integrated AMOLED displays in the future. For AMOLED displays, threshold voltage degradation of a-Si TFTs by gate voltage bias is the most serious problems as well. Polycrystalline Si (poly-Si) based TFTs show higher TFT performance, but at present, they require more process steps and show non-uniformity over large areas. Microcrystalline Si (μc-Si:H), on the other hand, has the potential to be employed in AMOLED displays in the future. The same and well-established bottom-gate a-Si TFT fabrication process and equipment can be used in the existing LCD manufacturing facilities.

Microcrystalline TFTs were fabricated at Ecole Polytechnique/CNRS using a conventional PECVD, four-mask, bottom-gate process. The only modification is to use SiF_4 for the microcrystalline layer deposition instead of SiH_4. This allows achieving a fully crystallized material even for very thin layers (20 nm) without any amorphous layer at the interface with the silicon nitride gate dielectric, i.e. in the channel region.

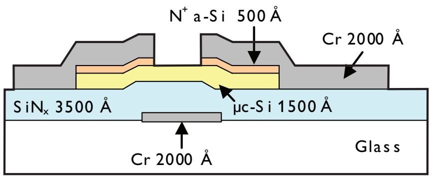

Figure 1: Schematic of standard bottom gate TFT in which the a-Si: H layer has been replaced by μc-Si:H.

Due to the high crystallinity at the bottom interface and stable Si/SiN_x interface, the off-current and the threshold voltage of the TFTs are slightly modified after application of DC stress for extended period of time. A DC stress was applied to verify the use of μc-Si TFTs for AMOLED displays. After 20h of application of the stress (V_{GS}=25V, V_{DS}=0.1V), the off-current was even lowered, sub-threshold slope variation was less than 5% and mobility drift near 2%.

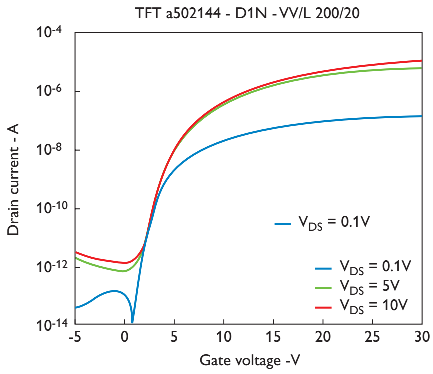

Figure 2: Typical transfer characteristics of the μc-Si TFTs. We can see no kink current. The on-current, off-current, sub-threshold slope and mobility were $1.2x10^{-5}$A, $1.2x10^{-13}$A, 0.7V/dec and $0.95cm2.V^{-1}.s^{-1}$ respectively. Without complicated lightly doped drain (LDD) or dual-gate structures, an off-current order of 10^{-13}A was achieved.

Without changing the existing a-Si TFT fabrication process, and using the same masks as for a-Si TFT fabrication, Ecole Polytechnique/CNRS have developed a μc-Si TFT technology with low off-current and high stability. The maximum process temperature was 200°C, compatible with flexible substrates. Due to the high crystallinity at the bottom interface and stable Si/SiN_x interface, the off-current of the TFTs does not change even after application of DC stress for extended period of time. After removal of the stress, the residual TFT degradation was almost negligible. Based on these experimental results, we foresee μc-Si:H TFTs as a key element to develop AMOLED displays (flexible or not) with very simple pixel design.