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Paper Title

Active matrix color LCDs on ultra-thin glass substrates

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We have fabricated a full color 4-inch quarter-VGA amorphous Silicon AMLCD on 75 µm flexible glass substrate. Reliable working active matrix backplanes with TFT characteristics which are similar to results we obtain earlier on 0,7mm glass substrates were achieved. We demonstrate that the incorporated ultra-thin glass substrates are stable enough to be compatible with a standard color AMLCD process.

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Active matrix color LCDs on ultra-thin glass substrates

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Abstract

We have fabricated a full color 4-inch quarter-VGA amorphous Silicon AMLCD on 75 µm flexible glass substrate. Reliable working active matrix backplanes with TFT characteristics which are similar to results we obtain earlier on 0,7mm glass substrates were achieved. We demonstrate that the incorporated ultra-thin glass substrates are stable enough to be compatible with a standard color AMLCD process.

1. Introduction and objective

In the last years display development goes to more and more thinner and flexible devices. Especially in the field of mobile devices like cell phones, PDAs or laptops there is a big interest to get a lightweight and thin device. But when people think of flexible substrates, they first think of polymer foils because of their robust mechanical properties [2]. Glass foils seem to be more fragile and more sensitive to flaws. But ultra-thin glass foils have several advantages over plastic foils. Glass enables improved resolution, registration, performance and lifetime. Ultra-thin glass is inherently very strong after forming. It’s more a matter of contact induced damage and stresses during glass handling what determines the lifetime of the glass foil. Previous approaches to achieve mechanical compatibility with device fabrication have included the use of organic coatings [3] and the use of temporary process carriers which serve to protect the glass from mechanical damage and increased handling stresses. Another approach is to fabricate the display on thicker glass substrates and reduce the device thickness afterwards in a very complex and cost expensive chemo-mechanical thinning process [4].

In this paper we demonstrate a full color AMLCD device which was directly built on ultra-thin glass without the use of protective coatings or carrier systems. We reported elsewhere before about this thin glass device [1]. In this paper we present more details of the process issues and how we solved them. The target of this work was to show that the incorporated ultra-thin glass has suitable properties to be used in a conventional display manufacturing process like AMLCD fabrication.

2. Flexible glass

There are many requirements display glass substrates must fulfill. Surface quality is very important to assure a stable working AM-backplane and homogenous LCD geometry [5]. Substrates must be thermally and dimensionally stable to be compatible with the elevated processing temperatures and layer-to-layer registration required for high quality displays. As mentioned, substrates must also have the mechanical reliability required for both device fabrication and end-use applications.

The flexible glass substrates used in this work had a thickness of 75 µm and a width x length of 100 mm x 120 mm. The surface roughness is <1 nm. It has a CTE of $<10^{-6}$/C° and also the Young’s Modulus is quite similar to commonly used AMLCD glasses. Demonstrating a flexible display was not the goal of this work. Nevertheless the substrate flexibility offers an indication of its mechanical strength. The high surface and edge strength of the ultra-thin glass used in this work enabled the substrates to be bent to a radius of 3 cm before device fabrication. The flexible glass mechanical reliability was maintained throughout the AMLCD fabrication process by handling techniques that minimize glass defects and tensile stresses.

3. Fabrication of ultra-thin glass AMLCDs

The active matrix was realized with a standard bottom gate a-Si TFT process and back-channel-etch (BCE). This process has previously been performed on 1.1 mm glass substrates in our lab [6]. To transfer the whole process to the ultra-thin glass substrates it was necessary to modify several process steps and also handling of the thin glass had to be adjusted. In particular, the photolithographic steps had to be changed to match the ultra-thin glass properties. For a more homogeneous curing of the photoresist an oven was used instead of the hotplate and due to the different heat capability of the thin glass the soft bake temperature was reduced. Adjustment of development and etch times were also performed. In addition, blowing the ultra-thin glass dry with a nitrogen gun required laying the substrates on a cleanroom cloth. To prevent contaminations, additional cleaning steps are necessary.

The entire process flow is shown in Figure 2. First, MoTa is deposited by sputtering. Due to MoTa layer stress (tensile) on ultra-thin glass, the sputter parameters (gas flow and sputter power) had to be adjusted to maintain flat substrates. Figure 1 shows the ultra thin glass substrates with a sputtered 200nm MoTa layer before and after adjustment of the sputter parameter. As an optimum it was found out to use 27% sputter power and an argon gas flow of 59,3sccm. In general 20% sputter power is used for processes on thicker glass substrates..

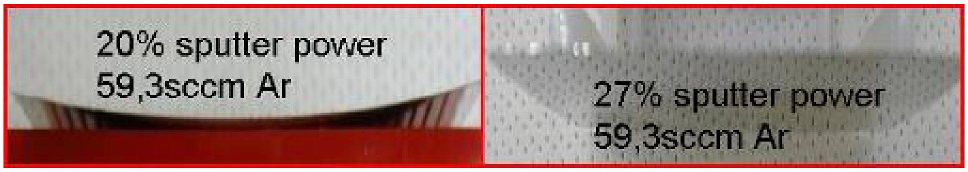

Fig. 1. MoTa layer stress on ultra-thin glass

The MoTa layer is patterned as row and gate metallization. Afterwards a layer stack of gate dielectric (Si_3N_4), a-Si and n^+ a-Si is deposited by PECVD. A second MoTa layer is deposited and patterned afterwards to get the columns and drain/source contacts of the pixels. The resulting metal pattern acts as a mask for the following self-aligned BCE process. It follows another etch step to form the intrinsic a-Si layer. Like the n^+ layer, the a-Si is next masked by the column metal. In the next step a Si_3N_4 passivation is deposited, vias to contact the TFTs and storage capacitors are realized by plasma etching and the contact pads for row and column wires outside the display region are laid open for driver bonding. Last step on the backplane is the transparent pixel electrode Indium tin oxide (ITO) which is sputter deposited and patterned. Five photolithographic masks are required to fabricate the backplane.

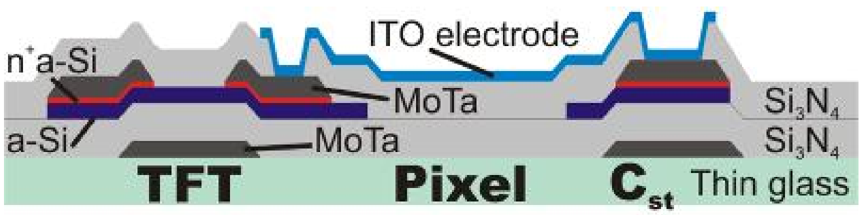

Fig. 2. Five mask a-Si backplane process

The used flexible glass enabled a maximum backplane fabrication temperature of 300°C which is similar to previous work on 1.1 mm thick glass substrates [6]. The pixel layout is shown in Figure 3. The technical details of the display are listed in Table 1.

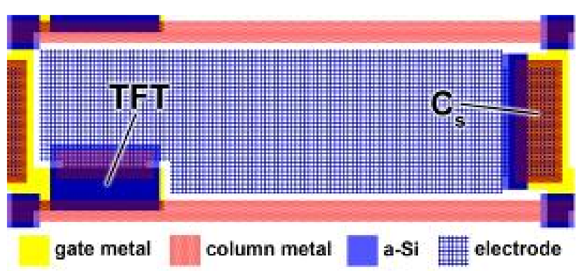

Fig. 3. Lateral design of a single pixel

Table 1: Details of designed AMLCD

LCD type	Twisted Nematic
Display Size	80 mm x 60 mm
Resolution	320 x RGB x 240 pixel
Pixel Size	83 µm x 250 µm
TFT channel length	10 µm
TFT channel width	50 µm
Aperture	52 %

To reach a stable and reliable process on flexible glass, the design rules of the pixel TFTs were chosen rather conservative. No mismatches between the alignment marks of the individual layers on the front- and backplane were observed, which demonstrates the expected dimensional stability of the used ultra-thin glass substrates. Figure 4 shows a photograph of the completely manufactured ultra-thin glass active matrix backplane.

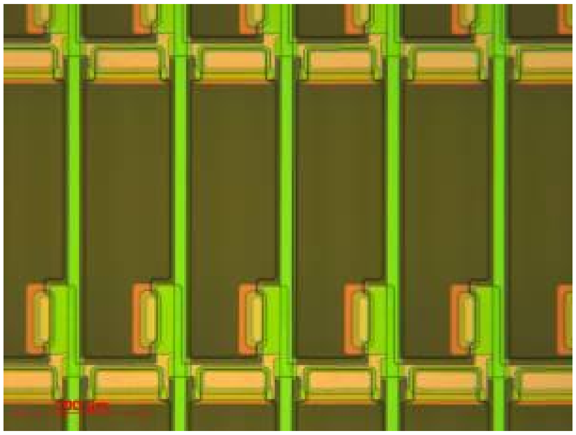

Fig. 4. Completely fabricated ultra-thin glass backplane

For the frontplane (Fig. 5) a sputtered inorganic black matrix, spin coated color filters from Fuji Film Arch as well as the unpatterned ITO backing electrode and the organic topcoat PC403 are realized. This requires five masks. The maximum processing temperature for the frontplane was 230°C.

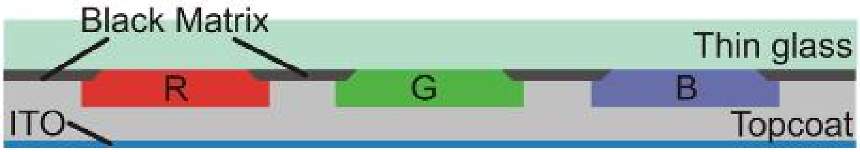

Fig. 5. Frontplane layer stack (upside down)

To complete the front- and backplane, polyimide SE-130 from Nissan is spin coated and brushed with a velvet cloth on each substrate for orientation of the LC. The frontplane has to be cut to get access to the bond contacts later. Spacer with a size of 5 µm are sprayed onto the fronplane and a glue frame with fill opening is drawn onto the backplane. The cell is assembled and vacuum filled with Merck TN liquid crystal MLC-12049-000. It was necessary to double the number of spacers per pixel from about 5 to 10 and also modify the fill opening and the cell fixation process when using the ultra-thin glass cells due to their flexibility. In Figure 7a and 7b a test cell is depicted when using the standard number of spacers per pixel and conventional cell filling. One can see clearly the air bubbles inside the cell and an inhomogeneous cell gap. When applying the optimized parameters the test cell looks very homogeneous (Fig. 6c and 6d). The cells in Figure 6 were not switched (U=0V).

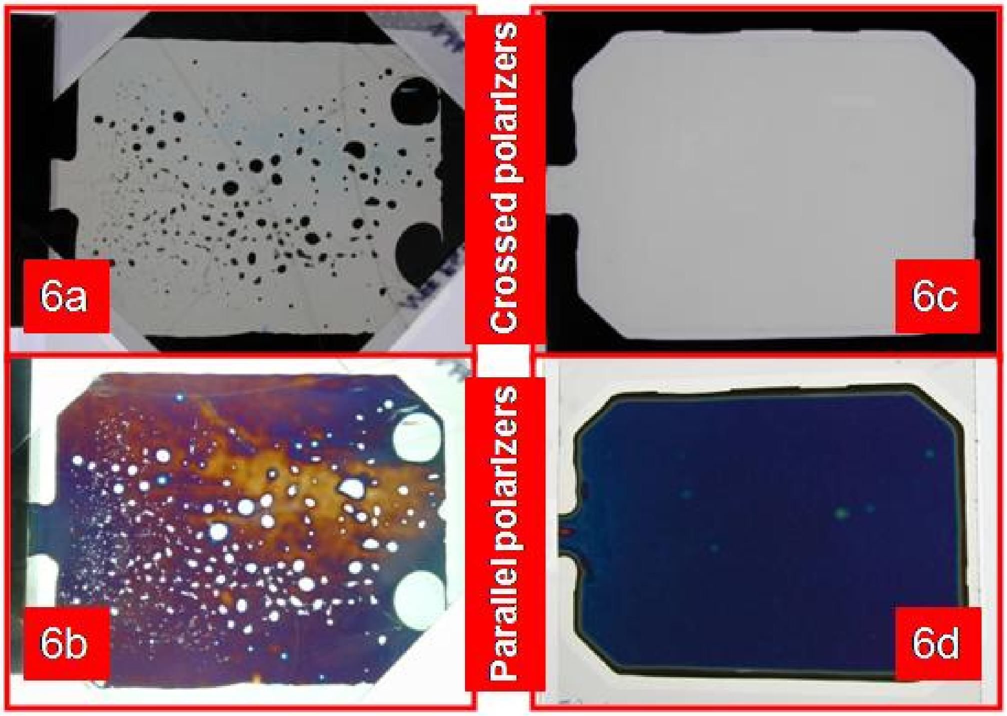

Fig. 6. Conventional and optimized LC cell assemby for ultra-thin glass

To finish the display, crossed foil polarizers from Sanritz are applied. Before driver chip bonding, the backplane also has to be cut. The cutting process of front- and backplane is one of the most critical process steps during display fabrication on thin glass because of the potential to affect the glass mechanical strength by creating microcracks. These microcracks could propagate during the subsequent handling. Despite this concern for potentially damaging the substrates, the glass strength required for display assembly and driver bonding was achieved.

The last step is driver chip bonding. In Figure 7 the ultra-thin glass AMLCD with all bonded driver chips is depicted. Even with the incorporated 75 µm glass substrates, reliable and safe bonding of small pitches (54µm) is possible.

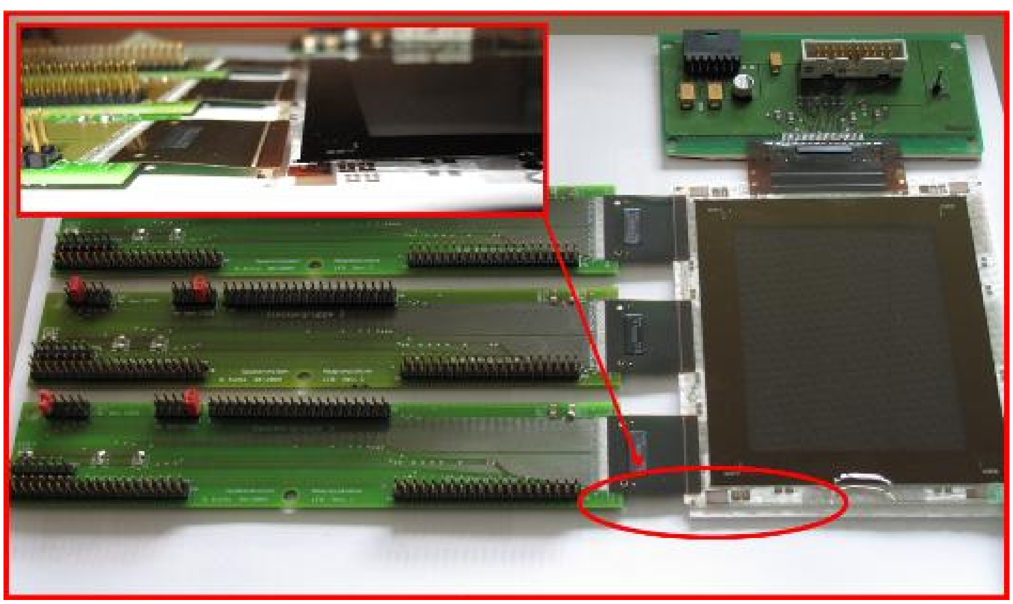

Fig. 7. Ultra-thin glass display with bonded driver electronic

4. Results

For process control, test-TFTs are located in each corner of the backplane close to the matrix. In Figure 8 transfer characteristics of test-TFTs are displayed. Figure 8 left shows curves of TFTs made on the ultra-thin glass whereas Figure 8 right shows examples of TFTs made on the thicker 0,7mm standard glass. In both curves a threshold voltage shift is visible which seems to be caused by electrostatic charges. With on/off values of more than 10^6, off currents in the order of 10^{-12}A and mobilities of 0.4-0.6 cm^2/Vs the TFTs on ultra-thin glass are quite similar to those on thicker standard glass [5]. However these results are well suited for an AMLCD and the addressed ultra-thin glass matrixes show homogeneous behavior.

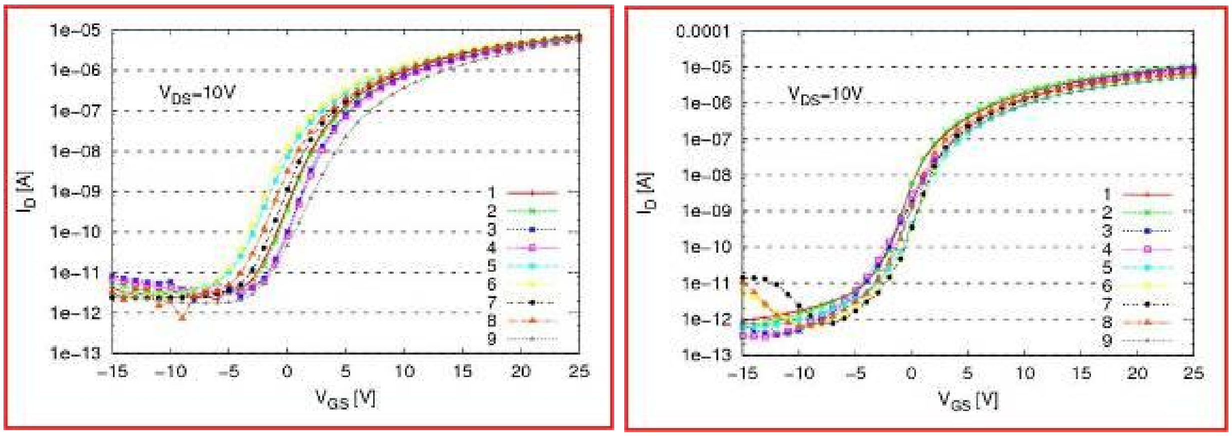

Fig. 8. Transfer characteristics of test-TFTs on 75µm glass (left) and 0,7mm glass (right)

The photo on the left in Figure 9 shows an alignment mark of the backplane of our display design. Layer-to-layer registration on both back- and frontplane on ultra-thin glass is possible with an accuracy of ± 2 µm. The same was observable when aligning the front- to the backplane (alignment mark on the right in Figure 9). Here we also reach an accuracy of ± 2 µm.

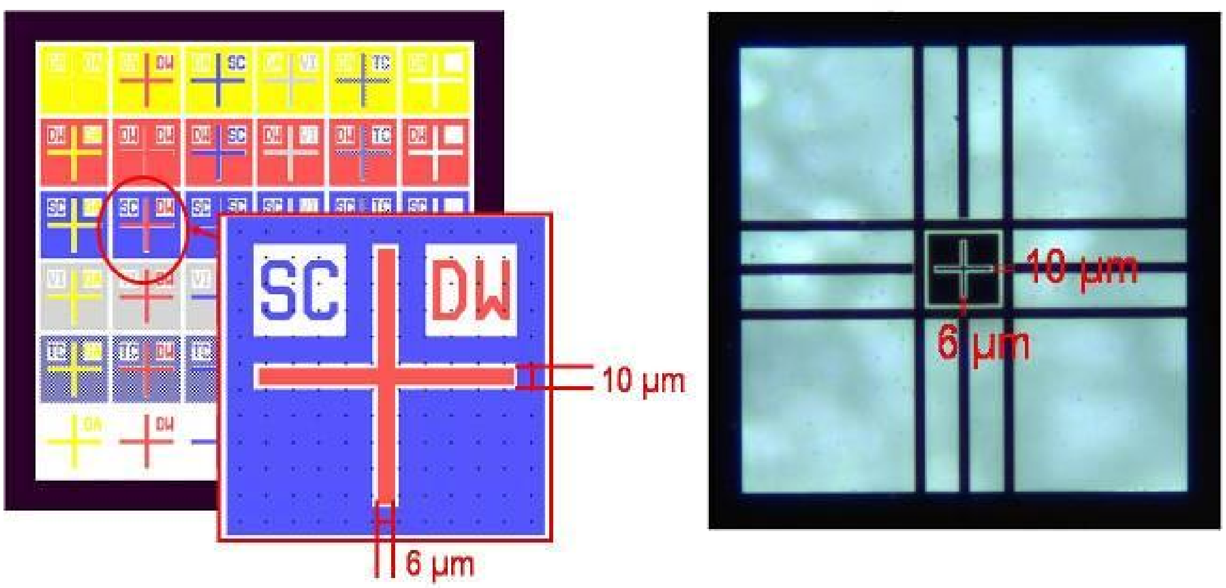

Fig. 9. Alignment marks layer-to-layer (left) and frontplane to backplane (right)

Two images of the addressed full color ultra-thin glass AMLCD are depicted in Figure 10. Displayed are yellow LfB labels on black and red stripes on the left. On the right side a color test-pattern is shown. Despite the manual handling during the fabrication in a university lab, the display shows very limited defects. The visible pixel defects are often caused by particles and the few column and row defects are caused by broken metal wires. Due to an imperfect bond connection during column driver bonding the right side of the display is not fully addressable.

Fig. 10. Working AMLCD prototype on ultra-thin glass

5. Summary

We produced a full color qVGA a-Si AMLCD on 75µm thick ultra-thin glass. The display was presented for the first time on the International Display Workshops 2010 in Fukuoka, Japan [1]. It is the first demonstation of an active matrix display which was built without the use of additional, protective glass coatings and/or carrier substrates and/or glass thinning process directly on 75 µm thick glass. The overall LC cell thickness is <170 µm.

For a university lab, reliably working AM-backplanes and displays are achieved. The fabricated displays demonstrate furthermore the mechanical compatibility of ultra-thin glass substrates with a standard active matrix display process. These results should give a first impression of what could be possible in future flexible displays for a variety of applications that incorporate flexible glass substrates.

6. References

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