Full Color AM-LCDs on Flexible Glass Substrates

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ABSTRACT

We have realized a full color 4-inch quarter-VGA amorphous Silicon AM-LCD on 75 µm flexible glass substrates. The overall thickness of the LC cell is <170 µm. With this work we demonstrate that the incorporated ultra-thin glass substrates have suitable properties to be compatible with a standard color AM-LCD process and achieve active matrix backplanes with reliable performance.

1. INTRODUCTION

Nowadays display development is targeting thinner and more flexible devices. Especially for portable panels like mobiles, PDAs, laptops and for automotive display applications, weight and thickness reduction of the devices play an important role. At a first glance, polymer foils are the material of choice for flexible substrates because of their robust mechanical properties [1]. In comparison, ultra-thin flexible glass substrates have been considered more fragile due to their low fracture toughness and sensitivity to flaws.

Nevertheless, glass foils have several advantages that enable high quality displays. Glass has a higher thermal and dimensional stability, lower surface roughness, excellent barrier properties for O_2 and H_2O and also a higher chemical durability. Ultra-thin glass is inherently very strong after forming. The actual process compatibility is determined by contact induced damage and stresses during glass handling. Previous approaches to achieve mechanical compatibility with device fabrication have included the use of organic coatings [2] and the use of temporary process carriers which serve to protect the glass from mechanical damage and increased handling stresses. Another possibility, which was recently published, is to fabricate the display on thicker glass substrates and reduce the device thickness subsequent in a very complex process by polishing the glasses [3].

In this paper we demonstrate a full color AM-LCD device which was directly built on ultra-thin glass without the use of protective coatings or carrier systems. Reliable device fabrication is achieved by proper handling methods that minimize damage and stresses. We show that the incorporated ultra-thin glass has suitable properties to be used in a conventional display manufacturing process like AM-LCD fabrication.

2. FLEXIBLE GLASS PROPERTIES

Display glass substrates must fulfill a multitude of requirements. Surface quality is very important to assure a stable working AM-backplane and homogenous LCD geometry [4]. 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. Although demonstrating a flexible display was not the goal and flexibility during device processing was not needed, 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 AM-LCD fabrication process by handling techniques that minimize glass defects and tensile stresses.

3. PROCESS FLOW OF ULTRA-THIN GLASS AM-LCDs

To realize the active matrix backplane a standard bottom gate a-Si TFT process with back-channel-etch (BCE) is used. In our laboratory this process has previously been performed on 1.1 mm glass substrates [5]. Several modifications regarding processing and handling of the flexible glass were necessary to transfer the whole process to 75 µm thick glass substrates. In particular, the photolithographic steps had to be adjusted to match the ultra-thin glass properties. The photoresist soft bake was changed in temperature and an oven was used instead of a hotplate to obtain a more homogeneous curing. Due to different handling of the ultra-thin glass during wet chemical process steps, 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 1. Five photolithographic masks are required for the whole backplane process.

First, MoTa is deposited by sputtering. Due to MoTa layer stress on ultra-thin glass, the sputter parameters had to be adjusted to maintain flat substrates. With the first photolithographic mask, 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 for ohmic contacts to the drain/source metal is deposited by PECVD without vacuum break. Then a second MoTa layer is deposited (Fig. 1a) and wet chemically patterned 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 (Fig 1b). Followed by another dry etch step with a third mask, the intrinsic a-Si layer is patterned (Fig. 1c). Like the n^+ layer, the a-Si is next masked by the column metal. For the channel region of the TFTs, all crossings of row and column wires (to prevent problems caused by undercutting), as well as borders of the TFT contact and the storage capacitor $C_{st,}$ are masked. In the fourth step a Si_3N_4 passivation is deposited by PECVD, vias to contact the TFTs and storage capacitors are realized by plasma etching (Fig. 1d) and the contact pads for row and column wires outside the display region are laid open for later driver bonding.

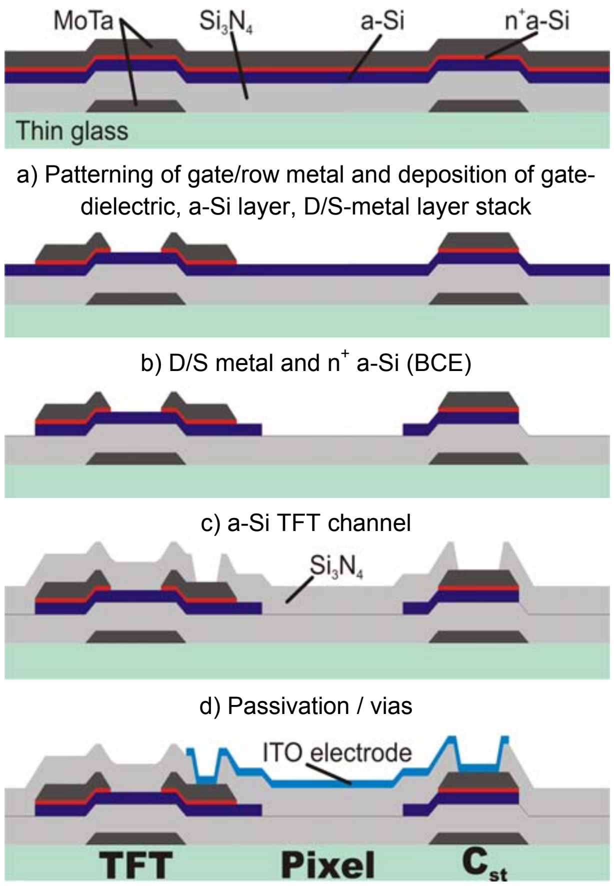

Fig. 1. Five mask a-Si backplane process

Afterwards the transparent pixel electrode Indium tin oxide (ITO) is sputter deposited and patterned (Fig. 1e).

The pixel electrode connects the source contact of the TFT with the storage capacitor C_{st} whose lower contact is the following gate/row wire. Similar to previous work on 1.1 mm thick glass substrates [5], the flexible glass enabled a maximum backplane fabrication temperature of 300°C. The pixel design is depicted in Figure 2. The technical details of the display are listed in Table 1.

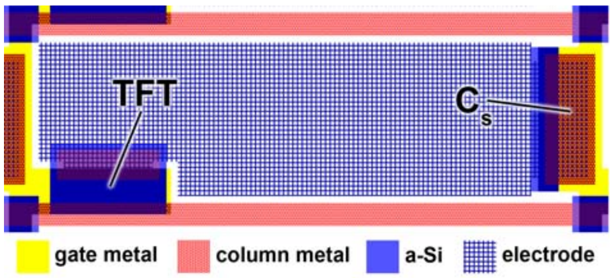

Fig. 2. Lateral design of a single pixel

Table 1: Details of designed AM-LCD

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 %

With the rather conservative chosen design rules of the pixel TFTs we reach a quite stable and reliable process on flexible glass. Figure 3 shows a photograph of the completely manufactured active matrix with all layers up to the pixel electrode on ultra-thin glass.

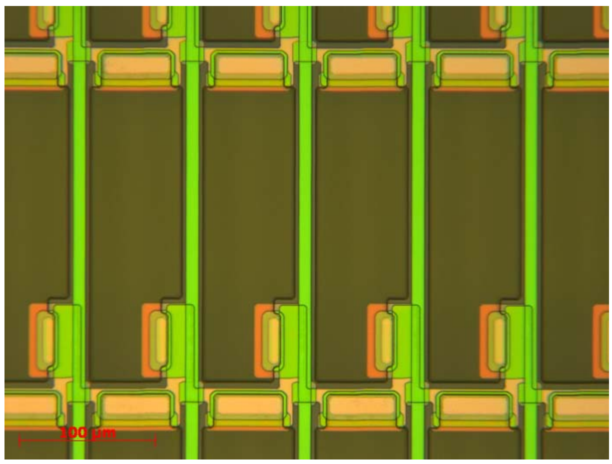

Fig. 3. Completely fabricated ultra-thin glass backplane

No mismatches between the alignment marks of the individual layers were observed, which demonstrates the expected dimensional stability of ultra-thin glass substrates.

For the frontplane (Fig. 4) a sputtered inorganic black matrix, spin coated color filters CR-7001 (red), SG-2000L (green) and SB-2000L (blue) from Fuji Film Arch as well as the unpatterned ITO backing electrode and the organic topcoat PC403 (to planarize the topology) are realized. This requires five masks. The maximum processing temperature for the frontplane was 230°C. To finish the frontplane and backplane, polyimide SE-130 from Nissan is spin coated with a thickness of 20 nm and brushed with a velvet roller on each substrate for orientation of the LC.

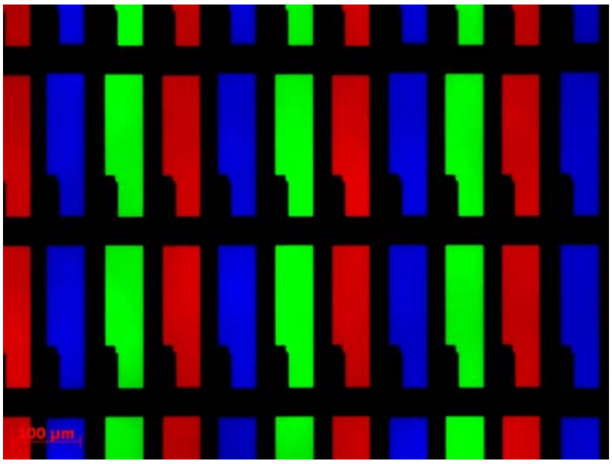

Fig. 4. Color filter with black matrix on ultra-thin glass

The frontplane has to be cut to get access to the bond contacts later. The cell is assembled and vacuum filled with Merck TN liquid crystal MLC-12049-000 mixed with a dopant MLC-6241. It was necessary to modify the fill opening and the cell fixation process when using the ultra-thin glass cells due to their flexibility. To complete the display, crossed polarizers from Sanritz are applied. Before driver chip bonding, the backplane also has to be cut. The cutting process of frontplane 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 new ultra-thin glass provided sufficient strength for display assembly and driver bonding.

The last step is driver chip bonding. In Figure 5 the ultra-thin glass AM-LCD with all bonded driver chips and enhanced column driver bond connection is depicted.

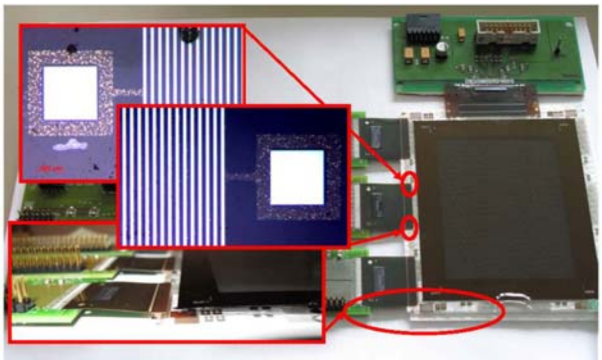

Fig. 5. Display with precise bond connection / MoTa (white) on Au contacts of TAB

Even with the incorporated 75 µm glass substrates, reliable and safe bonding of small pitches (54µm) is possible.

4. RESULTS AND DISCUSSION

To be able to control the process, test TFTs are placed in each corner of the backplane close to the matrix. In Figure 6 transfer characteristics of test-TFTs are displayed. The visible threshold voltage shifts seem to be caused by electrostatic charges. Similar to what we observed on thicker standard glass substrates, an additional temper step can eliminate these charges. The addressed matrixes however show homogeneous behavior. 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 well suited for an AM-LCD.

Figure 7 shows typical output characteristics of the test-TFTs with a good saturation behavior. These TFT results are very comparable to bottom gate a-Si TFTs which were manufactured earlier on thicker standard glass substrates [5].

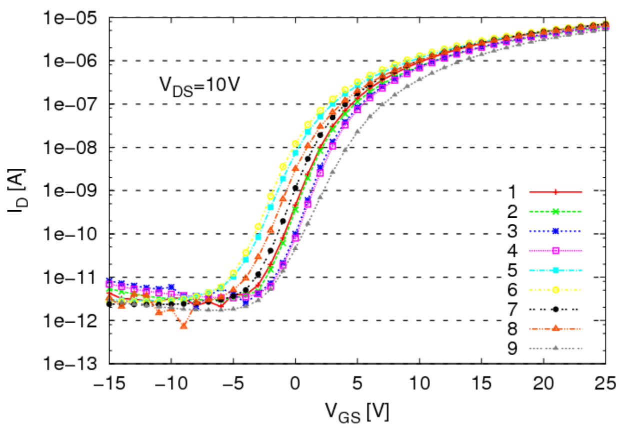

Fig. 6. Transfer characteristics of test-TFTs

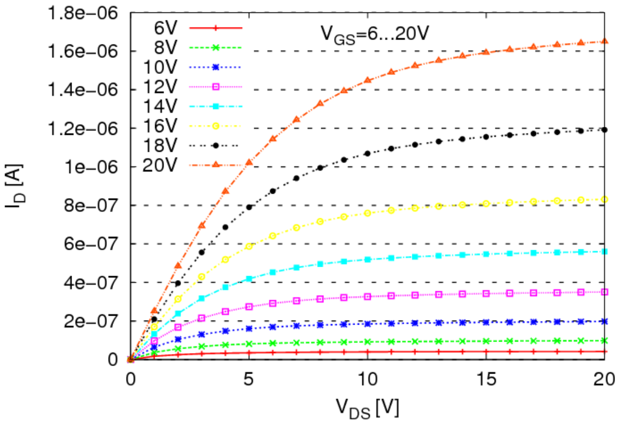

Fig. 7. Output characteristics of test-TFTs

Despite the manual handling during the fabrication in a university lab, the display shows very limited defects. Pixel defects are often caused by particles. The few column and row defects are caused by broken metal wires. An image of the addressed full color AM-LCD is shown in Figure 8.

Displayed are yellow LfB labels on black and blue stripes, generated by a pattern generator. LfB is the German abbreviation for Chair of Display Technology.

Due to an imperfect bond connection during column driver bonding the right side of the display is not fully addressable.

Fig. 8. Working AM-LCD prototype on ultra-thin glass

5. SUMMARY

We produced a full color qVGA a-Si AM-LCD on ultra-thin glass with an overall LC cell thickness of <170 µm. To our best knowledge, this is the first presentation of an active matrix display which was directly built on 75 µm thick glass without the use of additional glass coatings and/or carrier substrates.

The fabricated displays demonstrate the mechanical compatibility of ultra-thin glass substrates with a standard active matrix display process. For a university lab, efficient AM-backplanes and displays are achieved.. These results provide great insight for obtaining thinner devices in future flexible displays for a variety of applications that incorporate flexible glass substrates.

6. ACKNOWLEDGEMENTS

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