Metal Induced Continuous Grain Polycrystalline Silicon Thin Film Transistors and Its Application for Field Sequential Color-Liquid Crystal Display (FSC-LCD)

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Abstract

Metal induced polycrystalline silicon (poly-Si) films composing of continuous zonal domain (CZD) have been obtained through pre-defined crystalline nucleation lines. The crystallization process is precisely controllable and the annealing time can be shorter than one hour. P-channel thin film transistors (TFTs) built on CZD poly-Si present high performance and high uniformity. In this paper, we also demonstrate the application of CZD TFT to fast addressing active matrix field sequential color-liquid crystal display (FSC-LCD). A prototype display panel has been fabricated. Large aperture ratio, excellent color purity and fast moving image can be obtained.

Key words: active matrix LCD, metal induced crystallization, field sequential color

I. Introduction

Low temperature crystallization of amorphous silicon (a-Si) thin film has attracted considerable attention because of its potential applications to large area electronics on inexpensive glass substrates and its high mobility. Thin-film transistors (TFTs) built on metal-induced unilateral crystallized (MIUC) polycrystalline silicon (poly-Si) have shown high carrier mobility and good device uniformity. They can be used to realize active-matrices for flat-panel display and image sensor applications [1].

However, MIUC-TFTs [2] have problems of subsequent mask misalignment induced by glass substrate shrinking during the crystallization process. Additionally, residual nickel in the poly-Si channel affects the long term stability of the TFTs.

There have been several attempts to reduce the Ni content in MIC based TFT. Giant grain silicon (GGS) has been obtained by Ni-mediated crystallization of a-Si with a silicon-nitride (SiNx) cap layer [3] or using solution based metal-induced crystallization (SMIC) [4]. The problem of subsequent mask misalignment induced by glass substrate shrinking can be solved with these technology, but the random distribution of crystalline nuclei leads to longer annealing time, which is not acceptable for large area glass substrate.

A new implementation scheme which can reduce residual nickel in poly-Si as well as annealing time is proposed and demonstrated. The nickel content and distribution in crystallized CZD poly-Si film is analyzed by time of flight Secondary Ion Mass Spectrometry (Tof-SIMS). P-channel TFTs built on this CZD poly-Si exhibit high performance and high uniformity.

We also applied the CZD TFT to a field sequential color-liquid crystal display (FSC-LCD). FSC LCD can realize full color without color filter by using a field sequential LED backlight. FSC LCD has the merit of high efficiency, low cost and low power consumption. In this paper, the fast addressing active matrix for FSC-LCD is designed and fabricated with the technology of metal induced CZD poly-Si TFTs. This panel provides fast addressing characteristics and large aperture ratio.

II. CZD material formation and analysis

2.1 CZD material formation

The fabrication process began with the deposition of 300nm silicon oxide (SiO_2) using plasma enhanced chemical vapor deposition (PEVCD) on Eagle 2000 glass substrate. Then 50nm a-Si was deposited by low-pressure chemical vapor deposition (LPCVD) at 550 ºC. A SiO_2 nano-cover layer was formed on the surface of a-Si, and then it was defined as uniformly distributed lines in width of 1.5μm and space of 30μm from the neighboring lines. The length of the line is equal to the width of the substrate. After the photolithography, the photo-resistor was removed by a mixed solution of H_2SO_4 and H_2O_2 at 120 ºC. At the same time a ~2nm layer chemical oxide was formed. Then an ultra-thin layer of nickel was sputtered on the cover layer. The schematic of the CZD structure was shown in Fig. 1. After annealing at 590 ºC for 1 hour the a-Si was fully crystallized. The width of the zonal domains was half of the distance between two neighboring crystalline nucleation lines (CNL), and the length of the zonal domains was the same as the width of the substrate, which can be tens of centimeters to several meters.

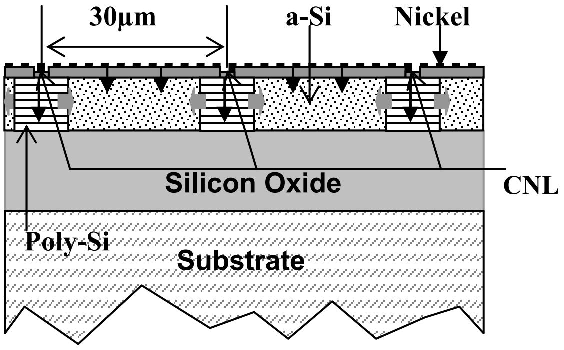


Fig.1. Cross section of the CZD structure

2.2 Comparison with GGS poly-Si

The metal induced poly-Si films composed of CZD in exactly same width can be obtained through pre-defining CNL on a nano-layer of silicon dioxide. After the crystallization process, the entire poly-Si film can be the active layer of high performance thin film transistors (TFTs), so the impact of glass substrate shrinking on subsequent alignment process is eliminated. All crystallized zonal domains have exactly the same width and length so that the crystallization process is strictly controllable and the annealing time is shorter than one hour at 590 ºC. Fig. 2 shows the optical microscopy images of amorphous silicon films after one hour annealing at 590 ºC in nitrogen (N_2) atmosphere using GGS and CZD technology respectively. The films are etched by tetra-methyl ammonium hydroxide (TMAH). As shown in Fig. 2 the CZD film has been fully crystallized and the GGS film still has a lot of areas not crystallized. Fig. 3 shows the average crystallization fraction over large area substrate of the film employing GGS and CZD technology as a function of the annealing time at 590 ºC. 100% crystallization fraction can be obtained using CZD technology at 60 minutes, while that is just about 50% for the GGS technology.

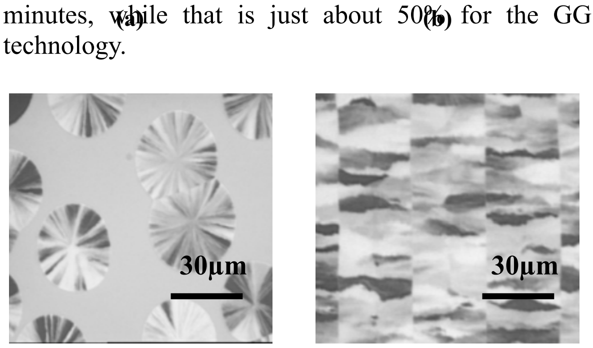


Fig.2. Optical microscopy images of amorphous silicon film after one hour annealing at 590 ºC in N_2 atmosphere employing (a) GGS technology and (b) CZD technology.

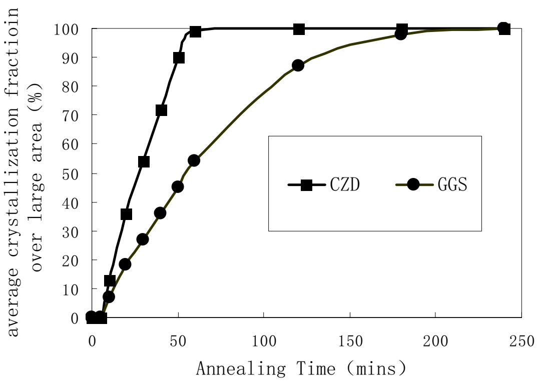


Fig.3. The average crystallization fraction over large area using CZD and GGS technology versus the annealing time at 590 ºC.

2.3 Comparison with MIUC poly-Si

To compare the residual nickel concentration in CZD and metal induced lateral crystallization (MILC) poly-Si films after the crystallization process, the Ni content and distribution in CZD and MILC poly-Si films were measured by time of flight Secondary Ion Mass Spectrometry (Tof-SIMS). The nickel content in CZD film is two orders of magnitude lower than that in MILC film (Fig. 4(a)). Fig. 4 (b) and (c) show the two-dimensional (2D) distribution of Ni in CZD and MILC poly-Si films respectively. Nickel and/or nickel silicide are denoted as bright dots in the 2-D images. In 2-D image of MILC poly-Si film (Fig.4 (b)), the bright columns on both sides are MIC regions and the dim line in the middle is the intersection of two MILC regions. It reveals that the nickel content is a little higher at the intersection and much higher in the MIC regions.

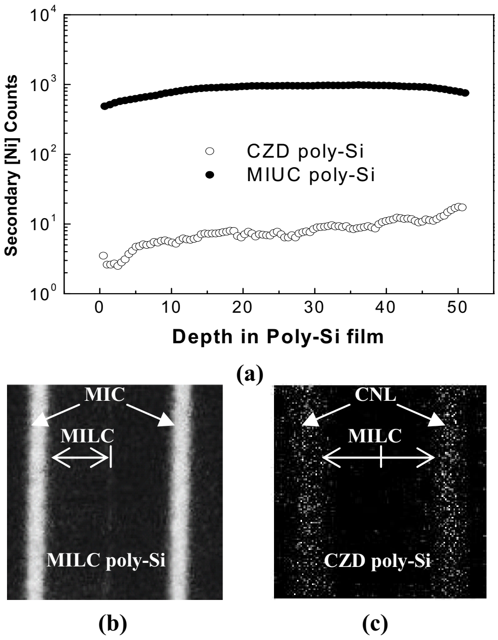


Fig. 4. The SIMS depth profiles of nickel content (a) and 2-D image of Ni distribution in (b) MILC poly-Si film and (c) CZD poly-Si film traced by SIMS.

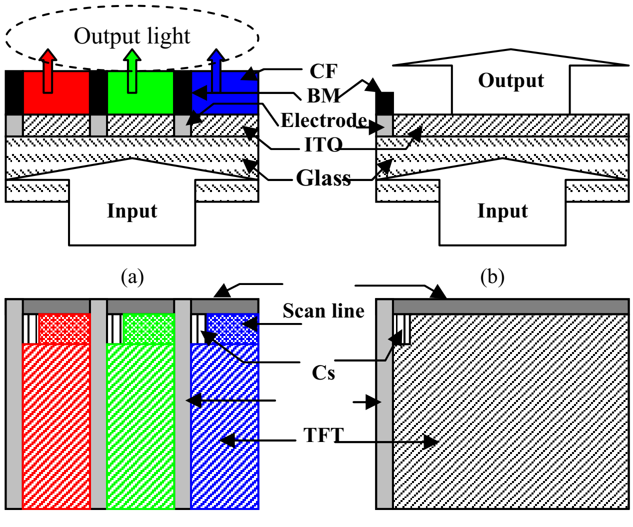
In the 2-D image of CZD poly-Si film (Fig.4 (c)), similar to the MIC region of MILC films, a higher Ni concentration is distributed at the crystalline nuclei lines region (CNL). But the ratio of MIC region to MILC region in MILC films was much higher than that of CNL region to MILC region in CZD films. It means that there is no area on the CZD poly-Si which contains a very high concentration of Ni. The entire poly-Si film is available for the active layer in TFT. So it means that the CZD poly-Si films have lower Ni concentration and higher uniformity.

III. Field sequential color display

Liquid-crystal display (LCD) is presently the dominant FPD technology because of its portability, low power consumption and mature manufacturing practice.

High resolution, high optical efficiency, high color purity, and low cost are becoming the critical factors for LCD displays, especially for portable applications. [5]

Color representation in a conventional liquid crystal display (LCD) with color filter is realized by a combination of liquid crystal cells, micro color filters (CF) on each pixel, and a white backlight. Here, a pixel is consist of 3 sub-pixels in R, G and B, [6] as shown in Fig.5(a). 70-80% of the backlight are absorbed by the CF.[7] So in conventional LCD with CF, the efficiency of the backlight is only <10%.



(a) (b)

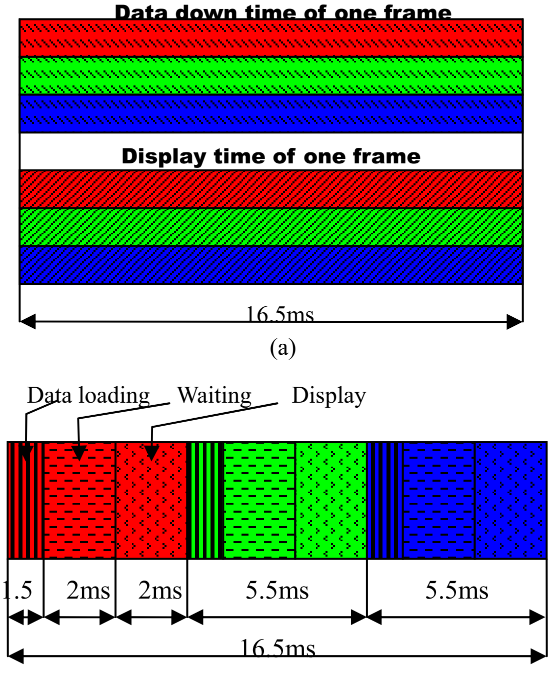
(c) (d)

Fig.5. The schematic of cross section for traditional Color filter LCD (a) and color sequential LCD (b). Layout of the traditional Color filter LCD (c) and color sequential LCD (d) for a pixel.

A field sequential color (FSC)-LCD reproduces R,G and B colors in a pixel in a time sequence using synchronously pulsed colored LED backlights and a liquid crystal cell without micro color filters. [8] The pixel structure is shown in Fig.5(b). This method can produce higher brightness display since there is no the color-filter (CF) which absorbs more than half of the backlight. The number of pixels of the FSC display is only one third of that of a display with CF. As a result, a FSC-LCD is expected to have a higher aperture ratio (AR) than a color filter display with the same resolution, or it can realize three times higher resolution using the same technology.[9]

The working principle of a FSC-LCD is by using a field sequential LED backlight. Color mixing can be achieved by controlling the on and off of the LCD when different color LED is flashing. For example, if we want to have red color, the LCD is in the off state when the red LED backlight is on and the LCD is in the on state when the green and blue LED backlight is off. By controlling the gray-level of LCD, full color display can be obtained.

As a compensation for reduction of two thirds of pixels, each pixel of the color sequential LCD should be driven three times as fast as a conventional LCD, assuming the same frame rate. The principle of the driving for CS-LCD is shown in Fig. 6(b). For a QVGA display with 60Hz frame rate, one frame can have a duration of approximate 16.5ms, which contains 3 sub-frames. The time limit for each sub-frame is only 5.5ms. The minimum response time of LCD needs 2ms and the minimum LED illumination needs about 2ms. Therefore, only around 1.5ms is left for data loading, as shown in Figure 6(b). For a color-filter LCD with the same resolution, the frame time is also around 16.5ms. The data loading, LDC response and LED illumination occurs at same time, as shown in Fig. 6(a). That means the loading time for FSC-LCD is 1/10 of that for color filter LCD assuming the same resolution. Compared to a-Si TFT, the CZD poly-Si TFT presents larger mobility and larger on state current at the same time which meets the requirements of FSC-LCD. That is why the CZD poly-Si TFT was selected to applied for FSC-LCD.



(a)

(b)

Fig.6. Driving principle of QVGA color-filter LCD (a) and field sequential color LCD (b)

IV. Fabrication for Active Matrix

The CZD poly-Si film was patterned into active islands by wet etching with Freckle etchant. 50nm low temperature oxide (LTO) was subsequently deposited by LPCVD at 425 ºC as the gate insulator. Following defining gate electrodes and the scan line, boron at a dose of $4\times10^{15}/cm^2$ was implanted into the source and drain. A 500nm PECVD oxide as isolation layer was deposited and contact holes were opened on the gate electrode. Subsequently, 700nm aluminum-1%Si was sputtered and patterned to form the inter-connections. Contact sintering was then performed in forming gas at 420 ºC for 30mins and the dopants were activated at the same time. The pixel electrode indium thin oxide (ITO) was patterned by lift-off process. Finally the black matrix was defined to reduce the reflection of Al electrode. The panel was the ready for LCD integration.

Electrical characteristics of CZD poly-Si TFTs were measured with HP4156 semiconductor parameter analyzer. Transfer characteristic curves and their field effect mobility (μ_{FE}) of TFTs are shown in Fig. 7. The p-channel CZD poly-Si TFTs exhibited a maximum field effect mobility (μ_{FE}) of $65.21cm^2/V\cdot s$, a sub-threshold swing (S) of 0.56V/dec and a threshold voltage (V_{th}) of -3.6V. The on state current and off state current of the TFTs are 7.36×10^{-4}Å and 4.1×10^{-11} Å respectively. The ratio of on-state to off-state drain current is 2.6×10^{7}.

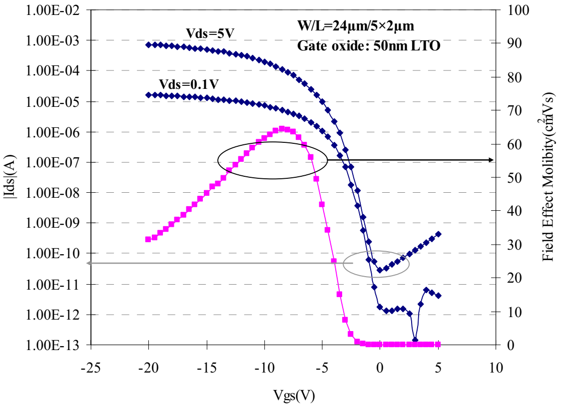


Fig.7.Ttransfer characteristic curve and the field effect mobility (μ_{FE}) for TFTs.

A transient mode LCD based on optical rebounce was employed [10]. This mode has previously been used for making a passively driven FSC display. It relies on the optical bounce which is a transient effect. Thus it overcomes the difficult requirement of having to use a very fast LCD mode. Details of the operation and principle of this LCD has been discussed before. Essentially it is noted that with a sub-frame time of only 5.5ms, it is very difficult to have a transition from one stable LC alignment to another LC alignment. However, the transient can occur very fast. Since in FSC, the LED is on for a very short time (2ms) it is in fact not necessary for the LC alignment to be a stable state. A transient state works perfectly. Fig. 8 shows the representative image from this 3-inch QVGA active matrix FSC-LCD.

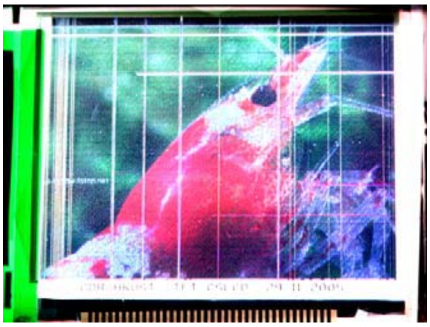


Fig.8. The representative image from the 3-inch QVGA active matrix CS-LCD

V. Conclusion

A new implementation scheme is presently proposed to realize continuous zonal domain (CZD) polycrystalline silicon (poly-Si) films. This new technology can eliminate the impact of glass substrate shrinking on subsequent alignment process. At the same time the crystallization process is strictly controllable and makes the annealing time shorter than one hour at 590℃. The P-channel TFTs built on this CZD poly-Si exhibit high performance and high uniformity. 3 inch QVGA Active Matrix for FSC-LCD was fabricated based on the above technology. The display realizes good colors and fluent video display.

VI. Acknowledgments

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