論 文 内 容 の 要 旨

In-Ga-Zn-O (IGZO) is an ionic amorphous oxide semiconductor, which has high field effect mobility (10 ~ 30 cm²/V•s), transparence to visible light (bandgap of ~ 3.2 eV), and room temperature deposition. These properties make IGZO thin film transistors (TFTs) a promising candidate for active-matrix backplane of flat panel displays (FPDs). A low power consumption, high frame rate and ultra-high resolution are some advantages of FPDs driven by an IGZO TFT array compared with an amorphous Si TFT. In FPDs, a negative voltage is normally applied to the gate electrode when the pixel is held. Besides of that the TFTs also be illuminated by back light unit. Therefore, the TFTs are worked under negative bias and illumination stress (NBIS). On the other hand, a positive voltage is applied to the gate electrode when TFT is operated at the on-state. The TFTs are worked under positive bias stress (PBS). Therefore, reliability of TFTs under NBIS and under PBS are required for the display application. However, reliability of IGZO TFT under PBS and under NBIS has been known as the critical issues. This research focuses on investigation of the degradation mechanism of IGZO TFT under PBS and under NBIS. Based on the investigated degradation mechanism, method to improve the reliability of IGZO TFT under PBS and NBIS was proposed. This dissertation includes 8 chapters.

+) Chapter 1 is an overview about the history of display technology and of material for TFTs, which have been used in FPDs backplane. The reasons for high carrier mobility in amorphous IGZO will also be explained comparing to that in amorphous silicon.

+) Chapter 2 will describe the working principle of the deposition and evaluation equipment, which were used in this research, such as DC-magnetron sputtering, Plasma enhanced chemical vapor deposition (PECVD), X-ray reflectivity measurement (XRR), and Secondary ion mass spectrometry (SIMS) measurement, and so on.

+) In chapter 3, we will introduce our new measurement method named as positive gate pulse mode (PGPM). PGPM was used to investigate the NBIS degradation mechanism. Due to the importance of the NBIS reliability issue in FPDs application,

numbers of researches relating to the NBIS degradation have been reported. Trapped holes in the gate insulator (GI), generated defects in the channel have been widely accepted as reasons for the NBIS instability in IGZO TFT.

In the previous reports, TFT transfer characteristic has been measured by single sweeping mode (SSM), in which the gate voltage was swept haft cycle, for instance from a negative voltage to a positive voltage. However, we found that the SSM did not fully capture the NBIS degradation behaviors. Therefore, double sweeping mode (DSM) was used to measure the transfer characteristics of IGZO TFT under NBIS. DSM is a transfer characteristic measurement method in which gate voltage was swept one cycle, for instance from a negative voltage to a positive voltage and reversed. By using DSM, a new NBIS degradation behavior, that is a positive shift in reverse curve, was observed during NBIS stress time. Threshold voltage (V_{th}) in reverse measurement (V_{rev}) shifted positively without subthreshold swing (Ss) degradation. The change in V_{rev} with NBIS stress time was well fitted by a stretched-exponential equation. These results indicate that trapped electrons at the back channel interface are the reason for the positive shift in reverse curve. By using DSM, a new mechanism for the NBIS instability, which is the trapped electrons at the back channel interface, was found.
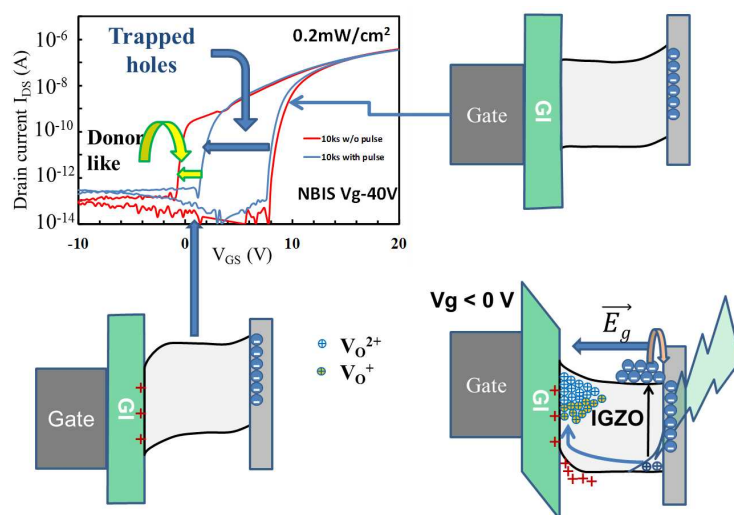

Figure 1: NBIS degradation mechanism

Using DSM, we also found that TFT hysteresis (V_h) increased with NBIS duration. Based on the results of our studies, the trapped holes and the generated defects could be reasons for the increasing in hysteresis. Therefore, a quantitative effect of the trapped

holes and the generated defects is necessary for finding a method to improve the NBIS reliability. In order to do that, we developed a novel measurement method, named as positive gate pulse mode (PGPM). PGPM is a transfer characteristic measurement method in which a short positive gate pulse is applied to the TFT before every transfer characteristic measurements. Results measured by PGPM indicate that the hole trapping in the GI are the main cause of the NBIS instability in IGZO TFT. The contribution of hysteresis induced by the trapped holes to the hysteresis was 80%. Therefore, reducing the trapped holes in the GI will significantly improve the NBIS stability of the IGZO TFT. Based on the results measured by DSM and PGPM, a new degradation mechanism of the IGZO TFT under NBIS was proposed and illustrated in figure 1. Figure 1 shows that quality of the IGZO channel, of the back channel interface and of the GI shall strongly affect to the NBIS reliability of IGZO TFT. Therefore, the effects of channel film density and of the back channel quality on the NBIS reliability will be discussed in chapter 4, and 5, respectively. Chapter 6 will discuss about the hole trapping mechanism and method to improve the NBIS reliability of the IGZO TFT.

+) In chapter 4, the effect of film density of IGZO channel on the defect creation in IGZO TFT under NBIS was investigated by using PGPM. The IGZO channel was deposited by DC-magnetron sputtering at a substrate temperature of without heating, 150, 250°C. The film density of IGZO channel which was measured by X-ray reflectivity (XRR) measurement increased with deposition temperature. Figure 2 shows the effect of IGZO deposition temperature on the NBIS degradation behaviors. The PGPM was conducted to quantitative analyze the effect of IGZO deposition temperature on the trapped holes and on the generated defects. Results indicate that the generated defects in the channel can be reduced by increasing the film density of the IGZO channel. Figure 2 also shows that the positive shift in reversed curve enhanced when the film density of the channel decreased. This result implies that the electron trapping at the back channel interface were reduced with the IGZO film density. In other word, a high film density of the channel can reduced generation of the defects not only in the channel but also at the back channel interface, resulting an improvement of the NBIS reliability. However, it was also found that the hole trapping in GI did not depend on the IGZO film density.
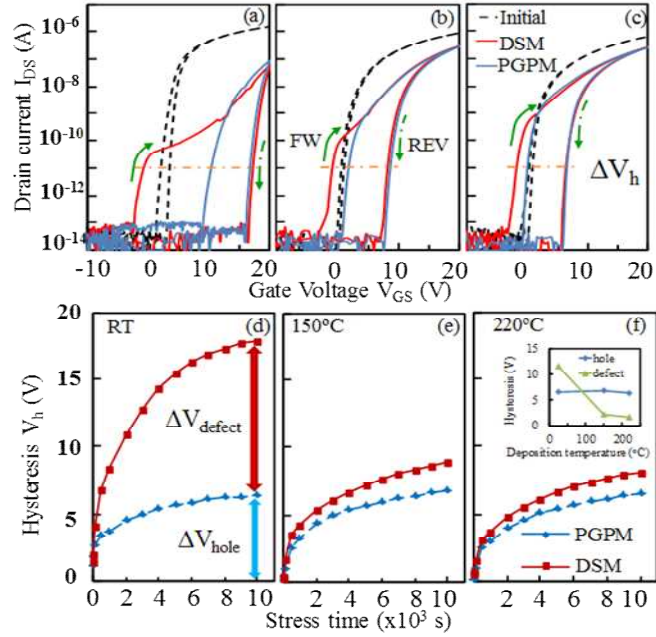
Figure 2: Effects of IGZO deposition temperature on the NBIS reliability

+) In chapter 5, we will investigate the effects of back channel interface quality on the NBIS reliability. Quality of the back channel interface was varied by the PE-CVD plasma power of SiO_x etching stopper (ES) deposition. The plasma power of SiO_x ES deposition was varied as 40, 50 and 55 W. Figure 3 shows the effects of the plasma power of ES deposition on the NBIS reliability. A positive shift in reverse curve and hysteresis induced by generated defects reduced when the plasma power decreased. This result implies that the generation of the defects at the back channel interface and in the channel could be reduced by decreasing the plasma power of the SiO_x ES deposition.
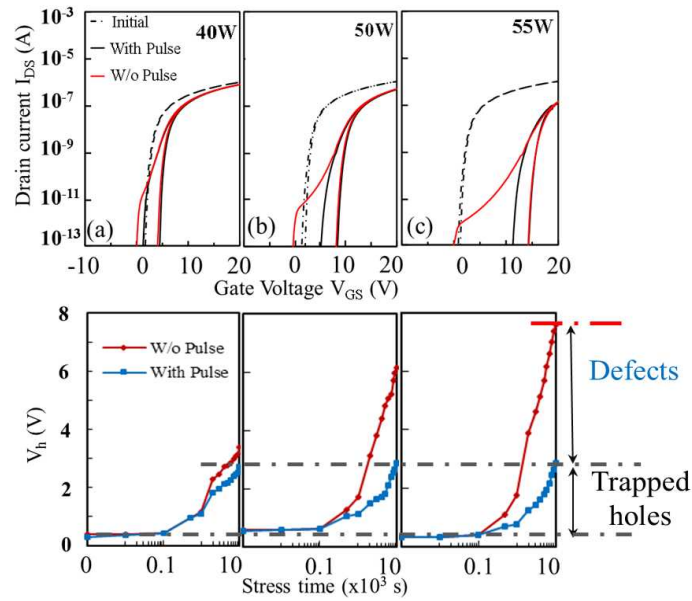
Figure 3: Effects of ES deposition condition on the NBIS reliability in IGZO TFT

+) Chapter 6: Hole generation mechanism an driving method to improve the NBIS reliability.

As discovered in chapter 3, the results obtained from PGPM indicated that the hole trapping at the GI/channel interface are the main cause of the NBIS instability in IGZO TFT. A reduction of the hole trapping at the GI/channel interface shall strongly improve the NBIS reliability. One way to reducing the hole trapping is an increase of potential barrier for hole trapping at the GI/channel interface. However, it is difficult to evaluate the energy barrier for hole trapping if the effects of trapped holes and generated defects on the NBIS instability were not separated. Using PGPM to separate this effect, the average effective energy barrier for hole trapping in GI was calculated to be 0.39 eV. The SiO_x and AlO_x have been found to be the best GI material to reducing the hole trapping in the GI. Therefore, the hole generation mechanism was investigated in order to find another method to further reducing the hole trapping in the GI. The hole generation mechanism was classified by studying the effects of negative duration and of light intensity on the NBIS degradation behaviors. The obtained results suggest the hole generation which is shown in figure 4. The generated defects are unstable and act as midgap trap states for hole generation. These results suggest that a reduction of DOS exiting at midgap will improve the NBIS stability. The results obtained from PGPM

suggested that, the midgap trap state could be stabilized by a positive gate pulse. Therefore, the NBIS stability of the IGZO TFT could be improve by applying a positive gate pulse alternatively with a negative gate pulse. In other word, in order to improve the NBIS stability, the FPDs need to be working at high frame rate and low refresh time.
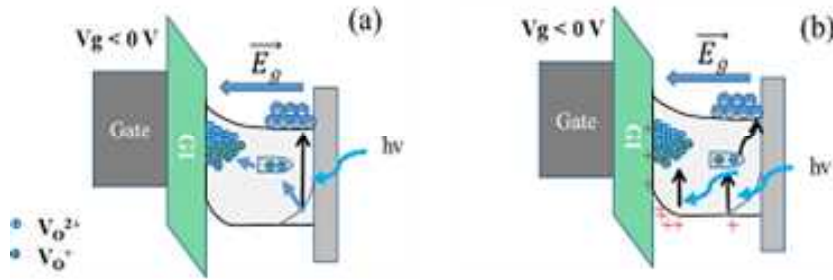

Figure 4: Hole generation mechanism

+) Chapter 7: PBS degradation mechanism and method to improve the PBS reliability.

PBS reliability of IGZO TFT is not so serious problem as compared with the NBIS reliability; however the reliability of the IGZO TFT under PBS has also gathered attention of many researchers. The PBS degradation mechanism has been extensively investigated. The trapped electrons at the GI and deep defects creation in the channel have been widely accepted as reasons for the PBS instability. The deep defect creation in IGZO TFT under PBS has been predicted by the study of the activation energy of electron trapping into and detrapping from (recovery process) the GI. However, the direct evidence of the deep defect creation and the energy level of the created defects have not been reported yet. It is due to the fact that, the trapped electrons and the created deep defects induce the same degradation behavior in both transfer and C-V characteristic. In this study, the conductance measurement method was used to investigate the PBS degradation mechanism of the IGZO TFT. The conductance measurement method is not only measure the density of state at the GI/channel interface but also extract the defect properties such as capturing cross section and capturing time. These information are important to recognize the characteristic of the defects which was overlapped each other. The obtained results indicate that the stabilization of donor like interface defects are reason for the PBS instability. We also

investigate the effects of post annealing time on the PBS stability of the IGZO TFT. Results show that, the PBS stability increased with post annealing time. When the post annealing time increased from 1 to 5 hours, the electron trapping at the IGZO/SiO$_x$ interface was reduced. This is a reason for the PBS improvement mentioned above. However, when the post annealing time was increased to 5 hours, the deep acceptor like interface defects were detected. The defects located just below Fermi level. This result also suggests that the PBS degradation mechanism was changed from donor like defects stabilization to the deep acceptor like defects creation.

+) Chapter 8: Conclusions.

The NBIS degradation mechanism of IGZO TFT was investigated by using the DSM and PGPM. We clarified that hole trapping in the GI, generation of the defects in the TFT channel and electron trapping at the back channel interface were reasons for the NBIS instability of the IGZO TFTs. The PGPM, a new measurement method, was successfully developed to separate the effects of the hole trapping and of the defect generation on the NBIS instability. Results obtained from PGPM indicate that the hole trapping was the main case of the NBIS instability. By separating the effects of the hole trapping and of the defects generation, the hole trapping energy barrier of 0.39 eV was calculated for the IGZO/SiO$_x$ interface. The electron trapping at the back channel interface and the defect generation could be controlled by either the film density of the channel or the PE-CVD plasma power of the SiO$_x$ ES deposition. The generated defects were unstable and act as midgap traps for hole generation. Based on these results, a control algorithm of FPDs driving was also proposed to improve the NBIS stability of the IGZO TFT. An increasing frame rate and reducing refresh time of the FPDs significantly improved the NBIS stability of the IGZO TFT. Results in chapter 3,4,5,6 prove that the PGPM is an effective measurement method to investigate the degradation mechanism. The results of PGPM have high value in the work to improve the NBIS reliability of IGZO

The PBS degradation mechanism of IGZO TFT was also clarified by conductance measurement method. The donor like interface defects act as the electron trap states and could be stabilized by capturing electron. The stabilization of donor like interface defects was the main reason for the PBS instability in the TFT. An increasing post annealing time reduced electron trapping in the GI of PE-CVD SiO$_x$. The acceptor like

interface defects were experimentally detected by the conductance measurement method. The PBS reliability of IGZO TFT can be improved by increasing the post annealing time.