IGZO TFT behavior Under X-ray Irradiation in DXD Panel

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ABSTRACT

Recently, digital X-ray detector technology is required for realization of high quality and dynamic image and low-dose exposure at X-ray imaging systems. For this purpose, it is trying to apply oxide TFTs for switching device, so it is necessary to study the degradation phenomena of oxide TFTs under the X-ray irradiation.

1 Introduction

Digital X-ray Detector (DXD) provides more enhanced x-ray images quality and faster than analog images by chemical developing in medical diagnosis and industrial inspection area. As computer engineering and IT technology developed, X-ray images began to be displayed on the monitor directly. Recently, they are making efforts to reduce the time and place to take, check, and store x-ray images by converting to digital methods.[1]

In particular, the indirect type DXD using scintillator with amorphous Si (a-Si) TFT and a-Si PIN diode backplane has high sensitivity and can drive by low voltage, so it is possible to fabricate a compact mobile detector, which is a technology that has grown significantly in recent years. In addition, development of DXD backplane using high-performance oxide TFT is in progress for diagnosis through dynamic images as well as static images.[2],[3]

It is possible to improve the image quality due to increase the signal to noise ratio from the low leakage current of the oxide TFT, and The harm to the human body can also be lowered by reducing the x-ray dose. Also high-speed detector driving through the high mobility of oxide TFTs enables computerized tomography (CT) for non-destructive inspection of industrial products and diagnostic medical x-ray imaging for children and animals with a lot of movement.

Conventionally, CMOS detectors using crystal Si have been mainly used for dynamic X-ray imaging, but when X-rays irradiation accumulates, the crystal Si lattice is damaged by x-ray, so the image quality of the detector is degradation and the life of the detector is shortened. Therefore, in order to develop high performance DXD using oxide TFT, it is necessary to accurately know the deterioration characteristics of the device by X-ray cumulative irradiation. Therefore, in this paper, we investigated the deterioration characteristics of the oxide TFT under the X-ray irradiation in various ways and the causes of degradation.

2 Experiment

We fabricated the pixel structure of amorphous InGaZnO (a-IGZO) switching TFTs under the a-Si PIN diode as a light receiving photo sensor for oxide DXD backplane. To measure the difference of the characteristics of device before and after X-rays irradiation, it was prepared many TFT samples on the plate and exposure the X-ray step by step. In addition to oxide TFT, a-Si TFT and poly-Si TFT devices fabricated on glass were also measured for changes in device characteristics according to X-ray irradiation. TVX-IL3205CT system from Tech Valley Corporation was used as a device for X-ray irradiation, and an X-ray source capable of continuous emission. Its available voltage was up to 320KV and maximum power was 800W possibly.

The X-ray dose rate was used at 40 Gy/Hr in the actual experiment. Besides the direct irradiation to the TFT device, x-ray irradiation evaluation was conducted on the oxide TFTs under the scintillator. Because the real X-ray irradiation effect is that from the remaining X-ray after passing through the scintillator in the actual systems. The scintillator used at this time was a 600um thick CsI:Tll film of Hamamatsu Inc. Another experiment was evaluating the differences of oxide TFTs according to the energy range of the X-ray by using Al filter which was high pass filter of X-ray. We simulated the X-ray spectrum using Al filter and expected under 40KVp energy was blocked by 10mm Al Filter from the X-ray tube accelerated to 120KVp. And also we irradiated to samples X-ray that was from the x-ray tube accelerated 40KVp for low energy investigation. (Dose rate was 5gy/Hr) Additionally, the exposure of gamma ray (1.17 MeV + 1.33 MeV, dose rate 40 Gy/hr) was also conducted to compare the electrical deterioration characteristics of oxide devices according to photon energy. All electrical measurements were performed using Keithley 4200 SCS instrument. (All samples were made in LG Display R&D Fab. and X-ray system was not for medical X-ray imaging)

3 Results and Discussion

In the Fig. 1, there are the characteristics of a-Si TFT, low temperature poly-Si (LTPS) TFT, and oxide TFT based in a-IGZO which were widely used in the LCD manufacturing process, before and after cumulative irradiation of 50Gy of X-ray. The condition of x-ray was accelerated 100KVp, 10mA at the X-ray tube. In Fig.1, we can find that the electrical properties of a-Si TFT, which is currently commercially used in DXD backplane, didn't any change caused by X-ray exposure. On the other hand, in the case of LTPS TFT, it was confirmed that the sub-threshold slop was greatly collapsed and the TFT characteristics deteriorated. This is believed to be related to the short lifetime characteristics of DXD made of crystal phased Si (Si wafer), which is used in existing high-performance X-ray detectors. Unlike amorphous phased Si, it is thought that the lattice of crystal Si was broken by X-ray irradiation and the device characteristics were deteriorated.

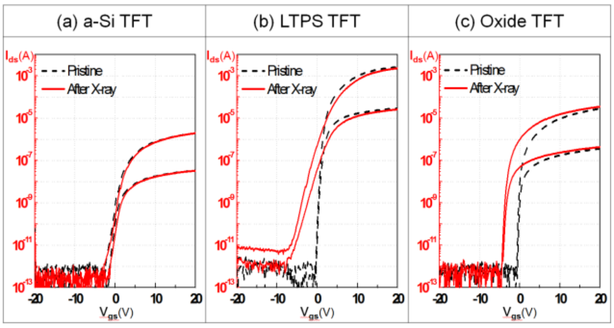

Fig.1. Electric transfer curves of (a) a-Si TFT, (b) LTPS TFT, (c) Oxide TFT before and after x-ray irradiation. Black dashed line is pristine and red solid line is after x-ray irradiation.

In the case of oxide TFT, although the device characteristics differ from the initial characteristics according to X-ray irradiation, it can be seen that only V_{th} is negatively shifted without changes such as degradation of sub-threshold slop or increasing off current. Similar to a-Si material, a-IGZO, which has an amorphous phase, was not occurred the kinds of issues such as lattice breakage by X-ray. However unlike a-Si TFT, it shows large negative shift of threshold voltage (V_{th}) that was judged to be a phenomenon caused by the increase of carrier in the TFT channel by X-ray.

In order to confirm this phenomenon, we made devices by varying the oxygen partial pressure condition of IGZO sputtering. In general, the field-effect mobility of IGZO TFT increases as decreasing the oxygen partial pressure during sputtering, because a lot of carriers from the oxygen vacancy ionization are created in the oxide semiconductor layer under the lack of oxygen condition.[4] Each TFT exhibits different mobility of 13 cm^2/Vs, 10 cm^2/Vs, and 5 cm^2/Vs respectively. In the Fig.2 we can find the results of measuring V_{th} fluctuations of these TFTs by X-ray irradiation and there was no difference in device degradation characteristics according to each TFT's mobility. It is believed that the oxygen vacancy in the IGZO thin film is not the main cause of the negative V_{th} shift under the x-ray irradiation.

Another possible cause of the increase in carriers is hydrogen (H). H is primarily considered a shallow donor and/or defect passivator in oxide semiconductors.[5] It is thought that H in the buffer or GI layer is separated by x-ray irradiation, and this H penetrates into the IGZO layer and then increases carriers in TFT channel. This hydrogen effect from the peripheral insulator films may well explain about negative V_{th} shift after x-ray exposure rather than oxygen vacancy in the oxide TFT.[6].

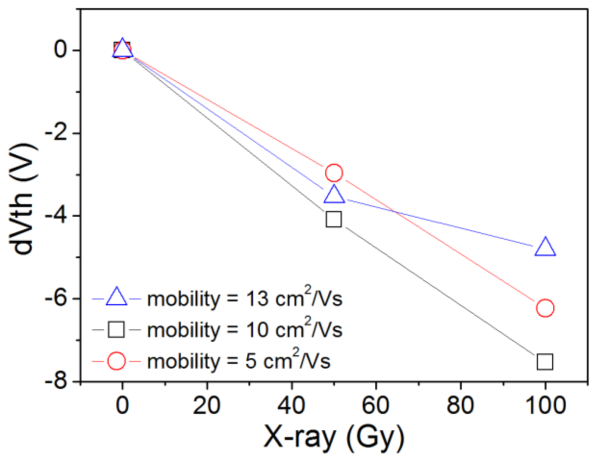

Fig.2. Threshold voltage shift of oxide TFTs, which is made by different mobility conditions, by increasing x-ray irradiation.

In the Fig.3, the graph shows that the changes of the threshold voltage were evaluated by accumulating X-rays on the oxide TFT. The X-ray tube was accelerated to 100 KVp, 10mA and accumulated up to 130Gy based on dose rate. And also it was measured in which the CsI Scintillator was attached in front of the oxide TFT device in the same way. Both measurements showed linearly changing characteristics as the X-ray dose was accumulated, and reproducible results were also shown through related repeated our ther experiments. From the result that the V_{th} change of the oxide element under the scintillator at 100 Gy of X-ray is same as the V_{th} shift under directly 5Gy, the transmittance of the x-ray through the scintillator film could be estimated to be about 5%, and it was same value measuring by dosimeter directly.

Scintillator made by CsI:Tll has the characteristic of absorbing X-ray and converting it into green light with a wavelength of 530nm, so most of the X-rays are absorbed by scintillator and converted into visible light. Therefore, compared to the case of direct exposure without scintillator, it was confirmed that a very small amount of X-ray was exposed and thus a very small level of change occurred when they operate in real DXD products, so it is thought that the changes of oxide TFT characteristics are no big issue for the diagnostic medical x-ray systems. The CsI:Tll film used in this experiments was a 600um thick film from Hamamatsu Photonics Inc..

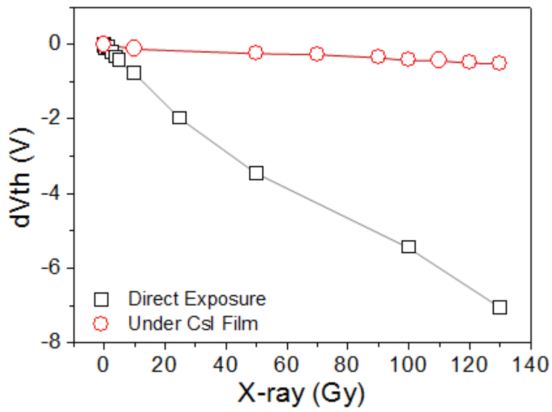

Fig.3. Threshold voltage shift of oxide TFTs by increasing x-ray irradiation. Square shows the data in directly exposure x-ray and circle shows under the scintillator film in same x-ray exposure.

The medical chest x-ray examination system uses only high-energy range of X-rays to ensure image quality from scattering and to minimize the amount of dose entering the human body. Other medical X-ray examination system, mammography, requires observing the breast cancer, so low-energy x-rays are used. In addition, high energy of 150 KVp or higher is used in X-ray CT inspection to analyze defects of PCB boards or die casting products used in industrial non-destructive inspection. Therefore, it is important to study changes of device characteristics by various X-ray energies because different X-ray energies are used by many different types of detectors. From this point of view, evaluation was conducted for the cases in which the X-ray energy range was different.

Figure 4 shows that the characteristics of V_{th} shift in the oxide TFT according to the different X-ray energy region. When high-energy X-ray with Al filter irradiated, the V_{th} shift was less than that of the TFT irradiated with low-energy X-ray. In particular, the case of gamma ray irradiation with much higher energy than X-ray showed very small amount of V_{th} shift. In other words, it was confirmed that the low energy X-ray affects the oxide TFT more than the high energy X-rays. This can be explained because the low energy photon reacts more with the constituent atoms of each layer of the TFT. Short-wavelength X-rays penetrate the medium well, so we call them hard x-rays, and long-wavelength x-rays are easily absorbed, so they are called soft x-rays.[7] In developing oxide TFT technology for DXD application, it is important to consider not only the accumulated amount of X-rays but also the energy of X-rays used for degradation characteristics caused by X-rays.

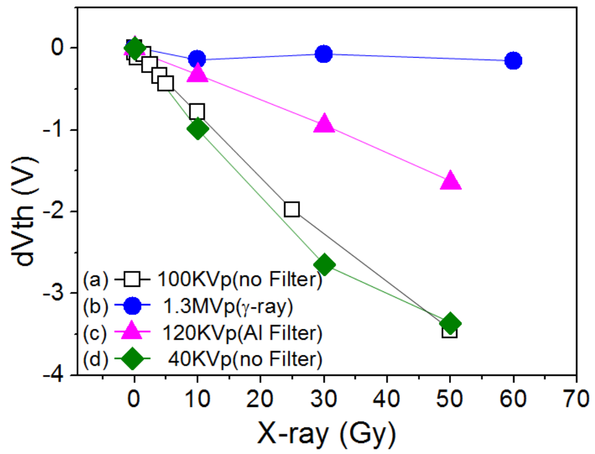

Fig.4. The threshold voltage shift by X-ray exposure according to X-ray energy level. (a) High energy under 100 KeV, (b) Discrete Energy only 1.3MeV, (c) High energy over 40 KeV, (d) Low Energy under 40KeV

4 Conclusions

We evaluated the characteristics that the oxide TFT for DXD is deteriorated by X-ray. When X-ray is irradiated to the oxide TFT, only V_{th} is linearly shifted without change in sub-threshold slope or off current. This phenomenon is presumed to occur as hydrogen in the insulation film around the IGZO flows into the channel layer by X-rays. In addition, it was confirmed that it was affected more by low energy X-ray than high energy. This means that it is necessary to clearly understand the deterioration phenomena caused by X-ray and reflect them for product design. In order to understand the characteristics of the actual product operation, it is necessary to evaluate how the irradiation affects the device under the driving voltage applied. Therefore, in the future, we will characterize the device under the x-ray irradiation in a state where a bias is applied to the device.

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