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Effects of Pixel Electrode Structure on Image Lag of STACK-CCD Image Sensor

Eiji OBA, Ryouhei MIYAGAWA, Hisanori IHARA, Michio SASAKI, Hirofumi YAMASHITA, Hiroyuki TANGO, Okio YOSHIDA and Sohei MANABE

ULSI Research Laboratories, Research and Development Center, Toshiba Corporation
1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki, 210, JAPAN

Pixel electrodes are an essential component of solid state image sensor with overlaid photoconversion layer. The three dimensional structure of the electrode affects the electrical characteristics of the photodiode. We have fabricated test elements of different pixel electrode structure and studied the effects on the photodiode electrical characteristics. The results suggest that high electric field is formed at the upper edge of the electrode. Holes are injected into photoconversion layer due to the high electric field and these holes, in turn, increase the transient photocurrent causing long image lag in the image sensor.

1. INTRODUCTION

Electrical proprieties of the amorphous silicon films have been improved in the past several years. Image sensor has been an attractive device for the application of amorphous silicon[1]. Image sensor with overlaid photoconversion layer has 100% aperture ratio and shows low smear noise, low moire noise and smooth image.

However, the electrical characteristics of the amorphous silicon photoconversion layer deposited on solid state scanning device exhibit a considerable degradation, when compared to those deposited on a planar substrate. The photocurrent transient decay in the photodiode of the STACK-CCD image sensor is strongly dependent on the topography of the underlying CCD register[2]. Slow decay of the transient photocurrent may result in image lag degrading the image quality for motion picture application. Control of this image lag is essential for the application.

The cross section of the STACK-CCD imager is schematically illustrated in Figure 1. Photogenerated carriers in the amorphous silicon photoconversion layer are read out into the register through the pixel electrode array, formed on the upper surface of the CCD register. Reverse bias voltage is applied to the photoconversion layer during the integration period to collect the signal carrier into the pixel electrode. The output characteristics of the sensor is determined by the diode characteristics of the photoconversion layer.

We investigated the factors which deteriorate the electrical characteristics of amorphous silicon photoconversion layer deposited on substrate with pixel electrodes. Our results clarify the degradation mechanism of the electrical characteristics of these amorphous silicon photodiode deposited on substrate with pixel electrode array.

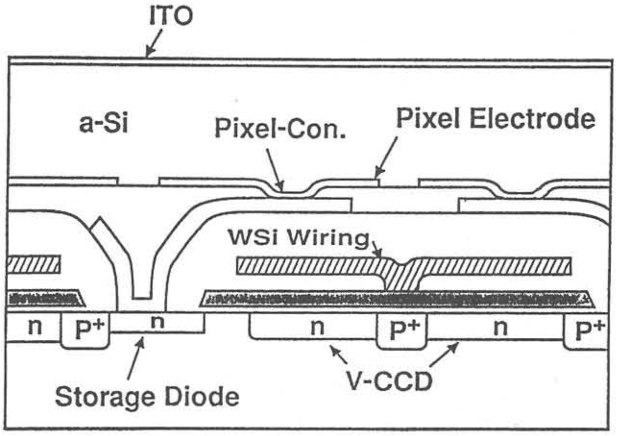

Fig.1 Schematic cross sectional view of STACK-CCD cell structure.

2. EXPERIMENTAL DETAILS

To verify the effects of these pixel electrode structure on the electrical characteristics of the photoconversion layer, we have fabricated a substrate wafer with test element group of different pixel electrode structures. The pixel electrodes normally used in area sensor are squared. In our study, we fabricated long rectangular electrodes array to simplify the structure and the fabrication process. The separation gap between the electrodes was formed by reactive ion etching. The width between the adjacent rectangular electrodes was varied from 0.6 microns to 1.2 microns and the pitch of the electrodes was 5.0 microns. The pixel electrodes of the test elements were fabricated on a flat oxide buffer layer deposited on a crystal silicon wafer. A test element was also fabricated on an undulated buffer oxide layer. The electrode separation gap was formed at the ridge of the undulated oxide and the electrode edge of this test element was more acute compared to those deposited on flat oxide. A test element with a large single flat electrode was also fabricated as a reference. The thickness of the pixel electrode layer was 500Å. An iip (a-SiC(i)/a-Si(i)/a-SiC(p)/ITO) structure multi-layer was deposited on this substrate wafer.

The I-V characteristics was measured in static mode at room temperature. The transient photo-current was measured under reverse bias with a negative voltage applied to the ITO electrode. Light was supplied by red color LEDs and the transient current was measured after switching off the light. The light intensity was adjusted so as to provide a current density of 2.6×10^{-7} A/cm^2, regardless of the electrode structure.

We also calculated the electric field profile and the potential distribution in the inter-electrode region with a conventional crystal silicon simulator to foresee the critical aspects determining the degradation.

3. RESULTS AND DISCUSSION

Figure 2 shows the simulation results of the electric field vector profile and potential distribution in the

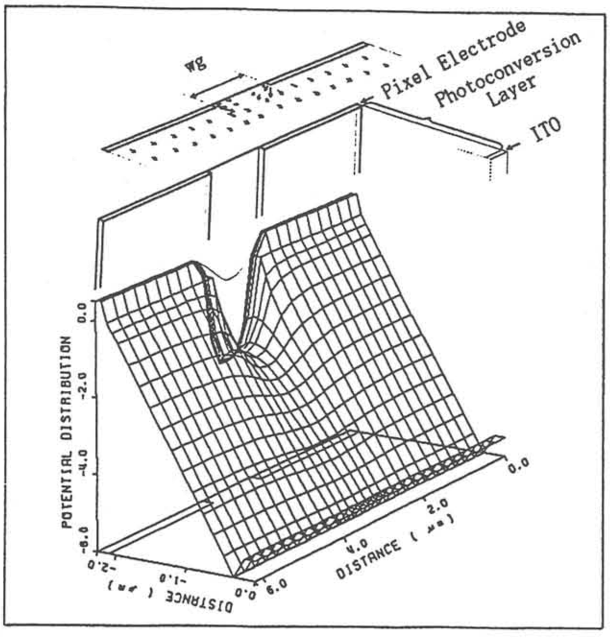

Fig.2 Electric Field vector and 2D electrostatic potential distribution at applied reverse voltage of 6 V.

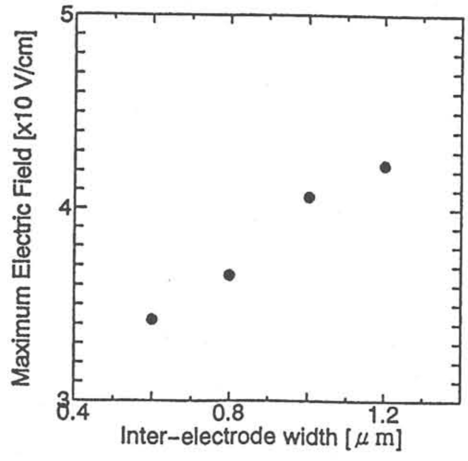

Fig.3 Simulation result of the maximum electric field at the pixel electrode upper edge versus the inter-electrode separation width.

photoconversion layer above the inter-electrode region. A maximum in the electric field has been observed at the upper edge of the electrode. And a low electric field has been also observed in the central region of the inter-electrode space. Figure 3 shows the dependence of the maximum electric field on the inter-electrode separation width. The maximum electric field increases with increasing inter-electrode separation width.

Figure 4 shows the experimental results of dark current versus the reverse bias voltage characteristics. First, we analyze the leak current at high applied voltage. The test element with a single large planar electrode exhibits the lowest leak current. The dark leak current dependence on the inter-electrode separation width is similar to that of maximum electric field shown in Figure 3. Moreover, the test element with acute electrode structure exhibits the highest leak current. Therefore, these facts suggest that the increase of the leak current is caused by the injection of holes due to the high electric field formed at the upper edge of the pixel electrode and shows that the leak current is strongly dependent on the acuteness of pixel electrode edge structure. In the low applied voltage region, only a small difference is observed between different test elements suggesting that the electric field formed at the electrode edge is not a dominant factor.

The normalized transient current of the third television field is shown in Figure 5. The third field signal, which is the integrated image over 33 to 50 milliseconds in the NTSC television system, is largely used to evaluate the image lag characteristics of the television system. Firstly, the transient current decreases with increasing applied voltage and then increases beyond a certain voltage. In low voltage region, the total transient current directly reflects the carrier collection speed and the decay rate increases with increasing applied field. Secondly, in the low voltage region, only a small

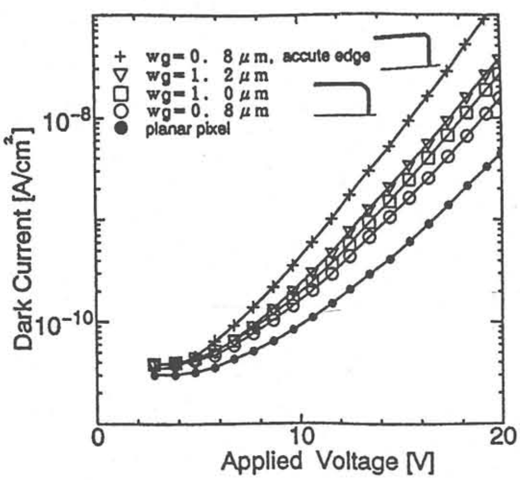

Fig.4 Dark current as a function of applied voltage and its dependence on the inter-electrode separation width w_g and electrode edge acuteness.

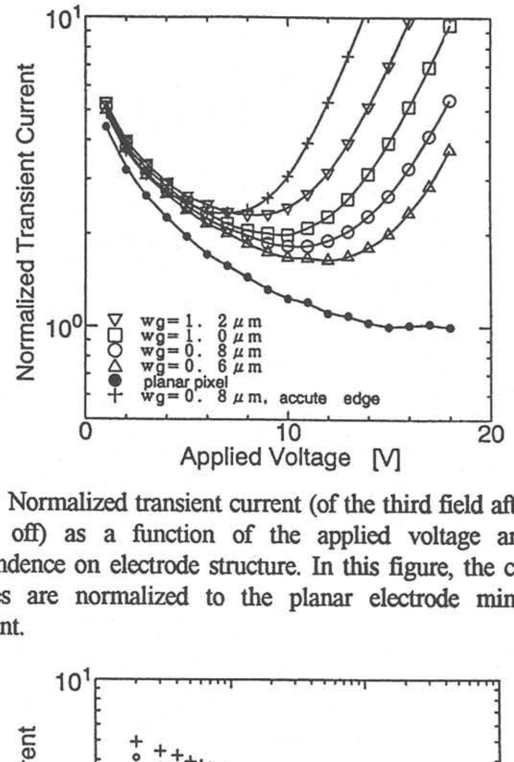

Fig.5 Normalized transient current (of the third field after the light off) as a function of the applied voltage and its dependence on electrode structure. In this figure, the current values are normalized to the planar electrode minimum current.

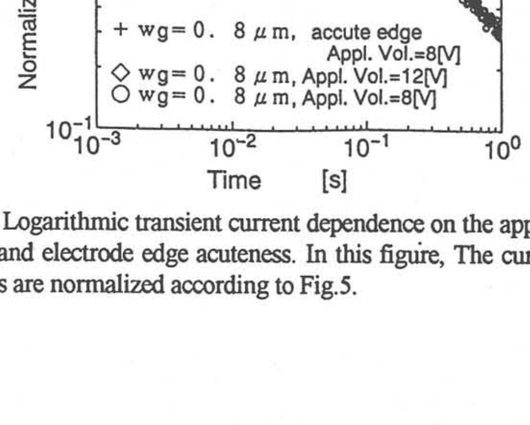

Fig.6 Logarithmic transient current dependence on the applied field and electrode edge acuteness. In this figure, The current values are normalized according to Fig.5.

difference of transient current is observed between different test elements. Thirdly, in the high voltage region, a considerable increase in the transient current is observed with increasing inter-electrode separation width. And the test element with acute electrode edge exhibits a large transient current compared to the normal test element. The above results show a strong correlation between the dark leak current and the transient photocurrent characteristics.

The time dependence of the transient current is shown in Figure 6. First, we compare the transient current under different applied voltages. In the early stage within a few milliseconds, the transient current decreases faster under higher applied voltage. However, the current decay rate after this stage is lower and a longer transient current is observed. The current decay rate of the test element with an acute edge is also lower and it exhibits a longer transient current. We conclude that the holes injected in the photoconversion layer, caused by means of either high applied voltage or the high electric field at acute electrode edges, is an important factor determining the low decay rate of transient current after a few milliseconds, at applied voltage higher than about 4 V.

4. CONCLUSION

The pixel inter-electrode width and the electrode edge structure are important factors determining the electric field distribution in the photoconversion layer. At low applied voltage, the low electric field formed in the inter-electrode region delays the carrier collection. At high applied voltage, local high electric field formed at the electrode upper edge becomes a dominant factor of the hole injection. The decay rate of the transient current decreases with increasing applied voltage, or electrode acuteness. These results indicate that the above mentioned holes injected from the pixel electrode edge play an important role in the degradation of the transient current decay rate.

Narrow inter-electrode separation width or obtuse electrode structure will result in lower leak current and lower image lag. The structure of the pixel electrode separation spacing structure must be carefully designed so as to satisfy high definition and low image lag, simultaneously.

References:

1) S. Manabe, et al., ISSCC Digest of Technical Papers, **32** (1988) 50

2) H. Yamashita, et al., ISSCC Digest of Technical Papers, **37** (1994) 224.