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A 2.20-um square pixel IT-CCD constructed from single-layer electrode

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Abstract *– A 5M-pixel 1/2.5-inch inter line transfer CCD (IT-CCD) image sensor constructed from single-layer electrodes has been developed. This novel structure provides advantages such as high sensitivity, low smear ratio and lower power consumption as compared with conventional multi-layer electrode structures. These advantages are especially relevant to small pixel size, in this study enabling a 2.2-um square pixel IT-CCD.*

1. Introduction

CCD image sensors have been used for camcorders, digital still cameras (DSC) and cellular phones for many years. These applications have continuously demanded improvements in resolution, or in other words a smaller pixel size. The trend in miniaturization of pixel size is shown in Fig.1. The pixel size has been decreasing year by year. The smallest pixel size among Inter-line Transfer CCD (IT-CCD) image sensors in the 2004 DSC market was 2.20-um square.

IT-CCD development has so far been able to match the demand for miniaturization using the multi-layer electrode structure. However, as the pixel size becomes reduced further, multi-layer electrode IT-CCDs will no longer be able to provide improvements in the performance of the image sensor in regard to such as sensitivity and smear ratio. Furthermore, the mobile imaging market also desires the image sensor to have a lower power consumption.

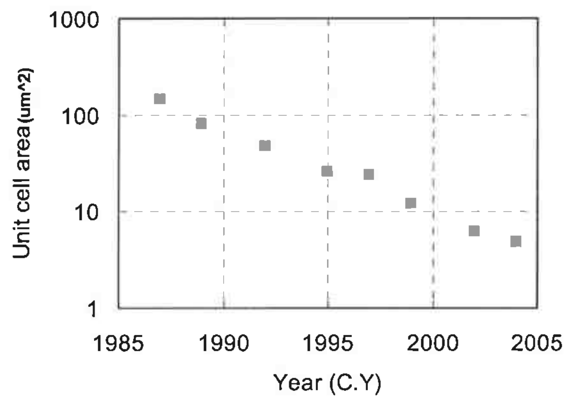

Fig.1 Trends of pixel size of CCD in SONY

We have developed and confirmed the effectiveness of a single -layer electrode structure IT-CCD image sensor that realizes higher sensitivity, a lower smear ratio and lower power consumption. This novel single-layer electrode structure IT-CCD image sensor has several advantages over conventional multi-layer electrode CCDs.

2. Single electrode structure

A cross-section SEM micrograph of the novel single-layer electrode structure IT-CCD is shown in Fig.2. There are obvious differences when compared with the multi-layer electrode structure. The transfer electrode does not overlap and the gap edge of each electrode section is perpendicular. The height of the light shield from the Si surface is very low and the light shield surface is very smooth.

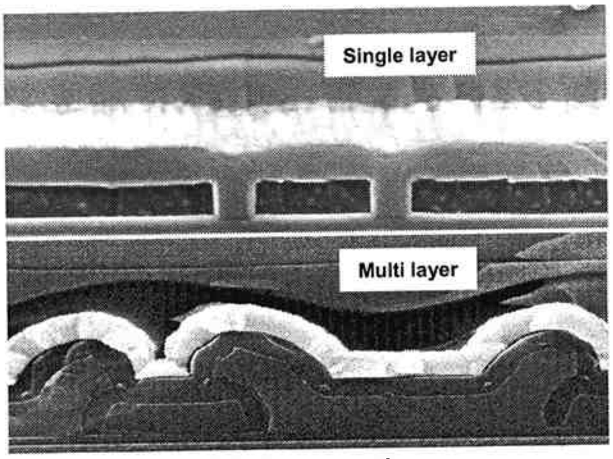

Fig2. Cross section

This structure is formed by a very simple process. The electrode is etched by a general dry etching technique and the gap is filled with a conventional CVD film. We achieved a 0.10-μm narrow gap without adverse effects. Signal charges are transferred across the gap without affecting the transfer efficiency because the gap is very narrow.

3. Sensitivity

The single-layer electrode structure allows the layer from the silicon surface to the top of the light shield on the gate electrode to be thin. This thinner layer enables light rays incident on the photo diode to enter more efficiently, because having the photo shield layer closer limits obstruction of the incident light to the photo diode; thus the sensitivity is improved.

A simple ray trace optical simulation is used to estimate the sensitivity. The results are shown in Fig.3. It is observed that the single-layer structure has a higher sensitivity compared with the double-layer structure in all F number regions.

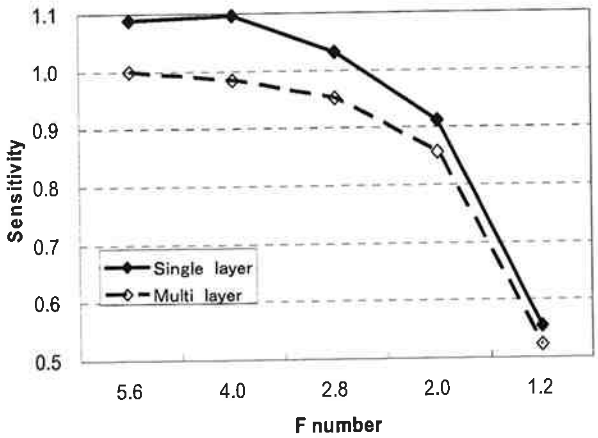

Fig.3 Sensitivity dependency of F-number

4. Low temperature process

This single-layer structure enables lower temperature wafer processing because an oxide layer is not required as exists between multi poly-Si electrode layers, which requires a high temperature oxidization process.

This lower temperature processing brings many benefits for device performance such as a small impurity diffusion length and a steep potential slope, as shown in Fig.4.

The steep potential slope indicates a high electrostatic capacity. Thus the vertical register charge handling capacity has been increased compared to the multi-layer electrode and a narrower channel size can be achieved.

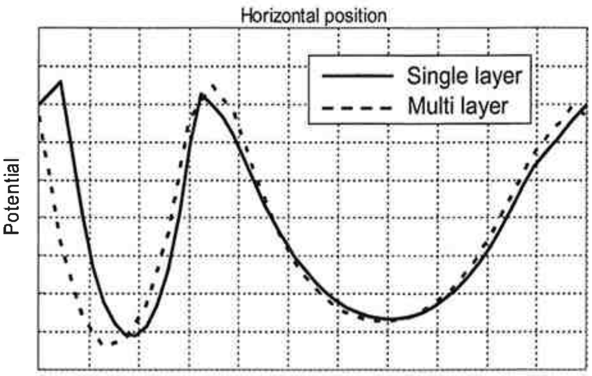

Fig.4 Potential diagram

In order to decrease the smear noise, we applied a narrow vertical register. The smear ratio of the conventional multi-layer structure, constructed in a higher temperature process, and the single-layer structure, constructed in a lower temperature process, are shown in Fig.5.

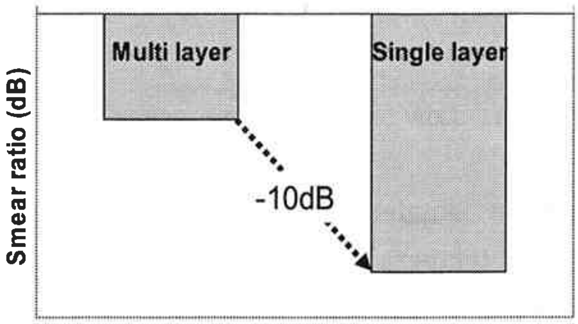

Fig.5 Conparison of smear ratio

We can see that the narrow vertical resister is effective in reducing smear noise, which arises from diffraction of incident light.

5. Power consumption

The single-layer structure has lower power consumption than the multi-layer structure because the single-layer electrode structure does not suffer from the parasitic capacitance resulting from the stacked portion between electrodes, as shown in Fig.6.

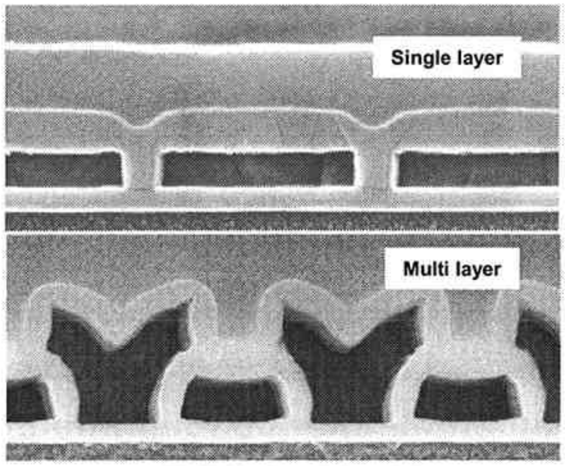

Fig6. Horizontal register

The power consumption of the horizontal CCD register is given by the simple equation:

$$W \propto CV^2f$$

Where W is power consumption, C is the gate electrode capacitance, V is the swing voltage of the gate electrode and f is the frequency of operation. The single-layer electrode structure reduces the gate electrode capacitance by approximately 30%. Due to the non-overlap gate electrode structure, we achieved lower power consumption for the horizontal register, which consumes the greatest amount of power.

6. Device performance

The above-described single-layer structure was incorporated into a 1/2.5-inch 5M pixel IT-CCD image sensor.

The specifications of this IT-CCD are shown in Table.1.

Parameters	Values
Optical format	1/2.5 inch
Chip size (mm x mm)	6.63 x 5.40
Total number of pixels	2668 x 1970
Number of active pixels	2616 x 1960
Pixel size (um x um)	2.2 x 2.2
Horizontal clock rate	27MHz
Saturation output (mV)	420
Sensitivity (mV/Lux)	180

Table 1. Specification of test device

The sensitivity of this sensor is 180 mV/Lux. The measured performance is almost the same as a 2.5-um square pixel IT-CCD. Thus, we produced a 2.2-um square pixel IT-CCD without any degradation of device performance using the newly developed single-layer electrode structure. This device performance is satisfactory for current high-resolution camera applications.

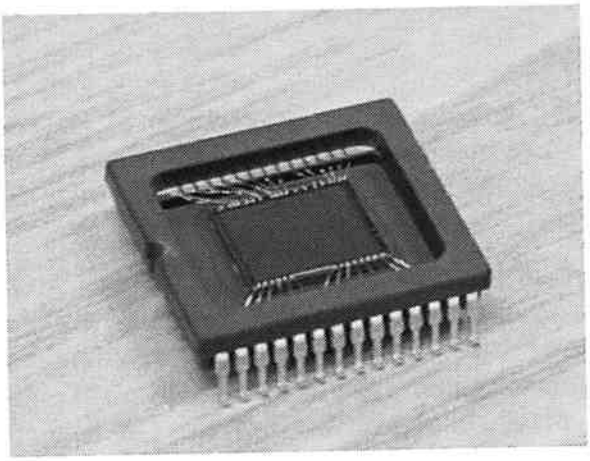

Fig.7 Test device

7. Conclusions

A single-layer electrode, IT-CCD image sensor has been developed and applied to a 1/2.5-inch 5M pixel high resolution CCD image sensor. The performance of this new image sensor is very suitable for application to small pixel size image sensors. The novel structure confers advantages such as high sensitivity, low smear ratio and lower power consumption compared with conventional multi-layer electrode structures. These advantages are especially relevant to small pixel size, in this study enabling a 2.2-um square pixel IT-CCD.

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