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Performance of FT-CCD image sensor with Single Layer Poly-Silicon Electrode

Yoshihiro Okada, Yuzo Ohtsuru, Shin'ichiro Izawa, Nobuhiro Taino, Minoru Hamada

CCD Development Department, MOS-LSI Division, SANYO Electric Corporation
180, Ohmori, Anpachi-Cho, Anpachi-Gun, Gifu, JAPAN
Phone:+81-584-64-4280, Fax:+81-584-64-4943
E-mail:okad050317@swan.sanyo.co.jp

[Abstract]

We experimentally fabricated a 1/4-inch 360k pixel FT-CCD image sensor for ITU601 format with a single layer poly-Si electrode structure. We have adopted 0.45um as a gap width to keep the balance of the charge handling capability and optical sensitivity.

We optimized the membrane structure to improve optical sensitivity. We adopted the sandwich structure that poly-Si gate is put between two silicon-nitride layers which have a high refractive index, to suppress the reflection on the poly-Si surface. 30% of sensitivity improvement was achieved by this structure.

FT-CCD image sensor with this new structure is very simple and has high performance.

1.Introduction

CCD image sensor is used as an input device for multimedia commodity such as PC camera, PDA terminal, digital still camera (DSC) and digital video camera (DVC). Several features like high sensitivity, low voltage, small size and low price are required especially for CCD image sensor to use in PC camera. To satisfy these demand, we have newly developed a frame transfer CCD (FT-CCD) image sensor with a single layer poly-Si electrode [1],[2] which can achieve high sensitivity with a simple structure.

In this paper, specifications of a 1/4-inch 360k pixel FT-CCD image sensor are mentioned first. Next, the structure of vertical and horizontal CCD with a single layer poly-Si electrode is explained. It is explained that sensitivity and charge handling capability depend on the gap width between a single layer electrode here. Continually, simulation and measurement results of spectrum sensitivity characteristic are shown, achieved by a new membrane structure of poly-Si electrode for a sensitivity improvement. Finally, the characteristic of an experimental FT-CCD image sensor with a single layer poly-Si electrode structure is shown.

2.Test Device

We have confirmed the operation of a single layer poly-Si electrode structure by constructing a 1/4-inch 360k pixel FT-CCD image sensor for ITU601 format.

The specification of a 1/4-inch 360K-pixel FT-CCD image sensor is shown in Table 1. This device has 736(H)*490(V) effective pixels in the imaging area and storage area. The pixel size is 5.0(H)*5.55(V)um^2. The imaging area and the storage area are operated by the three-phase clock. The frame shift frequency is 3.8MHz. The Ye, Cy, Mg complementary color striped filter is adopted. The horizontal shift register is driven by a two-phase clock. The readout frequency is 13.5MHz. The operating voltage is 5V or 3.3V. The signal charges are transformed to voltage by a conventional floating diffusion amplifier, then they are amplified by the output circuit composed of three-stage source-follower amplifiers. In addition to the progressive scan read out, the interlace scan read out is possible with charge mixing in the horizontal shift register.

Table1. Device Structure and driving Specification

Optical format	1/4-inch
Number of effective pixels	736(H)*490(V)
Pixel size	5.0(H)*5.55(V) um^2
Chip size	4.9(H)*6.15(V) mm^2
Color filter	Complementary color stripe filter
Horizontal CCD register	3.3V drive, 13.5MHz
Power supply	12 / 5 / -7V

3.Single Layer Poly-silicon Electrode Structure

Conventionally two-layer poly-Si electrodes of overlap structure were used for FT-CCD image sensor. However, low consumption electric power and small pixel size is required. Since the influence of an overlap part becomes large, a characteristic improvement become difficult. To solve this problem, we developed FT-CCD image sensor with the new single layer poly-Si electrode structure.

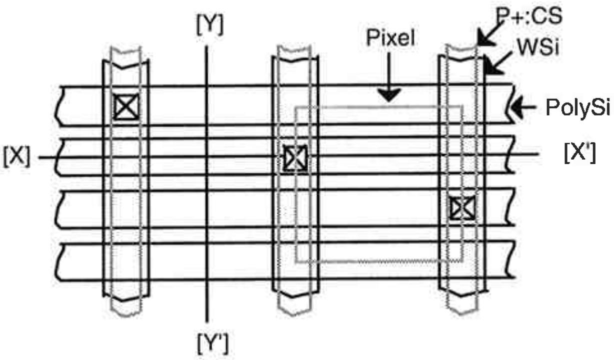

Figure 1. Top view of the imaging area

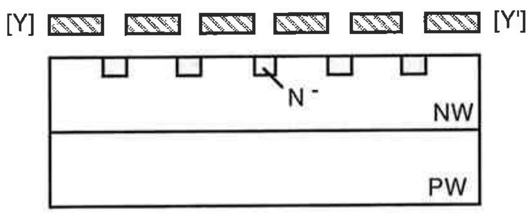

Figure 2. Cross-sectional view of the imaging area

The top and cross-sectional views of an imaging area that we newly developed this time are shown in figure 1 and 2 respectively. A single layer poly-Si electrode structure is very simple and has some merits like that the inter-electrode gap works as a conventional window region and the capacity between electrodes decreases. Sensitivity and saturation voltage as a function of the gap width are shown in figure 3. The more the gap width is wide, the more the sensitivity improves. On the other hand, keeping the same pixel size, wide gap decreases the saturation voltage because electrode area becomes small. We have adopted 0.45um as a gap width that is able to keep the balance of the saturation voltage, sensitivity, and micro processing in this device. In the inter-electrode gap, boron is implanted to prevent the potential dip or barrier, so that charge transfer efficiency has not degraded.

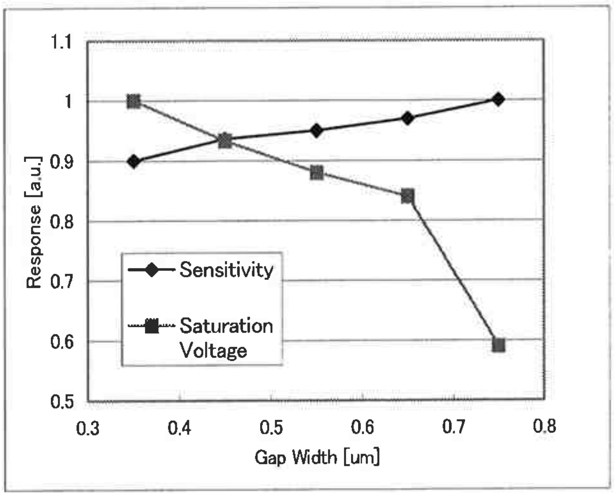

Figure 3. Sensitivity and Saturation voltage as a function of the gap width .

A single layer poly-Si electrode structure is adopted to horizontal CCD:H-CCD, too. The structure is shown in figure 4. The potential barriers for a 2 phase CCD are formed by the difference of the gate oxide thickness and arsenic ion-implantation. This structure is easy to use in mask alignment. We confirm that H-CCD operates with a driving voltage less than 3.3V.

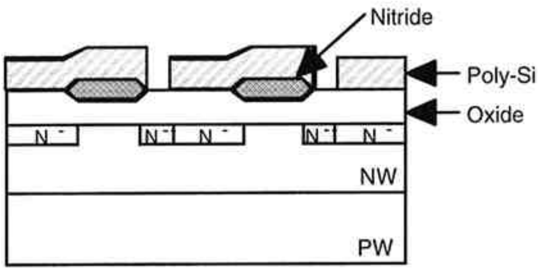

Figure 4. Cross-sectional view of the horizontal shift register .

4.Thin Poly-silicon Electrode

As for a single poly-Si layer electrode structure blue sensitivity becomes good in comparison with conventional overlap structure, because the inter-electrode gap works as a conventional window region. However, blue sensitivity of this structure is still inferior to that of Interline Transfer CCD (IT-CCD) with micro lens, because poly-Si electrode exists on the imaging area. Therefore, we formed poly-Si electrode thinly [3],[4]. Figure 5 shows the spectral response as a parameter of poly-Si thickness. From this result, 50nm was chosen as the gate poly-Si thickness, because this thickness gives the response peak wavelength at 500nm.

But the membrane thinned poly-Si gate could not achieve high speed frame shift as it was, because of its high resistance which reduce clock amplitude. To prevent this problem, we used a WSi_2 on poly-Si shunt structure to reduce the resistance of poly-Si electrode. By this structure, frame shift frequency 3.8MHz is achieved.

5.The application of multiple membrane interference

We optimized the membrane structure to improve optical sensitivity in this device. We adopted the sandwich structure that poly-Si gate is put between two silicon-nitride layers which have high refractive index, to suppress the reflection on the poly-Si surface. This structure has decreased the reflection of short wavelength light and has improved the blue sensitivity. Each film thickness is Si_3N_4=60nm,Poly-Si=50nm,Si_3N_4=80nm. The effect is shown in figure 6. The membrane structure is optimized, so that the sensitivity is increased by 30%.

On the other hand, the gate dielectric is formed by 30nm SiO_2 layer covered with 80nm Si_3N_4 layer to increase the charge handling capacity.

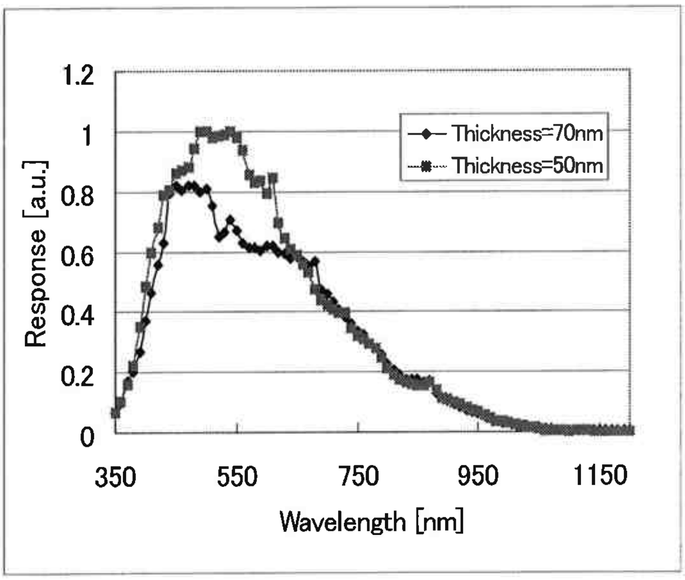

Figure 5. Spectral response as a parameter of poly-Si thickness .

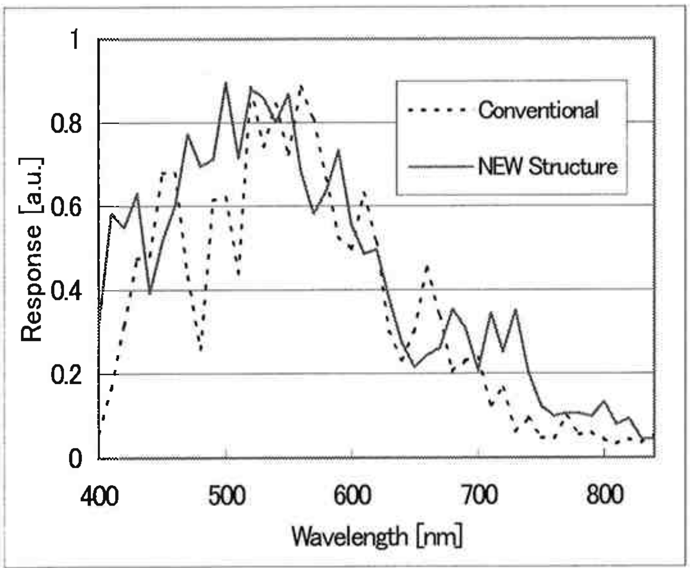

Figure 6. Calculated spectral response of the new structure.

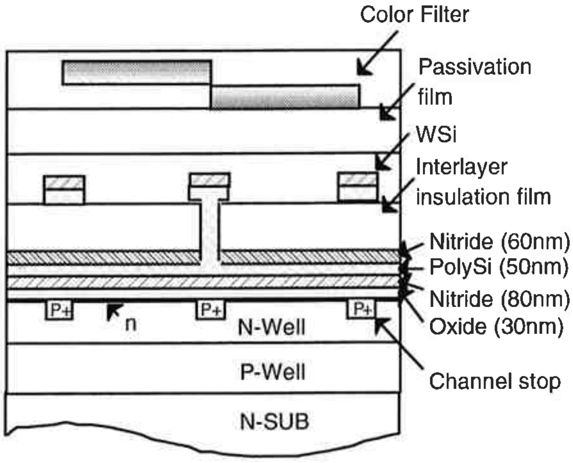

Figure 7. Cross-sectional view from x to x' of Figure 1.

6.Characteristics

Characteristic of 1/4-inch 360K-pixel FT-CCD image sensor with a single layer poly-Si electrode structure is shown in Table2 at the interlace scan mode. Yellow sensitivity 70mV/lx, saturation output 1000mV were obtained, by adopting new structure.

Table2. Device Characteristics (Interlace scan Mode)

Sensitivity	70mV/lx (Yellow signal, 2800K, 1/30s)
Smear(V/10)	0.04%
Saturation Voltage	1000mV
Conversion efficiency	30uV/e
Electronic shutter speed	1/8 to 1/4000s
Blooming suppression	>×1000

7.Conclusions

In conclusion, we have developed a 1/4-inch 360k-pixel FT-CCD image sensor with a single layer poly-Si electrode. To increase the sensitivity we adopted thin poly-Si electrode and new membrane structure (Si_3N_4/Poly-Si/Si_3N_4). Optical sensitivity has increased by 30% in comparison with conventional structure.

New structure developed this time has proved that simple single poly-Si electrode can achieve high sensitivity without a micro lens.

In future we go on investigating this structure and will develop FT-CCD image sensors that have high sensitivity and high resolution.

8.Acknowledgement

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9.References

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