Source-Follower-Type Image Sensor Driven From Back Electrodes

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1. Introduction

An amplifying image sensor is proposed that achieves high photo-sensitivity and a wide dynamic range. It is driven from the back of the image sensing area and detects channel potential modulated by the stored signal charge. The performance of such a sensor with 1000 × 1000 cells/cm^2 was simulated using three-dimensional transient numerical analysis simultaneously to solve continuity equations for the potential and the electron and hole currents.

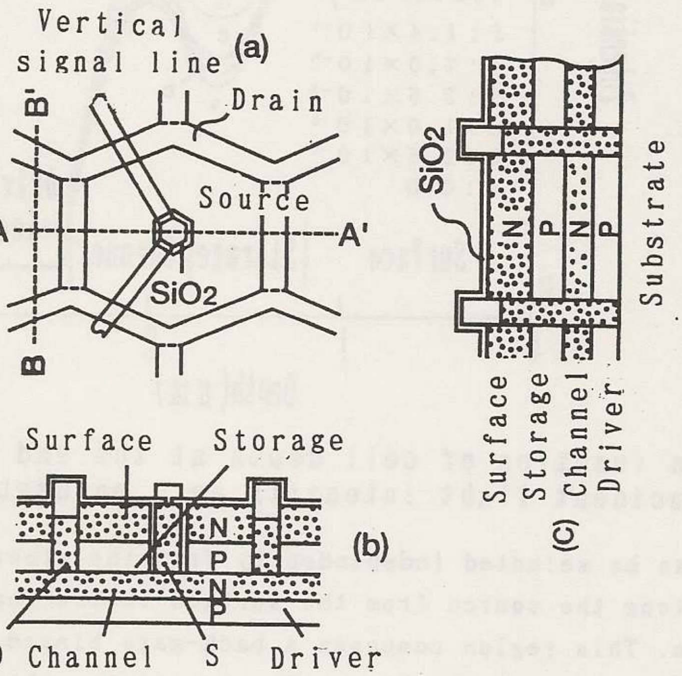

Fig.1 Device structure.

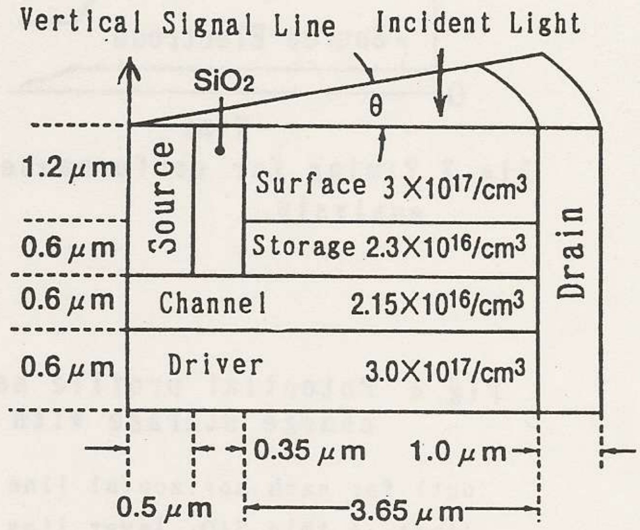

Fig.2 Cell structure for performance analysis.

2. Device structure and simulation model

Each cell consists of four layers arranged from the front to the back as shown in Fig. 1. From the top, a high-donor concentration thick naked n-type surface layer for photo-electric conversion, a high-acceptor-concentration

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thin p-type layer for charge storage, an n-type channel layer for channel potential detection and a p-type drive electrode buried in an n-type substrate. The channel and driving electrode also act as an overflow barrier and overflow drain, respectively, to suppress blooming. A common drain (0 volts: standard voltage) surrounds these layers; a source is located at the center of a cell that is connected to a vertical signal line (1). The driving electrode extends horizontally, so the operation mode (reset, charge storage, or read-

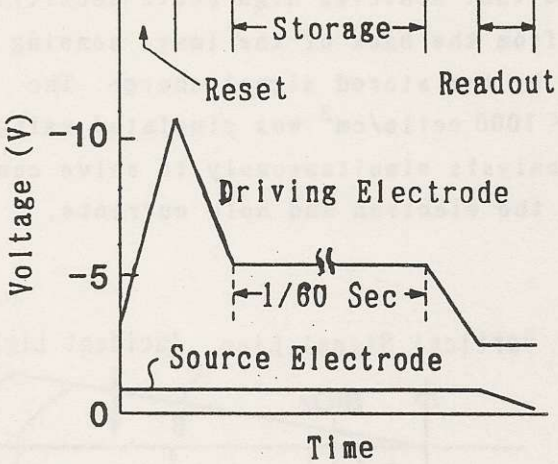

Fig. 3 Timing for performance analysis.

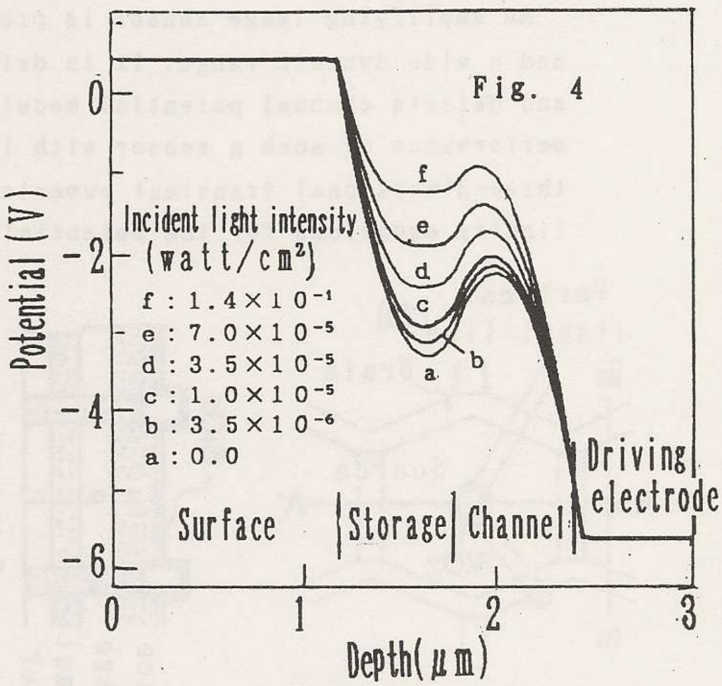

Fig. 4 Potential profile as a function of cell depth at the end of charge storage with incident light intensity as a parameter.

out) for each horizontal line can be selected independently from the other lines. A thin SiO_2 layer lies along the source from the surface to the channel to suppress current between them. This region composes a back-gate biased MOS transistor having a gate biased at the source voltage. The transistor therefore does not turn on.

During operation, a reset is done by lowering the driving electrode voltage. After 1/60-second charge storage, the driving electrode voltage is raised. Then, the channel potential is readout from the vertical signal line by using a constant current source. High photo-sensitivity is attained due to the thick surface layer; a wide dynamic range is obtained due to the high acceptor concentration in the storage region. Both characteristics are achieved at a low operation voltage because the surface layer hardly consumes any voltage. In this device, photo-sensitivity can be improved by increasing the surface layer thickness without changing the other characteristics.

The cell structure used for performance simulation is shown in Fig. 2. An axis symmetry cell (symmetric with regards to the cell center) was used to shorten the calculation time. Figure 3 shows the simulation timing. All the transient times were set at 0.5 μ sec to achieve reset and signal readout in a

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short horizontal blanking period. Forty five calculation steps were used.

A driving method was used in the simulation that suppresses blooming (signal charges spreading into neighboring cells) during long-term storage, while permitting it during a very short readouts. This method completely turns off the channel during charge storage. The output voltage is defined as the source voltage at which the channel current becomes constant when the source voltage is varied from a low to a high level, as shown in Fig. 3. The signal voltage is the difference between the output voltages with and without incident light.

3. Simulation results

Reset: At reset, the number of holes was reduced to 6.6×10^{-4} and 2.5/cell, when -12 and -10.8 V, respectively, were applied to the driving electrode. Therefore, an image lag will not appear at a -10.8-V reset.

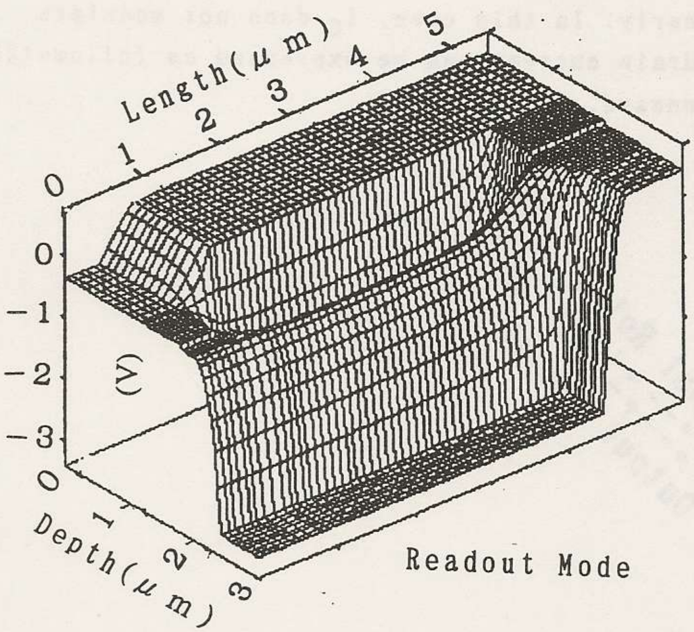

Fig. 5 Potential profile at read out time (incident light intensity $=1.0\times10^{-5}$ watt/cm²).

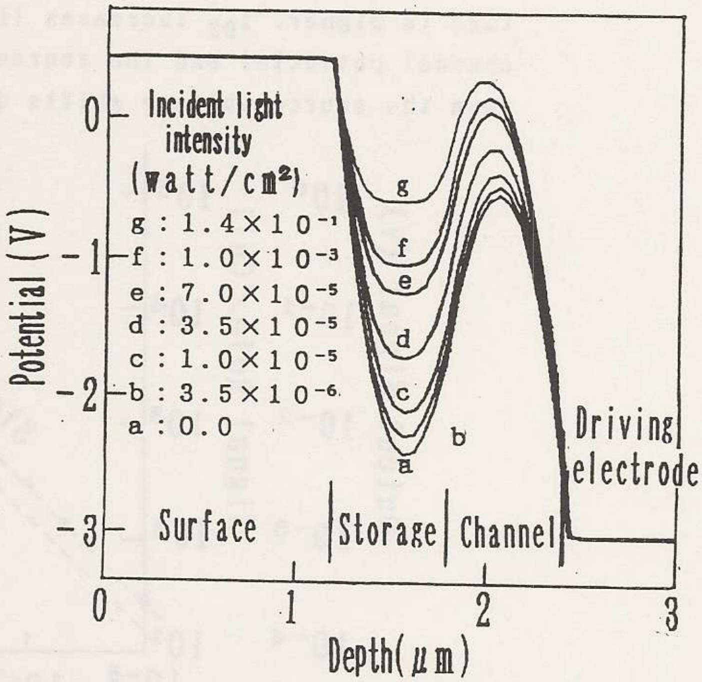

Fig. 6 Potential profile as a function of cell depth with incident light intensity as a parameter.

Storage: Figure 4 shows the potential profiles along the cell depth at the end of charge storage at a point 2.2 μm from the cell center. The driving electrode voltage was -5.2 V. The potential in the cell increased with light intensity due to the stored signal hole increase; the potential barrier, which permits holes to overflow into the driving electrode, became lower. The relation between the amount of the stored signal charge and the incident light intensity is illustrated in Fig. 7. The storable signal charge reached 1.53×10^{5} holes/cell at the saturation exposure (7×10^{-5} watt/cm² illumination from 3200° K black body). This is 2.1 times larger than the values reported for devices driven from the surface side(1) that had almost same cell size and operational voltage. This suggest that the charge-handling capability of the proposed device is superior to that of conventional ones. The amount of signal charge at 2000 times greater exposure was slightly more than that at saturation exposure, as is shown by curves e and f in Fig. 4.

Read out: Figure 5 shows the potential profiles in a cell corresponding to 1.0×10^{-5} watt/cm^2 illumination. Figure 6 shows the potential profiles at the position described above. In Figs. 5 and 6, the readout current was constant ($I_C=2\pi\times10^{-8}$ A/cell). The driving electrode voltage was -2.6 V. Fig.6 shows that the channel potential increased with incident light intensity. If the source voltage is lower than the voltage needed I_C to flow, source drain current I_{DS} decreases exponentially. On the other hand, when the source voltage is higher, I_{DS} increases linearly. In this case, I_C does not modulate channel potential and the source drain current can be expressed as follows(2) when the source voltage shifts downward.

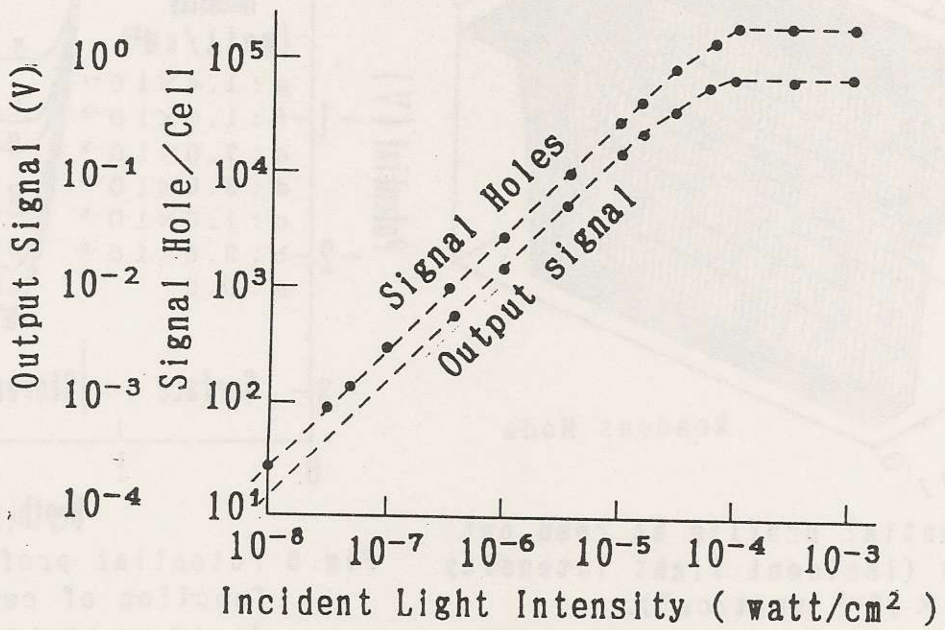

Fig.7 Relation between stored signal charge or signal voltage and incident light intensity.

$$I_{DS}=I_C\exp(-q\,\delta V_S/kT) \qquad (1),$$

where δV_S is the source voltage shift from the readout point.

The readout signal thus corresponds to the channel potential difference with and without a signal charge. In Fig. 7 , the output signal is plotted as a function of incident light intensity. However, as it is difficult to determine accurate output voltages at a low light level, the signal voltage is plotted by as a dashed line for these regions. By comparing the number of signal holes and the output signal level, the conversion factor was calculated to be 3.7 μV. It is worth noting that for 2000 times greater exposure, the storage region becomes back-biased to the surrounding regions, as shown in Fig. 6, The stored charge does not overflow into neighboring cells, so no blooming occurs. It is necessary to confirm that the channel is completely off during charge storage, even for 2000 times greater exposure. The minimum channel potential in Fig. 4 is -0.90 V for the maximum exposure. On the other hand, the minimum channel potential in Fig. 6 is -0.55 V for no exposure. The source drain current thus becomes $I_C \exp(-q \times 0.35/kT)$ for the maximum exposure. This value is negligible in comparison with I_C. Therefore, during readout, the source drain current does not interferes with the read out signal.

4. Conclusions

An image sensor was proposed that is driven from the back of the image sensing area and that detects channel potential modulated by the stored signal charge. The characteristics of a sensor with 1000×1000 cells/cm^2 were numerically simulated . In this analysis, a driving method was used that suppresses blooming during the charge storage, but allows it during very short readouts. The analysis indicated that the charge-handling capability reaches 1.53×10^5/cell and that the conversion factor is 3.7 μ V/hole. This sensor thus has a high photo-sensitivity and a wide dynamic range.

References:

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