Amorphous Silicon Photoconductive Contact Image Sensor


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The photoresponse and voltage response of amorphous silicon photoconductive cells were measured. Rising and falling photopulse currents showed power-law dependence on time. The power value changed at τ (≤3 msec) that seems to be the carrier packet life time. Generated carriers are considered to be stored in gap states when no voltage is applied. This increased the output voltage 4 times larger than in the case of static voltage application. An A4-8d/mm amorphous silicon photoconductive image sensor was fabricated to confirm experimental results.

1. Introduction

Amorphous silicon image sensors are expected to take over CCD image sensors, because of its large area deposition capability and its cost reduction potentiality. Many kinds of amorphous silicon photodiode sensors have been reported5,2,13]. The photodiode sensor has good photoresponse, because generated carriers travel only once between the electrodes. However, this means that photo sensitivity can not be expected to be larger than unit quantum efficiency. Therefore, a low noise amplifier and a switching LSI must be used to read out the signal. This makes the sensor rather expensive.

On the other hand, a photoconductive sensor4 has poor photoresponse compared to a photodiode sensor, but has better photosensitivity that potentially will reduce cost.

In this report, the photoresponse, voltage response and the fabricated A4-8d/mm image sensor are introduced.

2. Experiment

The samples for the experiment were prepared as follows.

A 0.2 μ thick SiNx layer, 1 μ thick none doped a-Si:H and 0.1 μ thick P doped a-Si:H were successively deposited on a corning 7059 glass substrate. Ti was deposited and formed as an electrode on the top of the p doped a-Si:H film, by relective etching of Ti and P doped a-Si:H.

The dimensions of the electrode are listed in Table 1 and the configuration is shown in Fig. 1.

<table>
<thead>
<tr>
<th>Sample</th>
<th>L (μ)</th>
<th>D (μ)</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1: Sensor Cell dimension

![Fig. 1 Configuration of sensor cell.](image)

The photoresponse was measured by switching on and off a green LED, whose peak wave length was 570 nm. (Fig. 2)

The voltage response was measured by switching on and off the readout circuit and changing the pulse interval. (Fig. 7)
The response is shown in Fig. 3. The photoresponse is plotted on a log-log scale in Fig. 4, so as to correlate with Scher's stochastic theory. The plotted data shows that the rising and falling current is expressed in the form of power-law dependency on time \( t \) (3)-(4).

\[
I(t) \propto t^{(\xi + \alpha)} : \text{Rise} \quad (3)
\]

\[
I(t) \propto t^{(\xi + \alpha)} : \text{Fall} \quad (4)
\]

The calculated power is shown in Table 2.

The figure shows that in each plot, there is a bending point where the power changes. This bending time \( t_{\tau} \) is listed in Table 3. \( t_{\tau} \) for all the samples were quite consistent to be 3.0 msec.

The voltage response, which is important when the sensor is driven by a matrix circuit, has never been reported precisely.

The high resistivity and high trapping density of amorphous silicon seems to have different
characteristics from crystal semiconductors, such as charge trapping.

This charge storage characteristics were measured by applying read out pulses with various intervals (Fig. 6).

The test circuit is shown in Fig. 7.

The voltage response is shown in Fig. 8.

Resulting plotted output voltage is shown in Fig. 9.

The voltage increases as the interval time increases and then finally saturates to be 4 times as large as the static driven voltage $V_0$.

This suggests that the charges are stored.

\[
\frac{\partial n}{\partial x} \\
\frac{\partial^2 n}{\partial x^2} \\
\frac{\partial \varepsilon}{\partial x} \\
\varepsilon
\]

Fig. 5 Movement of photogenerated carriers

\[
\begin{align*}
\text{(a)} & \quad \text{Quasi-Fermi level for electrons} \\
\text{(b)} & \quad \text{Quasi-Fermi level for holes}
\end{align*}
\]

Fig. 6 Read out timing

Fig. 7 Voltage response measurement circuit

Fig. 8 Voltage response

Fig. 9 Voltage response after interval $T_2$

\[
V_1/V_0 = \log T_2
\]

3. Discussion

The basic transient current dependence on time is not exponential but follows power-law. This means the process can not be explained by the transport equation (5).

\[
\frac{3n_p}{\tau_n} = -\frac{np}{\tau_n} + Dn \frac{2n_p}{\tau_n} \frac{2}{\varepsilon x^2}
\]

This indicates Gaussian space distribution propagation that is not consistent with the power law.
Power-law dependence is similar to Scher's continuous random-walk (CTRW). However, a big difference from this theory is as follows.

The Scher's CTRW model concerns a blocking that rejects re-injection from the electrode when an electron is absorbed at the opposite electrode, whereas the sample in this paper has an ohmic contact where carriers propagate until they recombine with holes or are trapped.

The results listed in Table 2 show that $\xi$ is far less than 1, which is the case for blocking diode CTRW.

Even though there was a large variation of $\xi$, $t_\tau$ values for all the samples were almost the same.

The larger $\xi$ is, the number of carriers that propagates becomes larger until $t_\tau$. This means $\xi$ denotes the carrier packet velocity.

The number of carriers injected from the back was larger than the top injected carrier. (Fig. 5)

The steady-state-Fermi level for electrons (quasi-electron Fermi level) becomes close to the conduction band that increases the number of carriers in the extended band that is thermally in equilibrium to the electrons in a steady state Fermi level.

If light is injected from the top (Fig. 5 (a)), carriers are generated only in the cell gap.

The generated carrier diffuses into a neighbouring region with no incident light. This causes slower photoresponse than back light injection (Fig. 5(b)) where carriers are generated totally on the substrate.

Voltage response will now be discussed with the result shown in Fig. 9.

Figure 9 shows that the output voltage $V_1$ is in proportion to the logarithm of storage time $T_2$ described in Eq. (6).

$$ V_1 = \log T_2 $$

$V_1$ saturated at $T_2$ which was 100 $\mu$s, where the output voltage became almost 4 times larger than the steady state voltage $V_0$.

The author would like to speculate this phenomenon as follows.

The state density below the conduction band is explained by Eq. (7)

$$ N_t (c) = N_0 \exp \left( \frac{-c}{RTc} \right) $$

where $c$ is the depth of the electron traps below the conduction band, and $T_c$ is a characteristic temperature.

Accumulated photocarriers starts being trapped from a deep state since they have a lower possibility of being thermally activated.

Then the top level of traps $c_{fe}$ increases as described by Eq. (8), if $G_n$ is defined to be the photocarrier generation ratio

$$ c_{fe} \int_0^{T_2} \int_0^{c_{fe}} \exp \left( \frac{-c}{RTc} \right) \exp \left( \frac{-c}{RT} \right) dc \int_0^{G_n} dt $$

where $c$ is the trapped depth and $R_0$ is the mid gap depth.

There are two kinds of carriers which possibly are stored and moved.

One kind is the carriers on the conduction band $c_{fe}$ and the other is the carriers in the trapped level $c_{fe}$.

At this moment, detailed analysis has not been done yet to prove this. However, just after voltage is applied to the electrode, voltage starts dropping as shown in Fig. 10.

The voltage drop is expressed by Eq. (9).

$$ V(t) \propto t^{-0.23} $$

The power 0.23 is just the same as the photoresponse in Table 2. This means that carrier recombination compensates the storage carrier.

The model is shown in Fig. 11.