Low dark current pinned photo-diode for CMOS image sensor

Ikuko Inoue, Hisanori Ihara, Hirohumi Yamashita, Tetsuya Yamaguchi, Hidetoshi Nozaki, and Ryohei Miyagawa

Microelectronics Engineering Laboratory, Toshiba Corporation, Semiconductor Company
8, Shinsugita-cho, Isogo-ku, Yokohama, 235-8522, Japan
Telephone: +81-770-3642
Fax: +81-770-3571
email: ikuko.inoue@toshiba.co.jp

Abstract
We have developed CMOS image sensor which has high sensitivity comparable to CCD imagers by realizing a very low leakage photo-diode. A low dark current of 0.1 nA/cm² in 5.6 μm² pixel has been achieved by a pinned photo-diode structure and a sensor-specified process for a 1/4-inch 330 K pixel CMOS image sensor. The noise floor of the imager has also been reduced by an appropriate circuit design in the readout path.

Introduction
CMOS image sensor applications are thought to be limited to low-end camera use although its low cost, low power, and on-chip functionality. [1] It is because that CMOS imagers had low sensitivity mainly caused by their large photo-diode leakage current. The photo-diode leakage current origins were the surface damage and the dislocations and defects near LOCOS (LOCal Oxidation of Silicon) as shown in Fig.1(a). The newly developed pinned photo-diode structure, as shown in Fig.1(b), with a sensor-specified process has drastically reduced the leakage current.

Low dark current for the pixel structure and the processes
CMOS sensor adopts LOCOS for an isolation in pixel which is compatible to standard CMOS process. LOCOS process induces very large stress in the photo-diode and causes the dislocation along the LOCOS. The SEM photograph of pixel in Fig.2(a) shows large etch pits with the conventional process. We have refined our process and added some modification to relieve the stress of LOCOS and other damages. The dislocations in pixel has been disappeared with the modified process as shown in Fig.2(b). The modified process has also reduced the dark current as low as 0.3 nA/cm² with the conventional photo-diode structure. It is a third of that with the conventional process as shown in Fig.3.

The surface area depletion generates a large dark current because of the surface defect states. The pinned PD has an additionally shallow p+ layer on the deep n-PD diffusion layer.[2][3] The pinned photo-diode structure shields the surface area by the p+ layer. This structure has been built in 5.6 μm² pixel with using 0.6 μm design rule and the modified
process described above. The dark current has been reduced to the extremely low level of 0.1nA/cm², which is comparable to CCDs' level as shown in Fig.3. Figure 4 shows the reproduced image in the dark for the different processes and structures.

**Low dark current for the circuit**

All the noises in the readout path has also been successfully suppressed below the CCD sensors' level by the appropriate circuit design. Figure 5 shows the sensor architecture. The noise cancel circuit functions as an off-set cancel of pixel amplifier[5], and a signal charge amplifier. The sufficient large charge gain in the noise cancel circuit enables the noises in the readout path to be below the detection limit. The pixel amplifier has the same noise spectrum as that of CCDs' charge detector in principle. However, the pixel amplifier is operated in column-parallel. The amplifier noise is smaller than that of the CCDs because of its narrower bandwidth. Therefore, we have gotten high sensitivity and high quality image equal to CCD image sensor.

**Conclusion**

In conclusion, the low dark current of the pinned photo-diode has been developed for the CMOS image sensor using a modified process. The characteristics of pinned photo-diode and the conventional image sensor are summarized in Table 1. As a result, a CMOS image sensor has been realized high sensitivity and high quality to compared with CCD image sensor.

**Reference**


<table>
<thead>
<tr>
<th></th>
<th>Conventional photo-diode</th>
<th>Pinned photo-diode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>5.6×5.6 µm²</td>
<td>5.6×5.6 µm²</td>
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<tr>
<td>Design rules</td>
<td>0.6 µm</td>
<td>0.6 µm</td>
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<tr>
<td>Saturation current</td>
<td>45 nA</td>
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<td>Dark Current at RT</td>
<td>0.3 nA/cm²</td>
<td>0.1 nA/cm²</td>
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<td>FPN(leak current at RT)</td>
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<td>Frame rate</td>
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<td>Power supply</td>
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<tr>
<td>Power dissipation</td>
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</table>

Table 1 Characteristic of 1/4-inch 330 K pixel CMOS image sensor.
Figure 1. Cross-sections of the photo-diodes

(a) Conventional Photo-Diode

(b) Pinned photo-diode with modified process

Figure 2. Etch pit of defect

(a) Conventional process  (b) Modified process

Figure 3 Dark current of the photo-diodes

A: Conventional CMOS  
B: Pinned photodiode (R.M. Guidshu et al.)
C: Modified process
D: Pinned photodiode with Modified process
(0.6 μm CMOS Process, 60°C, Tint=1/60s)

Figure 4. Reproduced Images under dark conditions

Figure 5. CMOS Sensor Circuit Diagram