CHAPTER 9.5
CHARGE TRANSFER DEVICE (CTD) IMAGERS

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MONOLITHIC SOLID-STATE SELF-SCANNED IMAGE SENSORS

Monolithic solid-state self-scanned image sensors of the charge-coupled-device (CCD) and charge-injection-device (CID) types are extremely versatile and can be applied to high- and low-light-level imaging, optical character recognition, and facsimile reproduction. Solid-state devices offer advantages over vidicons for imaging applications: they provide lag-free, burn-free imaging and operate at low power in a self-scanned mode; they are lightweight and have high sensitivity. Advanced metal-oxide-semiconductor (MOS) technology is employed to fabricate the closely spaced single- or multiple-capacitor imaging elements, called *pixels*. Linear or area configuration of the pixels, with the appropriate on-chip scanning circuit and low-noise preamplifier, constitute the focal-plane image sensor in a camera system.

CCD IMAGING

The principle of operation is based on the transfer of photogenerated minority-carrier charge packets to adjacent pixels. Sequentially clocked voltage pulses applied to adjacent pixels create potential wells, which transfer charge packets to adjacent positions across the surface. Each charge packet corresponds to a pixel-sized optical image element. Thus, the moving charge packets and transferred to a low-capacitance output diode that has typical values on the order of 0.2 pF to obtain the video signal. This is one of the major advantages of the CCD imagers and produces high signal-to-noise output signals. Two implementations of CCD imagers are possible, one using charge transport in a surface channel and the other in a buried or bulk channel.

In the surface-channel device (SCCD) the conduction channel is at the semiconductor-oxide interface and allows the signal charge packets to interact with interface states. The resultant interface-state trapping can be reduced by introducing a bias charge 5 to 20 percent of full well, referred to as “fat zero.” The performance is limited by temporal noise resulting from interface state trapping and a spatial or fixed pattern noise caused by nonuniform fat-zero insertion.

For a buried-channel device (BCCD) the conduction channel is ion-implanted approximately 0.5 μm into the bulk with respect to the semiconductor-oxide interface. The charge packets interact with low density (of the order of 10^{11} cm^{-3}) bulk states, but the bulk trapping noise is insignificant even for signals as low as approximately 10 electrons per pixel per frame at –20°C. The charge transfer efficiency is also improved over the surface-channel device because of the larger fringing fields between the pixels present in the channel.

CID Imaging

The CID is an *XY* addressed matrix of MOS capacitor pairs in which each capacitor pair constitutes a pixel. Charge transfer occurs only between the capacitor pairs within a pixel, and the photogenerated charge packets are not transferred to a common output. The charge packets are stored by biasing at least one of the capacitors. When the capacitor pair of a pixel is simultaneously pulsed to zero, the potential well collapses and the stored minority carrier charge is injected into the substrate, where most of the carriers recombine. This injected charge provides the video signal. A reverse-biased epitaxial junction in the substrate collects the unrecombined minority carriers to prevent them from diffusing back into the same pixel or into neighboring pixels, which would degrade the resolution.

An alternative low signal-to-noise readout technique uses an output circuit that senses the relative magnitude of the stored charge in a given pixel by transferring the charge between the capacitor pairs. Even with this improvement, the effective output capacitance of a CID is still approximately an order of magnitude higher than that of a CCD. This is a definite disadvantage for low-light-level imaging, but the superior antiblooming control and the random-access features provided by the CID scheme are useful in many other applications.

CHARGE-TRANSFER-DEVICE ARCHITECTURE

Charge-coupled-device area imagers have been fabricated in two main configurations. One uses a frame-storage mode and the other in interline transfer mode. The former has nearly 100 percent optically sensitive imaging area with transparent electrodes or backside illumination but can suffer from optical transfer smearing effects. For certain applications not requiring TV readout rates, e.g., astronomical observations and space telescopes, full frame imagers can be used.

The frame-storage device is illustrated in Fig. 9.5.1. Charge is integrated in the imaging section and then rapidly moved into the frame-storage section for subsequent readout through the serial shift register. In this mode both frontside and backside illumination is possible. Interlaced readout is obtained by imaging under different electrode sets, giving alternate readout of frame A and frame B. The shaded regions are opaque.

The interline transfer device is shown in Fig. 9.5.2. The charge is integrated in the photosensitive areas and is shifted into opaque columns for subsequent transfer to the readout serial shift register. In this mode only frontside illumination is possible. Interlacing is obtained by integration under different electrodes in subsequent frames (*A* and *B* in the figure). Shaded regions are opaque.

In the charge-injection-device area imager (Fig. 9.5.3) a particular column is allowed to float, and the change in potential after a row transfer under that column provides the pixel signal readout. Area imaging is obtained by suitable scanning of the horizontal and vertical registers. The device has the advantage of random access and is also free of optical smearing effects. Transparent electrodes allow about 100 percent optically active areas with a sensitivity that depends on the readout scheme.

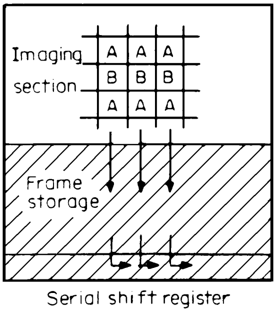

FIGURE 9.5.1 Frame-storage charge transfer device.

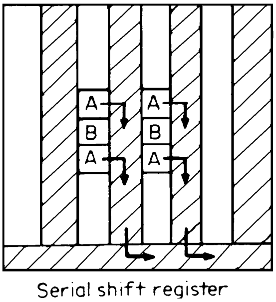

FIGURE 9.5.2 Interline charge transfer device.

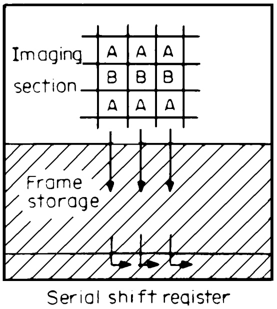

FIGURE 9.5.3 Charge injection area imager.

LOW-LIGHT-LEVEL IMAGING

Image-intensifier technology can be used with charge transfer devices for low-light-level applications, and two methods are available. In the EBS-CCD approach (electron-bombarded silicon-CCD), the phosphor screen, in a proximity-focused and/or inverter-type image intensifier, is replaced by a backside thinned and accumulated silicon CCD. The impinging 8- to 15-kV photoelectrons produce high gains in the approximately 10-μm-thick CCD substrate. The maximum theoretical gain is $V/3.5$, where V is the accelerating voltage of the incident electrons.

In this mode of operation the effective preamplifier noise of a cooled direct-view CCD is reduced by the approximately 1000 to 2500 electron gain in the CCD, and low-light level imaging has been demonstrated under overcast night-sky illuminance levels of 8 μlx. The second method uses image intensifiers, fiber optically coupled directly to either a frontside-illuminated CCD or CID area array. This hybrid approach allows the selection of conventional image intensifiers based on an optimum trade-off between gain, life expectancy, noise figure, and charge-transfer-device noise.

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