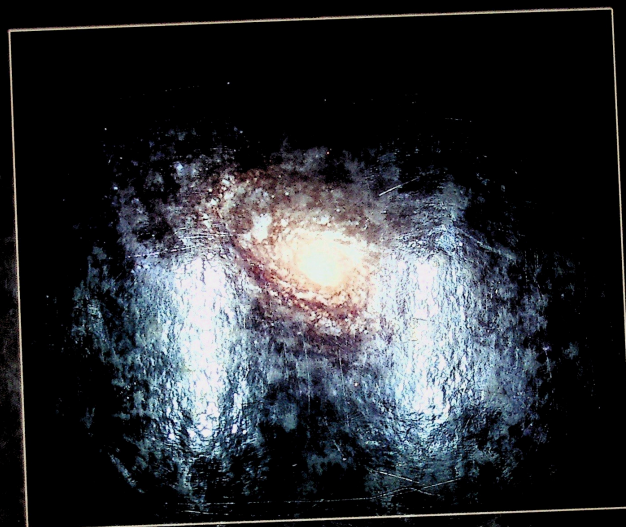




Scientific Charge-Coupled Devices

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photons are known as interacting photons. An ideal CCD would have 100% QE at all wavelengths, but nature is rarely this kind. QE is highly dependent on wavelength, falling off steeply at the near-infrared (NIR) and blue wavelengths. Charge generation takes place in the silicon body of the CCD. When a photon interacts with this material, it creates one (or for higher-energy photons, several) free electron(s) by a physical process known as the photoelectric effect.

Interaction only occurs if the photon has enough energy to do so. This is because silicon exhibits an energy gap of approximately 1.14 eV, which is bounded by the valence and the conduction energy bands. Photon energy E (eV) can be converted to a wavelength using the equation

$$\lambda = \frac{12,390}{E(\text{eV})}, \quad (1.1)$$

where λ is the wavelength ($\text{\AA}$).

Example 1.1

What is the wavelength of a 1.14-eV photon?

Solution:

From Eq. (1.1),

$$\lambda = 12,390/1.14,$$

$$\lambda = 10,868 \text{ \AA}.$$

Most photons with energies < 1.14 eV pass through the chip; i.e., silicon is transparent in the far infrared. Some of these photons do in fact interact but do not generate signal carriers, a process called free-carrier absorption. Interacting photons with sufficient energy will excite an electron into the conduction band, creating an electron-hole (e-h) pair. The e-h pair created is free to move and diffuse in the silicon lattice structure. For high-quality silicon, the lifetime of the electron is several milliseconds before recombining.

A photon with energy of 1.1 to 3.1 eV (11,263 $\text{\AA}$ –4,000 $\text{\AA}$) will generate a single e-h pair. This spectral range covers the near infrared (NIR) and visible spectrum (4,000–7,000 $\text{\AA}$). Energies > 3.1 eV will produce multiple e-h pairs when the energetic conduction band electron collides with other valence electrons.¹⁷ The average number of electrons generated for a photon with energy E (eV) > 10 eV is

$$\eta_i = \frac{E(\text{eV})}{E_{e-h}}, \quad (1.2)$$

3.1 CHARGE GENERATION

The photoelectric effect is responsible for generating signal charge when incident photons interact with the photosensitive volume of the CCD. The challenge for CCD manufacturers is to let incoming photons interact. Quantum efficiency is the performance parameter that tells us how well they have accomplished this task, and is defined as

$$QE = \eta_i QE_I, \quad (3.1)$$

where QE_I is the interacting QE and η_i is the quantum yield. An interacting photon is one that is absorbed by the CCD and generates one or more e-h pairs. The definition above may produce QE values greater than unity because multiple electron-hole pair generation is possible. Interacting QE is always less than unity and is usually the QE value specified by the CCD manufacturer.

Example 3.1

Calculate QE performance assuming a quantum yield of $3 e^-$ /interacting photon and an interacting QE of 50%.

Solution:

From Eq. (3.1),

$$QE = 3 \times 0.5,$$

$$QE = 1.5.$$

For frontside-illuminated CCDs, incident photons must pass through the poly gates before they can interact with the epitaxial layer. As shown below, gate absorption represents a significant QE loss mechanism, especially for photons with short absorption lengths. Reflection loss also degrades QE performance over a major portion of the working spectrum. Transmission loss is important for very long and very short wavelength photons that penetrate the epitaxial layer without interaction.

Example 7.40

What is the aluminum shield thickness required to attenuate a 1 MHz EMR to 1%? Assume the skin depth is $84.5 \mu\text{m}$.

Solution:

From Eq. (7.99),

$$x = [\ln(1) - \ln(0.01)] \times (8.45 \times 10^{-3}),$$

$$x = 3.89 \times 10^{-2} \text{ cm.}$$

7.2.6 GROUNDING

Common impedance noise is generated when signal currents from two different circuits flow through the same ground return. There are two principal grounding philosophies to consider. They are referred to as single-point grounding and multi-point grounding and are illustrated in Fig. 7.54.

Series single-point or “daisy-chain” grounding is undesirable when applied to CCD camera design. Although it is the simplest grounding scheme, the circuits share ground currents, which in turn causes cross talk problems. The parallel ground arrangement is a better choice because it isolates ground currents for

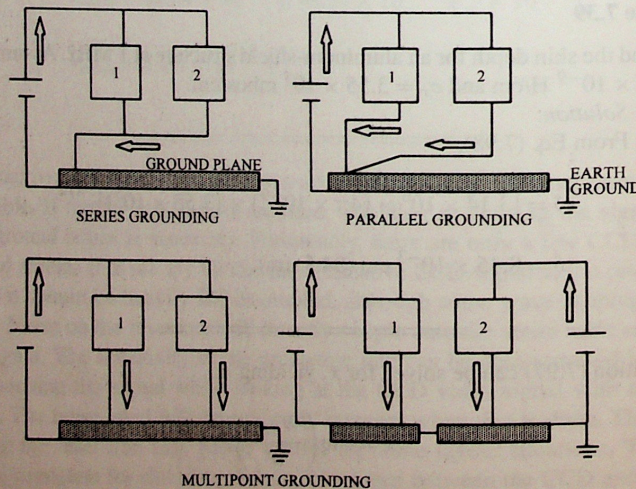


Figure 7.54 Single-point and multipoint grounding schemes.

dose enhancement

The process by which charge generated in the silicon by ionizing radiation finds its way into the oxide and enhances the dose.

dosimeter

An instrument used to measure total radiation absorbed dose.

drain pinch-off

A MOSFET bias condition that fully depletes the drain region into the saturation region.

drive capacitance

The pixel capacitance which includes oxide, depletion, overlap, field, and sidewall capacitances; given in F/pixel/phase.

dual gate insulator

A two-layer gate dielectric, usually silicon nitride deposited on top of silicon dioxide.

dual-stage amplifier

A high-speed output amplifier configuration that allows pixels rates greater than 22 Mpixels/sec.

dynamic range

The ratio of full well to read noise.

E-center

See P-V center.

effective threshold

The channel potential ($V_{\max}$) under a gate when the gate is held at ground potential.

elastic interaction

An elastic scattering interaction of a high-energy ion and the coulomb potential presented by the target ion that can result in displacement damage.

electron

The signal carrier generated, collected, transferred, and measured in n-channel CCDs.

electron confinement range

The physical width in depth where a charge packet is confined in the signal channel.

electron-hole pair

A carrier pair produced when a photon or particle photoelectrically interacts with a silicon atom.

electrostatic discharge (ESD)

The rapid discharge of static electricity from one material to another.

proton

A positively charged subatomic particle slightly less than the mass of a neutron but about 1,836 times heavier than an electron.

proton transfer

A CCD radiation transfer curve that plots displacement damage as a function of proton energy.

punch-through effect

A MOSFET effect where the drain and source depletion regions merge under the channel, causing premature breakdown; also called the *short channel effect*.

QE transfer

A transfer curve that characterizes interacting QE as a function of wavelength.

QE-pinned

An important backside-illuminated condition that achieves 100% internal QE.

quantizing noise

The pixel encoding noise related to the analog-to-digital converter.

quantum yield

The number of electrons generated per interacting photon.

quantum efficiency (QE)

The number of electrons generated per incident photon.

quantum efficiency hysteresis (QEH)

Instability related to QE performance.

RTS dark spike

A dark spike that generates charge erratically, generating a random telegraph signal.

radiation absorbed dose (RAD)

The standard unit of radiation dose, equivalent to the deposition of 100 ergs of energy per gram of material in the form of electron-hole pairs.

radiation events

Charge generated by energetic ions interacting with the CCD (also referred to as *interference events*).

radiation shield

A shield, usually made of aluminum or tantalum, placed near a CCD to reduce the dose received by the CCD.

radiation trap inefficiency factor (RTI)

The measured proportionality constant between the damage measured in terms of CTE and the theoretical CTE based on the number of vacancies predicted by NIEL and SRIM.