Nalanda Open University

M.SC Part-1

Course : Physics

Paper : 8

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Topic- Charge Coupled Device (Electronic device)

Charge Coupled Device

Charge Coupled Devices can be defined in different ways according to the application for which they are used or based on the design of the device.

It is a device used for the movement of electrical charge within it for the charge manipulation, which is done by changing the signals through stages within the device one at a time.

It can be treated as CCD sensor, which is used in the digital and video camera for taking images and recording videos through photoelectric effect. It is used for converting the captured light into digital data, which is recorded by the camera.

It can be defined as a light sensitive integrated circuit imprinted on a silicon surface to form light-sensitive elements called pixels, and each pixel is converted into an electrical charge.

Types of CCD

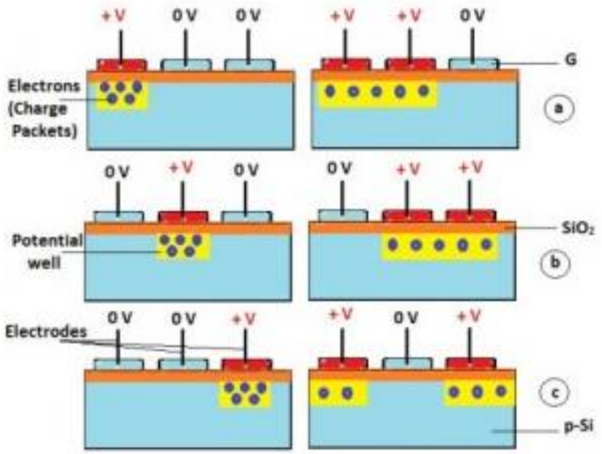
There are different CCDs such as electron multiplying CCDs, intensified CCD, frame-transfer CCD and buried-channel CCD. A CCD can be simply defined as Charge Transfer Device. The inventors of the CCD, Smith and Boyle also discovered a CCD with greatly enriched performance than a general Surface Channel CCD and other CCDs; it is known as Buried channel CCD and is majorly used for practical applications.

Charge Coupled Device's Working Principle

The silicon epitaxial layer acting as a photoactive region and a shift- register-transmission region are used for capturing images using a CCD.

Through the lens image is projected onto the photo active region consisting of capacitor array. Thus, the electric charge proportional to the light intensity of the image pixel color in the color spectrum at that location is accumulated at each capacitor.

If the image gets detected by this capacitor array, then the electrical charge accumulated in each capacitor is transferred to its neighbor capacitor by performing as a shift register controlled by the control circuit.



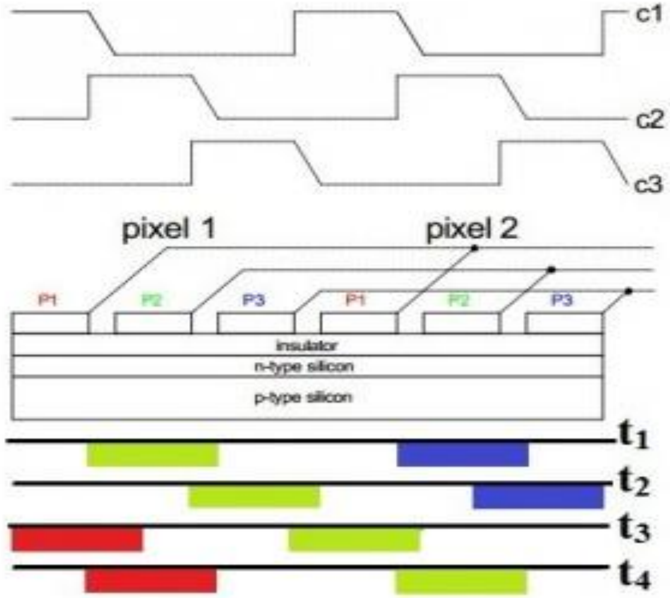
Working of Charge Coupled Device

In the above figure, from a, b and c, the transfer of charge packets is shown according to the voltage applied to the gate terminals. At last, in the array electrical charge of last capacitor is transferred into the charge amplifier in which the electric charge is converted into a voltage. Thus, from the continuous operation of these tasks, entire charges of the capacitor array in the semiconductor are converted into a sequence of voltages.

This sequence of voltages is sampled, digitized and then stored in memory in case of digital devices such as digital cameras. In case of analog devices such as analog video cameras, this sequence of voltages is fed to a low-pass filter to produce a continuous analog signal, and then the signal is processed for transmission, recording and for other purposes. To understand the charge coupled device principle and charge coupled device working in depth, primarily the following parameters need to be understood.

Charge Transfer Process

The charge packets can be moved from cell to cell by using many schemes in Bucket Brigade style. There are various techniques such as two phase, three phase, four phase, and so on. Every cell consists of n-wires passing through it in n-phase scheme. The height of the potential wells is controlled by using each wire connected to transfer clock. Charge packets can be pushed and pulled along the line of the CCD by varying the height of the potential well.



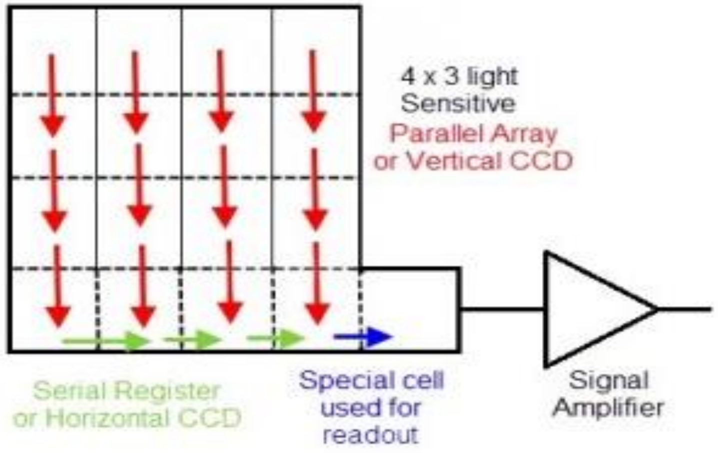
Charge Transfer Process

Consider a three-phase charge transfer, in the above figure, the three clocks (C1, C2 and C3) which are identical in shape but in different phases are shown. If gate B goes high and gate A goes low, then the charge will move from space A to space B.

Architecture of CCD

The pixels can be transferred through the parallel vertical registers or vertical CCD (V-CCD) and parallel horizontal registers or horizontal CCD (H-CCD). The charge or image can be transferred using different scanning architectures such as full frame readout, frame transfer and interline transfer. The charge coupled device principle can be easily understandable with the following transfer schemes:

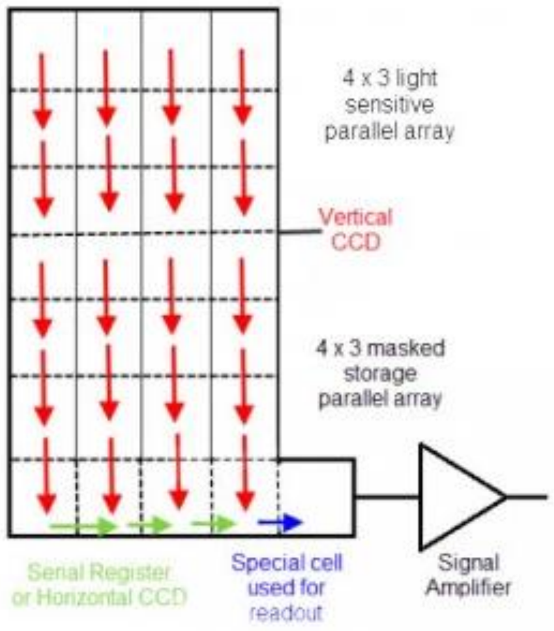
1. Full-Frame Readout



Full Frame Readout

It is the simplest scanning architecture which requires a shutter in a number of applications to cut off the light input and to avoid smearing during the passage of charges through parallel-vertical registers or vertical CCD and parallel-horizontal registers or horizontal CCD and then transferred to output in serial.

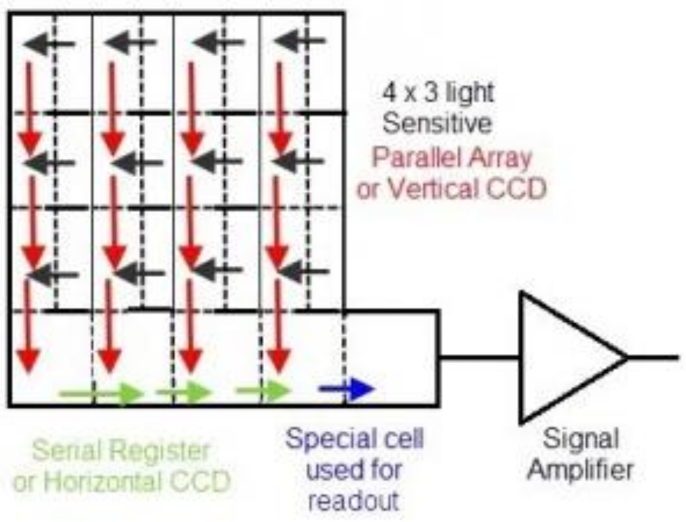
2. Frame Transfer



Frame Transfer

By using the bucket brigade process the image can be transferred from image array to opaque frame storage array. As it does not use any serial register, it is a fast process compared to other processes.

3. Interline transfer



Interline Transfer

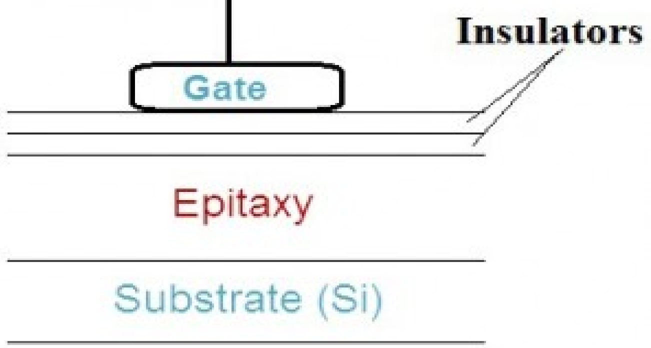
Each pixel consists of a photodiode and opaque charge storage cell. As shown in the figure, the image charge is first transferred from light sensitive PD to the opaque V-CCD. This transfer, as the image is hidden, in one transfer cycle produces a minimum image smear; hence, the fastest optical shuttering can be achieved.

MOS Capacitor of CCD

Every CCD cell has metal oxide semiconductor, even though both surface channel and buried channel MOS capacitors are used in manufacturing the CCD. But frequently CCDs are fabricated on a P-type substrate and manufactured by using buried channel MOS capacitors; for this a thin N-type region is formed on its surface. A silicon dioxide layer is grown as an insulator on the top of the N-region, and gates are formed by placing one or more electrodes on this insulating layer.

CCD Pixel

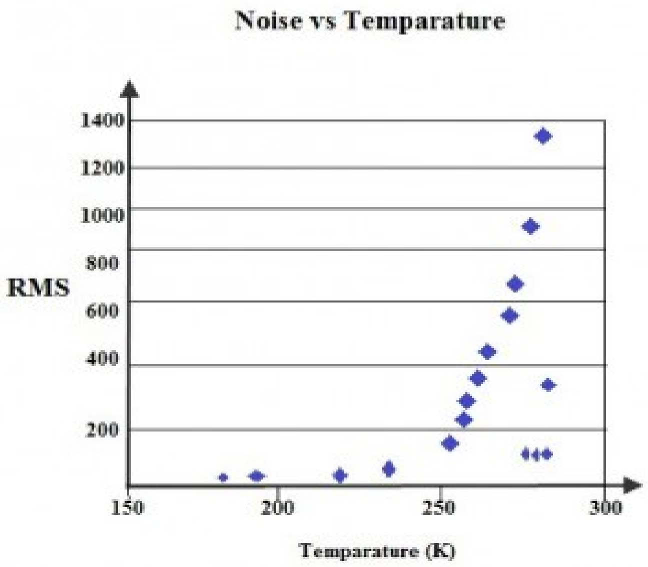
Free electrons are formed from photoelectric effect when the photons strike the silicon surface, and because of the vacuum, simultaneously, positive charge or the hole will be generated. Instead of choosing difficult process of counting the thermal fluctuations or heat formed by the recombining of hole and electron, it is preferred to collect and count electrons to produce an image. This can be achieved by attracting electrons generated by striking photons on silicon surface towards the positively biased distinct areas.



CCD Pixel

Full well capacity can be defined as the maximum number of electrons that can be held by each CCD pixel and, typically, a CCD pixel can hold 10ke to 500ke, but it depends on the size of the pixel (the bigger the size more electrons can be accumulated).

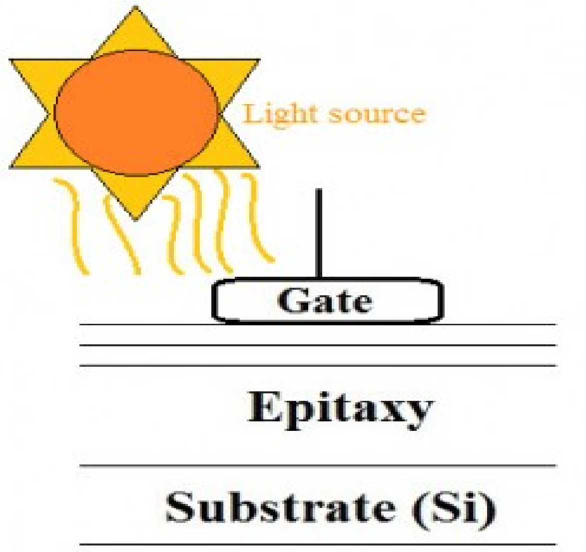
CCD Cooling



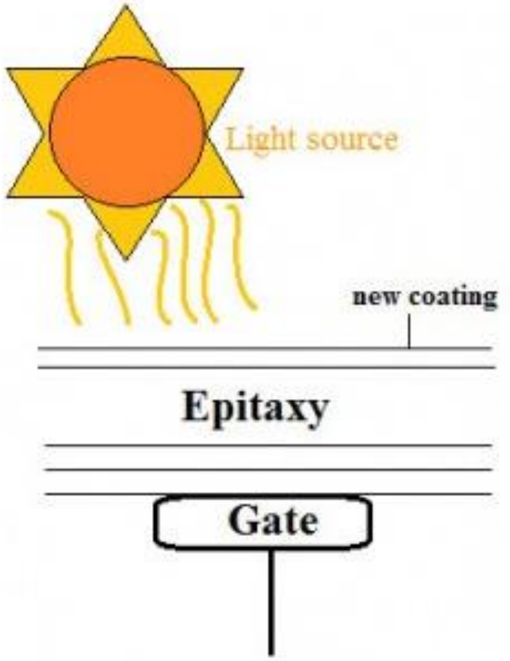
Generally CCDs work at low temperature, and thermal energy can be used for exciting inappropriate electrons into image pixels which cannot be differentiated from the real-image photoelectrons. It is called as a dark current process, which generates noise. The total dark current generation can be reduced by two times for every 6 to 70 of cooling with certain limits. The CCDs do not work below -1200 and the total noise generated from the dark current can be removed by cooling it around -1000, by thermally isolating it in an evacuated environment. CCDs are frequently cooled by using liquid nitrogen, thermo-electric coolers and mechanical pumps.

Quantum Efficiency of CCD

The rate of generation of photoelectrons depends on the light incident on the surface of the CCD. The conversion of the photons into electric charge is contributed by many factors and is termed as Quantum Efficiency. It is in the better range of 25% to 95% for CCDs compared to other light- detection technique.



The front- illuminated device generates a signal after the light passes through the gate structure by attenuating the incoming radiation.



Quantum Efficiency of Back Illuminated Device

The back-illuminated or back-thinned CCD consists of excess silicon on the underside of the device, which is imprinted in a way that unrestrictedly allows generation of photoelectrons.