Designation: E2642 – 09 (Reappproved 2021)

Standard Terminology for Scientific Charge-Coupled Device (CCD) Detectors[1]

This standard is issued under the fixed designation E2642; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This terminology brings together and clarifies the basic terms and definitions used with scientific grade cooled charge-coupled device (CCD) detectors, thus allowing end users and vendors to use common documented terminology when evaluating or discussing these instruments. CCD detectors are sensitive to light in the region from 200 nm to 1100 nm and the terminology outlined in the document is based on the detection technology developed around CCDs for this range of the spectrum.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E131 Terminology Relating to Molecular Spectroscopy

3. Significance and Use

3.1 This terminology was drafted to exclude any commercial relevance to any one vendor by using only general terms that are acknowledged by all vendors and should be revised as charge-coupled device (CCD) technology matures. This terminology uses standard explanations, symbols, and abbreviations.

4. Terminology

4.1 *Definitions:*

advanced inverted mode operation (AIMO), *n*—a commercial tradename given to a method of reducing the rate of generation of dark current. Also known as **multi-pinned phase** operation.

analog-to-digital (A/D) converter, *n*—an electronic circuitry in a CCD detector that converts an analog signal into digital values, which are specified in terms of bits that can be manipulated by the computer.

anti-blooming structure, *n*—a structure built into the pixel to prevent signal charge above full-well capacity from blooming into adjacent pixels.

Discussion—Anti-blooming structures bleed off any excess charge before they can overflow the pixel and thereby stop blooming. These structures can reduce the effective quantum efficiency and introduce nonlinearity into the sensor.

antireflective (AR) coating, *n*—a coating applied to either the front surface of the CCD or the vacuum window surfaces, to minimize the amount of reflected energy (or electromagnetic radiation) so as to maximize the amount of transmitted energy.

back-illuminated CCD (BI CCD), *n*—a type of CCD that has been uniformly reduced in thickness on the side away from the gate structure (see Fig. 1b) and positioned such that the photons are detected on that side.

Discussion—A BI CCD leads to an improvement in sensitivity to incoming photons from the soft X-ray to the near-infrared (NIR) regions of the spectrum with the highest response in the visible region. However, compared to a front-illuminated CCD, it suffers from higher dark currents and interference fringe formation (etaloning) usually in the NIR region. Also called back-thinned CCD.

binning, *n*—the process of combining charge from adjacent pixels in a CCD prior to read out.

Discussion—There are two main types of binning: *(1)* vertical binning and *(2)* horizontal binning (see Fig. 2). Summing charge on the CCD and doing a single readout results in better noise performance than reading out several pixels and then summing them in the computer memory. This is because each act of reading out contributes to noise (see **noise**).

CCD bias, *n*—the minimum analog offset added to the signal before the A/D converter to ensure a positive digital output each time a signal is read out.

Discussion—The CCD bias is set at the time of manufacture and remains set over the lifetime of the camera.

[1] This terminology is under the jurisdiction of ASTM Committee E13 on Molecular Spectroscopy and Separation Science and is the direct responsibility of Subcommittee E13.08 on Raman Spectroscopy.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

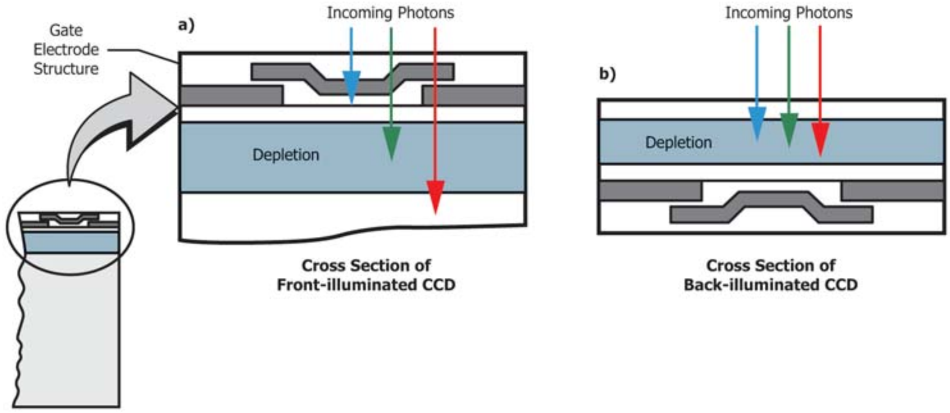

FIG. 1 Cross Sections of Front-Illuminated (a) and Back-Illuminated (b) CCDs

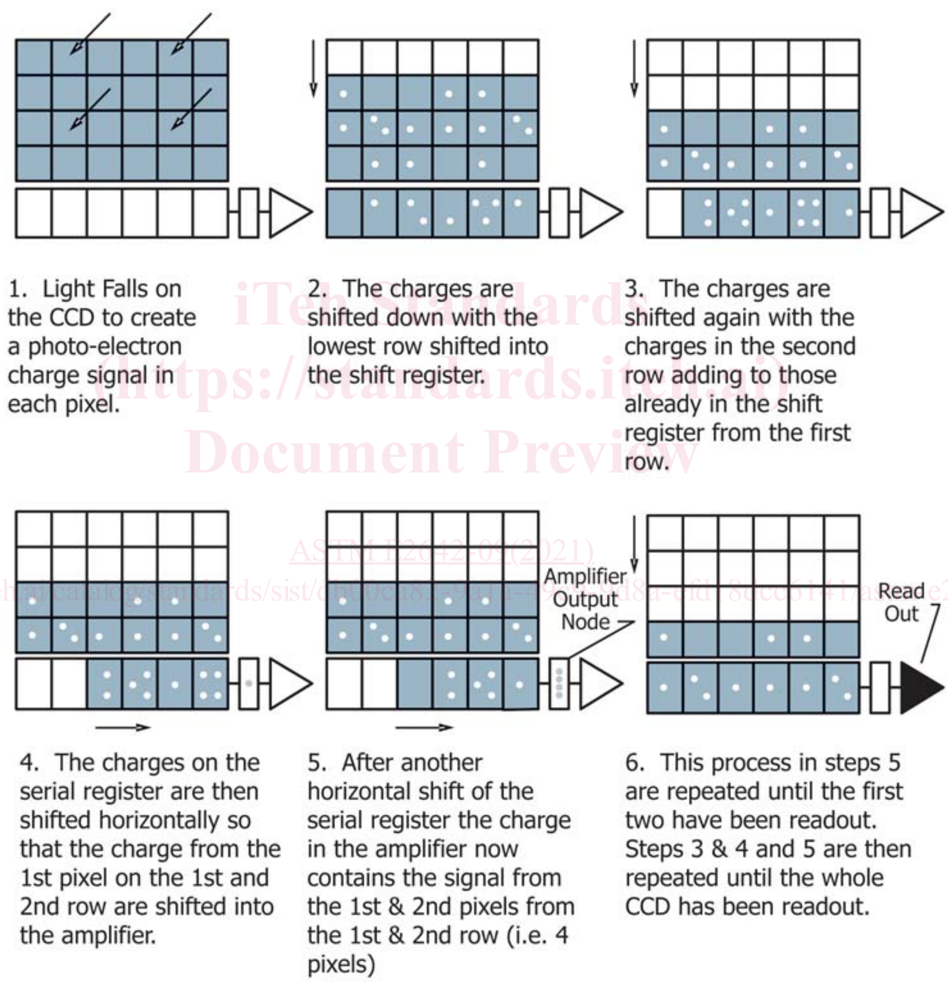

FIG. 2 Example of a 2 × 2 Vertical and Horizontal Binning Methodology

charge, *n*—measure of number of electrons that are contained in a pixel potential well.

charge-coupled device (CCD), *n*—a silicon-based semiconductor chip consisting of a two-dimensional matrix of photo sensors or pixels (see Fig. 3).

DISCUSSION—The matrix is usually referred to as the image area. Electronic charge is accumulated on the image area and transferred out by the application of electrical potentials to shielded electrodes. The size of pixels in the sensor is typically 26 µm × 26 µm; however, sensors can be manufactured in a variety of different pixel sizes ranging from 6 µm × 6 µm to 50 µm × 50 µm. Although mathematically incorrect, the dimension unit of a square pixel is typically given in square microns (for example, a pixel of dimension 26 µm × 26 µm is specified as 26 × 26 μm^2).

charge transfer, *n*—the process by which a CCD moves electrons or charge from one pixel to the next.

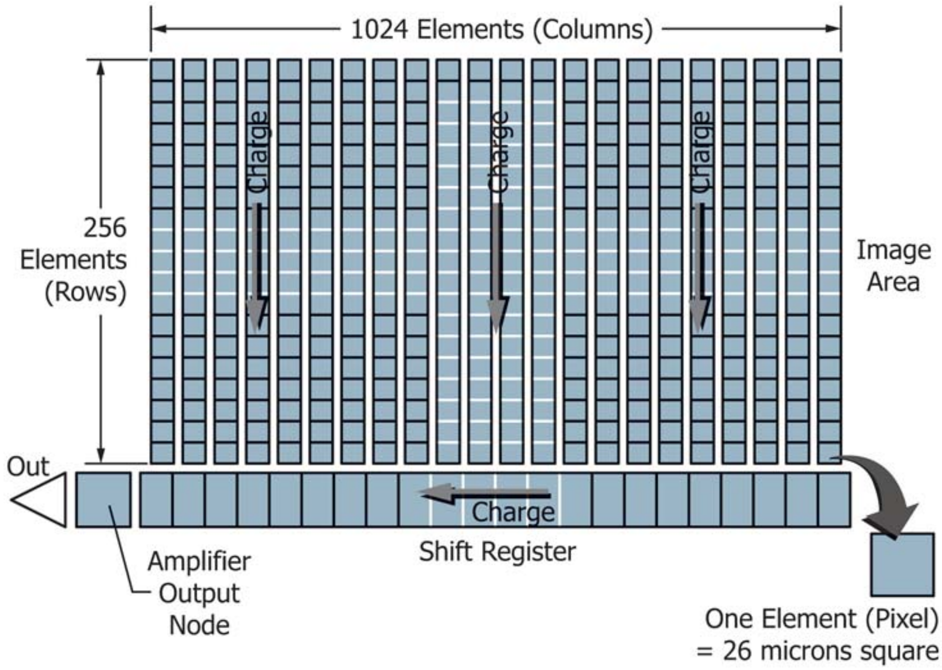

FIG. 3 Typical 1024 × 256 (26 × 26 μm² pixel) Element CCD Sensor Used for Spectroscopy

charge transfer efficiency (CTE), *n*—measure of the ability of the CCD to transfer charge from the point of generation to the device output.

Discussion—It is defined as the fraction of the charge initially stored in a CCD element that is transferred to an adjacent element by a single clock cycle. The value for CTE is not constant but varies with signal size, temperature, and clock frequency.

column, *n*—a line of pixels in the CCD's image area that is perpendicular to the horizontal register.

complementary metal oxide semiconductor (CMOS), *n*—technology widely used to manufacture electronic devices and image sensors similar to CCDs. In a CMOS sensor, each pixel has its own charge-to-voltage conversion circuit, and the sensor often also includes amplifiers, noise-correction, and digitization circuits. Due to the additional components associated with each pixel, the sensitivity to light is lower than with a CCD, the signal is noisier, and the uniformity is lower. But the sensor can be built to require less off-chip circuitry for basic operation (see Fig. 4).

correlated double sampling, *n*—a readout sampling technique used to achieve higher precision in CCD readout.

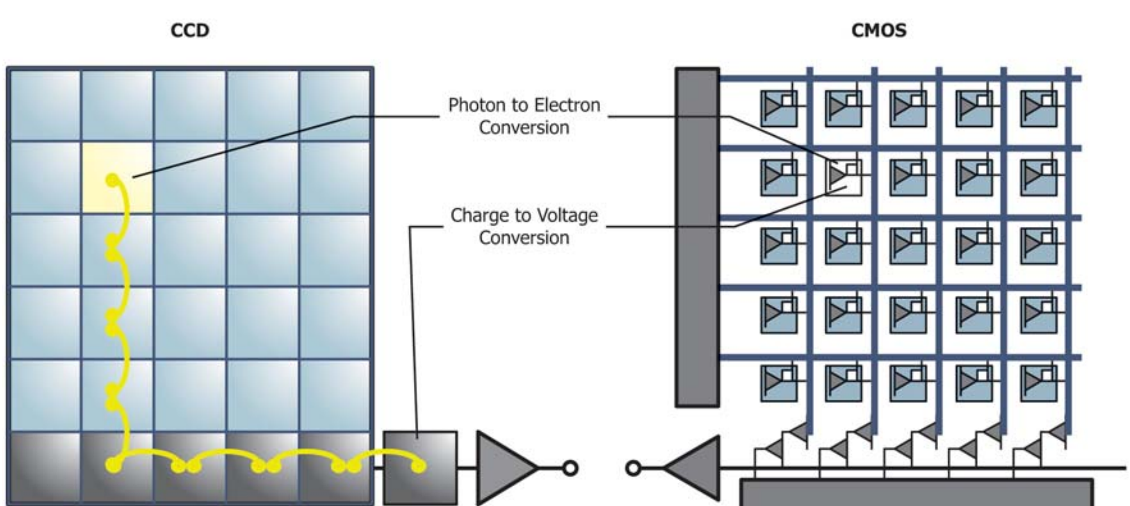

FIG. 4 Typical Architectures of CCD and CMOS Sensors

Discussion—The sampling circuit is set to a predetermined reference level and then the actual pixel voltage is sampled in order to find the difference between the two. The resulting correlation minimizes read noise, especially in ultra-low-noise CCD detectors.

cosmic event, *n*—a spurious signal caused by a cosmic ray or particle hitting the CCD sensor. It is typically observed to result in a high intensity signal coming from a single pixel or small group of pixels.

dark current, *n*—a current that occurs naturally through the thermally generated electrons in the semiconductor material of the CCD. It is intrinsic to semiconductors and is independent of incident photons.

Discussion—Dark current is dependant on the CCD's temperature. It is expressed in electrons/pixel/unit time.

dark noise, *n*—the shot noise associated with the dark current for the given exposure time, and is approximately equal to the square root of the dark current times the exposure time used. It is usually expressed in terms of number of electrons.

deep depletion CCD, *n*—a CCD that has been designed with a thicker active area to provide enhanced sensitivity in the NIR and hard X-ray regimes.

Discussion—Both front-illuminated and back-illuminated CCDs can be manufactured with a deep depletion process to enhance the NIR response; however, such devices cannot be operated in AIMO and are also more susceptible to cosmic rays. A back-illuminated deep depletion CCD will have reduced etaloning effects that are typically observed in back-illuminated devices exposed to NIR signals (see Fig. 5).

dynamic range, *n*—the ratio of the full well saturation charge to the system noise level. It represents the ratio of the brightest and darkest signals a detector can measure in a single measurement.

Discussion—A true 16-bit detector will have a dynamic range of 65 535:1.

electron-multiplying CCD (EMCCD), *n*—type of CCD that has a two-way readout register, that is, the shift register and the gain register, each with its own output amplifier. When the charge is read out through the shift register, the detector works like a standard CCD detector, and when the charge is read out through the gain register, it undergoes charge amplification as a result of a different electrode structure embedded underneath the pixels of this register (see Fig. 6).

Discussion—Passing charge through the gain register allows the signal to be amplified before readout noise is added at the readout amplifier, thus improving the signal-to-noise ratios making the camera highly sensitive in the low-light regime.

etaloning, *n*—a phenomenon by which constructive and destructive interference fringes are produced in a back-illuminated CCD caused by internal reflections between the two parallel surfaces of the CCD. Typically BI CCDs experience etaloning effects when subjected to NIR signals (see Fig. 5).

Discussion—This effect causes the device to become transparent to incoming photons in the NIR region.

exposure time, *n*—the length of time for which a CCD accumulated charge.

frame, *n*—one full image that is read out of a CCD.

frame-transfer CCD, *n*—a type of CCD whose active image area is divided into two sections, that is, image area and the storage area. The image area is the light sensitive area of the CCD and the storage area is masked to make it insensitive to light (see Fig. 7).

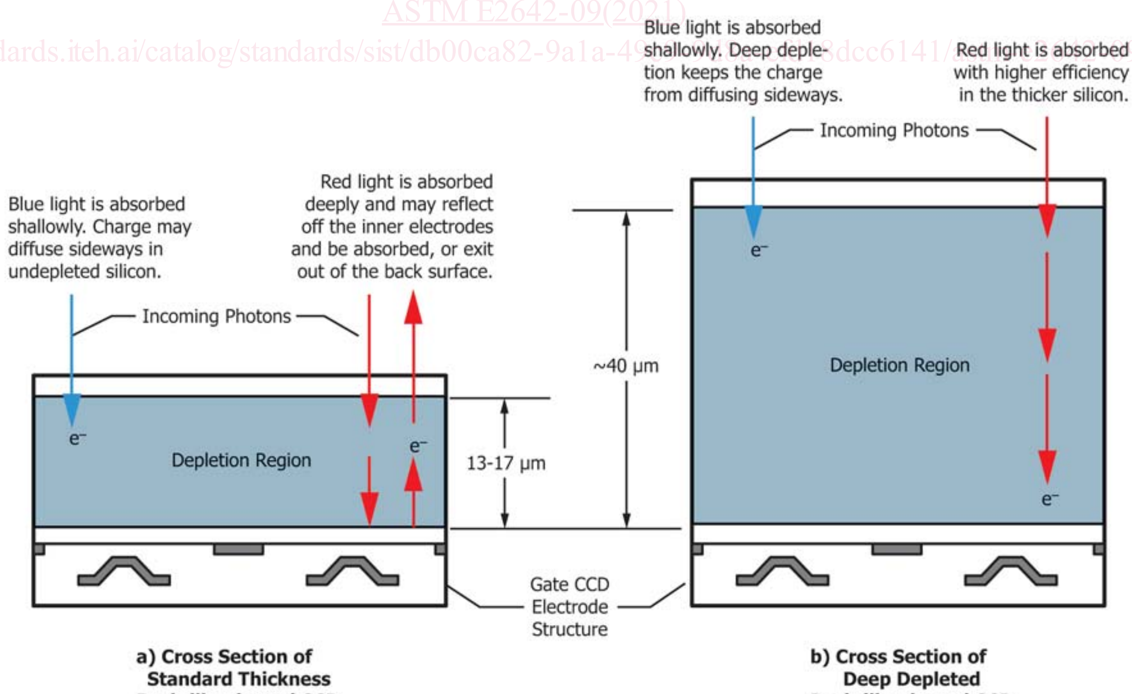

FIG. 5 Cross-Sections of Back-Illuminated (a) and Back-Illuminated Deep Depletion (b) Devices

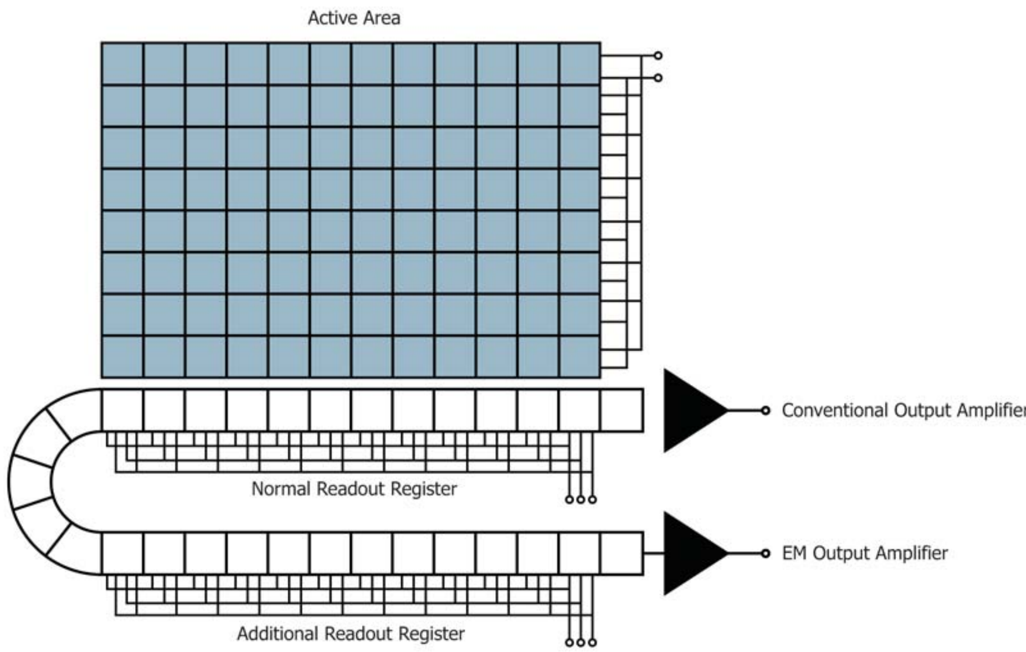

FIG. 6 Typical Sketch of Full-Frame EMCCD Sensor

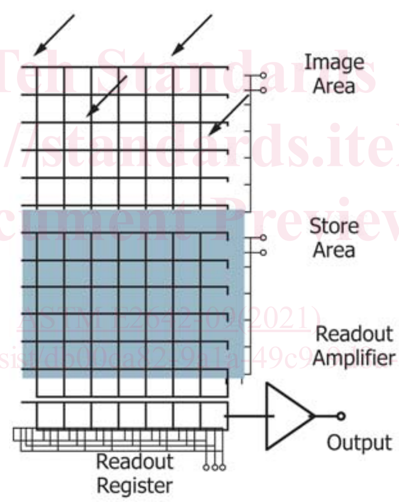

FIG. 7 Typical Sketch of a Frame-Transfer CCD

DISCUSSION—During operation the charge accumulated in the image section is rapidly transferred to the storage section at the end of the exposure time. The storage area is then readout as the image section accumulates charge for the next exposure. This type of CCD reduces or eliminates the need for a shutter, depending on the speed of the transfer from image to storage.

front-illuminated CCD (FI CCD), *n*—a type of CCD in which the photons are detected through the gate structure located in front of the silicon material of the semiconductor (see Fig. 1a).

DISCUSSION—This type of CCD has moderate quantum efficiency (see Fig. 8) over the spectral range it covers and it is also free from any etaloning effects that occur in the back-illuminated CCD when subjected to NIR signals. These devices are relatively less expensive to manufacture than the back-illuminated type.

full-frame CCD, *n*—a type of CCD that uses the entire silicon active area for photon detection. A shutter is required to eliminate image smear (see Fig. 3).

full well capacity, *n*—the maximum number of photoelectrons that can be collected on a single pixel in the image area or in the horizontal register of a CCD. It is typically specified in terms of number of electrons.

gate structure, *n*—a polysilicon arrangement of electrodes that create pixels and move charge.

horizontal binning, *n*—the process that allows charge from a row of pixels to be combined on the CCD chip prior to readout (See Fig. 2). Horizontal binning is commonly used