

N42.31

American National Standard for Measurement Procedures for Resolution and Efficiency of Wide-Bandgap Semiconductor Detectors of Ionizing Radiation

Accredited by the American National Standards Institute

Sponsored by the
National Committee on Radiation Instrumentation, N42



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Secretariat

The Institute of Electrical and Electronics Engineers, Inc.

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Abstract: Standard measurement and test procedures are established for wide-bandgap semiconductor detectors such as cadmium telluride (CdTe), cadmium-zinc-telluride (CdZnTe), and mercuric iodide (HgI₂) that can be used at room temperature for the detection and quantitative characterization of gamma-rays, X-rays, and charged particles. Standard terminology and descriptions of the principal features of the detectors are included. Included in this standard is an annex on interfering electromagnetic noise, which is a factor in such measurements.

Keywords: cadmium telluride, cadmium zinc telluride, CdTe, charged particle, CZT, electron-hole pair, gamma rays, HgI, ionizing radiation, ion pair, MCA, mercuric iodide, multichannel analyzer, semiconductor detector, X-ray

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Introduction

(This introduction is not part of ANSI N42.31-2003, American National Standard for Measurement Procedures for Resolution and Efficiency of Wide-Bandgap Semiconductor Detectors of Ionizing Radiation.)

This standard is the responsibility of the Accredited American Standards Committee on Radiation Instrumentation, N42. The standard was approved on N42 letter ballot of 10 July 2002.

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American National Standard for Measurement Procedures for Resolution and Efficiency of Wide-Bandgap Semiconductor Detectors of Ionizing Radiation

1. Overview

1.1 Scope

This standard applies to wide-bandgap semiconductor radiation detectors, such as cadmium telluride (CdTe), cadmium-zinc-telluride (CdZnTe, referred to herein as CZT), and mercuric iodide (HgI₂) used in the detection and measurement of ionizing radiation at room temperature; gamma rays, X-rays, and charged particles are covered. The measurement procedures described herein apply primarily to detector elements having planar, hemispherical, or other geometries in which charge carriers of both polarities contribute to the output signal. When the devices are an integral part of a system, it may not be possible for a user to make tests on the detector alone. In this instance, tests on the detector element must be established by mutual agreement between the manufacturer and the user.

1.2 Purpose

The purpose of this standard is to establish terminology and test procedures that have the same meaning to both manufacturers and users. Not all tests described in this standard are mandatory, but those used to specify performance shall be made in accordance with the procedures described herein. (Use of the word “shall” indicates a mandatory requirement, “must” a physical one, and “should” means “recommended.”)

1.3 Abbreviations

Abbreviations, defined in 3.3, are used liberally throughout this document.

2. References

Standards referred to herein are listed below. The details of the test instruments and the test procedures described in two of the standards—IEEE Std 301TM-1988 and IEEE Std 325TM-1996—are closely related to those described in this document and are recommended as adjuncts to it.

DOE Report DOE/ER-0457T (May 1990), Standard NIM Instrumentation System.¹

IEEE Std 194TM-1977, IEEE Standard Pulse Terms and Definitions.^{2,3,4}

IEEE Std 300TM-1988 (Reaff 1993), IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors.

IEEE Std 301-1988, IEEE Standard Test Procedures for Amplifiers and Preamplifiers used with Detectors of Ionizing Radiation.

IEEE Std 325-1996, IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors.

IEEE Std 759TM-1984, IEEE Standard Test Procedures for Semiconductor X-Ray Energy Spectrometers.

IEEE Std 1160TM-1993, IEEE Standard Test Procedures for High-Purity Germanium Crystals for Radiation Detectors.

3. Definitions, symbols, and abbreviations

3.1 Definitions

Specialized terms used in this standard plus some others that are relevant appear in this subclause. Most of the technical terms within the definitions are themselves defined here but, with a few exceptions, are not cross-referenced. Terms used infrequently in the document are defined where they appear; they may or may not be defined in this subclause.

3.1.1 active region: A region of a detector in which charge created by ionizing radiation contributes significantly to the output signal.

3.1.2 amplifier: An electronic instrument for increasing the amplitude of a signal.

3.1.3 amplifier shaping time: A nonspecific indication of the shaped-pulse width issuing from a pulse amplifier.

3.1.4 amplifier time constant: A misnomer for the width of the shaped pulse issuing from a pulse amplifier. See: **shaping-time index ($t_{0.5}$)**.

¹Available from Louis Costrell, NIM Committee Chairman, or Michael Unterweger, NIM Committee Vice-chairman, both at National Institute of Standards and Technology, Radiation Physics Division or from the National Technical Information Service, U.S. Dept. of Commerce, Springfield, VA 22161.

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³IEEE Std 194-1977 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://global.ihs.com/>).

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

3.1.5 analog-to-digital converter (ADC): An instrument that digitally encodes electrical pulses according to their amplitudes. An ADC is usually part of a multichannel analyzer (MCA).

3.1.6 area (of all or part of a spectral line): The counts accumulated within a selected number of channels in a spectral line.

3.1.7 background: Unwanted counts that appear in a spectrum due to ambient radiation, to a test source containing emitters other than the desired ones, or to spectral distortions caused by pulse pile-up.

3.1.8 background (ambient): The spectrum of ionizing radiation observed when a test source is replaced by a blank which is identical to the test source except for the absence of radioactivity.

3.1.9 ballistic deficit (BD): The loss in signal amplitude that occurs when the charge collection time in a detector is a significant fraction of the amplifier's differentiating time constant.

3.1.10 bandgap: The energy difference between the bottom of the conduction band and the top of the valence band.

3.1.11 baseline (of an electrical pulse): The average of the levels from which a pulse departs and to which it returns in the absence of an overlapping pulse (IEEE Std 194-1977).

3.1.12 baseline restorer (BLR): A circuit that rapidly restores the baseline following an amplifier's output pulse (or train of pulses) to the level that existed before the pulse.

3.1.13 bias, detector: The voltage applied to a detector to produce the electric field that sweeps out the signal charge.

3.1.14 bias resistor: The resistor through which the bias voltage is applied to a detector.

3.1.15 bipolar pulse: A signal pulse having two lobes, one above and the other below the baseline. When produced by a linear filter network, the two lobes have the same area but not necessarily the same peak amplitude.

3.1.16 capacitance, detector: The electrical capacitance measured between terminals of the detector under specified conditions of bias and frequency and with the amplitude of the signal used for the capacitance determination being small compared with the bandgap of the semiconductor comprising the detector.

3.1.17 carrier: *See: charge carrier.*

3.1.18 center line: *See: peak center line.*

3.1.19 channel: Refers to the channels in a multichannel analyzer.

3.1.20 charge carrier: A mobile electron or hole.

3.1.21 charge collection time: The time required for a charge produced by an ionizing event to be collected at the terminal of a detector under the influence of the detector bias voltage.

3.1.22 charge-sensitive preamplifier: An amplifier, preceding the main amplifier, in which the output amplitude is proportional to the charge injected at its input and virtually independent of detector capacitance (IEEE Std 301-1988).

3.1.23 contact: A conducting area applied to the surface of a detector to make electrical contact with it.

3.1.24 CR differentiator: A high-pass electrical filter section comprising a capacitor in series with the signal path followed by a resistor across the path.

3.1.25 $(CR)^m$ -(RC) ^{n} shaping: In an amplifier, the pulse shape produced by m CR high-pass filter sections (differentiators) in conjunction with n RC low-pass filter sections (integrators), all with the same time constant. If the input signal is a step function and no other high-pass sections are in the signal path, the pulse shape is unipolar if $m = 1$, bipolar if $m = 2$. For unipolar pulses, the waveform is described by $Kt^n e^{-t/\tau}$, where K is a constant, t is time, and τ is the time constant of the differentiator.

3.1.26 dead layer: In a semiconductor detector, a layer (frequently associated with a contact region) in which no significant part of the energy lost by photons or particles can contribute to the resulting signal.

3.1.27 dead time: The interval during which the second of two events is lost or is recorded with an error in its amplitude.

3.1.28 decay time constant: In the absence of a low-pass network preceding the point of observation, the time for a single-exponential waveform to decay to the fraction $1/e$ of its original amplitude.

3.1.29 depletion region: A region in which the mobile charge-carrier density is insufficient to neutralize the net fixed charge density of donors and acceptors. In a diode-type semiconductor radiation detector, the depletion region is the active (sensitive) region.

3.1.30 depletion voltage: The voltage at which a junction detector becomes fully depleted.

3.1.31 detector element: The semiconductor crystal including its contacts.

3.1.32 detector, semiconductor radiation: A semiconductor device in which the production and motion of excess free carriers is used for the detection and measurement of incident particles or photons.

3.1.33 differentiator: A high-pass filter network (usually a CR section) in which the waveform of the output signal approximates the mathematical derivative of the input waveform.

3.1.34 discriminator: A circuit having a threshold below which signals applied to the input will not cause an output signal and above which the input signal will trigger an output having an amplitude independent of the input signal height.

3.1.35 efficiency: In ANSI N42.31-2003, the total counts in a specified peak, corrected for background, divided by the total number of photons or particles emitted from a test source located 25 cm from the surface of the detector, or if so specified, from the entrance window of the detector housing. (The fraction so obtained, multiplied by 100, becomes the percentage efficiency.)

3.1.36 energy resolution: The full width at specified fractions of the maximum amplitude of a peak in a spectrum (after subtracting the background under the peak) expressed in units of energy or as a percentage of the energy corresponding to that peak.

3.1.37 enhanced energy resolution: Quality of a spectrum that has been improved by means of electronic-circuit signal processing beyond that of the filter network normally a part of a conventional, commercially available main amplifier. In the sense used here, the term “enhancement” does not apply to detectors having special geometries designed to overcome some of the shortcomings of planar detectors.

3.1.38 fall time t_f (of a pulse): The interval on the last transition (IEEE Std 194-1977) between the 90% and 10% points (unless other levels are specified) with respect to peak height. See: **transition (of a pulse)**.

3.1.39 filter, filter network: An electrical network designed to improve the signal-to-noise ratio in an amplifier and to shape the pulse issuing from the preamplifier according to the needs of the instruments following the main amplifier.

3.1.40 Fraznoid: Miller electron-hole pair coherent oscillation

3.1.41 full-energy peak (in a spectrum of ionizing radiation): The distribution, after subtracting the background spectrum, of the measured intensity as a function of energy of a monoenergetic stream of photons or particles.

Note—X-rays that may appear with energies below that of the full-energy peak are regarded as part of the background.

3.1.42 full width at half maximum (FWHM): The full width of a distribution measured at half the vertical distance between the background and the top of the peak. For a normal distribution, $FWHM = 2\sigma(2\ln 2)^{0.5} = 2.355$ times the standard deviation σ . As indicators of tailing, other parameters are useful, such as full width at 1/4th and 1/10th maximum (FW.25M, FW.1M).

3.1.43 Gaussian: Refers to the shape of a normal distribution or, incorrectly, to the shape of the output pulse issuing from a class of filter networks that includes the $(CR)^m-(RC)^n$ shaper. *See also:* **normal distribution, quasi-Gaussian, and semi-Gaussian.**

NOTE—The term “Gaussian peak” is more appropriately called a peak exhibiting a normal distribution. Gauss, who derived the equation for it in 1809, was not the first to do so. He was predated by DeMoivre in 1735 and Laplace in 1774 [B3].

3.1.44 geometry, detector: The physical configuration of a detector element (e.g., planar, hemispherical).

3.1.45 high-purity germanium (HPGe): Germanium with a low, net electrically active, uncompensated defect concentration, usually less than 10^{10} cm^{-3} .

3.1.46 high-side area: The area of a spectral peak measured above the background, and between the peak center line and the peak's high-energy toe.

3.1.47 high-side counting efficiency: Same as **efficiency** except that only the counts in the high-side area of the peak are recognized.

3.1.48 high-side width at half maximum (HSWHM): The width of the high-energy side of a peak measured from the peak center line at half of the vertical distance between the background and the top of the peak. (If the ratio of FW.1M to FWHM is less than 2.0, the HSWHM is exactly half of the FWHM.)

3.1.49 inactive region (of a semiconductor radiation detector): A region of a detector in which the charge created by ionizing radiation does not contribute significantly to the output signal. *See:* **dead layer.**

3.1.50 integrated pulse: In the absence of qualifiers (such as *true integration*), a pulse that has passed through one or more integrators. *See:* **integrator.**

3.1.51 integrator: In ANSI N42.31-2003, the term refers to a low-pass RC filter section.

3.1.52 junction: The transition boundary between semiconductor regions of different electrical properties (for example: $n-n^+$, $p-n$, $p-p^+$ semiconductors, or between a metal and a semiconductor).

3.1.53 leakage current: In the absence of external ionizing radiation and at the operating bias, the total current flowing through or across the surface of the detector element.