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Nuclear instrumentation – High-purity germanium crystals for radiation detectors – Measurement methods of basic characteristics

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CONTENTS

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NUCLEAR INSTRUMENTATION – HIGH-PURITY GERMANIUM CRYSTALS FOR RADIATION DETECTORS – MEASUREMENT METHODS OF BASIC CHARACTERISTICS

FOREWORD

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International Standard IEC 61435 has been prepared by IEC technical committee 45: Nuclear instrumentation.

This second edition cancels and replaces the first edition published in 1996 and constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

– Review the existing requirements.
– Update the terminology and definitions.

The text of this standard is based on the following documents:

FDIS	Report on voting
45/754/FDIS	45/760/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

Detector manufacturers demand numerical data that can be used to predict the performance of a detector having approximately coaxial geometry. However, because of the many variations in the physical characteristics, the completed detector performance cannot be fully predicted from measurements of the crystal manufacturer. This standard defines terminology and test methods for determining basic crystal parameters such as net electrically active impurity concentrations, deep-level impurity-centre concentration and crystallographic quality of crystals.

Production of germanium crystals of the necessary size and defined purity for high-purity germanium (HPGe) detectors for detection of ionizing radiation has special problems in characterization resulting from the high resistivity of the material (~10 kΩ·cm at 77 K), from the degree of impurity compensation, and from difficulties in suitably describing the impurity distribution in the large volume that may form a single device. Existing standards do not cover these problems.

One of the most important characteristics of HPGe is the net electrically active impurity concentration $(N_A - N_D)$ because it determines the depletion voltage required for an operating detector. The usual practice has been to determine $(N_A - N_D)$, with the sign indicating n-type or p-type, on the basis of transport measurements using the Van der Pauw method [1][1] on lamellar samples immersed in liquid nitrogen (LN).

In this technique, $(N_A - N_D)$ can be computed either from the resistivity or from the Hall coefficient. These in turn are obtained from a series of electrical measurements made on the sample.

[1] Numbers in square brackets refer to the Bibliography.

NUCLEAR INSTRUMENTATION – HIGH-PURITY GERMANIUM CRYSTALS FOR RADIATION DETECTORS – MEASUREMENT METHODS OF BASIC CHARACTERISTICS

1 Scope and object

This International Standard is applicable to high-purity germanium crystals used for radiation detectors for gamma-rays and X-rays. Such germanium is monocrystalline and has a net concentration of fewer than 10^{11} electrically active impurity centers per cm^3, usually of the order of 10^{10} cm^{-3}.

This International Standard specifies terminology and test methods for measurements of basic characteristics of high-purity germanium crystals. These characteristics are net electrically active impurity concentrations (hereinafter (N_A – N_D)), deep-level impurity-centre concentration and crystallographic quality of crystals.

These test methods are not mandatory but have found general use in the industry and provide verifiable and desired information to the detector manufacturer.

Test methods for completed assembled germanium detectors are given in IEC 60973 and IEC 60759.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 600050-393:2003, *International Electrotechnical Vocabulary (IEV) – Part 393: Nuclear instrumentation – Physical phenomena and basic concepts*

IEC 60050-394:2007, *International Electrotechnical Vocabulary (IEV) – Part 394: Nuclear instrumentation – Instruments, systems, equipment, and detectors*

IEC 60050-521:2002, *International Electrotechnical Vocabulary (IEV) – Part 521: Semiconductor devices and integrated circuits*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
semiconductor
substance whose total conductivity due to charge carriers of both signs is normally in the range between that of conductors and insulators and in which the charge carrier density can be changed by external means

Note 1 to entry: The term semiconductor generally applies where the charge carriers are electrons or holes.

[SOURCE: IEC 60050-521:2002, 521-02-01]

[SOURCE: IEC 60050-394:2007, 394-28-33]

3.1.2
high purity semiconductor detector
semiconductor detector using a high purity (e.g. high resistivity) semiconductor material

[SOURCE: IEC 60050-394:2007, 394-28-14]

3.1.3
Hall effect
production in a conductor or in a semiconductor of an electric field strength proportional to the vector product of the current density and the magnetic flux density

[SOURCE: IEC 60050-521:2002, 521-09-01]

3.1.4
Hall mobility
product of the Hall coefficient and the electric conductivity

[SOURCE: IEC 60050-521:2002, 521-09-02]

3.1.5
Hall coefficient
coefficient of proportionality R_H in the Hall effect quantitative relation:

$$\vec{E}_H = R_H(\vec{J} \times \vec{B})$$

$\vec{E}_H$ is the resulting transverse electric field strength;

$\vec{J}$ is the current density;

$\vec{B}$ is the magnetic flux density.

Note 1 to entry: The sign of the majority carrier charge can usually be inferred from the sign of the Hall coefficient.

[SOURCE: IEC 60050-521:2002, 521-09-02]

3.1.6
mobility
drift mobility of a charge carrier
quantity equal to the quotient of the modulus of the mean velocity of a charge carrier in the direction of an electric field by the modulus of the field strength

[SOURCE: IEC 60050-521:2002, 521-02-58]

3.1.7
impurity
foreign atoms or either an excess or a deficiency of atoms with respect to the stochiometric composition of a compound semiconductor

[SOURCE: IEC 60050-521:2002, 521-02-04]

3.1.8
resistivity
inverse of the conductivity when this inverse exists

[SOURCE: IEC 60050-121:1998, 121-12-04]

3.2 Symbols and abbreviations

3.2.1 Symbols

Frequently used symbols are defined below; infrequently used symbols are defined in the text.

A	diode area, expressed in cm^2;
B	magnetic flux density, expressed in teslas (T);
C	capacitance, expressed in farads (F);
C_d	capacitance of the depleted region in a diode;
C_i	initial capacitance;
C_f	capacitance at voltage V_r;
C_m	the capacitance of parallel equivalent circuit;
D_s	the series circuit dissipation factor;
D	Sample thickness, expressed in centimetres (cm);
e	electron charge, $1{,}60 \times 10^{-19}$ coulombs (C);
e_r	carrier emission rate from a localized electronic level, expressed in s^{-1};
E	energy associated with an electronic level in the band gap;
F	frequency, expressed in hertz (Hz);
f	is a factor dependent on ratio $\frac{R_{AB,CD}}{R_{BC,DA}}$;
K	Boltzmann constant, $8{,}617 \times 10^{-5}$ eV·K^{-1};
$(N_A - N_D)$*	net electrically active impurity concentration per cm^3;
N_T	deep-level impurity-centre concentration per cm^3;
N_B	net concentration of all shallower levels;
m	slope of the $C^{-2}(V)$ plot, in $(pF)^{-2} \cdot V^{-1}$;
Q	charge, expressed in coulombs (C);
r_H	Hall factor;
R	resistance, expressed in ohms (Ω);
R_H	Hall coefficient, expressed in $cm^3 \cdot C^{-1}$;
R_p	leakage resistance in parallel with the depleted region;
R_s	the series resistance of the sample, which includes the resistance of the undepleted region and of the contacts;
P	resistivity, expressed in Ω·cm;
T	temperature, expressed in kelvins (K);
T	time, expressed in seconds (s);
τ	emission time, expressed in seconds (s);
τ_{max}	the rate window at the peak temperature T_{max};

* The sign of the quantity indicates the type of carrier (n or p). Where only the magnitude is required, the expression will appear as $|N_A - N_D|$.

τ_r	the relaxation time of a carrier;
(τ_r^2)	average square of relaxation time;
μ	drift mobility, expressed in cm^2 V^{-1} s^{-1};
μ_H	Hall mobility, expressed in cm^2 V^{-1} s^{-1};
μ_n	electron mobility in a semiconductor crystal, expressed in cm^2 V^{-1} s^{-1};
μ_p	hole mobility in a semiconductor crystal, expressed in cm^2 V^{-1} s^{-1};
V	voltage;
V_{bi}	built-in potential of the diode;
V_p	filling pulse, expressed in volts (V);
V_r	quiescent reverse bias, expressed in volts (V);
W_p	duration of the filling pulse, expressed in seconds (s);
( )	average value;
ΔC_d	the capacitance transient amplitude;
ΔV_c	the increase the reverse bias V_r needed for rising minimal capacitance to the final value.

3.2.2 Abbreviations

DC	direct current;
DLTS	deep-level transient spectroscopy;
HPGe	high-purity germanium;
LN	liquid nitrogen.

3.3 Quantities and units

In the present standard, units of the International System (SI) are used. The definitions of radiation quantities are given in IEC 60050-393,IEC 60050-394 and IEC 60050-521.

Nevertheless, the following non SI units may also be used:

– for energy: electron-volts (eV);
– for time: minutes (min);
– for volume: litres (l);
– for temperature: kelvins (K);
– for thickness: centimetres (cm), millimetres (mm).

Multiples and submultiples of SI units will be used, when practicable, according to the SI system.

4 Measurement of net electrically-active impurity concentrations

4.1 Sample preparation for Van der Pauw measurements

4.1.1 General

Accuracy in the determination of $(N_A - N_D)$ is critically dependent on sample preparation, which shall be carried out with great care.