IEC 62830-5

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INTERNATIONAL STANDARD

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Semiconductor devices – Semiconductor devices for energy harvesting and generation –
Part 5: Test method for measuring generated power from flexible thermoelectric devices

Dispositifs à semiconducteurs – Dispositifs à semiconducteurs pour récupération et production d'énergie –
Partie 5: Méthode d'essai pour la mesure de la puissance générée par des dispositifs thermoélectriques souples

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The text of this International Standard is based on the following documents:

FDIS	Report on voting
47/2668/FDIS	47/2678/RVD

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

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

A list of all parts in the IEC 62830 series, published under the general title *Semiconductor devices – Semiconductor devices for energy harvesting and generation*, can be found on the IEC website.

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

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SEMICONDUCTOR DEVICES – SEMICONDUCTOR DEVICES FOR ENERGY HARVESTING AND GENERATION –

Part 5: Test method for measuring generated power from flexible thermoelectric devices

1 Scope

This part of IEC 62830 specifies the test method for measuring generated electric power from flexible thermoelectric devices under bending conditions. This document provides terms, definitions, symbols, configurations, and test methods that can be used to evaluate and determine the performance of flexible thermoelectric devices. This document also describes the test conditions such as temperature, temperature difference, contact conditions, insulation and bending radius of flexible thermoelectric devices. This document is applicable to flexible energy harvesting devices for flexible semiconductor devices.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
thermoelectric generator
device that converts heat (temperature difference) directly into electrical energy, using a phenomenon called the Seebeck effect

3.2
bending radius
minimum radius, measured to the inside curvature, of a pipe, tube, sheet, cable or hose that can be bent without kinking damaging it or shortening its life

3.3
Seebeck coefficient
S
magnitude of an induced thermoelectric voltage in response to a temperature difference across a material, and the entropy per charge carrier in the material

[SOURCE: IEC 62830-2:2017, 3.1]

3.4
thermal conductivity
k_c
at a point fixed in a medium with a temperature field, scalar quantity k_c characterizing the ability of the medium to transmit heat through a surface element containing that point: $\varphi = -k_c$ grad T, where φ is the density of heat flow rate and T is thermodynamic temperature

Note 1 to entry: It appears primarily in Fourier's Law for heat conduction. This value is dependent on temperature. Thermal resistivity is given by the reciprocal of thermal conductivity.

[SOURCE: IEC 60050-113:2011, 113-04-38, modified – the scalar quantity has been changed to k_c and the notes have been replaced by Note 1.]

3.5
temperature difference
T_{h-c}
difference between the cooling and heating sides

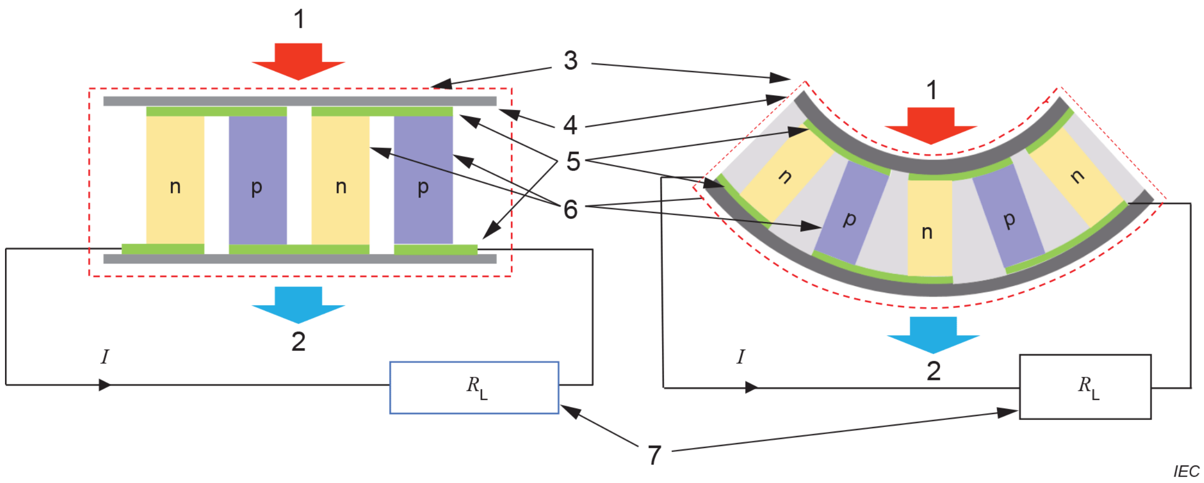
3.6
heat input
Q_{hot}
measured (or calculated) input thermal energy to the thermoelectric device

3.7
dissipated heat
Q_{cold}
measured (or calculated) dissipated thermal energy from the thermoelectric device

4 Testing method

4.1 General experimental apparatus

The general principle for the test set-up to measure the amount of power generation from thermoelectric devices, especially focusing on flexible thermoelectric devices, is described. In general, the thermoelectric device generates electric energy due to the temperature difference between one surface of the device and the other surface. Hence, in order to characterize the performance of the device, the temperature of both the cooling and heating sides in an experimental set-up should be maintained consistently. The general schematic diagram of the thermoelectric device, including the experimental set-up to measure the generated power, is illustrated in Figure 1. An explanation about the commonly used formulas related to the thermoelectric device and the experimental set-up is also included. The basic principle of the measurement method for both rigid and flexible devices is the same but the experimental apparatus can be different due to the flexibility of the flexible thermoelectric device. In order to use the advantage of a flexible thermoelectric device as well as to investigate its limitations, the performance of the flexible thermoelectric device should be determined under the bending condition.



Key

1 Heating side (Q_{hot})

2 Cooling side (Q_{cold})

3 Thermoelectric device for power generation

4 Insulator

5 Electrodes

6 Thermoelectric materials (n: n-type semiconductor, p: p-type semiconductor)

7 Load

Figure 1 – General measurement apparatus for generated power in thermoelectric device

As shown in Figure 1, when a temperature differential is applied across the faces of the thermoelectric device, it is possible to generate electrical power in the device. With no load, the open circuit voltage as measured between two surfaces is

$$V = S \times T_{h-c} \tag{1}$$

where

V is the output voltage from the thermoelectric generator, in V;

S is the average Seebeck coefficient, in V/K;

T_{h-c} is the temperature difference across the thermoelectric generator, in K,

where $T_{h-c} = T_h - T_c$:

T_h is the surface temperature of the hot side for the generator, in K;

T_c is the surfacce temperature of the cold side for generator, in K.

When a load is connected to the thermoelectric generator, the output voltage (V) drops as a result of the internal generator resistance. The current through the load is

$$I = \frac{S \times T_{h-c}}{R_c + R_L} \tag{2}$$

where

I is the thermoelectric generator output current, in A;

R_c is the average internal resistance of the thermoelectric device, in Ω;

R_L is the load resistance in Ω.

The total generated power in the device (P_g) is simply

$$P_g = I \times V \tag{3}$$

The total heat input to the thermoelectric generator (Q_{hot}) is

$$Q_{hot} = (S \times T_h \times I) - (0{,}5 \times I^2 R_c) + (K \times T_{h\text{-}c}) \tag{4}$$

where

Q_{hot} is the heat input, in W;

K is the thermal conductance of the generator, in W/K.

The efficiency of the generator is

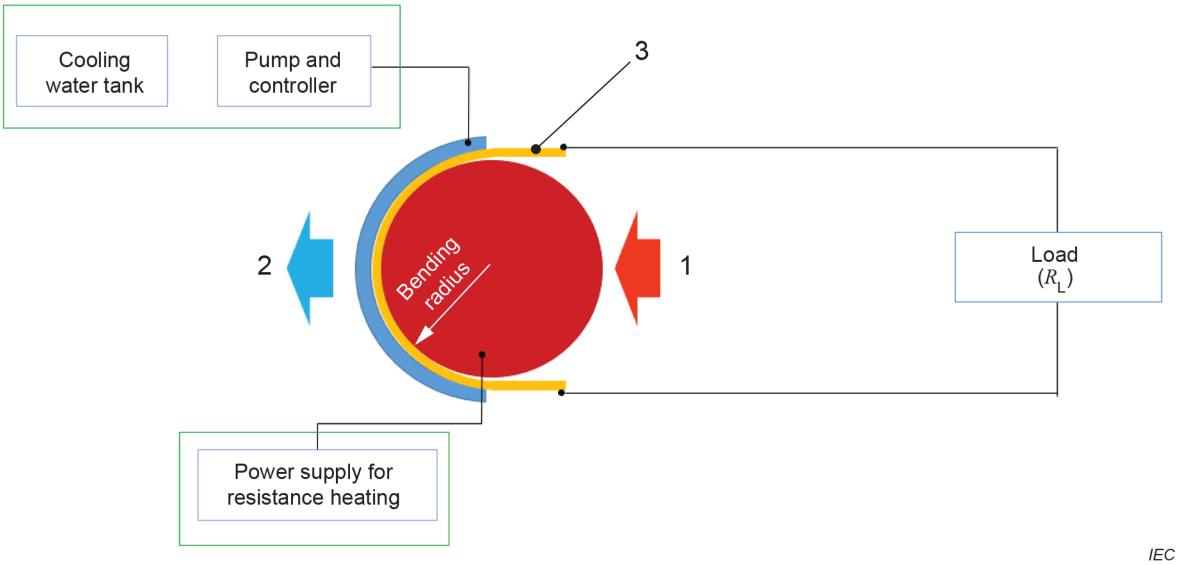
$$\eta = \frac{P_g}{Q_{hot}} \tag{5}$$

where

η is the efficiency of the thermoelectric generator.

4.2 Application to flexible thermoelectric devices

Subclause 4.2 gives the detailed experimental apparatus for measuring the generated power in a thermoelectric device. It focuses on the detailed experimental apparatus for measuring the generated power from flexible thermoelectric devices under the bending condition. In the case of flexible thermoelectric devices, the main focus for the measurement is the generated power under the bending condition. For this purpose, an experimental apparatus to determine the generated power is illustrated in Figure 2 as an example. As shown in Figure 2, an experimental apparatus enabling power measurement under the bending condition should be used in the case of a flexible device. For the cooling side, cooling water, a pump, and controller are used to maintain the temperature which is set to the cooling side. Electrical heating with resistance is used to maintain the temperature of the heating side. However, the method for cooling and heating can be employed according to the sample size and temperature range.



Key

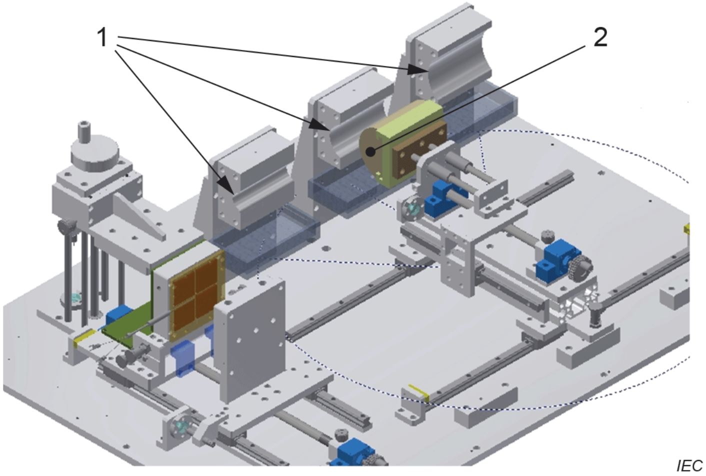
1 Heating side (Q_{hot})

2 Cooling side (Q_{cold})

3 Flexible thermoelectric device for power generation

Figure 2 – Experimental apparatus for generated power in flexible thermoelectric device

In the case of a flexible thermoelectric device, the performance, including efficiency, can change according to the bending radius of curvature. Hence, different bending radiuses of curvature can be suggested according to the applications as shown in Figure 3. A detailed schematic diagram for experimental set-up is described in Clause A.1. For example, in the case of flexible thermoelectric devices generating power from the temperature difference between the human body and environmental conditions, different bending radiuses according to the part of the human body can be summarized in Table 1 as an example.



Key

1. Different radiuses of curvature (cooling side, 30 mm, 60 mm, 90 mm)
2. Cylinder with different radiuses of curvature can be replaced (heating side)

Figure 3 – Experimental apparatus for different bending radiuses of curvature

Table 1 – Relation between the bending radius of curvature and typical parts of the human body

Parts of human body	Thumb	Wrist	Lower arm	Upper arm	Hand
Bending radius of curvature (mm)	9	28	40	50	It depends but it can be very large

Also, the amount of generated power from flexible thermoelectric devices can be different according to the temperature, temperature difference, and contact conditions. This is due to the fact that there should be a discrepancy in the temperature between the surface of the cooling or heating side and the surface of the device. This discrepancy is dependent on the contact conditions. The contact conditions between the surface of the device and the surface of the cooling or heating side can be characterized by measuring the contact pressure in the case of a rigid type thermoelectric device. In contrast, in the case of a flexible device, the contact pressure can vary greatly depending on the package type or material of the flexible thermoelectric device. Hence, it is strongly recommended that the description of the package type, structure, dimension of the device including the distance between the cooling and heating side, be included in the report. A detailed experimental set-up for measuring contact pressure is described in Clause A.2 as an example. Table 2 summarizes those parameters and Table 3 shows the performance parameters of the thermoelectric device including the conditions of the experimental set-up. In addition, an example of experimentally determined generated power under different conditions is presented in Clause A.3.