IEC 62951-5

Edition 1.0 2019-02

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Semiconductor devices – Flexible and stretchable semiconductor devices – Part 5: Test method for thermal characteristics of flexible materials

Dispositifs à semiconducteurs – Dispositifs à semiconducteurs souples et extensibles – Partie 5: Méthode d'essai pour les caractéristiques thermiques des matériaux souples

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

FDIS	Report on voting
47/2534/FDIS	47/2543/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 62951 series, published under the general title *Semiconductor devices – Flexible and stretchable semiconductor devices*, 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 – FLEXIBLE AND STRETCHABLE SEMICONDUCTOR DEVICES –

Part 5: Test method for thermal characteristics of flexible materials

1 Scope

This part of IEC 62951 specifies the test method for thermal characteristics of flexible materials. This document includes terms, definitions, symbols, and test methods that can be used to evaluate and determine thermal characteristics of flexible materials for practical use. The measurement method relies on non-contact optical thermometry that is based on temperature dependent optical reflectance. This document is applicable to both substrate and thin-film flexible semiconductor materials that are subjected to bending and stretching.

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
reflectance
ρ
ratio of the reflected optical power to the incident optical power at a given wavelength and temperature for a given surface of materials

Note 1 to entry: Reflectance can be defined as the ratio between reflected and incident radiant or luminous flux.

[SOURCE: IEC 60050-845:1987, 845-04-58, modified – temperature dependence of optical reflectance is added.]

3.2
thermoreflectance
temperature dependent optical reflectance of a given surface of materials

Note 1 to entry: Thermoreflectance has nothing to do with thermal reflectance.

3.3
local temperature
T_{loc}
temperature at a local position in a spatially distributed device or system

3.4
average temperature
T_{avg}
temperature within a substrate averaged over an area of interest at a given time

$$T_{avg} = \frac{1}{n}\sum_{i=1}^{n} T_{loc}(i) \quad (1)$$

where

n is the total number of measurement point

$T_{loc}(i)$ is the local temperature at the i^{th} measurement point

3.5
initial temperature
T_i
local or average temperatures when the sample is about to be powered on (t = 0)

3.6
final temperature
T_f
local or average temperatures when the sample is about to be powered off ($t = t_f$)

3.7
thermal time constant
τ
time taken to reach 63,2 % of the difference between the initial and the final temperatures

3.8
substrate
materials that are more than 20 times thick of the wavelength of the probing laser

Note 1 to entry: For 633 nm, the thickness criterion to determine the substrate materials is larger than approximately 12,7 μm.

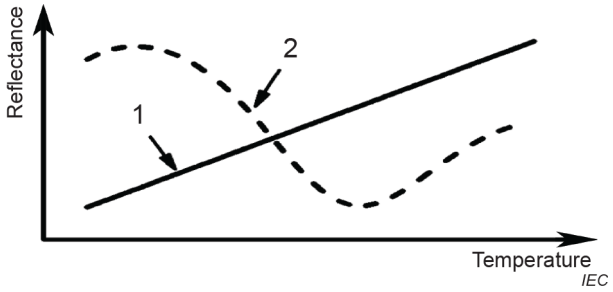
3.9
thin-film
materials that are less than 20 times thick of the wavelength of the probing laser

Note 1 to entry: For 633 nm, the thickness criterion to determine the thin-film materials is less than approximately 12,7 μm.

4 Testing method

4.1 General

Thermoreflectance is one of non-contact optical thermal characterization techniques that relies on the change of refractive index of materials as a function of temperature. Depending on their thickness, flexible semiconductor materials can be categorized as either substrate or thin-film. For substrate materials, their optical reflectance values change linearly with temperature. However, optical reflectance values of thin-film materials show highly non-linear behaviours as shown in Figure 1. For thin-films, non-linear optical reflectance is also strongly dependent on the sample thickness as shown in Figure 2. Such a non-linearity requires reflectance measurements at multiple wavelengths. Once optical reflectance values at one or more wavelengths are calibrated at various temperatures, thermal characterization is enabled.



Key

1 Substrate

2 Thin-film

Figure 1 – Thermoreflectance signals of substrate and thin-film materials as functions of temperature

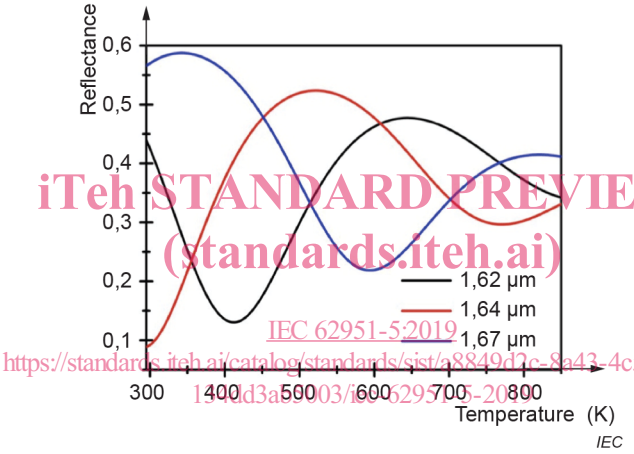
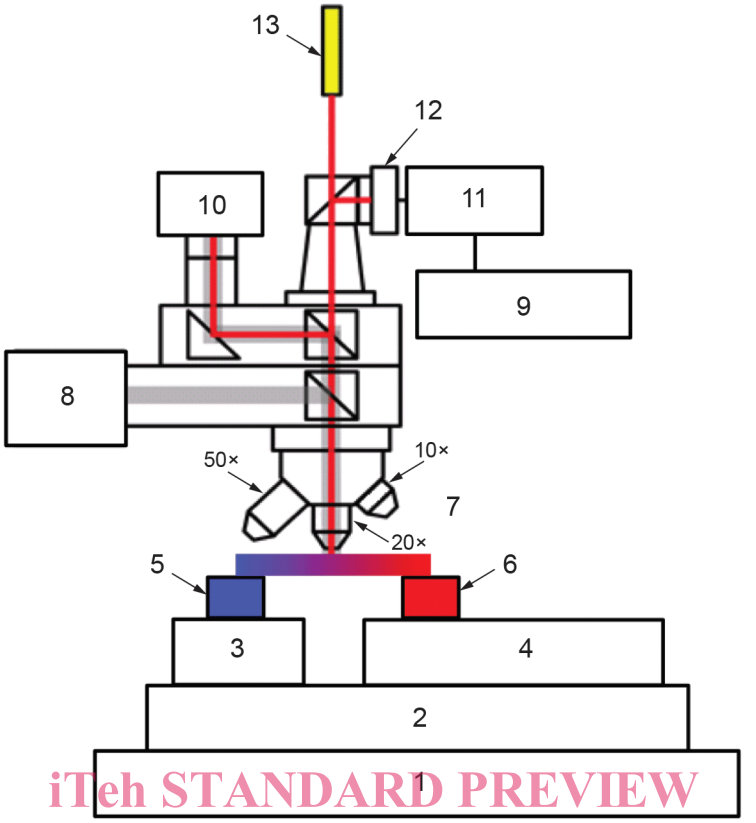


Figure 2 – Reflectance vs. temperature of silicon thin-films (thicknesses of 1,62 µm, 1,64 µm, and 1,67 µm) for the wavelength of 633 nm

4.2 Test apparatus

In case of substrate materials, thermoreflectance signals at a given wavelength tend to change linearly with increasing temperature. Thin-film materials, however, exhibit highly non-linear thermoreflectance behaviours as temperature increases. Therefore, single wavelength optical probing is necessary and sufficient for substrate flexible semiconductor materials and at least dual wavelength probing is required for thin-film materials. Thermoreflectance ratio at different wavelengths is still non-linear with temperature but can provide an acceptable match with the theoretical estimation and more precise temperature measurements. Figure 3 and Figure 4 show schematics of thermoreflectance thermometry with one laser source used for calibration and measurement (for example, wavelength, $\lambda = 633$ nm herein but other wavelength can be used), respectively. For calibration, heating or cooling blocks with fixed temperature are used. The substrate is joule heated with DC or AC (simple periodic sine) power supplies for actual measurements.

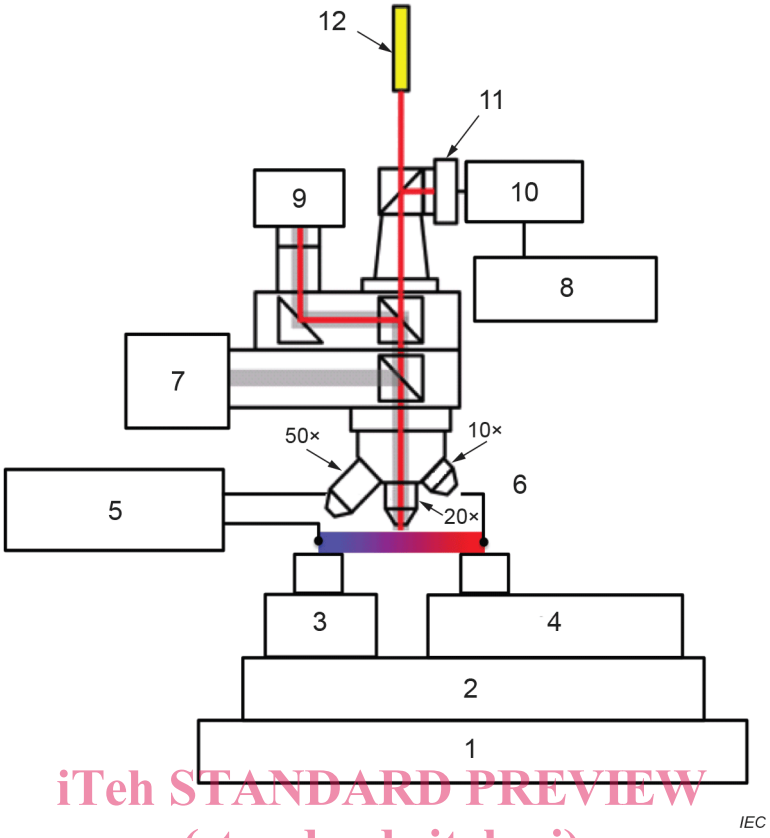


Key

1	Goniometer	2	Motorized xy stages
3	Fixed stage	4	Motorized linear stage
5	Cold temperature block	6	Hot temperature block
7	Objective lens	8	Halogen lamp
9	Multimeter	10	CCD
11	Variable terminal	12	Silicon detector
13	Laser		

NOTE The wavelength of the laser, λ, is 633 nm for this example but other wavelength can be used.

Figure 3 – Schematic of thermoreflectance thermometry with one laser source that is used for calibration



Key

1	Goniometer	2	Motorized xy stages
3	Fixed stage	4	Motorized linear stage
5	DC or AC power supply	6	Objective lens
7	Halogen lamp	8	Multimeter
9	CCD	10	Variable terminal
11	Silicon detector	12	Laser

NOTE The wavelength of the laser, λ, is 633 nm for this example but other wavelength can be used.

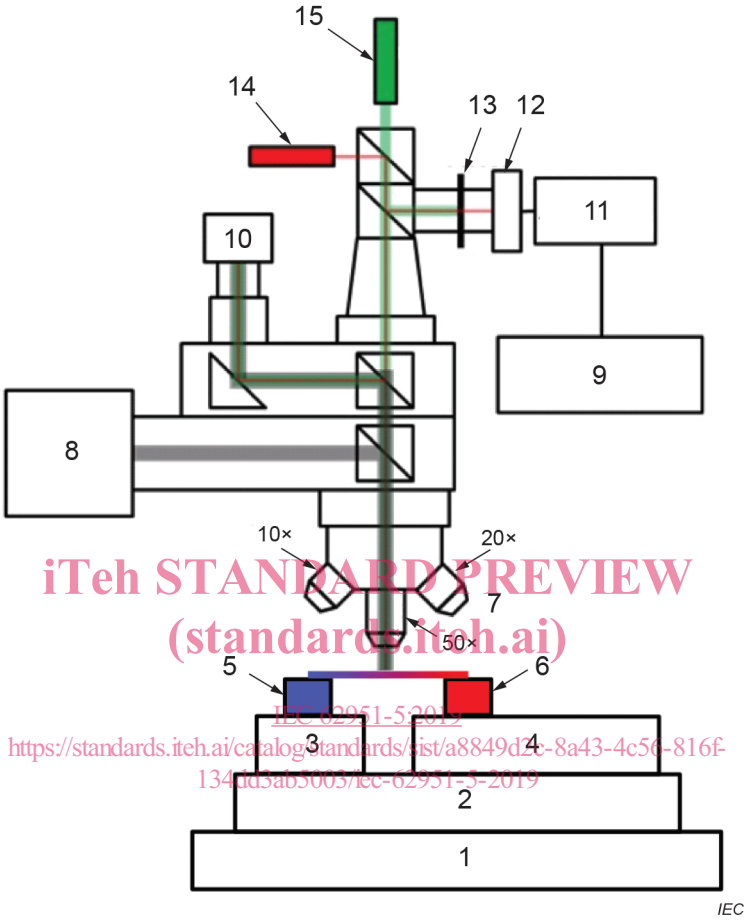
Figure 4 – Schematic of thermoreflectance thermometry with one laser source that is used for measurement

Figure 5 and Figure 6 show schematics of thermoreflectance thermometry with two lasers of different wavelengths that are well suited for thin-film materials but can be generally applicable to substrate materials. Three dimensional design of the dual wavelength thermoreflectance setup is also shown in Annex A. For calibration, heating or cooling blocks with fixed temperature are used. The substrate is joule heated with DC or AC (simple periodic sine) power supplies for actual measurements.

For tight focusing (or smaller focal spots), lasers in setups shown in Figures 3, 4, 5 and 6 are expanded by a beam expander and focused onto a sample under test using a microscope objective lens attached to a turret. The focal spot (d_0) is determined by

$$d_0 = \frac{2f\lambda}{D} \tag{2}$$

where, f is the focal length of the lens, D is the beam diameter at the lens entrance, and λ is the wavelength. Typically, 5x expansion is sufficient. The reflected light travels backwards and is guided towards a silicon photodetector. The photocurrent generated in the silicon detector is converted into a voltage via a variable terminal or a transimpedance amplifier and measured with a digital multimeter or a lock-in amplifier.



Key

1	Goniometer	2	Motorized xy stages
3	Fixed stage	4	Motorized linear stage
5	Cold temperature block	6	Hot temperature block
7	Objective lens	8	Halogen lamp
9	Multimeter	10	CCD
11	Variable terminal	12	Silicon detector
13	Low or high pass filter	14	Laser 1
15	Laser 2		

NOTE The wavelengths of the laser 1 and laser 2, λ_1 and λ_2, are 633 nm and 532 nm for this example but other wavelengths can be used.

Figure 5 – Schematic of thermoreflectance thermometry with two lasers of different wavelengths used for calibration