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TECHNICAL REPORT

colour inside

Printed electronics –
Part 304-1: Equipment – Sintering – Temperature measurement method for photonic sintering system

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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PRINTED ELECTRONICS –

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The text of this Technical Report is based on the following documents:

Draft	Report on voting
119/451/DTR	119/463/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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INTRODUCTION

The purpose of this document is to describe temperature measurement methods for the photonic sintering system. In the printed electronics industry, metallic nano particles (NPs) such as gold (Au), platinum (Pt), silver (Ag) and copper (Cu) are used as the type of ink or paste to print the desired patterns on paper or polymeric film for a wide range of applications, including printed sensors, organic solar cells, printed batteries, signage, lighting and wearable devices. Additionally, various organic and inorganic inks are used, including etch resist ink, photo solder resist ink, conductive polymer ink, and quantum dot ink. The photonic sintering system is used to heat the printed inks to show a better electrical performance such as electric conductivity, hole mobility in semiconductors, etc. whose standard test methods are shown in IEC 62899-202 and IEC 62899-203.

Among the sintering techniques, the photonic sintering technique is attracting much attention as the most promising alternative sintering technique to replace conventional thermal sintering, in terms of short processing times for low temperature. The advantage of a low temperature in the printed electronics application is that there is less structural degradation of the substrate because the printing process and post sintering process are performed at the low temperature on flexible substrates like paper or polymer.

The photonic sintering system is heating equipment with one or more flash lamps, and the surface temperature of the substrate with the printed patterns and films inside the photonic sintering system is one of the major performance data. The flash lamp emits radiation with the wavelengths between UV and IR with highest intensity in the visible range. An intense pulse of radiation with a duration shorter than the thermal equilibration time of the printed inks and substrate heats the printed inks quickly enough to sinter before they transfer much energy to the substrate. The process parameter for the photonic sintering is electrical pulse energies, the pulse duration, a flash frequency and the distance between the flash lamp and the substrate.

Due to its radiative heating mechanism, the process temperature measurement method inside the photonic sintering system is ambiguous because the sintering temperature is induced by the radiation energy absorbed in the printed pattern on the on the flexible substrates Therefore, the standard temperature measurement method inside the photonic sintering system provides the means to identify and ensure a robust product. Therefore, the standardization and sharing of a consistent method for a temperature measurement method inside the photonic sintering system is an effective way to facilitate the commoditization and raise the confidence and performance of relevant equipment industry and its users.

This document is intended to assist in technical information related to the temperature measurement methods for monitoring the surface temperature of the substrate with the printed patterns and films inside the photonic sintering system. A non-contact method using an infrared camera and a pyrometer and a contact method using a thermocouple are introduced along with case studies. It will help equipment makers and its users to select a suitable method for temperature measurement to innovate on the equipment and its performance.

PRINTED ELECTRONICS –

Part 304-1: Equipment – Sintering – Temperature measurement method for photonic sintering system

1 Scope

This part of IEC 62899, which is a technical report, provides technical information relating to surface temperature measurement of the substrate containing the printed patterns and films applicable to the photonic sintering system used in the printed electronics industry.

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 https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1
apparent temperature
uncompensated reading from an infrared thermography camera containing all radiation incident on the detector, regardless of its source

3.2
black body
ideal perfect emitter and absorber of thermal radiation at all wavelengths

[SOURCE: IEC TS 63070:2019, 3.2; ISO 18434-1:2008, 3.4.]

3.3
emissivity
ratio of the radiance of a target surface to that of a blackbody at the same temperature and over the same spectral interval

[SOURCE: IEC 60050-731:1991, 731-06-16, modified – the text “radiant emittance of a substance to the radiant emittance” is replaced with “radiance of a target surface to that”; the text “and over the same spectral interval” is added; and the Note is omitted.]

3.4
infrared (IR) camera
infrared camera
IR camera
instrument that collects the infrared radiant energy from a target surface and produces an image in monochrome (black and white) or colour, where the grey shades or colour hues are related to target surface apparent temperature distribution

3.5
Seebeck effect
thermoelectric effect in which a contact potential difference is temperature dependent

[SOURCE: IEC 60050-121:1998, 121-12-79, modified – Note omitted.]

3.6
radiant energy
energy emitted, transferred or received as radiation

[SOURCE: IEC 60050-731:1991, 731-01-21, modified – the text “energy that is emitted, transmitted or received via electromagnetic waves” is modified as “energy emitted, transferred or received as radiation”.]

3.7
radiation pyrometer
instrument for measuring the temperature of an object by means of the thermal radiation emitted by the object

Note 1 to entry: An alternative synonymous term used is “radiation thermometer”.

4 Temperature measurement methods

4.1 Infrared camera test

4.1.1 General

The thermal camera test utilizes an infrared (IR) camera such as a normal digital camera: an IR camera measures the infrared energy of objects. The camera converts the infrared data into an electronic image that shows the apparent surface temperature of the object being measured (see Figure 1). As thermal detector, the IR camera uses cooled bolometers and uncooled bolometers that sense the incident IR radiation by absorbing and converting it into heat. As a result of the heat produced in the bolometer, the temperature of the sensing material increases, which in turn changes the resistance of the bolometer membrane. The thermal radiation spectrum extends from 0,7 µm to 14 µm.

To estimate the ability of the IR camera to accurately resolve details and acquire the temperature measurements of an object, spatial resolution can be considered to define the smallest object size that can be detected (see Figure 2). A lower spatial resolution value means better detail and image quality. Spatial resolution of an infrared camera is based on detector pixels and the field of view (FOV) specification. The FOV is the largest area that the thermal imaging device can "see" at a set distance, and is defined by the lenses’ horizontal degrees by vertical degrees. Instantaneous field of view (IFOV) is the smallest detail within the FOV that can be detected or seen at a set distance and an important calculation in determining how much a single detector pixel can geometrically resolve or "see" in terms of the field of view (FOV).

An IR camera's detector resolution is the first factor that determines the camera's ability to produce high-quality images. The more detector pixels the detector has, the higher the resolution, so more energy is collected and more details can be seen in the image. The closer the object is, the smaller the area the pixel detects. A single pixel covers a larger area of interest as the object moves further away. The limits of spatial resolution depend on the detector pixel size and microscope lens choice, and high-resolution IR cameras with 1 280 pixels × 1 024 pixels can achieve resolutions in the micrometer range.

Temperature resolution is the smallest temperature difference that will be measured and is commonly referred to as temperature sensitivity. IR camera sensitivity varies from 0,020 °C up to 0,075 °C depending on the type of detector in the camera. The temperature resolution or sensitivity of an IR camera is usually expressed as noise equivalent delta temperature (NEDT). It is a measure of how well a thermal imager can distinguish very small differences in thermal radiation in an image. NETD is usually expressed in millikelvin (mK).

The ISO 18434-1 already provides an introduction to the application of IRT to machinery condition monitoring and diagnostics, where "machinery" includes machine auxiliaries such as valves, fluids and electrically powered machines, and machinery related heat exchanger equipment. Also, this part describes the procedure for calibration and date collection using IR cameras.

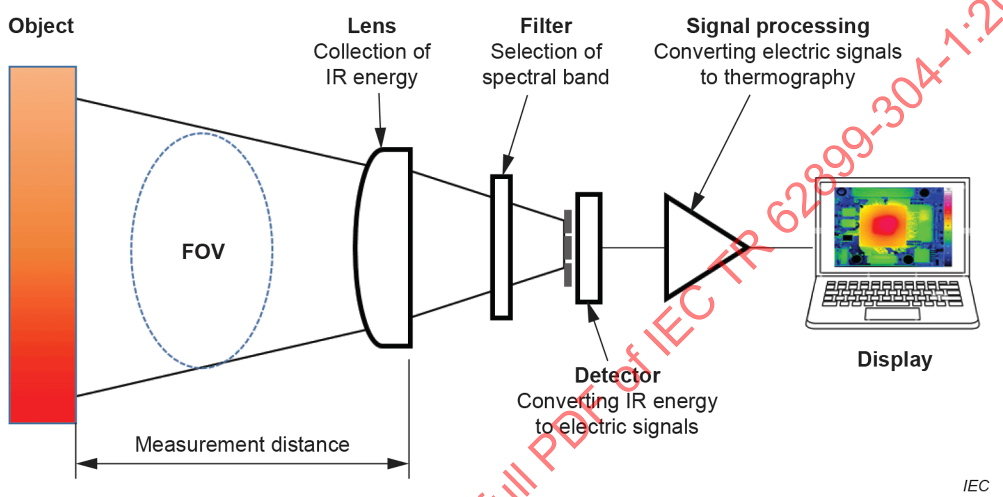


Figure 1 – Schematic diagrams of IR camera

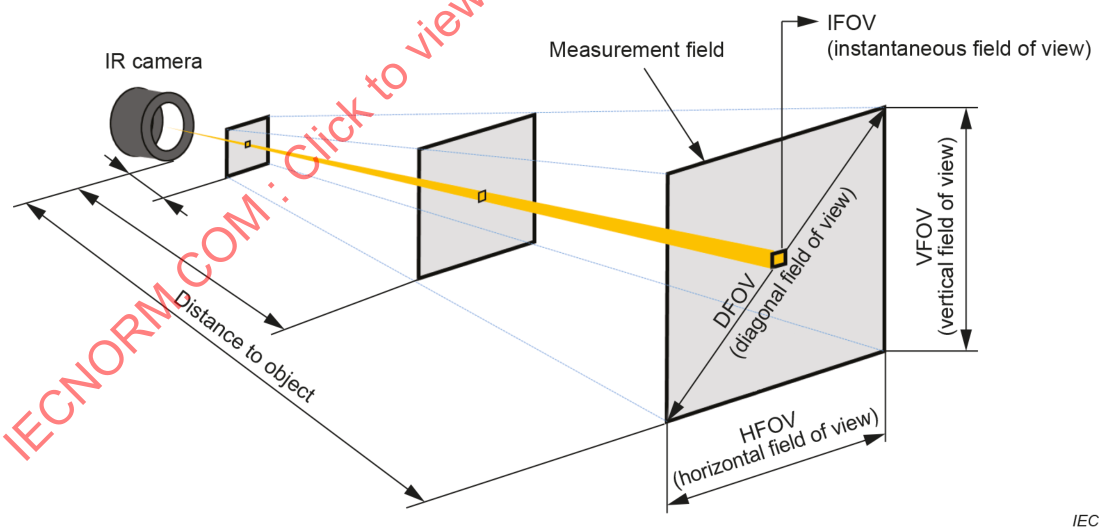
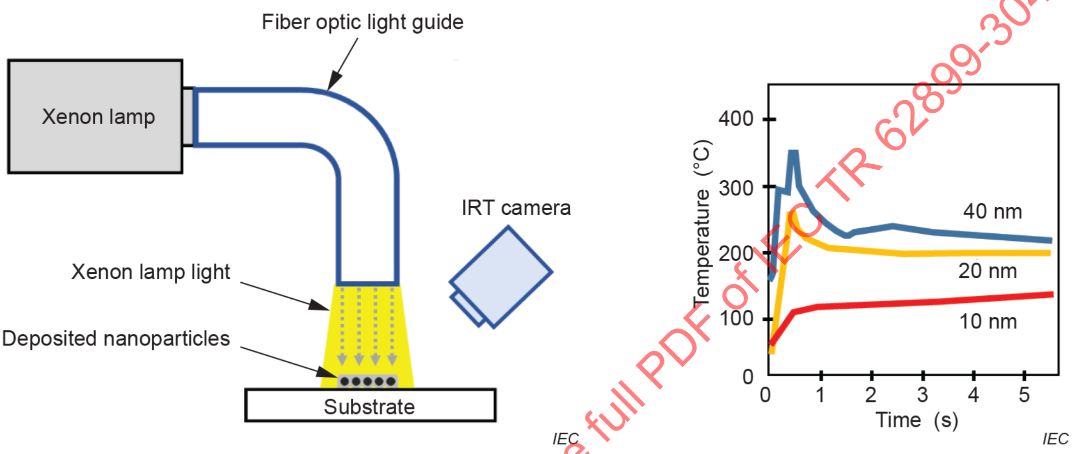


Figure 2 – Schematic diagrams of IR camera spatial resolution

4.1.2 Test apparatus

Figure 3 shows an example of an apparatus setup for surface temperature measurement using an IR camera in a xenon lamp-based photonic sintering system. A continuous xenon lamp source was used as the light source for photonic sintering experiments. The distance between the outlet of the light guide and the substrate is fixed by considering the light spot diameter and pattern area on the substrate. Metallic nanoparticle inks are deposited on substrates by various printing methods and exposed to computer-controlled commanded optical power for target exposure times. An IR camera is used to record temperature evolution during the sintering process. The emissivity of the nanoparticles and the substrate is calibrated by increasing the temperature of the substrate or nanomaterial on a hot plate, measuring the steady-state temperature using a thermocouple, and setting the emissivity to match the steady-state temperature readings from the thermocouple and the IR camera. The FOV and IFOV specification of the IR camera are taken into account to obtain optimal geometric resolution of surface temperature images.



A **B**

Figure 3 – Schematic diagrams of an apparatus for surface temperature measurement using (a) an IR camera and (b) temperature change for nanoparticle size during photonic sintering

4.2 Thermocouple test

4.2.1 General

A thermocouple is widely used as a temperature sensor to measure temperature sensitive voltage at the electrical junction of two dissimilar electrical conductors shown in Figure 4 as a result of the Seebeck effect. Because the thermocouple measures the temperature at the place where the electrical junction is located, it can measure the ambient temperature, the wall temperature and the printed ink sample temperature inside the photonic sintering system. Usually multiple thermocouples are used to measure the temperatures at the multiple places with a multiple-input-recording instrument.

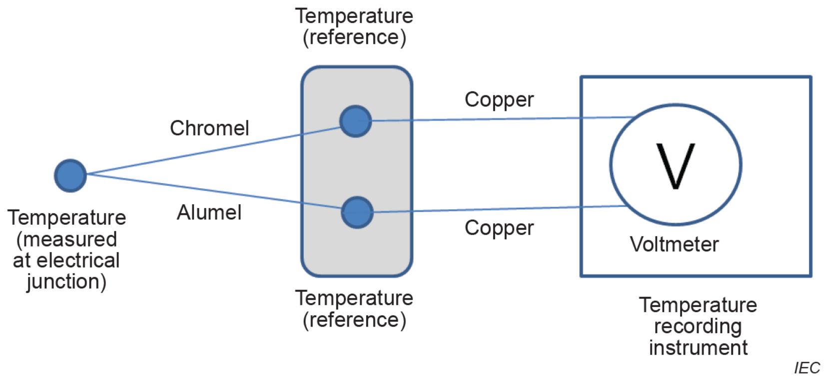
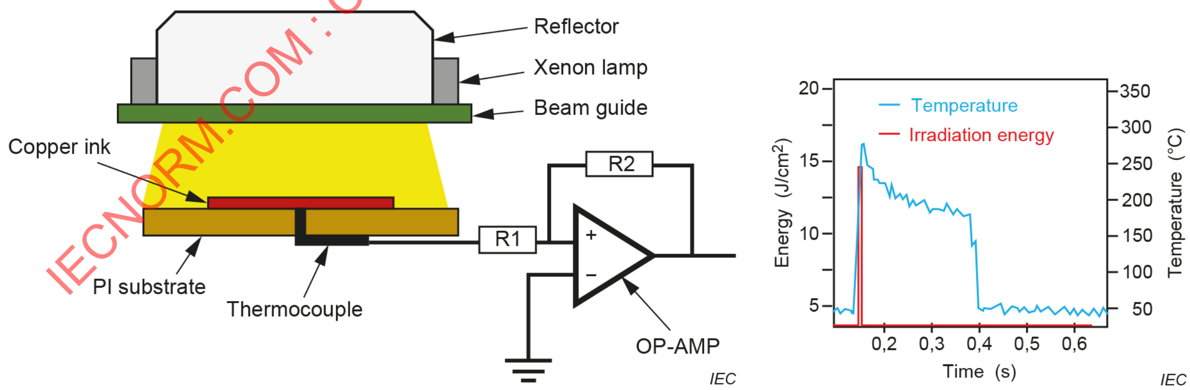


Figure 4 – Schematic of thermocouple measurement configuration with K-type thermocouple (chromel-alumel)

4.2.2 Test apparatus

IEC 60584-1 specifies reference functions and tolerances for letter-designated thermocouples (types R, S, B, J, T, E, K, N, C and A). Under the harsh environment inside the photonic sintering system, metal sheathed thermocouples (ASTM E608) are preferred in order to measure temperature reliably. The wires (copper wire in Figure 4) are extended when compensated connectors are used. All instrumentation and thermocouples sensors used in conjunction with this thermocouple method meet the requirements of calibration defined by the test methods in ASTM E207 and ASTM E220.

Figure 5 shows an example of an apparatus setup for surface temperature measurement using the thermocouple and the temperature measurement result. After punching a hole in a polyimide (PI) substrate using a pin, a thermocouple is inserted into the hole and fixed to the back of the PI substrate with polytetrafluoroethylene adhesive tape. Then, using the screen printing or doctor blade method, metallic nanoparticle ink is coated on the PI substrate to cover the thermocouple. The temperature measurement apparatus consists of a non-inverting amplifier circuit with an op-amp, a power supply and a type-K thermocouple. The flash light sintering system consists of a xenon flash lamp, a power supply, capacitors, a simmer triggering controller, a pulse controller, and a water cooling system. The coated copper nanoparticle PI substrate was placed at a distance of a few mm from the flash light lamp.



A B

Figure 5 – Schematic diagram of an apparatus for surface temperature measurement using a K-type thermocouple

4.3 Pyrometer test

4.3.1 General

The pyrometer can perform a non-contact temperature measurement of an object at a single point. The surface reaches the high temperatures when exposed to high temperature convective flow or other heating elements. The radiant energy emitted from the high temperature surfaces can be used to measure the surface temperature. The pyrometers are classified into two types; an optical pyrometer, and a radiation pyrometer. An optical pyrometer, which is one of the oldest pyrometer types, measures the infrared wavelengths of heat up to 0,65 µm and enables the users to see the heat distribution of an object. A radiation pyrometer is designed to detect thermal radiation in 0,7 µm to 20 µm wavelength region. It measures the temperature of object from radiation emitted by object.

The characteristics of the surface are most important in selecting the wavelength band of the pyrometer sensor. Temperature measurement of high temperature metal is mainly performed using a sensor (0,8 µm to 1,0 µm) in the near-infrared wavelength band, and a sensor of 5 µm is used to measure the surface temperature of glass. The temperature measurement of a plastic film (thickness < 2 mm) changes the transmission coefficient according to the thickness or type of the material; the temperature measurement of polyethylene and polypropylene is 3,43 µm, and is 7,9 µm for the polyester. In most cases, a sensor of 8 µm to 14 µm is suitable for low-temperature material temperature measurement. Since the emissivity has different values depending on the wavelength, the wavelength band measured according to the temperature will be selected. A typical pyrometer that measures a temperature below 700 °C uses a wavelength of 8 µm to 14 µm. However, a narrow-band wavelength of 2,2 µm or 3,8 µm is used to measure a very high temperature. In some cases, a narrow-band wavelength of 0,78 µm to 1,06 µm is used.

ASTM E639-78 has test methods for measuring surface temperature

4.3.2 Test apparatus

Optical resolution can be said to be the relationship between the measurement distance and the measured size of the object. The field of view (FOV) is determined according to the D:S ratio, and each pyrometer sensor has a specific FOV. Here, D is the distance between the pyrometer and the object, and S is the diameter of the spot size. Generally, pyrometer manufacturers provide specifications for D:S, the ratio of the measuring distance to the spot size diameter. This concept is shown in Figure 6. It is possible to measure up to about 140 mm while the diameter of the beam is kept narrow at about 1,3 mm, and if it goes further away, the diameter of the spot size increases. A distance at which the beam does not spread up to about 1,3 mm is called a focusing distance. The temperature of the pyrometer is calibrated with the aid of black bodies (emissivity = 1). The calibration process entails that the exact value of the radiation temperature of the black bodies is known. The temperature of the black bodies is measured using a contact thermometer, and then used for adjusting and calibrating the pyrometer.

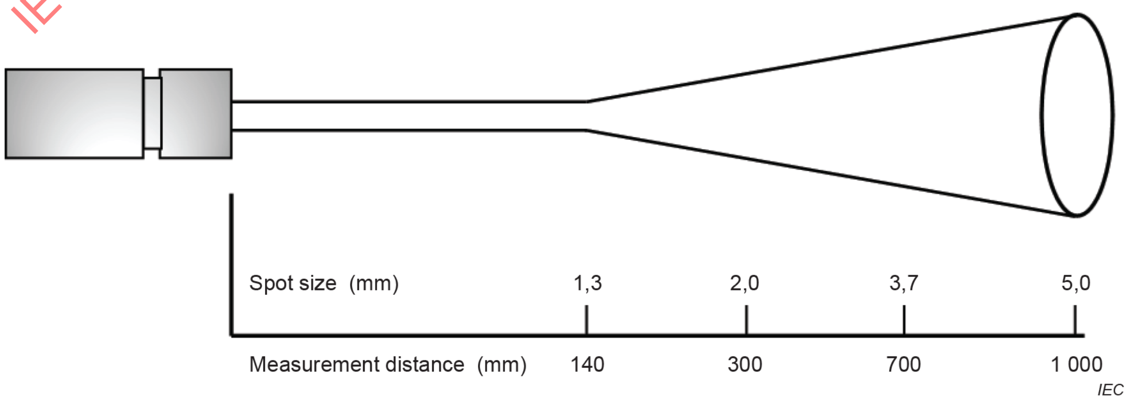
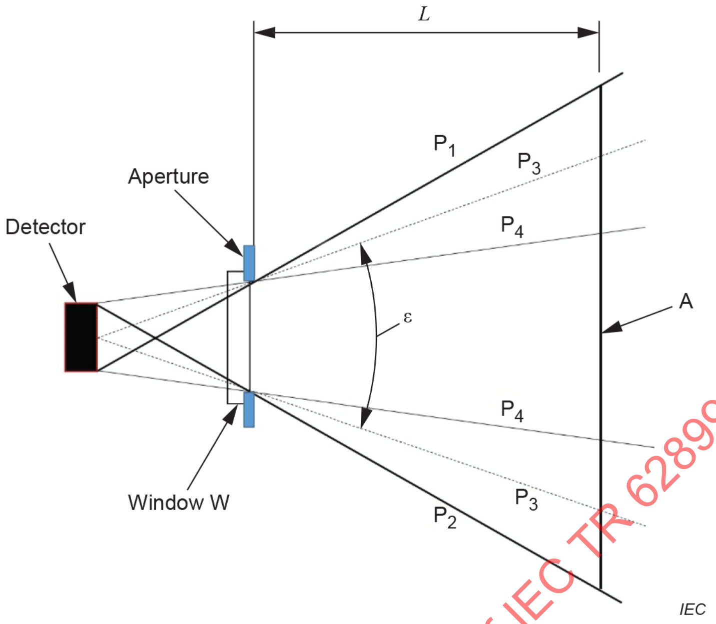


Figure 6 – Optical resolution of the pyrometer

The size of the area viewed is decided by the optics, which determines the amount of energy impinging on the detector. Because responsivity rely on the size of area, responsivity can be altered with the optics (see Figure 7, Figure 8 and Figure 9).



Key:

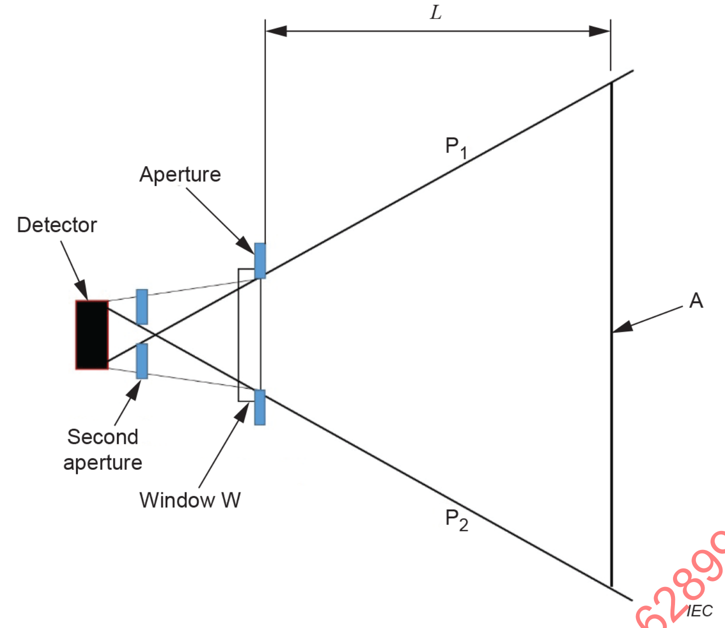
L distance between aperture and heated surface

P_i optical path

A viewed area of heated surface

ε effective solid angle

Figure 7 – Radiation pyrometer using one window and one aperture



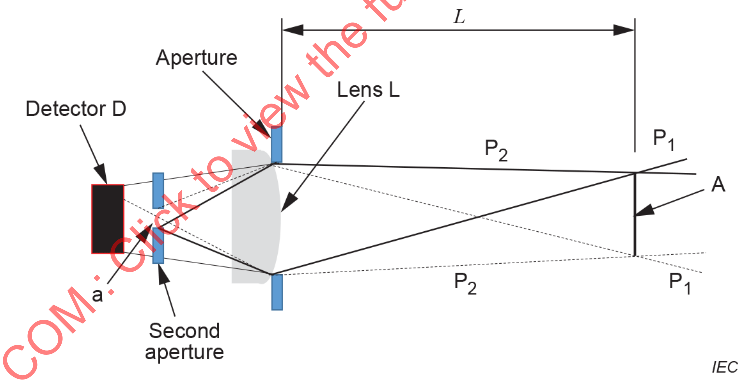
Key:

L distance between aperture and heated surface

P_i optical path

A viewed area of heated surface

Figure 8 – Radiation pyrometer using one window and two apertures



Key:

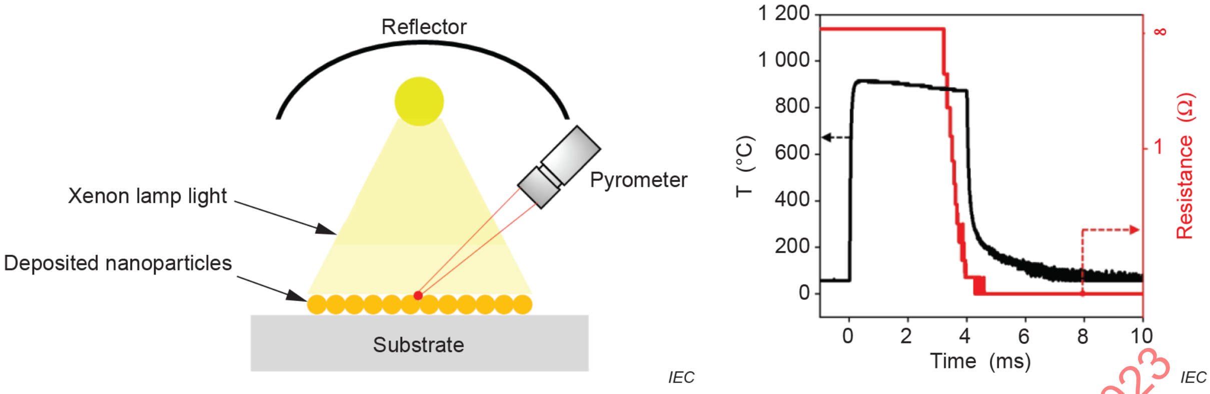
L distance between aperture and heated surface

P_i optical path

A viewed area of heated surface

Figure 9 – Radiation pyrometer using one lens and two apertures

Figure 10 shows an example of setup for surface temperature measurement using a pyrometer in a xenon lamp-based phonic sintering system. A xenon lamp source was used as the light source for photonic sintering experiments.



A **B**

Figure 10 – Schematic diagrams of setup for surface temperature measurement using (a) a pyrometer and (b) combined temperature and resistance measurement results