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Optics and photonics — Microlens arrays —

Part 1: **Vocabulary**

Optique et photonique — Réseaux de microlentilles —

Partie 1: Vocabulaire

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Contents

Page

Foreword ... **iv**
Introduction ... **v**
1 Scope ... **1**
2 Normative references ... **1**
3 Terms and definitions ... **1**
3.1 Symbols and units of measure ... 2
3.2 Basic definitions of microlens and microlens array ... 2
3.3 General terms and definitions ... 3
3.4 Terms relating to properties of the microlens array ... 6
3.4.1 Geometrical properties ... 6
3.4.2 Optical properties ... 7
4 Coordinate system ... **8**
5 Properties of individual lenses ... **9**
Annex A (informative) **Microlens array applications (1) — Telecommunications** ... **11**
Annex B (informative) **Microlens array applications (2) — Image sensor arrays** ... **12**
Annex C (informative) **Microlens array applications (3) — LCD projection panels** ... **13**
Annex D (informative) **Microlens array applications (4) — Wavefront sensors** ... **14**
Annex E (informative) **Microlens array applications (5) — Stereo displays** ... **17**
Annex F (informative) **Microlens array applications (6) — 3D imaging and light-field cameras** ... **18**
Bibliography ... **20**

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and Photonics*, Subcommittee SC 9, *Laser and electro-optical systems*.

This third edition cancels and replaces the second edition (ISO 14880-1:2016), which has been technically revised.

A list of all parts in the ISO 14880 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

The expanded market in microlens arrays has generated a need to agree on basic terms and definitions for microlens arrays and systems and this document aims to satisfy that need.

This document aims to improve the compatibility and interchangeability of lens arrays from different suppliers and to enhance the development of technology using microlens arrays.

Microoptics and microlens arrays are found in many modern optical devices[1]. They are used as coupling optics for detector arrays, the digital camera being an example of a mass market application. They are used to enhance the optical performance of liquid crystal displays, to couple arrays of light sources and to direct illumination for example in 2D and 3D television, mobile phone and portable computer displays. Microlens arrays are used in wavefront sensors for optical metrology and astronomy, lightfield sensors for three–dimensional photography and microscopy and in optical parallel processor elements.

Multiple arrays of microlenses can be assembled to form optical systems such as optical condensers, controlled diffusers and superlenses[2][3]. Furthermore, arrays of microoptical elements such as micro-prisms and micro-mirrors are used[4][5].Examples of some of these applications are described in Annexes A to F.

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Optics and photonics — Microlens arrays —

Part 1: Vocabulary

1 Scope

This document defines terms for microlens arrays. It applies to arrays of very small lenses formed inside or on one or more surfaces of a common substrate. This document also applies to systems of microlens arrays.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

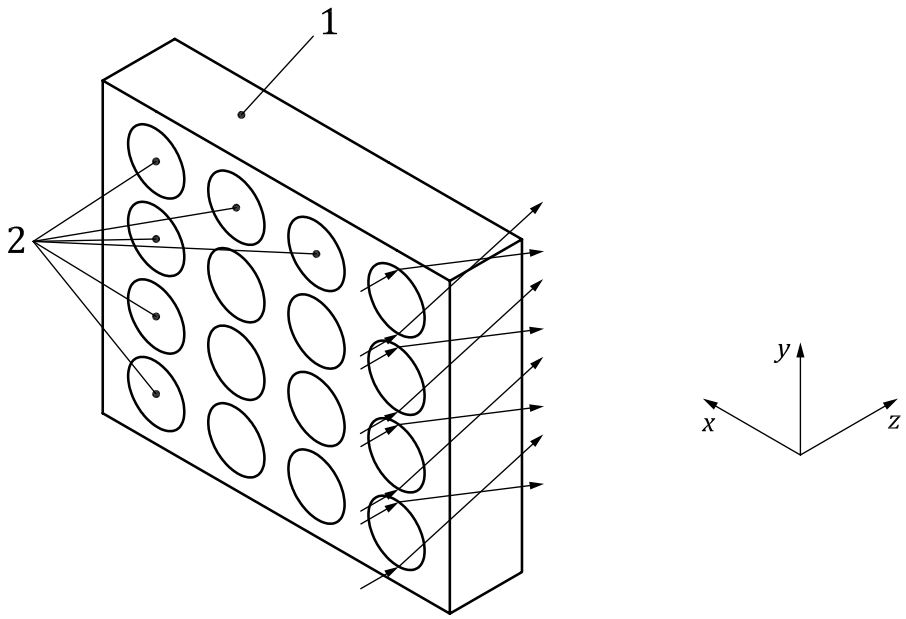
For the purposes of this document, the following terms and definitions apply.

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

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

— IEC Electropedia: available at http://www.electropedia.org/

NOTE 1 The coordinate system used for the description of the microlenses can be found in Figure 1. The description of the coordinate system and its application can be found in Clause 4.



Key

1 substrate

2 microlenses

Figure 1 — Microlens array with Cartesian coordinate system

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NOTE 2 Five common types of microlenses are illustrated in Figure 5, and described in Clause 5.

NOTE 3 For common microlens array applications, see Annexes A to F.

3.1 Symbols and units of measure

Table 1 lists symbols and units which are used in this document.

Table 1 — Symbols and units of measure

Symbol	Unit	Term
A_d	mm^2	diffraction-limited optical aperture
A_g	mm^2	geometric aperture
a_1, a_2	mm	lens radius
$2a_1, 2a_2$	mm	lens width
D_n	mm^{-2}	lens density
h	mm	surface modulation depth
L_1, L_2	mm	edge lengths of substrate
NA	none	numerical aperture
NA_d	none	diffraction-limited numerical aperture
NA_g	none	geometric numerical aperture
$n(x, y, z)$	none	refractive index
n_0	none	refractive index at the centre of the lens
P_x, P_y	mm	pitch
$f_{E,b}$	mm	effective back focal length
$f_{E,f}$	mm	effective front focal length
R_c	mm	radius of curvature
S_x, S_y, S_z	mm	coordinates of focal spot position
$\Delta S_x, \Delta S_y, \Delta S_z$	mm	focal spot position shift
T	mm	thickness of substrate
T_c	mm	physical thickness
w_x, w_y	µm	focal spot size
x, y, z	mm	coordinates of lens aperture centre position
Θ	degree	acceptance angle
Φ_{rms}	parts of wavelength	wavefront aberration
λ	nm	wavelength
v_{eff}	none	effective Abbe-number

3.2 Basic definitions of microlens and microlens array

3.2.1
microlens

lens in an array with an aperture of less than a few millimetres including lenses which work by refraction at the surface, refraction in the bulk of the substrate, diffraction or a combination of these

Note 1 to entry: The microlens can have a variety of aperture shapes: circular, hexagonal or rectangular for example. The surface of the lens can be flat, convex or concave.

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3.2.2
microlens array
regular arrangement of microlenses on/in a single substrate

Note 1 to entry: Irregular or structured arrays are sometimes used, for example, in beam shaping, diffusion, and homogenization.

3.3 General terms and definitions

3.3.1
effective front focal length
$f_{E,f}$
distance from the vertex of the microlens to the position of the focus given by finding the maximum of the power density distribution when collimated radiation is incident from the back of the substrate

Note 1 to entry: The effective front focal length can differ from the paraxial front focal length in the case of aberrated lenses.

Note 2 to entry: The effective front focal length is different from the classical effective focal length since it is measured from the lens vertex.

3.3.2
effective back focal length
$f_{E,b}$
distance from the back surface of the substrate or the vertex of the microlens to the position of the focal point, when collimated radiation is incident from the lens side of the substrate

Note 1 to entry: The effective back focal length can differ from the paraxial back focal length in the case of aberrated lenses.

Note 2 to entry: In case the microlens or microlenses are formed on both sides of the substrate, "effective back focal length" is defined from the vertex of the microlens to the position of the focal point.

3.3.3
radius of curvature
R_c
distance from the vertex of the microlens to the centre of curvature of the lens surface

Note 1 to entry: The radius of curvature is expressed in millimetres.

3.3.4
wavefront aberration
Φ_{rms}
root mean square of deviation of the wavefront from an ideal spherical or other wavefront

Note 1 to entry: The wavefront aberration is expressed in parts of the wavelength, λ.

3.3.5.1
chromatic aberration
change of the focal length with wavelength

Note 1 to entry: Chromatic aberration is characterized by the effective Abbe-number, which is given by:

$$v_{eff} = \frac{\frac{1}{f(\lambda_2)}}{\frac{1}{f(\lambda_1)} - \frac{1}{f(\lambda_3)}}$$

where the values of λ_1, λ_2 and λ_3 are specified in order to correspond to current practice in optical lens design. The effective Abbe-number is dimensionless.

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Note 2 to entry: At optical wavelengths the C line (656,3 nm) as λ3, d line (587,56 nm) as λ2, F line (486,1 nm) as λ1 are generally used. However, other wavelengths such as the infrared spectrum can be used where appropriate, provided that $\lambda_1 < \lambda_2 < \lambda_3$.

3.3.5.2
achromatic microlens array
microlens array designed to limit the effects of chromatic aberration

Note 1 to entry: Achromatic microlens arrays are generally corrected to bring radiation of two wavelengths into focus in the same plane, for example, red and blue light or infrared wavelengths where appropriate.

3.3.6.1
aperture shape
shape which is specified as square, circular, hexagonal, circular sector or other geometric shape

Note 1 to entry: For non-regular shapes, the vertices of the microlens aperture are to be defined by coordinates, Xa_{jk}, Ya_{jk}, where j is the microlens number index and k is the vertex number index.

3.3.6.2
geometric aperture
A_g
area in which the optical radiation passing through it is deviated towards the focused image and contributes to it

Note 1 to entry: For graded index microlenses where no obvious boundary exists, the edge is the locus of points at which the change of index is 10 % of the maximum value.

Note 2 to entry: The geometric aperture is expressed in square millimetres.

3.3.6.3
lens width
$2a_1$, $2a_2$
width of the microlens on the substrate defined by the geometric aperture of the microlens

Note 1 to entry: The widths are determined by measuring the longest distance ($2a_1$) and the shortest distance ($2a_2$) between the lens edges as shown in Figure 2. If the lens is circular symmetric, then the term diameter can be used.

Note 2 to entry: Lens widths are expressed in millimetres.

Note 3 to entry: The geometric aperture of the microlens can be given by a variety of shapes such as circular, rectangular, elliptical and so on.

3.3.6.4
diffraction-limited optical aperture
A_d
area within which the peak-to-valley wavefront aberrations are less than one quarter of the wavelength of the radiation with which it is tested

Note 1 to entry: The diffraction-limited optical aperture is expressed in square millimetres.

3.3.6.5
geometrical numerical aperture
NA_g
sine of half the angle subtended by the aperture of the lens at the focal point

3.3.6.6
diffraction-limited numerical aperture
NA_d
sine of half the angle subtended by the diffraction limited optical aperture of the lens at the focal point

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3.3.7
focal ratio
ratio of the focal length to the lens width of the geometrical aperture

Note 1 to entry: The focal ratio is equivalent to the practical *f*-number.

3.3.8
imaging quality
quality of the microlens which is determined by Modulation Transfer Function (MTF) according to ISO 15529 or the Strehl ratio

Note 1 to entry: The imaging quality should be measured in the conjugates in which the microlenses are to be used and preferably for a range of angles of incidence.

3.3.9
focal spot size
w_x, w_y
half width in the *x* direction and *y* direction, respectively, at which power density is decreased to the $1/e^2$ irradiance levels at the practical focus point when the microlens is irradiated with a uniform plane wavefront

Note 1 to entry: Focal spot sizes are expressed in micrometres.

3.3.10
lenticular microlens array
array of cylindrical microlenses

Note 1 to entry: Historically the term lenticular means lens-shaped, but in practice it is used to describe cylindrical lenses.

3.3.11
beam homogenizer
one or more microlens arrays designed to shape the intensity distribution of an incident wavefront

3.3.12
structured microlens array
microlens array with regular or random geometry designed to shape an incident wavefront, often used for applications with a broad range of wavelengths

3.3.13
condenser array
dual array of cylindrical or spherical microlenses designed to illuminate a large field at a relatively short working distance

Note 1 to entry: For convenience, the dual arrays can be formed either side of a single substrate.

3.3.14
Gabor superlens
optical system formed from a pair of afocal microlens arrays which can have different periods and focal lengths

Note 1 to entry: The Gabor superlens is able to produce “integral” images which are very different from those produced by conventional lenses.

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3.4 Terms relating to properties of the microlens array

3.4.1 Geometrical properties

3.4.1.1
structure of the microlens array
geometrical arrangement of the individual microlenses and feature of the substrate

Note 1 to entry: There are generally two types of arrangements: regular and irregular. Regular can be rectangular, hexagonal or polar regardless of the overlapping of microlenses on the substrate. The specification has to completely describe the arrangement for the microlens array. The lens array positions X_j, Y_j and aperture vertex coordinates are used to define this structure. For regular structures, only the spacing and geometry are to be defined.

3.4.1.2
lens aperture centre position
x,y,z
coordinates of the location of the centre of a given lens in the array

Note 1 to entry: The index *j* may be added as needed to identify a particular lens number.

Note 2 to entry: The coordinates of the lens aperture centre position are expressed in millimetres.

3.4.1.3
focal spot position
S_x, S_y, S_z
coordinates of the focal spot geometrical positions

Note 1 to entry: The index j may be added to specify a particular microlens.

Note 2 to entry: The focal spot position need not be specified if the array is telecentric and regular.

Note 3 to entry: The coordinates of the focal spot position are expressed in millimetres.

3.4.1.4
focal spot position shift
ΔS_x, ΔS_y, ΔS_z
offset distance from the *x,y,z* coordinates of the lens position to the focal spot position

Note 1 to entry: $\Delta S_x = x\text{-}S_x$, $\Delta S_y = y\text{-}S_y$, $\Delta S_z = z\text{-}S_z$.

Note 2 to entry: The focal spot position shift is expressed in millimetres.

3.4.1.5
pitch
P_x, P_y
distance between the centres of adjacent lenses which can vary across and will vary with direction

Note 1 to entry: P_x, P_y are defined as pitch of *x*, *y* direction as shown in Figure 2.

Note 2 to entry: The pitch is expressed in millimetres.

3.4.1.6
lens density
D_n
number of lenses per unit area of the array

Note 1 to entry: The lens density is expressed in millimetres to the power minus two.

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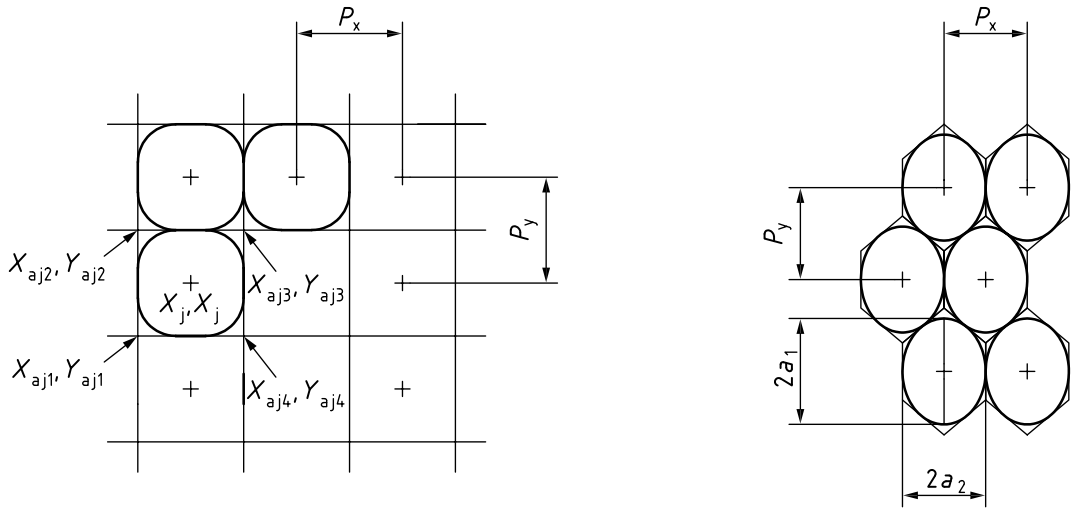


Figure 2 — Arrangement of the microlens array

3.4.1.7
fill factor
ratio of the area of the array occupied by the geometrical aperture of lenses to the total area

3.4.1.8
surface modulation depth
h
peak-to-valley variation of the surface height

Note 1 to entry: For a purely refractive microlens, this will be the same as the lens sag.

Note 2 to entry: The surface modulation depth is expressed in millimetres.

3.4.1.9
physical thickness
T_c
maximum local thickness of the array

Note 1 to entry: The physical thickness is expressed in millimetres.

3.4.1.10
substrate
piece of material on which or in which the microlens array is made

Note 1 to entry: The substrate can be homogenous or laminated. The refractive index and the substrate thickness of the material should be specified.

3.4.1.11
decentration
transverse separation between the optical axes of two or more microlens arrays

3.4.2 Optical properties

3.4.2.1
efficiency
ratio of the optical radiation power that is focused into the useful images to the total optical radiation incident on the array

Note 1 to entry: The definition of useful image will vary from one application to another and has to be defined unambiguously.

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3.4.2.2
diffraction limited efficiency
ratio of the incident optical radiation in a plane wave that falls within the area defined by the first minimum of the theoretical diffraction pattern to the total optical radiation incident on the array

3.4.2.3
stray radiation
ratio of optical radiation passing through the lens array that does not fall within the area of a useful image to the total radiation incident on the array

3.4.2.4
common focal plane
plane defined by the mean value of the focal points of all the lenses

3.4.2.5
deviation from common focal plane
measure of the deviation of the individual focal lengths from the common focal plane given by the standard deviation of the focal lengths

Note 1 to entry: The deviation from common focal plane is expressed in micrometres.

3.4.2.6
spectral transmission
variation of optical transmission of the microlens array with wavelength

4 Coordinate system

To describe the radiation propagation in a microlens array, a Cartesian coordinate system is used where the *z*-axis corresponds to the direction of propagation of the optical radiation and the *x*-axis and *y*-axis are on the surface of the substrate, as shown in Figure 1. The fundamental structure of a microlens array is illustrated in Figure 3. The microlenses on the second side can have the same diameter or, as shown in Figure 4, a different diameter to those on the first side.

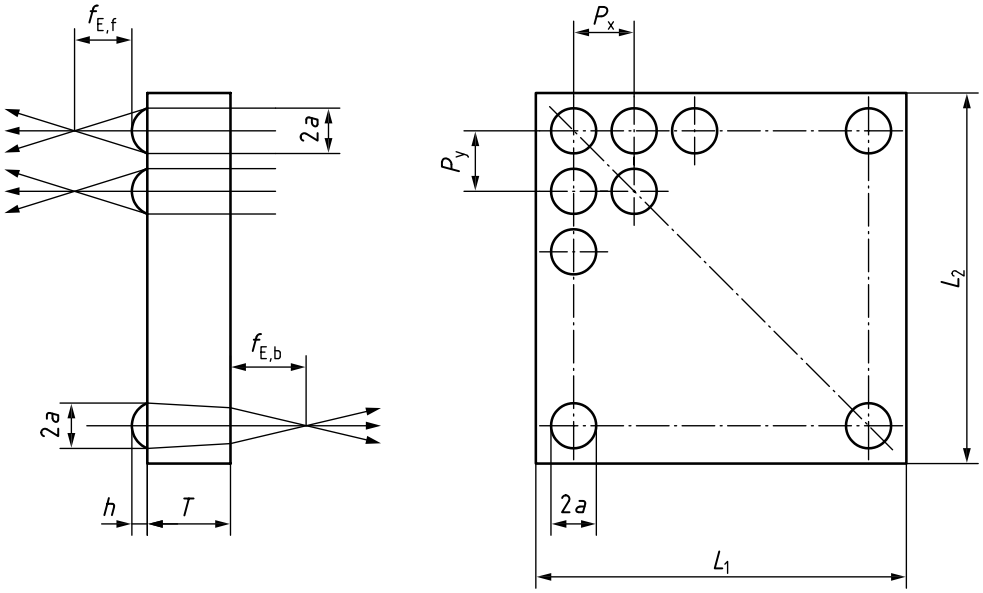


Figure 3 — Fundamental structure of microlens arrays

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