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Optics and photonics — Microlens arrays —

Part 2:
Test methods for wavefront aberrations

Optique et photonique — Réseaux de microlentilles —

Partie 2: Méthodes d'essai pour les aberrations du front d'onde

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Contents

Foreword

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This document was prepared by Technical Committee ISO/TC 172, *Optics and Photonics*, Subcommittee SC 9, *Laser and electro-optical systems*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 123, *Lasers and photonics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 14880-2:2006), which has been technically revised.

The main changes are as follows:

— text for Annex E was revised;

— Figure E.1 was replaced;

— references and numbering confirmed.

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.

Introduction

Examples of applications of microlens arrays include three-dimensional displays, coupling optics associated with arrayed optical radiation sources and photo-detectors, enhanced optics for liquid crystal displays, and optical parallel processor elements.

The market in microlens arrays has generated a need for agreement on basic terminology and test methods for defining microlens arrays. Standard terminology and clear definitions are needed not only to promote applications but also to encourage scientists and engineers to exchange ideas and new concepts based on common understanding.

Microlenses are used as single lenses and also in arrays of two or more lenses. The characteristics of the lenses are fundamentally evaluated with a single lens. Therefore, it is important that the basic characteristic of a single lens can be evaluated. However, if a large number of lenses is formed on a single substrate, the measurement of the whole array will incur a lot of time and cost. Furthermore, methods for measuring lens shapes are essential as a production tool.

Characteristic parameters are defined and examples of applications given in ISO 14880-1. It has been completed by a set of three other International Standards, i.e. ISO 14880-2, ISO 14880-3 and ISO 14880-4.

This document specifies methods for measuring wavefront quality. Wavefront quality is the basic performance characteristic of a microlens. Characteristics other than wavefront aberrations are specified in ISO 14880-3, ISO 14880-4 .

ISO/TR 14880-5 guides the user in selecting the appropriate measurement method from the ISO 14880 series of standards.

Optics and photonics — Microlens arrays —

Part 2:
Test methods for wavefront aberrations

1 Scope

This document specifies methods for testing wavefront aberrations for microlenses within microlens arrays. It is applicable to microlens arrays with very small lenses formed inside or on one or more surfaces of a common substrate.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14880-1, *Optics and photonics — Microlens arrays — Part 1: Vocabulary*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14880-1 apply.

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

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

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

3.2 Symbols and abbreviated terms

Table 1 lists associated symbols, abbreviated terms and units of measurement used in this document.

Table 1 — Symbols, abbreviated terms and units of measure

Symbol	Unit	Term
Φ	µm	wavefront aberration
Φ_{P-V}	µm	peak-to-valley value of wavefront aberration
Φ_{rms}	µm	root-mean-square value of wavefront aberration
λ	µm	wavelength
Θ	degree (°)	acceptance angle
NA	none	numerical aperture

NOTE The wavefront aberration, peak-to-valley values of wavefront aberration and root-mean-square values of wavefront aberration are often expressed in units of ”λ” based on the results of interferometer measurements. Wavefront aberration is expressed in multiples of ”λ” (wavelength (µm)) of the laser light source used in the interferometer.

4 Apparatus

The test system consists of a source of optical radiation, a collimator lens, a method of limiting the measurement aperture, a sample holding apparatus, imaging optics, an image sensor and a system for analysing interference patterns[4][5][7][8][12][15][25].

4.1 Standard optical radiation source.

A source of optical radiation shall be used, which is suitable for the testing of wavefront aberrations of microlenses. The aberrations of the wavefront incident on the test equipment shall have a rms deviation less than or equal to $\lambda/20$, at the wavelength of operation, over an area corresponding to the effective aperture of the microlens to be tested. For information on calculating rms values refer to ISO 14999-4:2015, 3.1.3.

Properties of the source to be specified include centre wavelength, half-width of the spectrum, the type of optical radiation source, states of polarization (randomly polarized optical radiation, linearly polarized optical radiation, circularly polarized optical radiation, etc.), radiance angle (in mrad), spot size or beam waist parameters. Otherwise, the specification of the radiation source shall be described in the test report. ISO 12005 deals with a method for determining the polarization state of a laser beam [11].

NOTE 1 He-Ne gas lasers are sometimes used. Other gas lasers, solid-state lasers, semiconductor lasers (LD), and light emitting diodes (LED) are also used.

NOTE 2 LDs and LEDs are used with beam-shaping optics where necessary.

4.2 Standard lens (reference lens).

Where a standard lens is used as a reference or for generating an ideal spherical wave, the wavefront aberrations of the standard lens shall be smaller by at least one order of magnitude compared to that of the lens to be tested or shall be less than $\lambda/20$ rms deviation.

The objective lens of an optical microscope used as the standard lens shall be specified with the effective numerical aperture. The following shall be given:

— effective aperture;

— focal length at the wavelength of operation.

The test geometry for the measurement of wavefront aberrations is restricted to the case with lens conjugates ∞/f.

4.3 Collimator.

The collimator optics shall have a numerical aperture greater than the maximum numerical aperture of the test sample sufficient to avoid effects due to diffraction. The wavefront aberrations should be less than the Maréchal criterion value and/or the Strehl definition value (both $\lambda/14$: 0,07λ rms). It is however recommended that they are less than $\lambda/20$ at the operational wavelength.

Otherwise the specification used should be described in the test report.

4.4 Beam reduction optical system.

A telescopic system consisting of two positive lenses in an afocal arrangement is used to adapt the beam cross-section to the array detector. The ratio of the focal lengths gives the reduction factor. It is recommended that the wavefront aberrations are less than $\lambda/20$ at the operational wavelength.

NOTE The diameter of the lens area to be evaluated can be selected with an effective aperture defined by software to avoid additional diffraction at a physical aperture.

4.5 Aperture stop.

A physical stop is placed in the optical radiation beam of the test equipment to limit the diameter of the optical radiation beam incident on the lens to be tested. Alternatively, the stop may be defined by truncation software during evaluation.

5 Test principle

The wavefront aberrations of the test microlens shall be determined with an interferometer or another wavefront test device as described in the Annexes. When small-diameter Gaussian beams are used, care should be taken because geometrical optical theory does not apply to the propagation of such beams. The detector surface shall be conjugate with the entrance or exit pupil of the test microlens. An aperture is used to analyse the data for the wave aberrations[13][14][16][17][18].

The test method shall be chosen to suit the application. Single-pass applications require testing using single-pass interferometers[13].

NOTE Interferometers often use laser sources for the interferometric test. Dielectric boundaries between lenses contribute to unwanted reflections, stray light and spurious fringe patterns. This can cause severe problems if a double-pass arrangement using reflected optical radiation is chosen, such as when Fizeau or Twyman-Green interferometers are used.

Arrangements using transmitted optical radiation are less affected by spurious fringes than reflection type interferometers. It is preferable to use interferometers of the Mach-Zehnder or lateral shearing type or Shack-Hartmann arrangements in transmitted optical radiation. For the measurement of wave aberrations a single-pass geometry in transmitted optical radiation will often be the first choice for reducing spurious reflections.

6 Measurement arrangements

6.1 Measurement arrangement for single microlenses

Interferometers or wavefront detectors shall be used to measure the transmitted wavefront of the microlens under test. Single-path interferometers such as Mach-Zehnder, lateral shearing or double-pass interferometers such as Fizeau, Twyman-Green, and Shack-Hartmann wavefront detectors can be used for testing as shown in Annexes B to D.

The requirements for the measurement shall be defined. Typical criteria for choosing a specific method are

— required uncertainty of measurement,

— required properties to be measured,

— flexibility of the measurement,

— costs, and

— spot test on one lens or complete measurement.

For more details see ISO/TR 14999-2.

6.2 Measurement arrangements for microlens arrays

Interferometers or wavefront detectors shall be used to measure simultaneously whole arrays or parts of them in the transmitted radiation. Typical test arrangements are described in Annexes E and F.

NOTE While the testing of single lenses selected from an array can be carried out by illuminating with a spherical wave this is in general not possible with array tests. In that case, illuminating with plane wave is more suitable or special provisions using diffractive array wavefront shaping elements have to be used[13].

6.3 Geometrical alignment of the sample

Usually the microlens being tested and its coupling optics shall be set or adjusted into coaxial alignment with the wavefront measuring instruments. Optical alignment instruments and/or devices are commercially available for this purpose.

The sample can be mounted on a stage such as an air-chuck, which has two or three directions of freedom for adjustment.

6.4 Preparation

The test equipment shall be maintained in a temperature-controlled environment and not exposed to vibration so as to obtain consistent results. The use of an optical table is recommended.

The optical surfaces to be tested shall be clean. Uncoated glass surfaces may be safely cleaned with alcohol and cotton wool. The cotton wool should be soaked in a very small amount of solvent before touching the surface and wiped only once across it before being discarded. This minimizes the chances of scratching the surface. Dust may be removed using a clean camel-hair brush or filtered compressed air.

Coated optical surfaces such as antireflection surfaces should be treated with great care and not cleaned unless absolutely necessary. They may be dusted using filtered compressed air.

Guidance should be sought on the correct use of solvents, cotton wool or other wiping materials.

7 Procedure

Measurement requirements and typical methods for measuring the wavefront aberration of individual lenses are described in the Annexes A to D.

Examples for measurements of wavefront aberrations of microlens arrays are described in the Annexes E and F.

8 Evaluation

The wavefront aberration can be calculated from the interferogram[12][16] or from other wavefront measuring systems described in Annexes A to F. From the wavefront aberrations of spherical lenses with circular apertures primary Zernike coefficients can be derived with a prescribed software aperture.

NOTE 1 Typical wavefront aberrations described by Zernike coefficients are

— spherical aberration,

— astigmatism, and

— coma.

NOTE 2 For other lens aperture shapes (such as rectangular), see ISO/TR 14999-2.

The measured wavefront aberrations of samples shall be evaluated and quoted, for example, as peak-to-valley or root-mean-square values. ISO 14999-4 gives definitions of these terms relating to optical measurements.

Care should be taken to interpret peak-to-valley values because they are influenced by spurious values. It is recommended to use multiple times (at least three times) the rms figure instead.

9 Uncertainty of measurement

The wavefront aberrations of a sample are measured by a wavefront test system, which may introduce some aberration of its own. The uncertainty of measurement can be improved by subtracting the system aberrations[9][10].

10 Test report

The test results shall be recorded and shall include the following information if applicable:

a) general information:

   1) test has been performed in accordance with ISO 14880-2:2024;

   2) date of test;

   3) name and address of test organization;

   4) name of individual performing the test;

b) information concerning the tested lens:

   1) lens type;

   2) manufacturer;

   3) manufacturer’s model;

   4) serial number;

c) test conditions (environmental conditions):

   1) temperature;

   2) relative humidity;

d) information concerning testing and evaluation:

   1) test method used;

   2) optical system used;

   3) irradiation:

      i) source type,

      ii) wavelength,

      iii) FWHM (full width at half maximum) of optical radiation spectrum,

      iv) polarization status,

      v) irradiance angle,

      vi) spot size;

   4) detector;

   5) aperture;

e) test results:

   1) peak-to-valley value of wavefront aberration Φ_{P-V};

   2) root-mean-square value of wavefront aberration Φ_{rms};

   3) Zernike polynomials or other polynomial coefficients.