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Optique et photonique — Optique diffractive — Vocabulaire

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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*.

This second edition cancels and replaces the first edition (ISO 15902:2004), of which it constitutes a minor revision. It also incorporates the Technical Corrigendum ISO 15902:2004/Cor 1:2005.

The changes compared to the previous edition are as follows:

— in 3.3.3.4, an explanation on the factor has been added in a note to entry;

— in 3.4.3.4, the sign has been corrected;

— other editorial changes have been made.

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

The term diffractive optical element is used for those optical elements which convert an input wavefront to a predetermined output wavefront (or wavefronts) in free space by means of the phenomenon of diffraction. There has been a rapid increase in the use of diffractive optical elements, especially in the field of optical data storage, and they are essential components in optical and electro-optical systems. They are used in a wide variety of applications.

Optics and photonics — Diffractive optics — Vocabulary

1 Scope

This document defines the basic terms for diffractive optical elements for free space propagation. The purpose of this document is to provide an agreed-upon common terminology that reduces ambiguity and misunderstanding and thereby aid in the development of the field of diffractive optics.

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 http://www.iso.org/obp

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

3.1 Diffractive optics technologies

3.1.1
diffractive optics
optical technology based on the phenomenon of the diffraction of optical radiation

3.1.2
binary optics
diffractive optics technology whose optical components have a quantized surface structure in height

Note 1 to entry: The word binary originally means a two-step structure in cross section, however, a staircase structure in cross section is usually referred to as binary as well, regardless of the number of the steps. This incorrect wording originates from the fact that these structures are fabricated using a mask lithography technique.

Note 2 to entry: See 3.3.2.8 and 3.3.2.9.

3.1.3
holographic optics
diffractive optics technology that uses holograms as optical elements for transforming an incident wavefront into a specific wavefront or wavefronts

3.2 Diffractive optical elements and their types

3.2.1
diffractive optical element
DOE
optical element for which the phenomenon of the diffraction of optical radiation is the operating principle, usually characterized in terms of its periodic spatial structure

3.2.2
amplitude diffractive optical element
optical element which utilizes the diffraction created by its periodic spatial amplitude modulation

3.2.3
phase diffractive optical element
optical element which utilizes the diffraction created by its periodic spatial phase modulation

3.2.4
transmission diffractive optical element
diffractive optical element that operates with transmitted optical radiation

3.2.5
reflection diffractive optical element
diffractive optical element that operates with reflected optical radiation

3.2.6
active diffractive optical element
diffractive optical element whose diffraction characteristics can be dynamically changed

3.2.7
holographic optical element
HOE
diffractive optical element fabricated with an interferometric method

3.2.8
computer-generated diffractive optical element
computer-generated hologram (CGH)
diffractive optical element which is computer-designed and fabricated under computer control

Note 1 to entry: A computer-generated diffractive optical element is generally fabricated using a mechanical method or by lithography, using optical radiation waves (including laser beams), electron beams or ion beams, and is often referred to as a "computer-generated hologram (CGH)".

3.2.9
binary optical element
BOE
phase-diffractive optical element having a binary-level or quantized multi-level surface-relief structure

Note 1 to entry: See Note 1 to entry in 3.1.2.

3.3 Structure of diffractive optical elements

3.3.1 General structure

3.3.1.1
substrate for diffractive optical elements
basic body of the diffractive optical element

Note 1 to entry: It may support the element's periodic structure on its surface, or it may contain that periodic structure within itself.

3.3.1.2
grating
periodic spatial structure for optical use

3.3.2 Phase structure

3.3.2.1
phase profile
phase distribution of a diffractive optical element, which is added to incident optical radiation

3.3.2.2
surface relief diffractive optical element
optical element whose diffractive property is created by a periodic relief pattern deposited on or corrugated in the substrate

3.3.2.3
Q-factor
Q-value
for a periodic structure with a sinusoidal refractive-index profile, this is given by

$$Q = \frac{2\pi\lambda T}{n_{av} \Lambda^2}$$

Note 1 to entry: The value is used to categorize gratings as either thick or thin. It should be noted that it is defined only for sinusoidal refractive index profile.

3.3.2.4
thin diffractive optical element
diffractive optical element which produces Raman-Nath diffraction

Note 1 to entry: For a diffractive optical element with a sinusoidal refractive index profile, it is characterized by $Q < 1$.

3.3.2.5
thick diffractive optical element
diffractive optical element which produces Bragg diffraction

Note 1 to entry: For a diffractive optical element with a sinusoidal refractive index profile, it is characterized by $Q >> 1$.

3.3.2.6
volume phase diffractive optical element
thick diffractive optical element whose diffraction is created by a three-dimensional periodic refractive index distribution within the substrate

3.3.2.7
phase step
stair step
step in binary phase structure

3.3.2.8
binary phase structure
discrete phase structure that may have either simple binary or quantized phase steps

Note 1 to entry: See Notes to entry to 3.1.2 and 3.3.2.9.

3.3.2.9
multi-level phase structure
binary phase structure that has more than two phase levels in one period

Note 1 to entry: Multi-level phase structure includes binary phase structure in its definition, however, each term is sometimes used as a synonym of the other.

Note 2 to entry: See Note 1 to entry to 3.1.2.

3.3.2.10
blazed diffractive optical element
surface relief diffractive optical element able to concentrate the diffracted optical radiation energy in a specified diffraction order or orders using a prismatic structure in one period

3.3.2.11
deep grating
surface relief grating whose phase depth is nearly equal to or greater than the incident wavelength

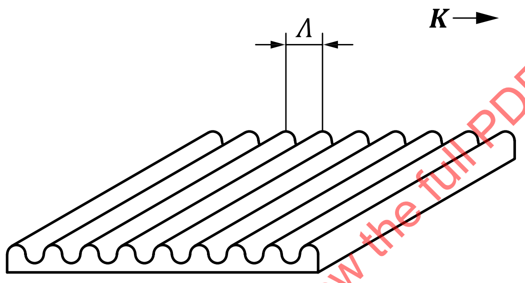
3.3.2.12
multi-diffraction-order structure
diffractive optical element containing parts that generate different orders of diffraction

Note 1 to entry: When parts form concentric zones, this structure is often referred to either as a harmonic Fresnel structure or a super zone structure.

3.3.3 Periodic structure

3.3.3.1
period
Λ
shortest length of the repetition in the spatial periodic structure of diffractive optical element

Note 1 to entry: For the surface relief grating, period *Λ* is shown in Figure 1.



Key

Λ grating period

K K-vector

Figure 1 — Schematic representation of a surface relief grating

3.3.3.2
local period
$\Lambda(\boldsymbol{x})$
local value of period $\Lambda(\boldsymbol{x})$, defined in terms of a function of the position vector $\boldsymbol{x}$ on the diffractive surface

3.3.3.3
spatial frequency
ν
number of modulations per unit of length (i.e. proportional to the reciprocal of the period)

3.3.3.4
local spatial frequency
$\nu(\boldsymbol{x})$
reciprocal of the local period: $\nu(\boldsymbol{x}) = 1/\Lambda(\boldsymbol{x})$

Note 1 to entry: Using the units in Table 1, a factor of 10^3 needs to be taken into account due to the units used, with the local period $\Lambda(\boldsymbol{x})$ expressed in µm and the local spatial frequency $\nu(\boldsymbol{x})$ expressed in mm^{-1}.

3.3.3.5
subwavelength structure
periodic structure whose period is smaller than λ/n, where n is the refractive index of the structure

Note 1 to entry: Depending on the incident angle, a subwavelength structure may not generate any diffracted optical radiation except for zero-order optical radiation. In this case the element is not a diffractive optical element. It is sometimes referred to as zero-order grating, anti-reflection structured surface or SWS.

3.3.3.6
chirped structure
periodic structure whose period varies gradually

Note 1 to entry: A grating having a gradually varying period is referred to as chirped grating.

3.3.3.7
K-vector
grating vector
$\boldsymbol{K}$
vector, whose absolute value is $2\pi\nu$ and whose direction is parallel to the direction of periodicity of a grating

Note 1 to entry: The K-vector is also referred to as grating vector. For the surface relief grating, the K-vector is shown in Figure 1.

3.3.3.8
amplitude of refractive index modulation
Δn when the index distribution of the diffractive surface is defined as

$$n(\boldsymbol{x}) = n_{\text{av}} + \Delta n \cos(\boldsymbol{K} \cdot \boldsymbol{x})$$

3.3.3.9
zone plate
diffractive optical element that functions as a lens and is composed of concentric zones

3.3.3.10
Fresnel zone plate
diffractive optical element made up of concentric zones that are alternately opaque-transparent, in which the radius of each zone is proportional to the square root of that zone's number, with the number one being assigned to the centermost zone, and the number of each succeeding zone increasing by one

Note 1 to entry: There are two types of these plates: those whose odd-numbered zones are transparent and those whose odd-numbered zones are opaque. The former type Fresnel zone plate is shown in Figure 2.

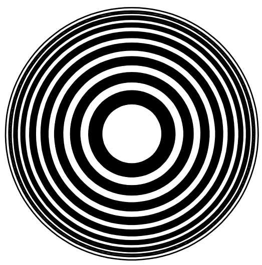


Figure 2 — Schematic representation of a Fresnel zone plate

3.3.3.11
phase Fresnel zone plate
Wood zone plate
diffractive optical element made up of concentric zones similar to a Fresnel zone plate, but where the zones, rather than alternating between opaque / transparent, alternate in terms of their effect on the phase of incident optical radiation:

zero radians / π radians / zero radians / etc.

or

π radians / zero radians / π radians / etc.

Note 1 to entry: Figure 3 shows the cross-section of phase Fresnel zone plate.

Figure 3 — Schematic cross section of a phase Fresnel zone plate

3.3.3.12
interferometric zone plate
diffractive optical element whose fabrication is based on the recording of the concentric circular fringe pattern formed by two interfering beams

3.3.4 Design of diffractive optical elements

3.3.4.1
grating equation
equation in which any change in the wave number is expressed by the grating K-vector and the diffraction order *m*

Note 1 to entry: See 3.4.2.1 and 3.4.2.2.

3.3.4.2
phase function
function that expresses, in terms of location on a diffractive surface, the degree of phase shift created when a ray passes through a given surface location, usually defined for the diffraction order $m = 1$

Note 1 to entry: Phase function $\phi(\boldsymbol{x})$ is generally given as "scalar potential" of K-vector $\boldsymbol{K}(\boldsymbol{x})$ such that $\boldsymbol{K}(\boldsymbol{x}) = -\nabla\phi(\boldsymbol{x})$.

3.3.4.3
optical path difference function
function that expresses, in terms of location on a diffractive surface, the degree of added effective optical path length created when a ray passes through a given surface location, usually defined for the diffraction order $m = 1$

Note 1 to entry: The phase function multiplied by $\lambda/2\pi$ is the optical path difference function.

3.3.4.4
complex transmission function
function that expresses, in terms of location on a diffractive surface, the complex amplitude transmittance of a diffractive optical element

3.4 Properties of diffractive optical elements

3.4.1 General properties

3.4.1.1
diffraction angle
angle between the normal to a diffractive optical element and the direction of any resulting diffracted optical radiation beam

Note 1 to entry: Also misused as the angle between the direction of an incident optical radiation beam to a diffractive optical element and the direction of any resulting diffracted optical radiation beam.

3.4.1.2
diffraction order
integer m on the right-hand side of the grating equation

Note 1 to entry: See 3.4.2.1 or 3.4.2.2.

3.4.1.3
diffraction efficiency
ratio of usable energy relative to total incident energy for individual diffraction orders of a diffractive optical element

3.4.2 Classification of diffraction

3.4.2.1
Bragg diffraction
diffraction that occurs in thick gratings

Note 1 to entry: The condition under which Bragg diffraction occurs, the Bragg condition, may be expressed in terms of its grating equation, as:

$$\boldsymbol{k}_2 - \boldsymbol{k}_1 = \pm m\boldsymbol{K}$$

i.e. $2n_{av}\Lambda \sin\theta_B = \pm m\lambda$

where $\boldsymbol{k}_i = \left(2\pi \frac{n_{av}}{\lambda}\right)\boldsymbol{N}_i$

Note 2 to entry: See Figure 4.

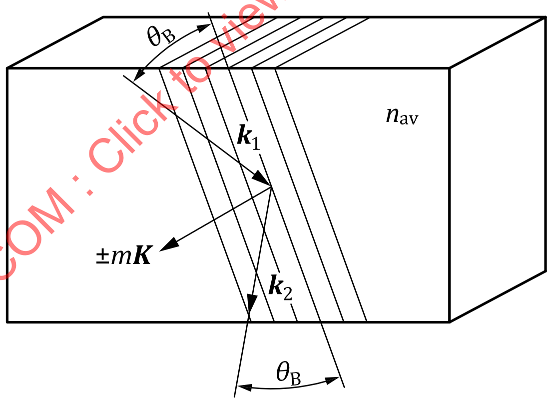


Figure 4 — Schematic drawing illustrating Bragg diffraction

3.4.2.2
Raman-Nath diffraction
diffraction that occurs in thin gratings

Note 1 to entry: The condition under which Raman-Nath diffraction occurs may be expressed in terms of its grating equation, as $(\boldsymbol{k}_2 \times \boldsymbol{N}) - (\boldsymbol{k}_1 \times \boldsymbol{N}) = \pm m\boldsymbol{K} \times \boldsymbol{N}$

i.e. $(n_2\boldsymbol{N}_2 \times \boldsymbol{N}) - (n_1\boldsymbol{N}_1 \times \boldsymbol{N}) = \pm m\lambda\boldsymbol{K} / (2\pi) \times \boldsymbol{N}$

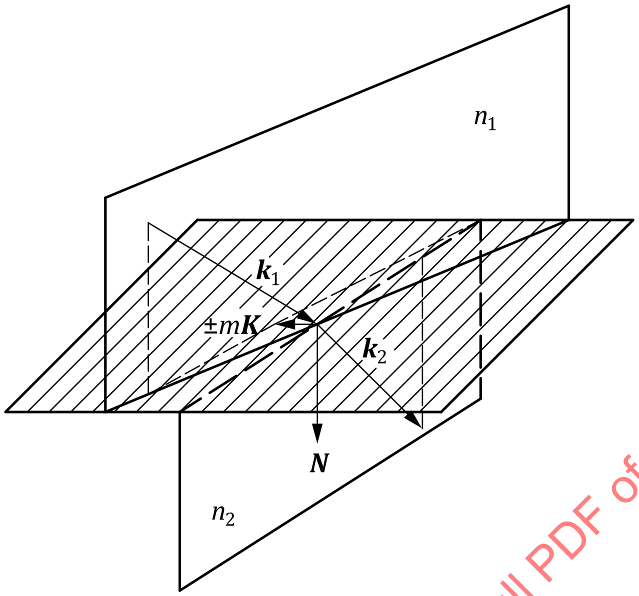
where $\boldsymbol{k}_i = \left(2\pi \frac{n_i}{\lambda}\right)\boldsymbol{N}_i$

See Figure 5.

When $\boldsymbol{k}_1$, $\boldsymbol{N}$ and $\boldsymbol{K}$ are on the common plane, then the grating equation becomes:

$$\Lambda(n_2 \sin\theta_2 - n_1 \sin\theta_1) = m\lambda$$

These equations are often referred to as “ray-tracing equations for diffractive optical elements”. When $\boldsymbol{K}$ = 0 or $1/\Lambda$ = 0, these equations become “Snell’s law” equations.



Key

$\boldsymbol{k}_1$ incident wave vector

$\boldsymbol{k}_2$ diffracted wave vector

n_1 refractive index of the space of incident radiation

n_2 refractive index of the space of diffracted radiation

Figure 5 — Schematic representation of Raman-Nath diffraction

3.4.2.3
scalar diffraction theory
diffraction theory used to predict the approximate diffraction efficiency based on the Helmholtz equation in which the period is much greater than the wavelength of the incident optical radiation

3.4.2.4
vector diffraction theory
rigorous electromagnetic theory used to predict diffraction efficiency by solving Maxwell's equations numerically for periodic structure

3.4.3 Dispersion properties

3.4.3.1
dispersion of diffractive optical elements
variation in diffraction angle due to variations in wavelength

3.4.3.2
effective Abbe number of diffractive optical elements
ratio of original wavelength to the change in wavelength in air, defined as $V_{\text{diff}} = \lambda/(\lambda_1 - \lambda_2)$ where $(\lambda_1 - \lambda_2)$ is the change in applicable wavelengths.

Note 1 to entry: Effective Abbe number of diffractive optical element at the d-line is defined by the following equation:

$$V_{diff,d} = \lambda_d / (\lambda_F - \lambda_C) = -3{,}453$$

The value of $V_{diff,d}$ is a minus-value constant.

On the other hand, Effective Abbe number of diffractive optical element at the e-line is defined by the following equation:

$$V_{diff,e} = \lambda_e / (\lambda_{F'} - \lambda_{C'}) = -3{,}333$$

The value of $V_{diff,e}$ is a minus-value constant.

3.4.3.3
effective partial dispersion of diffractive optical elements
ratio of two wavelength differences defined as

$$P_{diff} = (\lambda_1 - \lambda_2)/(\lambda_3 - \lambda_4)$$

3.4.3.4
standard partial dispersion of diffractive optical elements
effective partial dispersion of diffractive optical elements relative to F and C lines, defined as:

$$P_{diff,g,F} = (\lambda_g - \lambda_F)/(\lambda_F - \lambda_C) = 0{,}295\ 6$$

3.4.4 Polarization

3.4.4.1
TE-polarization
polarization of an incident wave, whose electric field vector is perpendicular to the K-vector

Note 1 to entry: See Figure 6.

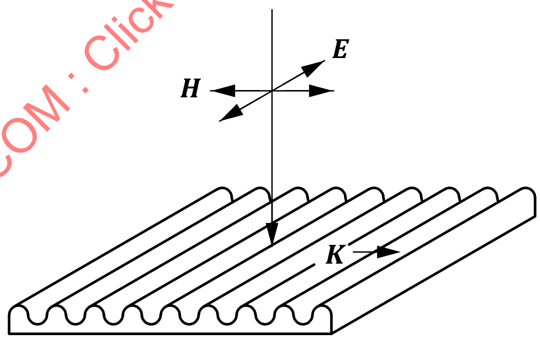


Figure 6 — TE-polarization

3.4.4.2
TM-polarization
polarization of an incident wave, whose magnetic field vector is perpendicular to the K-vector

Note 1 to entry: See Figure 7.

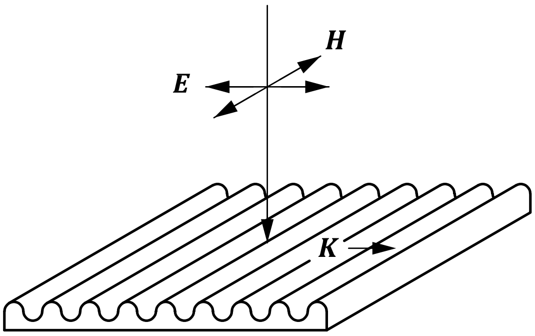


Figure 7 — TM-polarization

3.4.4.3
p-polarization
polarization of the incident wave, whose electric field vector is parallel to the plane including both the K-vector and the incident wave vector

Note 1 to entry: See Figure 8.

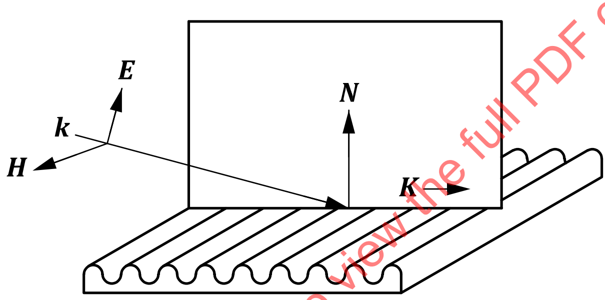


Figure 8 — p-polarization

3.4.4.4
s-polarization
polarization of the incident wave, whose electric field vector is perpendicular to the plane including both the K-vector and the incident wave vector

Note 1 to entry: See Figure 9.

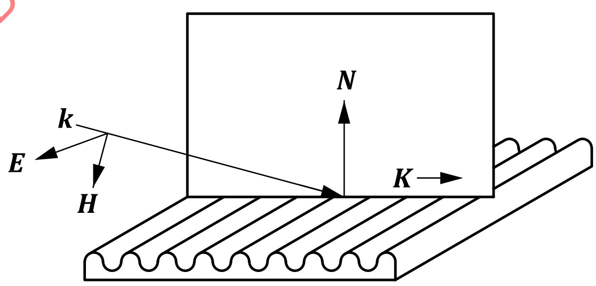


Figure 9 — s-polarization

3.5 Applications

3.5.1
diffractive lens
optical element to converge or diverge a bundle of rays from an object by utilizing the diffraction effect

3.5.2
diffractive power
power that, for a rotationally symmetric surface containing a quadratic phase function, is given by

$$D_{diff} = \left(m\frac{\lambda}{\pi} \right) \lim_{h \to 0} \left[\phi(h) / h^2 \right]$$

where

m is an integer;

$\phi(h)$ is the phase function of the diffractive surface

3.5.3
total optical power
sum of the refractive power and the diffractive power of the surface, i.e.,

$$D_{tot} = D_{ref} + D_{diff}$$

3.5.4
multifocal lens
diffractive lens for which rays of different diffraction orders merge in different foci

3.5.5
refractive diffractive hybrid lens
lens made by combining a refractive lens and a diffractive lens, or one in which a diffractive structure has been produced on the surface of a conventional refractive lens

4 Symbols and abbreviated terms

Table 1 lists symbols and units that are defined in detail in Clause 3.

Table 1 — Symbols and units of measurements

Symbol	Term	Unit
D	optical power	m^{-1}
D_{diff}	diffractive power of the diffractive surface	m^{-1}
D_{ref}	refractive power of the original refractive surface	m^{-1}
D_{tot}	total optical power of the surface	m^{-1}
$\boldsymbol{E}$	electric field vector	Vm^{-1}
h	height from the optical axis	mm
$\boldsymbol{H}$	magnetic field vector	Am^{-1}
$\boldsymbol{K}_i$	wave number vector of incident (i = 1) or diffracted (i = 2) ray	mm^{-1}
$\boldsymbol{K}$	K-vector	mm^{-1}
$\boldsymbol{K}(\boldsymbol{x})$	K-vector defined as the function of the position vector $\boldsymbol{x}$ on the diffractive surface	mm^{-1}
$\pm m$	diffraction order	1
n_{av}	average refractive index of the grating	1
n_i	refractive index of incident (i = 1) or exit (i = 2) space	1
$n(\boldsymbol{x})$	refractive index of the grating, defined in terms of a function of the position vector $\boldsymbol{x}$ on the diffractive surface	1
Δn	amplitude of refractive index modulation	1
$\boldsymbol{N}$	unit normal vector of the diffractive surface	1
$\boldsymbol{N}_i$	unit vector along incident (i = 1) or diffracted (i = 2) ray	1