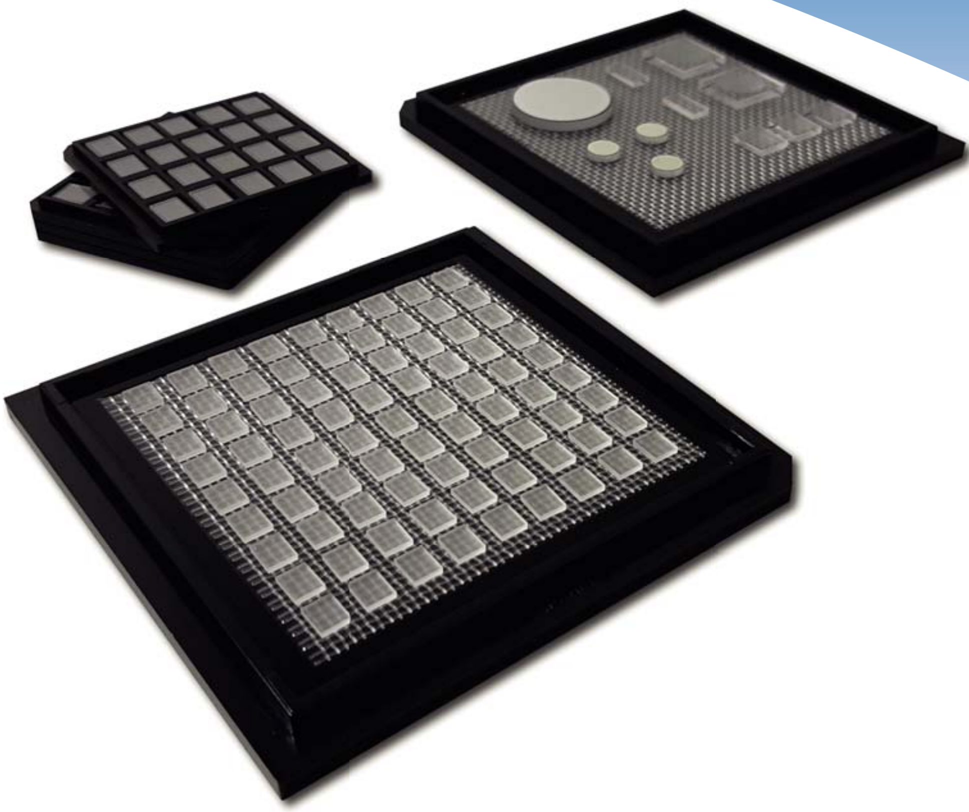
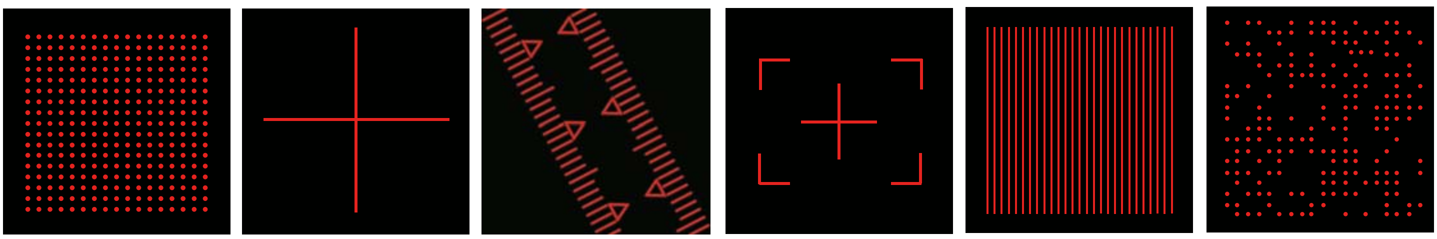
DOE

Diffractive Optical Elements





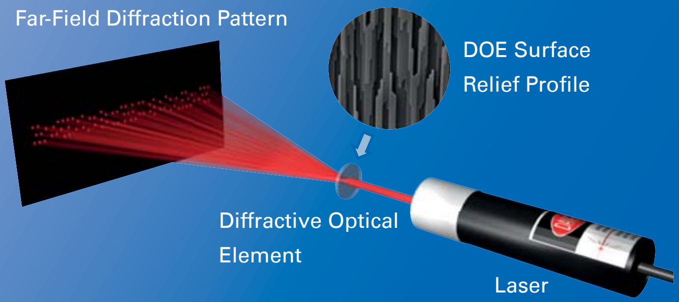
HOLOEYE

Pioneers in Photonic Technology

HOLOEYE's Diffractive Optical Elements (DOEs)

Off-the-shelf DOEs:
►Mounted versions are well suitable for lab-bench proof-of-concept experiments.
►Unmounted versions are easy to integrate into laser modules. Various reputable laser module makers offer integration of our off-the-shelf DOEs into their products.

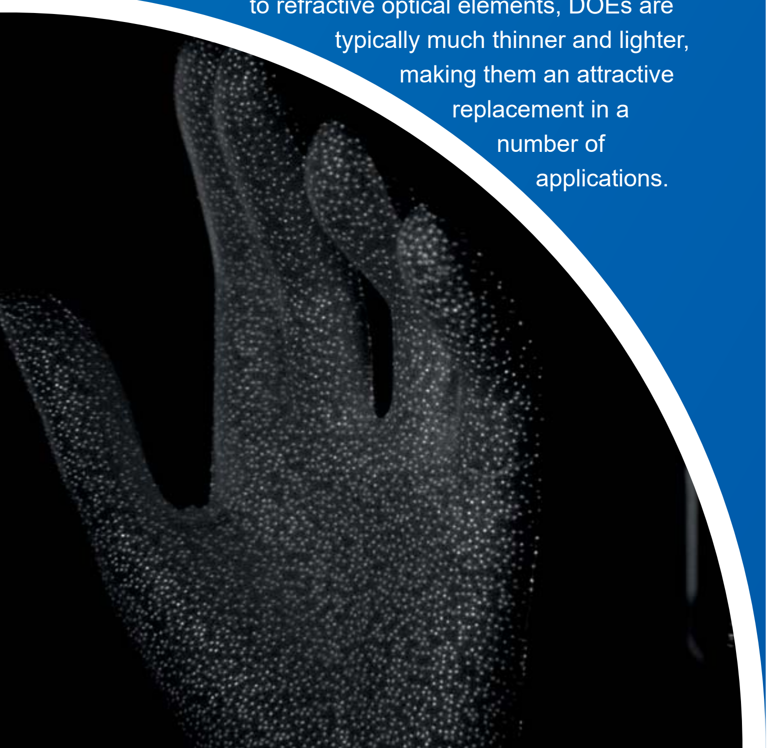
Costumized DOEs:
For requirements beyond the off-the-shelf product range, we offer **development of customized DOEs** tailored to your application.



Operation Principle of DOEs

The different types of DOEs (beam-splitters, pattern generators, kinoforms, beam shapers and gratings) utilize a microstructure surface relief profile for their optical function. Light transmitted by a DOE can be reshaped to almost any desired distribution, just by diffraction and the subsequent propagation. The DOE only encodes the shape of the desired intensity pattern, but maintains other parameters of the incident light source (e.g. beam size, divergence, polarization).

Due to their design flexibility, DOEs can have optical functions that can otherwise not be achieved at all, or only with complicated optical systems. Moreover, compared to refractive optical elements, DOEs are typically much thinner and lighter, making them an attractive replacement in a number of applications.



Essential Specification Parameters

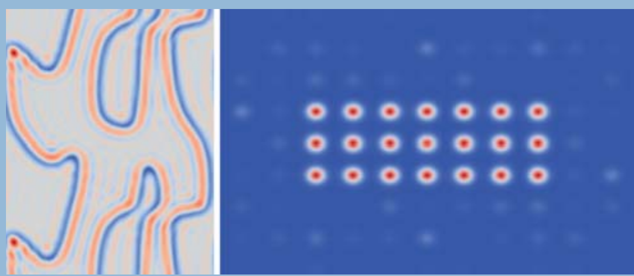
Light Source:
►Type (cw laser, pulsed laser, edge emitter/ VCSEL laser diodes, LED, other)
►Wavelength (center, bandwidth, tolerance, shift)
►Polarization
►Power/Energy (average and/or peak)
►Beam profile (diameter, divergence, M² beam quality parameter)

Optical Function:
►Desired light field distribution (shape, uniformity, contrast,...)
►Target surface/object (inclination, shape, ...) and sensor (CCD/CMOS/human eye/...)
►Field of view and working distance, or diffraction angles

Application:
►Element form factor (size, shape)
►Element material (glass/polymer/...)
►Environmental conditions (temperature, humidity, exposure to UV radiation, ...)
►Eye Safety requirements
►AR coating requirements
►Laser induced damage threshold (LIDT) requirements
►Packaging requirements
►Storage conditions

The required annual production volume and a price target are helpful in order to balance technical and economical requirements.

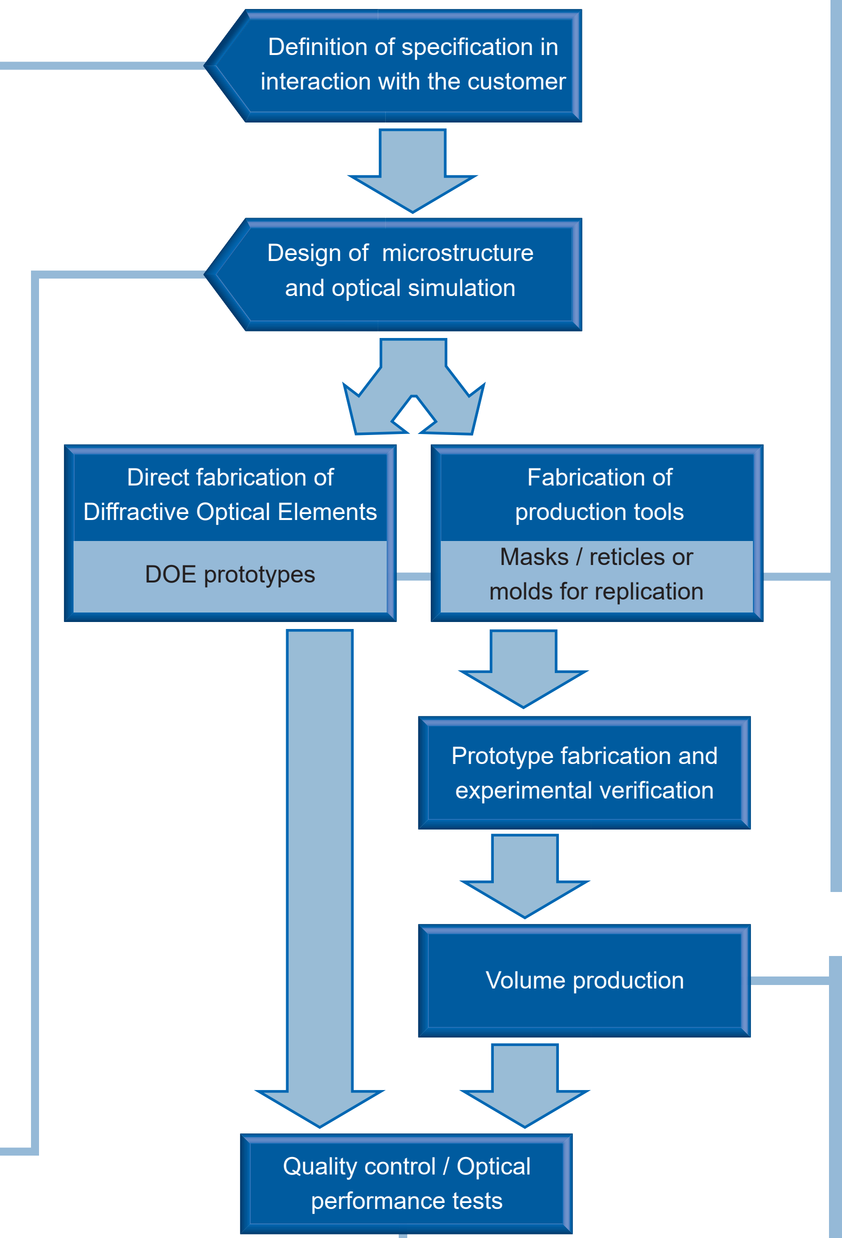
Design and Simulation



HOLOEYE utilizes its steadily growing experience in the design and simulation of diffractive optical elements to offer its customers a competitive solution. Using in-house developed as well as commercially available state-of-the-art software tools and algorithms, appropriate simulation methods (paraxial or rigorous electromagnetic) are used for optimization of the DOE design.

Fabrication constraints are taken into account right from the start, and a tolerance analysis is performed whenever necessary. Also the alignment requirements of the DOE within the optical system are determined, so that the assembly procedure can be designed accordingly.

Development of customized DOEs

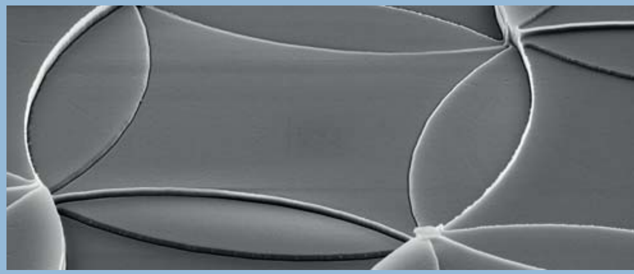


Quality Assurance and Implementation Support

After fabrication, HOLOEYE will validate the compliance of the DOEs with the specification experimentally. For volume production of elements, optical key properties can be monitored using automated equipment.

When an integrated solution like a DOE-based laser projection module is required in your application, HOLOEYE can be part of a joint development effort involving vendors for those products.

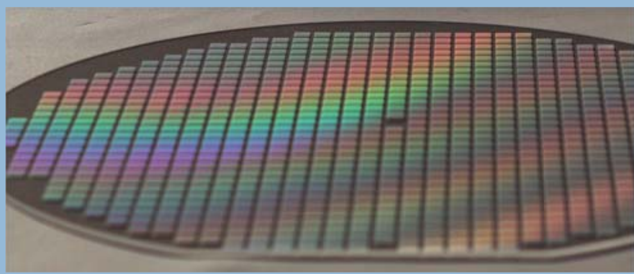
Mastering and Tooling



Direct write lithography processes are used to create either lithography masks or resist micro-relief profiles. Based on masks, micro-relief profiles are created by contact or projection lithography and subsequent etching processes like reactive ion etching to transfer the etch mask into the substrate.

The obtained micro-relief profiles serve as fused silica DOEs or templates for UV-curing based replication processes. Alternatively, electroplating can be used to create inverted resist profiles which are usable for embossing and molding processes of polymer materials.

Volume Fabrication



HOLOEYE offers diffractive elements fabricated by one of the following options:

(1) Bulk polymer elements, the substrate and a diffractive micro-relief surface are created by compression molding using materials like polycarbonate, PMMA, or Topas ®

(2) Acrylate-on-polymer elements, the diffractive layer is created by UV curing on a polymer substrate

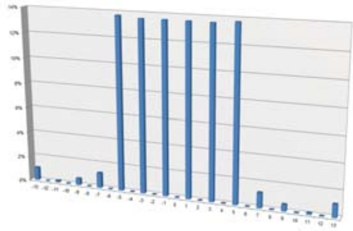
(3) Acrylate-on-glass elements, the diffractive layer is created by UV curing on a glass substrate

(4) Bulk fused silica elements, the diffractive micro-relief surface is created by reactive ion etching.

The sizes and shapes the DOEs can be specified by the costumer. Fresnel-type surface reflections can be reduced by dielectric anti-reflective coatings, or by moth-eye micro-relief surface structures on the otherwise plain substrate surface.

Diffractive Beam Splitter

A single incident laser beam is split into a 1-dimensional or 2-dimensional array of beams.



Typically diffractive beam splitters are used in combination with a focusing lens. If so, the output beam array becomes an array of focused spots at a certain distance behind the lens.

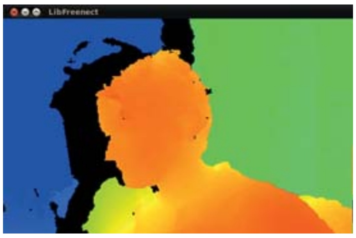
The arrangement of the spots is not limited to arrays in perpendicular x-y lattices. Also hexagonal or irregular lattices are possible. For more complex arrangement of spots, like for structured light pseudo-random spot patterns, the diffractive beam-splitters can also be referred to as ► *Diffractive Pattern generators*.

Applications:

►Multi-channel splitting for 1D or 2D sensors
►Process parallelization in material processing (laser dicing, laser scribing, …)
►Multi-Focal Microscopy
►Coherent beam combination
►Camera calibration

Diffractive Pattern Generators

Complex patterns with a very high depth of field can be created.



The pattern comprises of many spots, which may overlap so that the element could be referred to as a ►*Diffractive Diffusor*, or still be visibly as individual spots, so that the element could be referred to as a ► *Diffractive Beam-splitter*.

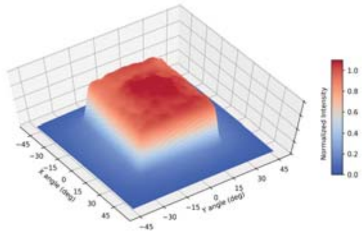
Due to the high accuracy of the microstructures, the diffraction angles can be extremely precise, in particular when using a frequency stabilized laser source.

Applications:

►Structured light and pattern projection for 3D sensing applications: pseudo-random spot patterns, fringe patterns, De Brujn patterns
►Graphics, range and chart projection for alignment and measurements
►Laser aiming, barcode scanners, POI patterns

Diffractive Diffusers

Flexible shaping of the emitted angular power distribution of various light sources can be achieved.



Diffractive Diffusers can be best used with VCSEL arrays, because they consist of many individual incoherent laser emitters. As a result, the angular far field diffracted light distribution is much less affected from interference-caused intensity modulations, and more uniform light distributions are obtained.

With tailored diffractive diffusers, HOLOEYE is able to create various light distributions for the application wavelength. By suppressing the zero order diffraction to well below 1% compared to the incident light even for large diffraction angles, the desired profiles can be obtained in very good approximation.

Applications:

►Time-of-Flight 3D sensing
►Laser autofocus
►2D sensing with flood illumination
►Illumination applications
►LIDAR

Diffractive Beam Shapers

An incident laser beam of ideally Gaussian intensity profile is transformed into a desired intensity profile at the target plane or workpiece.

In most cases, the target is a uniform ('flat-top') circular or rectangular beam profile. Other shapes and non-uniform profiles can be obtained as well.

For a custom development, precise information about the input beam intensity and phase profile is required. For beams with high beam quality of $M^2<1.3$, the phase profile is sufficiently described by the radius of curvature of its wavefront.

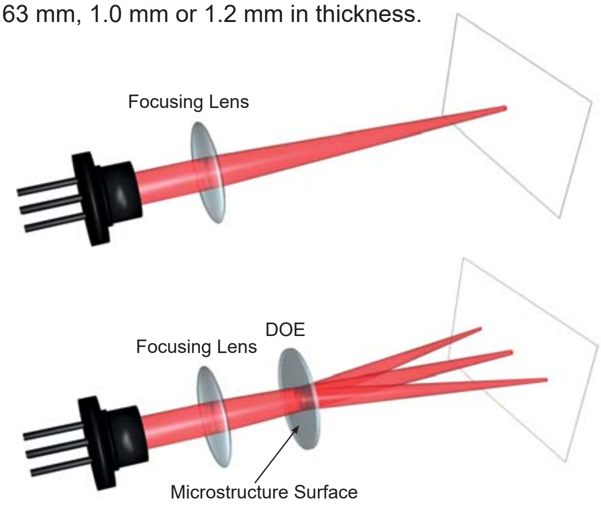
Applications:

►Laser material processing
►Lithography
►Biomedical devices

In most scenarios the incident laser beam is collimated, or focused to a fixed distance behind the DOE. HOLOEYE can offer solutions also for non-collimated or partially collimated light sources. To do so, the DOE microstructure combine pattern generation with focal power. In addition, the focusing properties of HOLOEYE's DOEs are not limited to fixed working distances. Instead, our pattern generators can provide required focal power to achieve focusing of the laser to strongly inclined target planes. In fact, the best focus location per diffraction direction can be matched to almost arbitrary surfaces.

Off-the-shelf Polymer DOEs

The elements are replicated using polymer materials like Polycarbonate (PC) or Polymethyl Methacrylate (PMMA). They have a standard size of 8.0 mm in diameter and 0.63 mm, 1.0 mm or 1.2 mm in thickness.



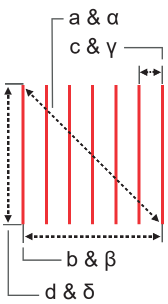
The DOEs are best used with collimated or slightly convergent laser sources (see figure to the left). The microstructure surface should be oriented towards the laser.

Pattern size and angles, as well as the intensity in the undiffracted central spot, will vary most with the laser wavelength. This zero-order spot is equivalent in size and shape to the incident laser beam observable if the DOE were removed from the optical system, but its power is strongly attenuated.

Most larger-angle patterns are subject to geometrical distortion due to their symmetry properties, if the respective DOE is used at laser wavelengths significantly different (Δλ > 50nm) from the design wavelength.

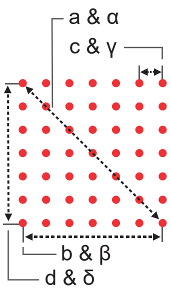
The recommended wavelength range is determined by the integration of the zero-order spot with the off-axis pattern. This is achieved by matching its intensity with that of the off-axis spots (e.g. for array beam-splitters), or by suppression of the zero order to an appropriate level for other pattern generating DOEs.

Multi Lines



DOE Item #	Description	Design Wavelength	Pattern Size @ 100 mm Distance, Values: mm a	b	c	d	Pattern Angles (@ Design Wavelength) α	β	γ	δ	Optimum Wavelength Range(s)
DE-R 213	11 Lines (Square)	635nm*	76.7	54.4	5.4	54.4	42.0	30.4	3.0	30.4	530-670 nm
DE-R 233	7 Lines (Square)	635nm*	54.0	38.2	6.4	38.2	30.2	21.6	3.6	21.6	530-670 nm
DE-R 250	5 Lines (Rectangular)	660nm*	55.0	10.9	2.7	53.9	30.8	6.2	1.6	30.2	590-670 nm
DE-R 251	7 Lines (Rectangular)	650nm	15.5	9.0	1.5	12.6	8.9	5.2	0.8	7.2	590-730 nm
DE-R 252	5 Lines (Square)	635nm*	42.7	30.2	7.5	30.2	24.1	17.2	4.3	17.2	530-670 nm
DE-R 253	11 Lines (Sq., Thin Lines)	635nm*	76.4	54.0	5.4	54.0	41.8	30.2	3.0	30.2	530-670 nm
DE-R 254	25 Lines (Square)	660nm*	68.4	48.3	2.0	48.3	37.7	27.2	1.1	27.2	530-670 nm
DE-R 255	65 Lines (Square, Central Line Thicker)	660nm*	45.6	32.2	0.5	32.2	25.7	18.3	0.3	18.3	530-670 nm
DE-R 284	41 Lines (Rectangular)	660nm*	133.4	104.0	2.6	78.0	67.4	54.9	1.4	42.6	600-700 nm
DE-R 348	10 Lines (Rectangular)	650nm*	125.5	90.0	10.0	87.5	64.2	48.5	5.4	47.3	600-700 nm
DE-R 350	15 Lines (Rectangular)	520nm*	65.5	42.1	3.0	50.2	36.3	23.8	1.7	28.2	480-550 nm
DE-R 381	11 Lines (Rectangular)	850nm*	155.6	41.5	4.15	150	75.8	23.5	2.3	74	830-880 nm
DE-R 386	3 Lines (Rectangular)	520nm*	50.7	8.0	4.0	50.0	28.4	4.6	2.3	28.1	490-550 nm
DE-R 387	5 Lines (Rectangular)	520nm*	50.7	8.0	2.0	50.0	28.4	4.6	1.15	28.1	480-560 nm
DE-R 391	81 Lines (Rectangular)	650nm*	156.0	124.8	1.6	93.6	75.9	63.9	0.8	50.2	600-700 nm
DE-R 392	3 Lines (Rectangular)	660nm*	54.7	10.8	5.4	53.6	30.6	6.2	3.1	30.0	600-700 nm

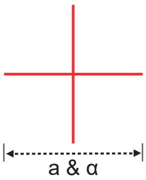
Dot Matrix



DOE Item #	Description	Design Wavelength	a	b	c	d	α	β	γ	δ	Optimum Wavelength Range(s)
DE-R 206	17 x 17 Dots	660nm	38.0	26.6	1.7	26.6	21.5	15.2	0.9	15.2	590-730 nm
DE-R 223	2 x 2 + 1 Dots	635nm	28.3	19.9	19.9	19.9	16.1	11.4	11.4	11.4	635&405 nm
DE-R 231	101 x 101 Dots	660nm	12.8	9.1	0.1	9.1	7.4	5.2	0.05	5.2	635-680 nm
DE-R 241	21 x 21 Dots	635nm	11.9	8.4	0.4	8.4	6.8	4.8	0.2	4.8	560-730 nm
DE-R 242	16 x 16 Dots	635nm	12.4	8.8	0.6	8.8	7.1	5.0	0.3	5.0	530-730 nm
DE-R 243	17 x 17 Dots	635nm	12.4	8.8	0.5	8.8	7.1	5.0	0.3	5.0	550-720 nm
DE-R 244	13 x 13 Dots	635nm	7.4	5.3	0.4	5.3	4.3	3.0	0.3	3.0	590-670 nm
DE-R 257	51 x 51 Dots	660nm*	56.9	40.3	0.8	40.3	31.8	22.8	0.5	22.8	560-720 nm
DE-R 258	11 x 11 Dots	635nm*	71.2	50.3	5.0	50.3	39.2	28.2	2.8	28.2	590-690 nm
DE-R 339	6 x 6 Dots	635nm	11.7	8.3	1.7	8.3	6.7	4.7	0.9	4.7	590-690 nm
DE-R 351	10 x 10 Dots	532nm	21.1	14.9	3.3	14.9	23.8	17.0	1.9	17.0	510-600 nm
DE-R 352	4 x 6 Dots	532nm	26.6	13.7	4.6	22.8	15.1	7.8	2.6	13.6	500-580 nm
DE-R 353	5 x 5 Dots	690nm	1.1	0.75	0.19	0.75	0.61	0.43	0.11	0.43	630-750 nm
DE-R 388	51 x 51 Dots	532nm*	46.8	33.1	0.66	33.1	26.4	18.8	0.38	18.8	480-600 nm
DE-R 389	21 x 21 Dots	520nm*	46.8	33.1	1.66	33.1	26.4	18.8	0.95	18.8	480-600 nm

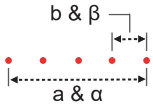
* Large-angle pattern that due to its symmetry properties is subject to geometrical distortion, if the DOE is used at laser wavelengths significantly different (Δλ > 50nm) from the design wavelength.

Crosshair



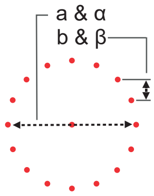
DOE Item #	Description	Design Wavelength	Pattern Size @ 100 mm Distance, Values: mm a	b	d	Pattern Angles (@ Design Wavelength) α	β	δ	Optimum Wavelength Range(s)
DE-R 205	Cross – 5@650	650nm	8.7			5.0			580-660 nm
DE-R 212	Cross – 25@532	532nm	45.1			25.4			500-640 nm
DE-R 214	Cross – 2@645	645nm	3.4			2.0			600-645 nm
DE-R 218	Cross – 15@640	640nm	26.3			15.0			500-640 nm
DE-R 239	Cross – 5@520	520nm	8.7			5.0			488-600 nm
DE-R 245	Cross – 10@633	633nm	17.5			10.0			570-690 nm
DE-R 246	Cross with high contrast area	633nm	17.5			10.0			530-670 nm
DE-R 247	Cross – 25@645	645nm	44.3			25.0			600-800 nm
DE-R 248	Cross – 37@645	645nm	66.8			37.0			630-700 nm
DE-R 249	Cross – 45@633	633nm	83.0			45.0			620-700 nm
DE-R 270	Cross – 30@640	640nm	53.6			30.0			590-660 nm
DE-R 280	Cross – 60@635	635nm	115.5			60.0			580-690 nm
DE-R 289	Cross – 15@520	520nm	26.4			15.0			480-550 nm
DE-R 299	Cross – 75@650	650nm	153.5			75.0			600-700 nm
DE-R 340	Cross – 60@450	450nm	116.1			60.3			420-520 nm
DE-R 342	Cross – 52@515	515nm	97.6			52.0			440-540 nm
DE-R 382	Cross - 30@450	450nm	53.6			30.0			440-480 nm

Dot Lines & Quasi-Continous Lines



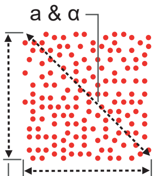
DOE Item #	Description	Design Wavelength	a	b	d	α	β	δ	Optimum Wavelength Range(s)
DE-R 263	1 : 5 Dot Line	635nm	10.5	2.6		6.0	1.5		450-700 nm
DE-R 264	1 : 9 Dot Line	670nm	1.6	0.2		0.9	0.1		630-780 nm
DE-R 265	1 : 19 Dot Line	650nm	24.0	1.3		13.7	0.8		500-540 & 630-690 nm
DE-R 266	QC- Line – 5@633	633nm	8.7	--		5.0	--		630-690 nm
DE-R 267	QC -Line – 30@532	532nm	53.8	--		30.1	--		470-560 nm
DE-R 281	1 : 11 Dot Line	650nm	28.9	2.9		16.5	1.6		600-730 nm
DE-R 282	1 : 99 Dot Line	660nm	33.7	0.3		19.1	0.2		600-700 nm
DE-R 283	QC - Line – 20@633	633nm	35.2	--		20.0	--		630-670 nm
DE-R 286	QC - Line – 30@660	660nm	54.6	--		30.5	--		600-700 nm
DE-R 287	QC - Line – 45@660	660nm	83.9	--		45.5	--		600-700 nm
DE-R 337	1 : 99 Dot Line	635nm	49.3	0.5		27.7	0.3		600-700 nm
DE-R 364	QC - Line – 45@940	940nm	83.0	--		45.0	--		890-980 nm
DE-R 369	QC - Line – 36@640	639nm	65.0	--		36.0	--		600-700 nm
DE-R 383	QC - Line – 51@840	840nm	95.0	--		50.6	--		790-880 nm

Circles & Dot Circles



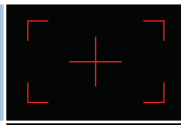
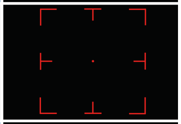
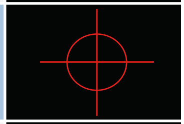
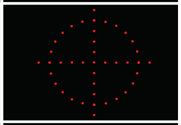
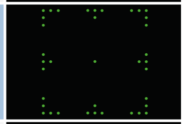
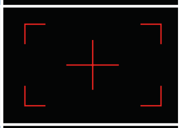
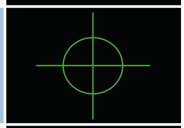
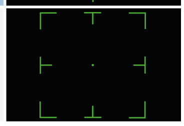
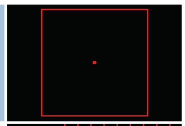
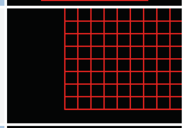
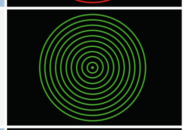
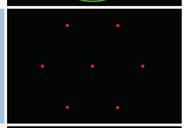
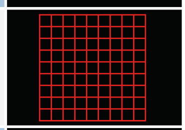
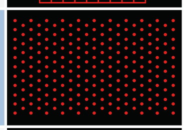
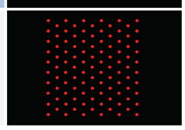
DOE Item #	Description	Design Wavelength	a	b	d	α	β	δ	Optimum Wavelength Range(s)
DE-R 219	Solid Line Circle	592nm	55.8	--		31.2	--		480-600 nm
DE-R 220	1 : 16 Dot Circle	515nm	81.9	16.1		44.5	9.2		480-532 nm
DE-R 221	1 : 72 Dot Circle	532nm	36.9	1.6		20.9	0.9		400-570 nm
DE-R 229	1 : 36 Dot Circle	532nm	6.1	0.5		3.5	0.3		480-560 nm
DE-R 238	Solid Line Circle	520nm	6.0	--		3.4	--		520-532 nm
DE-R 240	1 : 16 Dot Circle	635nm	18.9	3.7		10.8	2.1		530-700 nm
DE-R 268	Solid Line Circle	488nm	77.0	--		42.1	--		488-532 nm

Random Dot Patterns



DOE Item #	Description	Design Wavelength	a	b	d	α	β	δ	Optimum Wavelength Range(s)
DE-R 332	33000-Dot Pseudo-Random	830nm*	136.9	114.6	76.3	68.8	59.6	41.7	820-850 nm
DE-R 335	33000-Dot Pseudo-Random	645nm*	101.3	84.8	56.4	53.7	45.9	31.5	630-660 nm
DE-R 372	40100-Dot Pseudo-Random	850nm*	135.6	114.9	72.0	68.3	59.7	39.6	825-870 nm
DE-R 373	31806-Dot Truely-Random	830nm*	146.9	118.5	86.9	72.6	61.3	47.0	800-890 nm
DE-R 374	47708-Dot Truely-Random	830nm*	146.9	118.5	86.9	72.6	61.3	47.0	800-890 nm
DE-R 375	29594-Dot Pseudo-Random	830nm*	146.7	118.5	86.5	72.5	61.3	46.8	810-850 nm
DE-R 384	51978-Dot Truely-Random	640nm*	162.8	97.5	130.4	78.3	52.0	66.2	610-660 nm
DE-R 385	101050-Dot Truely-Random	640nm*	167.4	100.4	133.9	79.9	53.3	67.6	610-660 nm

* Large-angle pattern that due to its symmetry properties is subject to geometrical distortion, if the DOE is used at laser wavelengths significantly different (Δλ > 50nm) from the design wavelength.

DOE Item #	Description	Design Wavelength	Pattern Size @ 100 mm Distance, Values: mm	Pattern Angles (@ Design Wavelength)	Optimum Wavelength Range(s)	Image
Viewfinder						
DE-R 215	Viewfinder	645nm	Width: 26.9 mm Height: 18.0 mm Diagonal: 32.6 mm	Width: 15.3° Height: 10.3° Diagonal: 18.5°	570-750 nm	
DE-R 234	Viewfinder (Lines Square)	633nm*	Width: 60.6 mm Height: 60.6 mm Diagonal: 85.6 mm	Width: 33.7° Height: 33.7° Diagonal: 46.4°	590-730 nm	
DE-R 260	Viewfinder (Circle + Cross)	645nm	Width Cross: 37.0 mm Circle Ø: 18.5 mm	Width Cross: 21.0° Circle Ø: 10.6°	570-750 nm	
DE-R 261	Viewfinder (Dot Circle + Cross)	635nm	Width Cross: 11.0 mm Circle Ø : 8.8 mm Dot Spacing: 1.1 mm	Width Cross: 6.3° Circle Ø: 5.0° Angle betw. Dots: 0.63°	570-750 nm	
DE-R 262	Viewfinder (Dot Square)	532nm	Width: 12.3 mm Height: 12.3 mm Diagonal: 17.4 mm Dot Spacing: 0.5 mm	Width: 7.0° Height: 7.0° Diagonal: 10.0° Angle betw. Dots: 0.3°	480-670 nm	
DE-R 288	Viewfinder	650nm	Width: 83.0 mm Height: 53.7 mm Diagonal: 98.9 mm	Width: 43.7° Height: 27.9° Diagonal: 52.6°	590-730 nm	
DE-R 345	Viewfinder (Circle + Cross)	520nm	Width Cross: 49.9 mm Circle Ø: 24.6 mm	Width Cross: 28.0° Circle Ø: 14.0°	500-540 nm	
DE-R 394	Viewfinder	520nm	Width: 65.9 mm Height: 65.9 mm Diagonal: 93.2 mm	Width: 36.5° Height: 36.5° Diagonal: 50°	500-540 nm	
Special Patterns						
DE-R 236	Solid Line Square	633nm*	Width: 63.1 mm Height: 63.1 mm Diagonal: 89.5 mm	Width: 35.0° Height: 35.0° Diagonal: 48.2°	530-650 nm	
DE-R 256	Square Grid 51 x 51 Lines	660nm	Width: 40.3 mm Height: 40.3 mm Diagonal: 56.9 mm Line Spacing: 0.8 mm	Width: 22.8° Height: 22.8° Diagonal: 31.8° Angle betw. Lines: 0.45°	530-660 nm	
DE-R 259	5 Rings	645nm	Width: 51.3 mm Line Spacing: 5.1 mm	Width: 28.8° Line Spacing: 2.9°	530-700 nm	
DDE-R 269	10 Rings	515nm	Width: 96.2 mm Line Spacing: 4.8 mm	Width: 51.4° Line Spacing: 2.6°	488-532 nm	
DE-R 285	Hexagon	780nm	Width: 13.1 mm	Width: 7.5°	520-800 nm	
DE-R 354	Square Grid 10 x 10 Lines	658nm	Width: 72.8 mm Height: 72.8 mm Diagonal: 102.9 mm Line Spacing: 8.1 mm	Width: 40.0° Height: 40.0° Diagonal: 51.4° Angle betw. Lines: 4°	620-680 nm	
DE-R 396	21x11 Hexagonal Array	660nm*	Width: 61.1 mm Height: 35.3 mm Diagonal: 70.5 mm Dot Spacing: 3.5 mm	Width: 34.0° Height: 20.0° Diagonal: 38.8° Angle betw. Dots: 2.0°	580-730 nm	
DE-R 397	11x10 Hexagonal Array	660nm*	Width: 44.4 mm Height: 46.2 mm Diagonal: 64.1 mm Dot Spacing: 5.1 mm	Width: 25.1° Height: 26.0° Diagonal: 35.5° Angle betw. Dots: 2.9°	580-730 nm	

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