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Diffractive Optical Elements (DOEs) and relief-phase optical elements (RPOEs)

Laboratory of diffractive optics

Institute of automation and Electrometry SB RAS, Novosibirsk, Russia

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Content

1. Types of DOEs and RPOEs
2. Fabrication technology
3. Application of DOEs for wavefront measurement
4. Application of RPOE for wavefront correction
5. Conclusion

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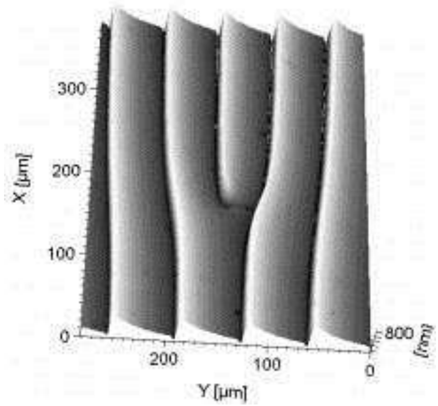
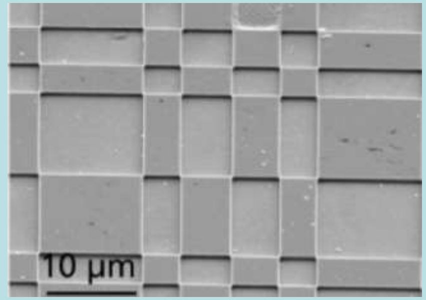
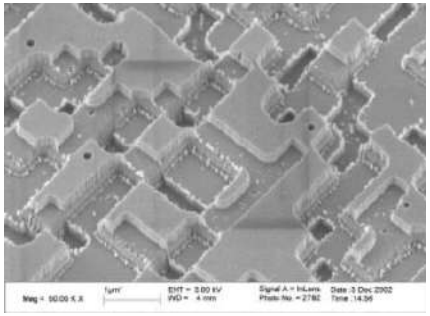
Types of relief-phase optical elements



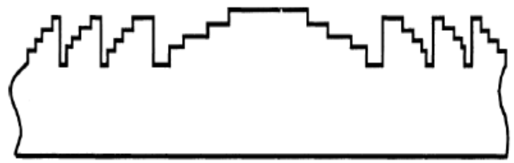
Piecewise-continuous DOEs



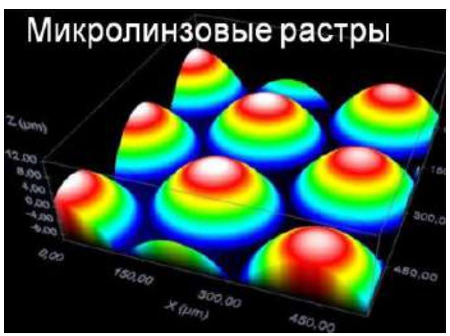
Бинарные ДОЭ



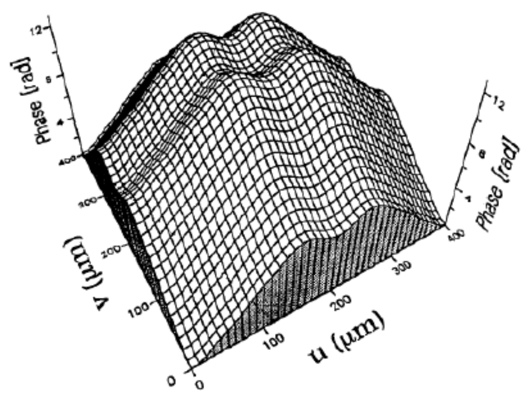
Многоуровневые ДОЭ, рассчитанные итеративными методами



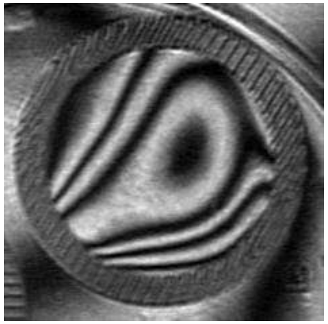
Multilevel DOE with analiticaly assigned phase function



Microoptical elements



Continuous elements (periodic and aperiodic)



Conformal elements and static aberration correctors.

Writing of DOEs: laser writing system with circular scanning

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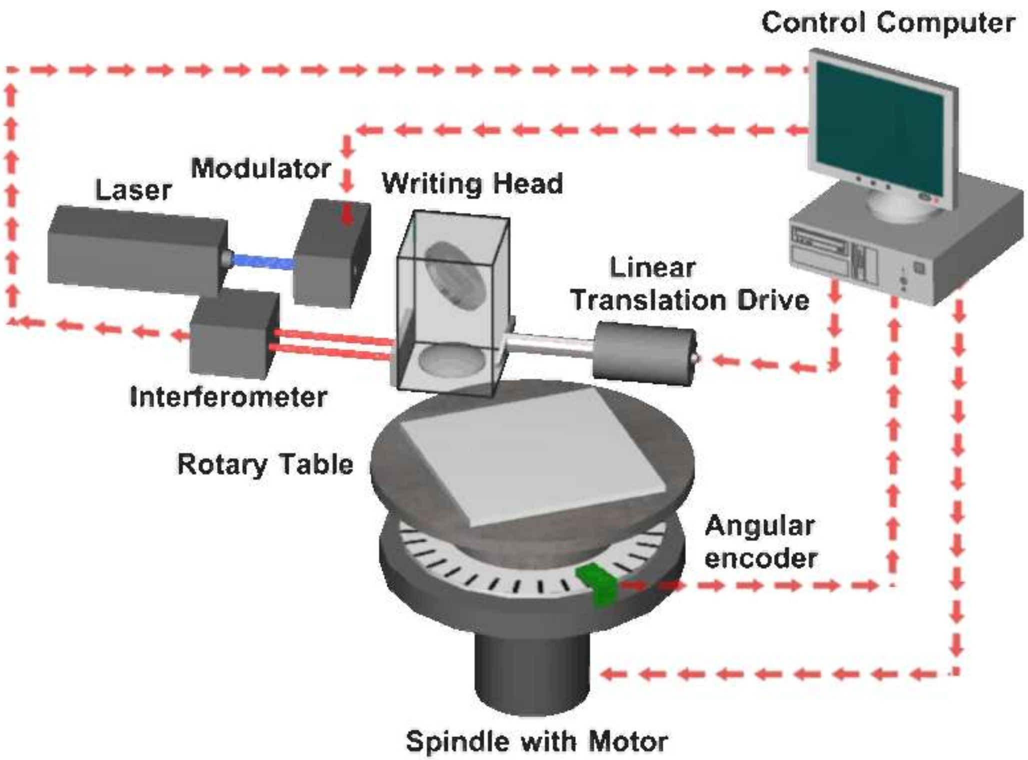

Scanning of focused laser beam in polar coordinates system

Advantages of polar coordinates system:

- High writing speed
- High accuracy of circular trajectory (10нм) in comparison with linear trajectory (1000 nm)

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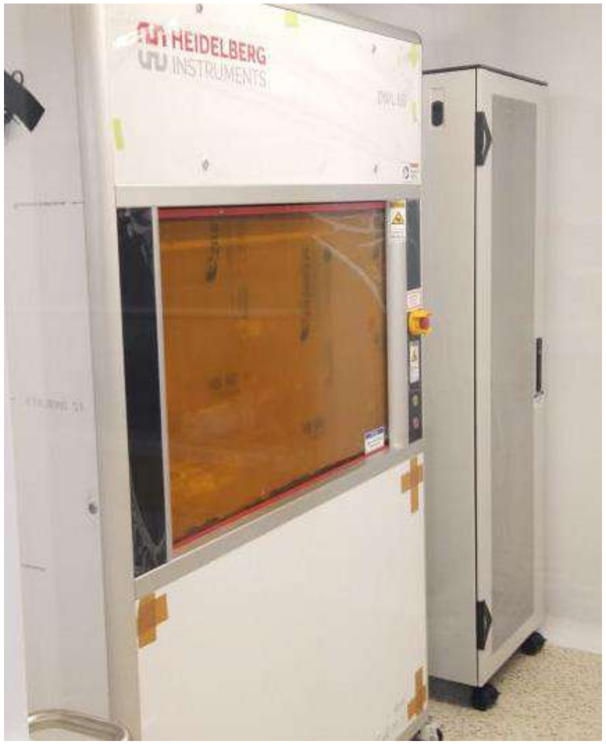
Writing of DOEs: XY system



Key features:

Maximum writing field - 200 x 200 mm2;

Substrate thickness – 1-13 mm.

Wavelength - 375 nm

Minimum linewidth – 0.3 /0.6 / 1 micron

Alignment with marks on back site of the substrate

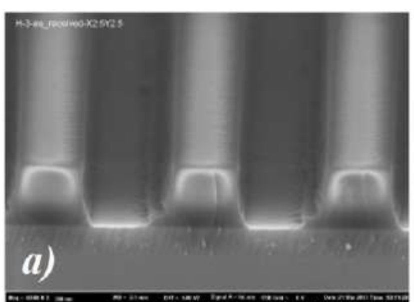
Gray-scale range – 256 levels

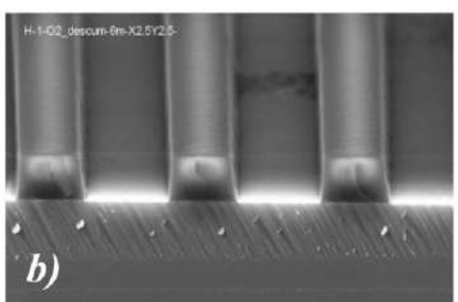
Error of alignment with first layer – 350 nm

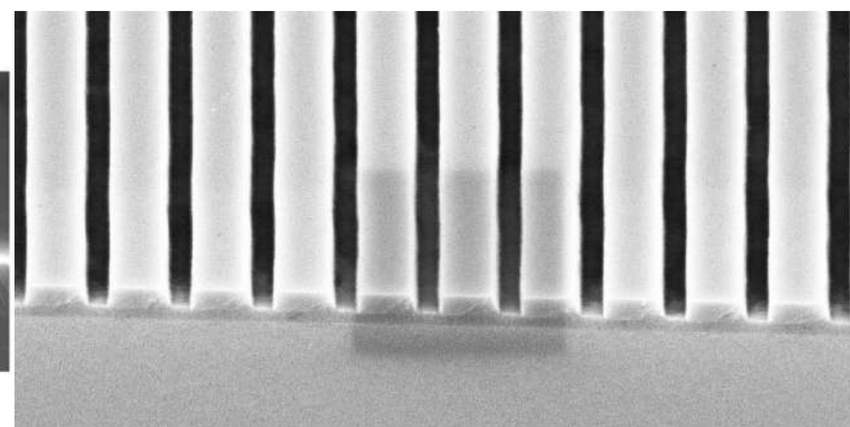
Address grid – 5/ 10/ 50 nm

Optical and pneumatic autofocus

Exposure rate – 2/10/110 mm^2/min







Thermochemical technology of DOE fabrication with binary relief

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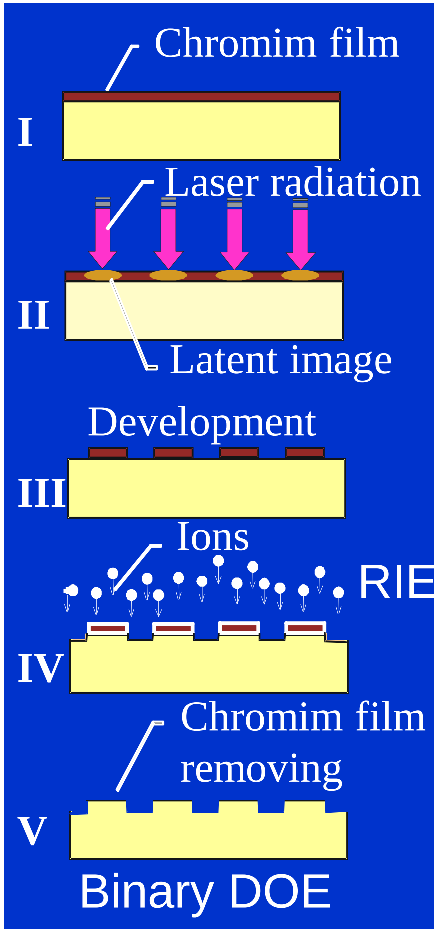

We have developed original technology of direct laser writing on Cr film without photoresist

The DOEs are mainly applied in optical metrology for aspheric surface testing.
Maximal diffraction efficiency – 40%

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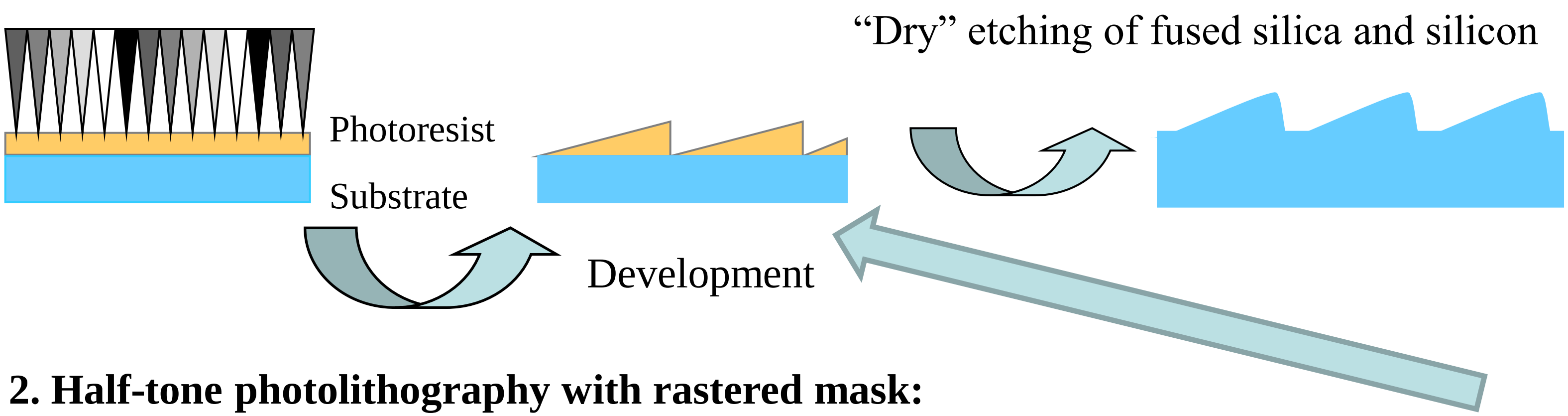
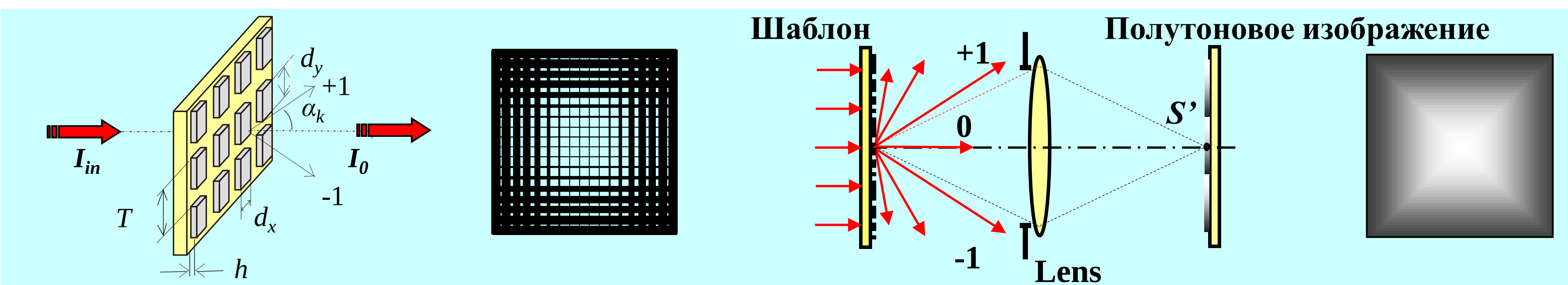
Fabrication of DOE with high diffraction efficiency

1. Direct writing on photoresist:

Wavelength: 355-375-405 nm



2. Half-tone photolithography with rastered mask:



The method was firstly proposed in our Institute. Now this method is widely used.

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Application of DOEs for wavefront measurement

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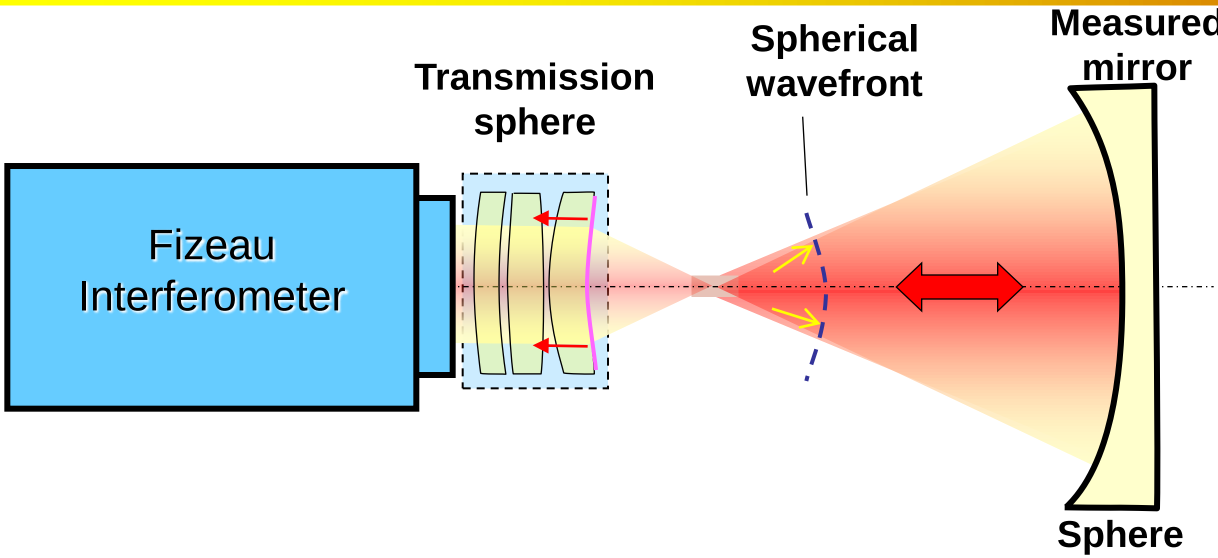
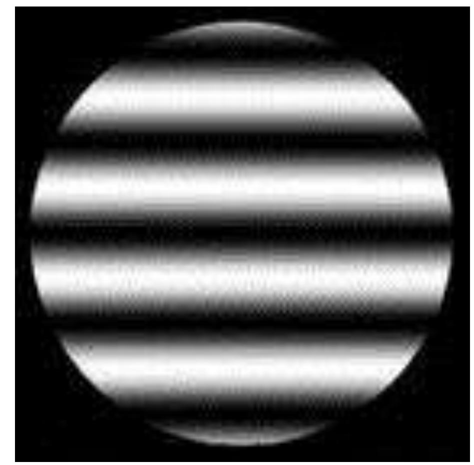
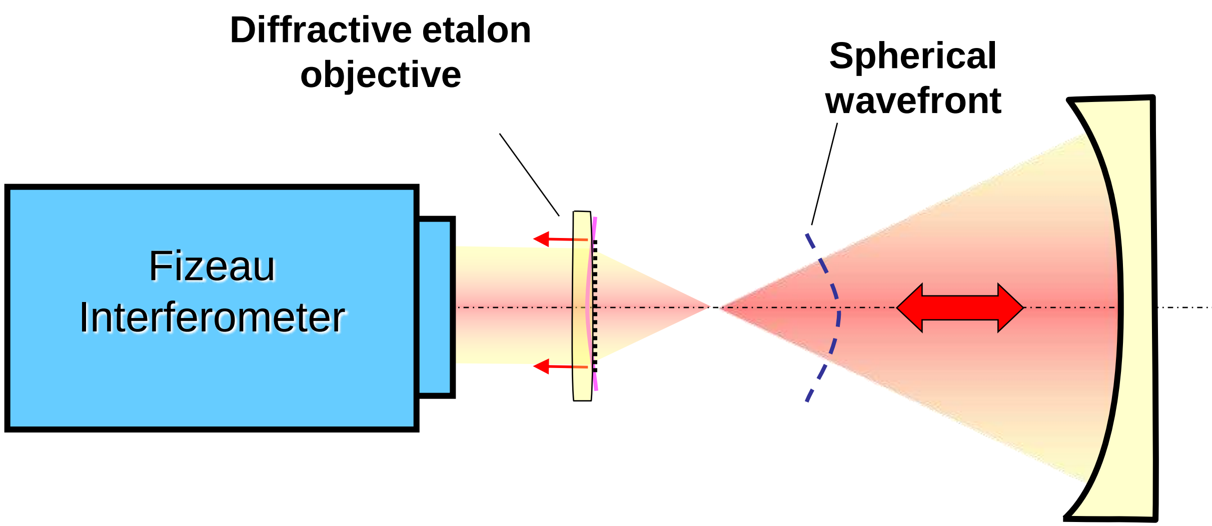
Spherical wavefront testing







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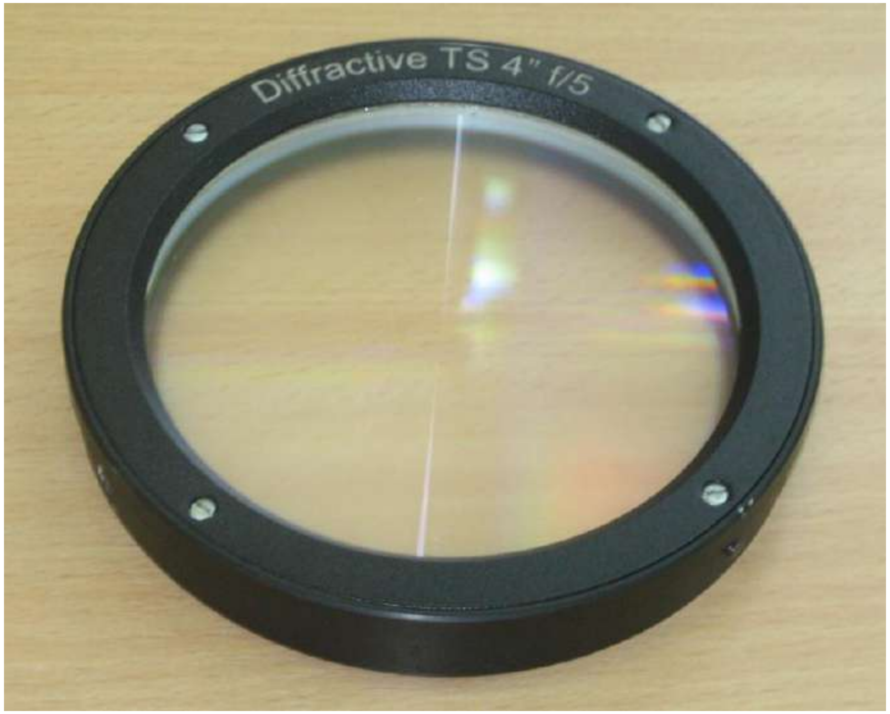
Diffractive etalon objectives



DIFFRACTIVE TRANSMISSION SPHERE
DTS 4″- f/15, R= ± 1500.00 мм, λ =632.28 um

DIFFRACTIVE TRANSMISSION SPHERE
DTS 4″- f/5, R= ± 500.00 мм, λ =632.28 um

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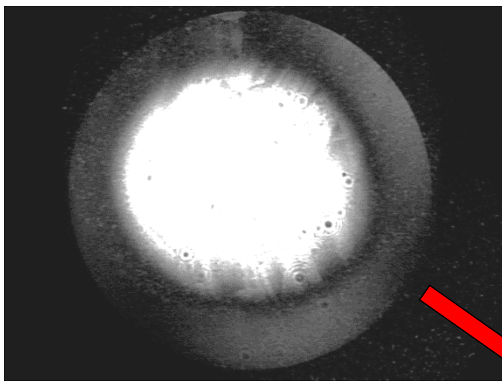
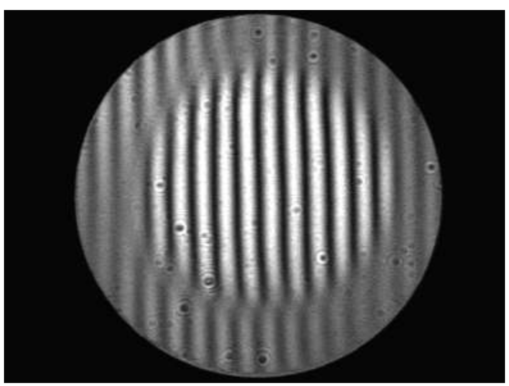
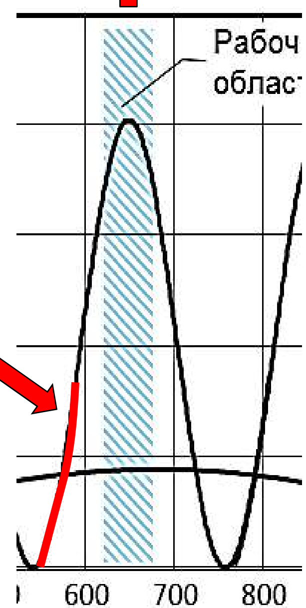
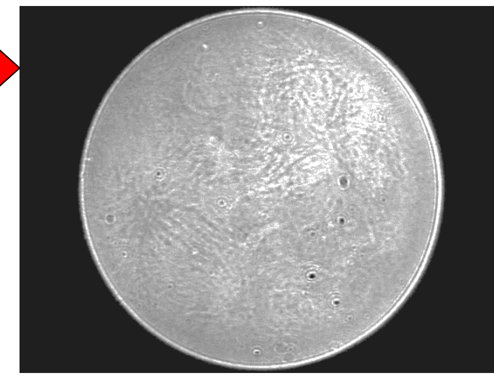
Problems at fabrication of diffractive etalon objective

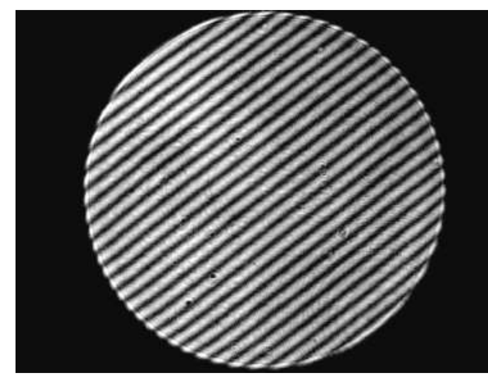
The main problem is the value of the etching depth of the structure and its uniformity over the entire surface of the element. The etching depth strongly affects the parameters of the reflected wavefront.











Example (f/15): substrate Ø115 мм.
Depth non-uniformity ~ 60 нм

Example (f/3.3): substrate Ø115 mmм.
Depth non-uniformity ~ 10 нм

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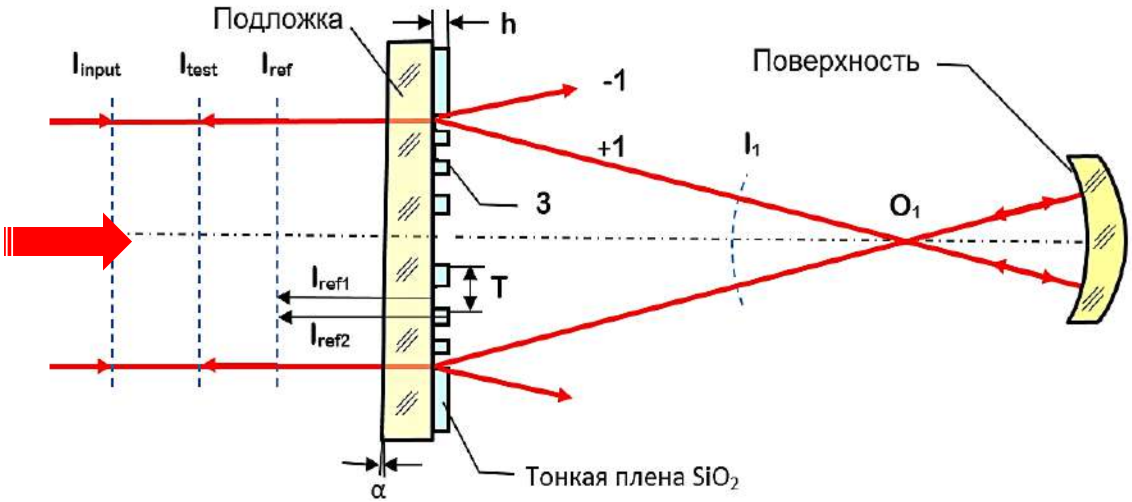
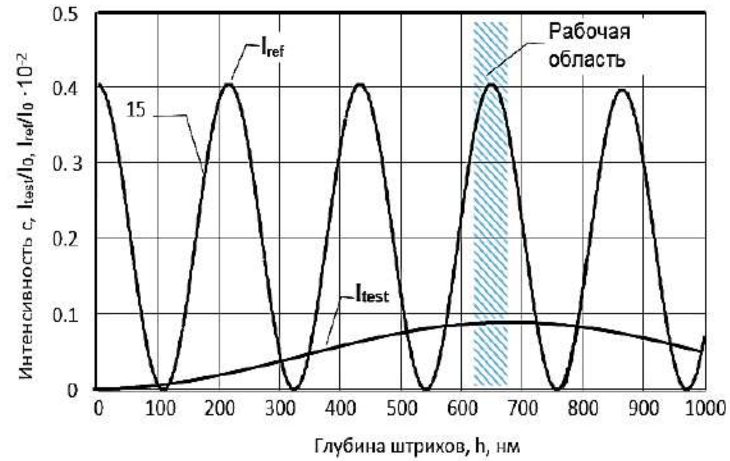
Diffractive etalon objective. Principle of operation.



Принцип работы эталонного дифракционного объектива (Патент № 2534435, 27.11.2014)



Интенсивности прошедшего и отраженного оптического излучения.

Интенсивность оптического излучения измерительного волнового фронта

$$I_{test} = I_0 \eta^2 r,$$

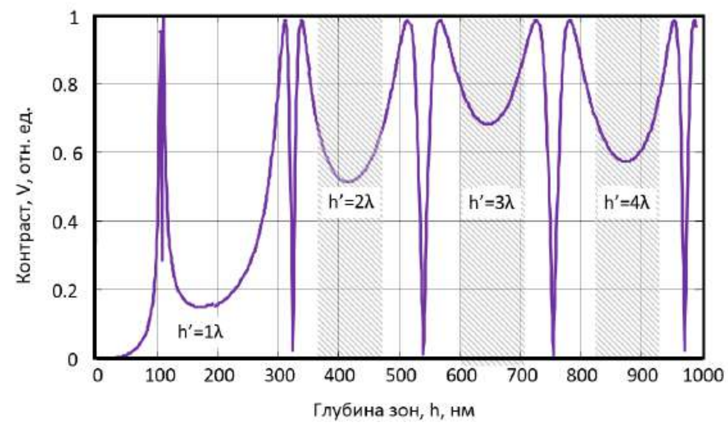
При r=5% и η~0.4, I_{test}= 0.008I_0. (около 1%)

Интенсивность отраженного оптического излучения со стороны подложки в нулевом (m=0) порядке

$$I_{ref} = 0.5 \cdot I_0 \cdot r_d \cdot (1+\cos(\psi)).$$

Фаза ψ отраженного оптического излучения пропорциональна глубине h_2 рельефа

$$h = N\lambda/2n,$$ **где N=0, 1, 2, 3, 4**



Контраст интерференционных полос в зависимости от глубины рельефа,

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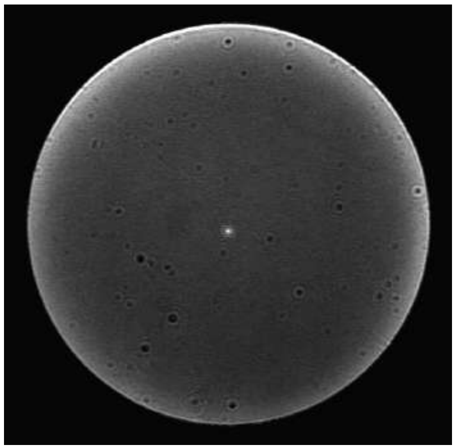
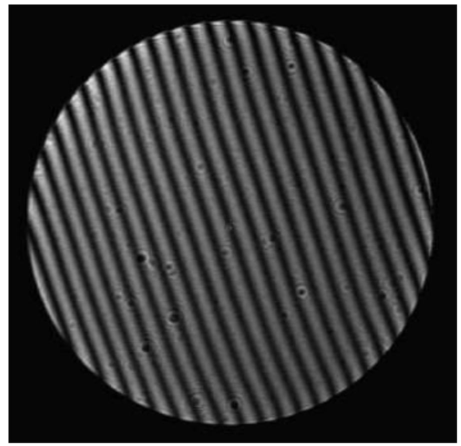
Testing of diffractive objective f/10

Parameters of etalon objective: D=102 mm, f=1000 mm

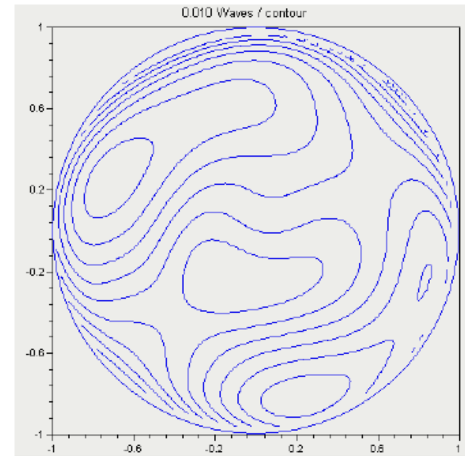
1. Исследование опорного волнового фронта (отражение от дифракционной структуры). Интерференция с 4’’ плоским эталоном (Tower).



Поле интенсивности

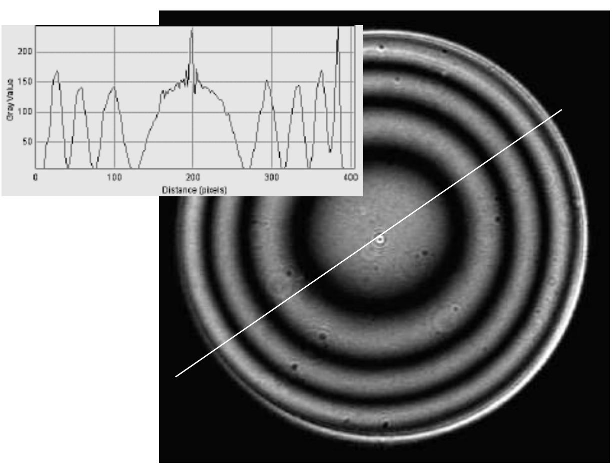


Интерферограмма

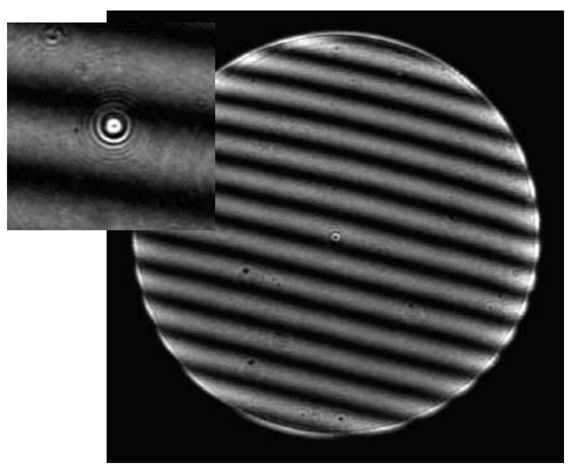


Карта погрешностей: 0.01λ (PV) 0.008 (rms)

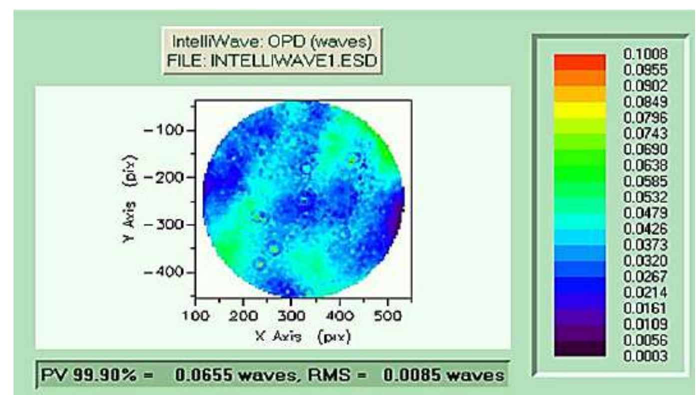
2. Исследование объектива с высококачественным тестовым сферическим зеркалом (стекло).



Интерферограмма (дефокус)



Интерферограмма



Карта поверхности (собственные погрешности)

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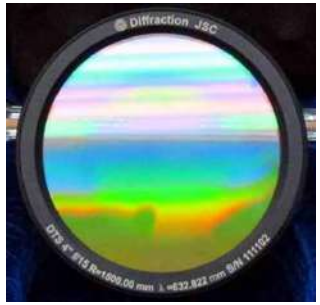
Comparison of diffractive and refractive etalon objectives



DIFFRACTIVE OBJECTIVE

Advantages	Drawbacks
Small weight and size	High accuracy is required at adjustment
Large light field Ǿвх = Ǿвых	Complicated fabrication technology (there is only in Russia)
Low price	Limited aperture f/# (f/2.4)
Positive and negative at the same time ± f	Parasitic diffraction orders
Testing of spherical and aspherical surfaces	Limited afficiency (40%)
Excellent transmitted wavefront quality (<0.1 λ)	

REFRACTIVE OBJECTIVE

Advantages	Drawbacks
Simple adjatments	Large weight and sizes, (especially for Ǿ > 6’’ - 8’’)
Mass production (> 10 фирм)	High price (> 10000$)
High quality of measurement (до λ/50)	Small light field Ǿin > Ǿout
	Only spherical wavefront
	Transmitted wavefront has low quality (~ 0.5-1.5 λ)

Application of DOE for aspherical wavefront measurement

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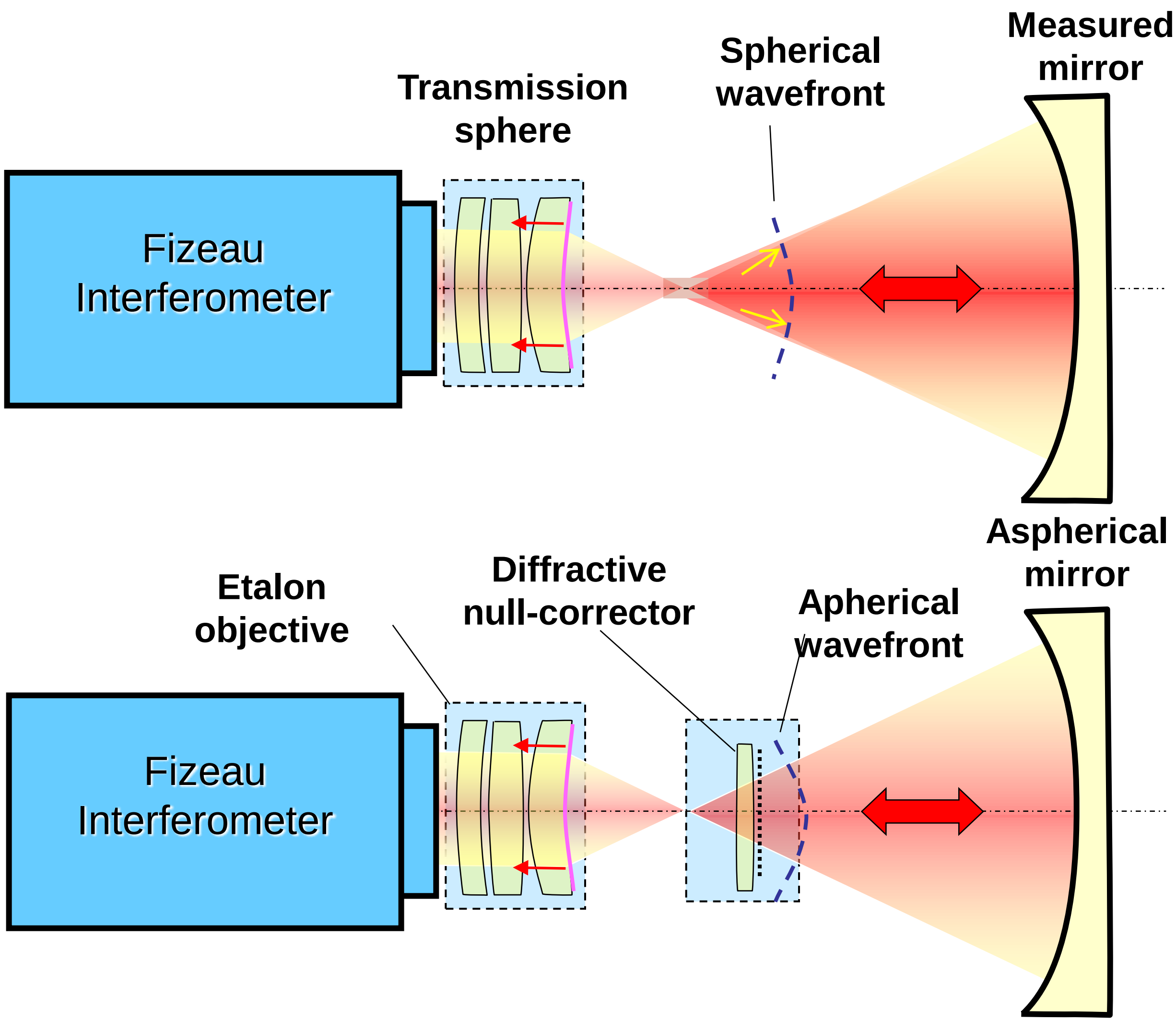
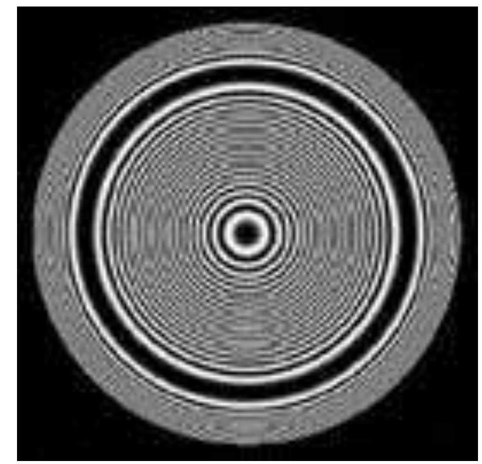
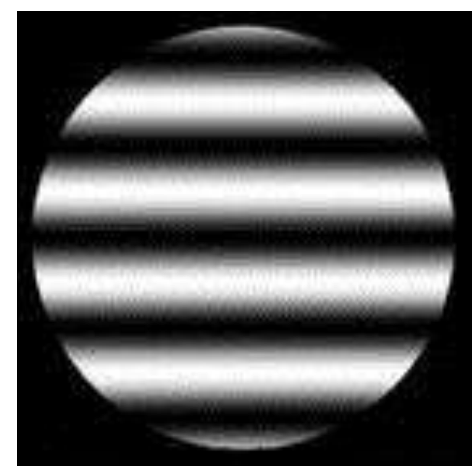
Testing of aspherical surfaces



Interferogram of aspherical mirror





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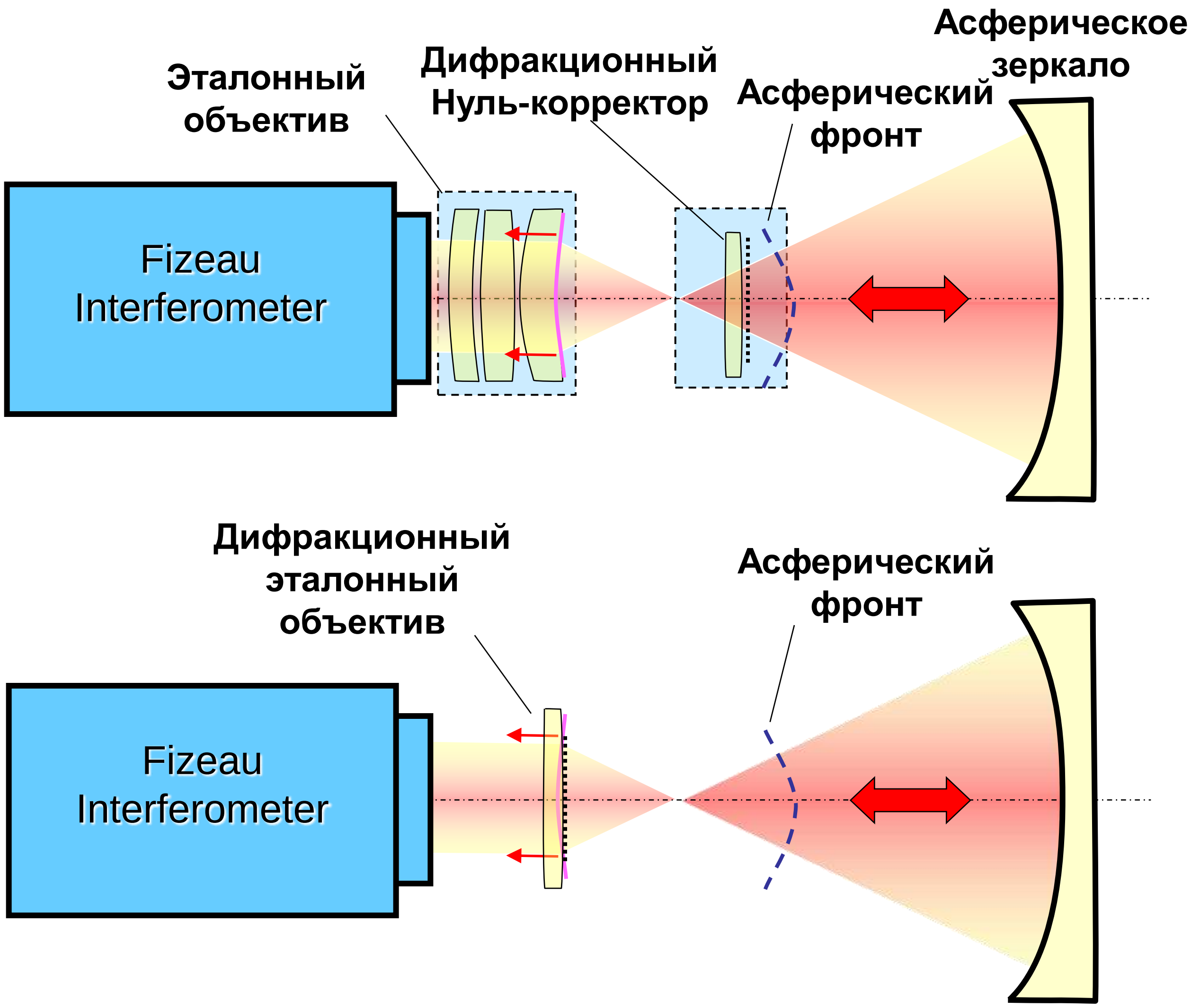
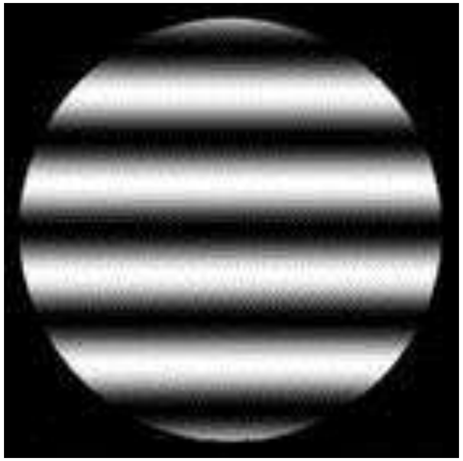
Testing of aspherical surfaces





Интерферограмма с прямыми полосами

Новая схема контроля асферики с дифракционным объективом в плоском выходном пучке интерферометра

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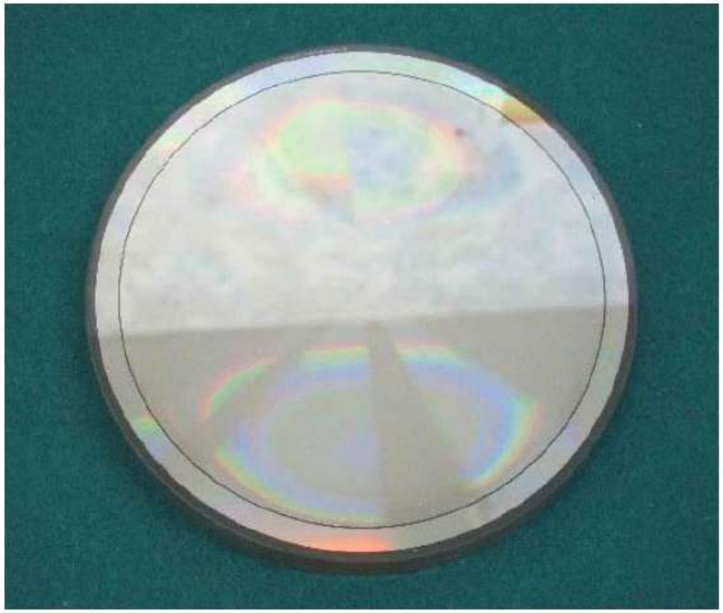
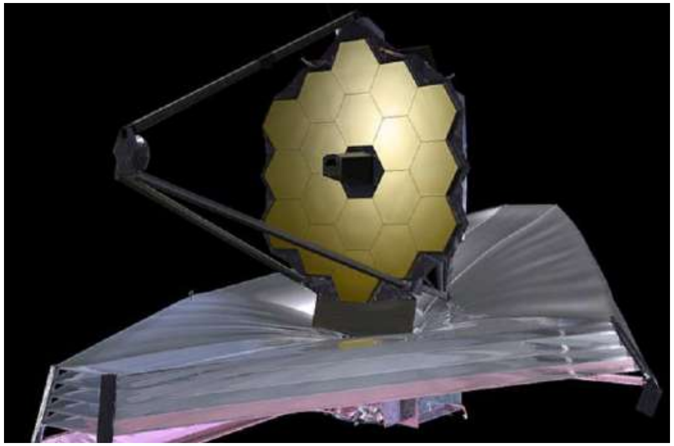
DOEs for testing James Webb telescope





In 2011 we have made set of holograms for testing of JWST's telescope segments and secondary mirrors.

Perfect operation of JWST proved the quality of Siberian holograms.

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Optical testing of optical head-mounted system with 3 lenses

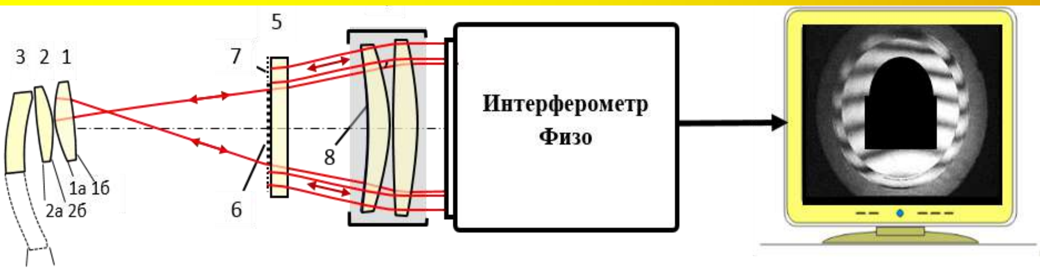
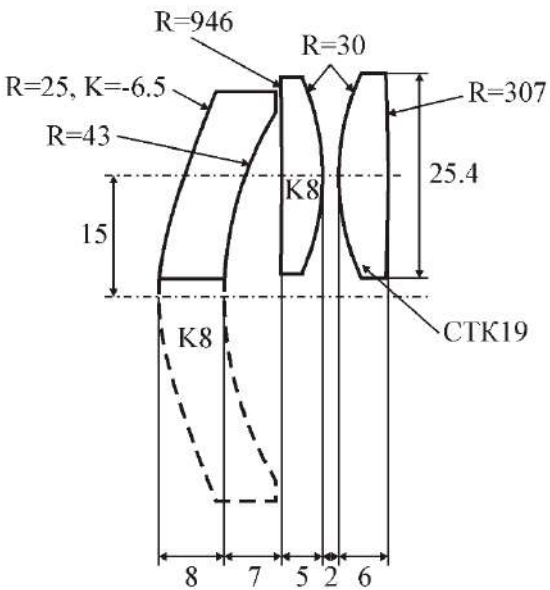
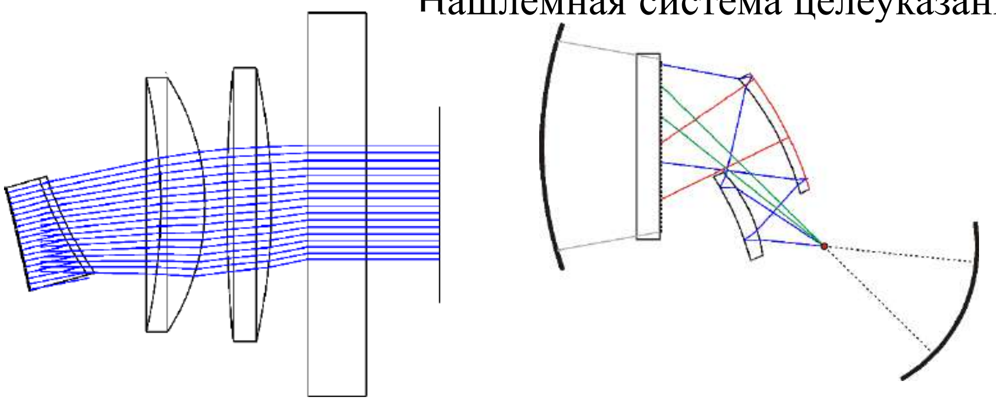


Схема контроля

Нашлемная система целеуказания



3-lens setup



Setups for testing of optical systems with lenses and mirrors

Оптическая системы была разделена на блоки по 2-3 линзы

Патент РФ № 2586097 Нашлемная широкоугольная коллиматорная дисплейная оптическая система.
Авторы: Воронова М.В. , Савицкий А.М. , Сокольский М.Н. , Строганов А.А. , Эфрос А.И. , Шукалов А.В.

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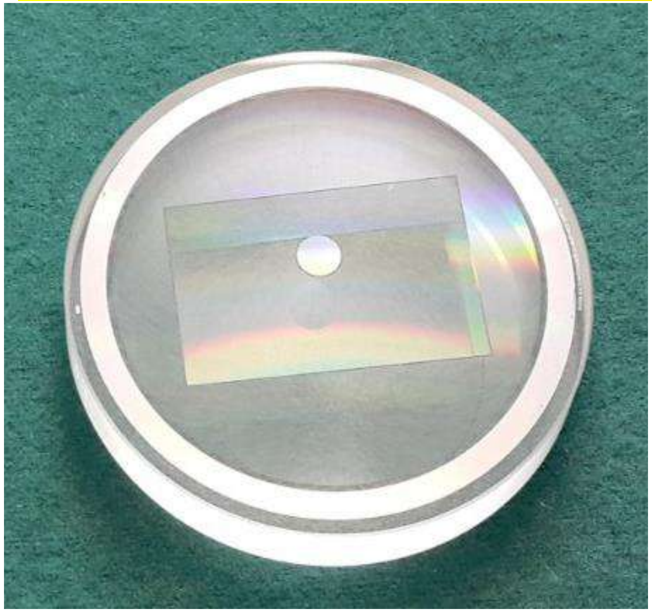
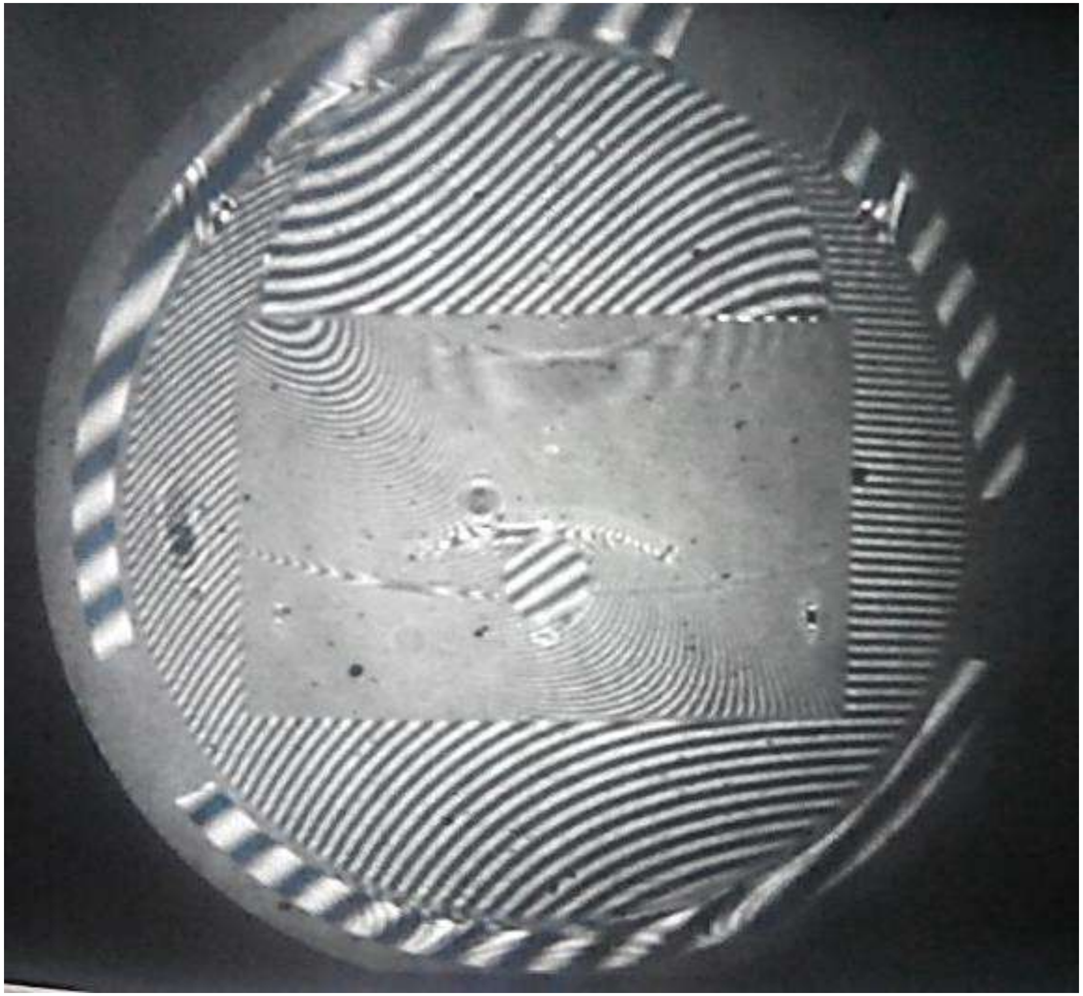
Experimental results for testing 3-lens adjustment



Fabricated DOE

Segments for each lens



Interferogram of wavefront passed through 3-lens setup and DOE.

Binary microlens arrays for Shack-Hartmann wavefront sensors

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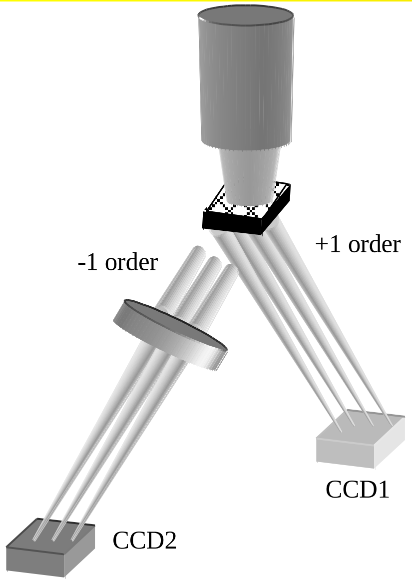

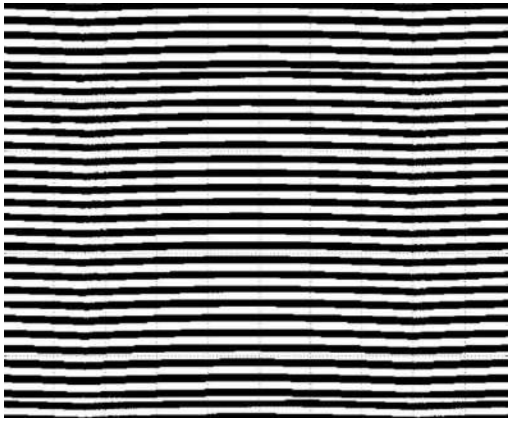

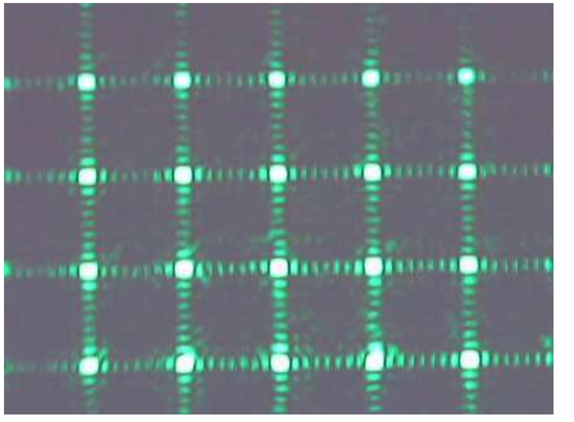

Wavefront sensor on the base of low-aperture off-axis microlens array

The use of binary microlens arrays in the raster sensor with a high quality of wave front formation and a high degree of repeatability of the parameters of individual elements made it possible to record WF slopes (~10 arc seconds) with high angular resolution. The total error of the measurement system (imaging systems, registration of the Hartmannogram and calculation of the angular displacement of the image CG) does not exceed 4.8 arc seconds (0.15 pixels in the registration plane), which leads to a root-mean-square deviation from the flatness of the reconstructed wave front, not exceeding 0.017λ .

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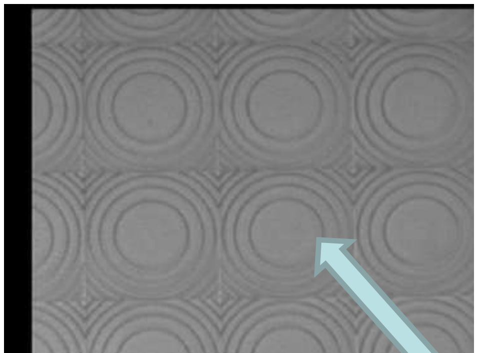
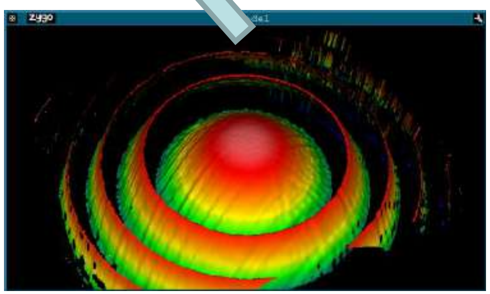
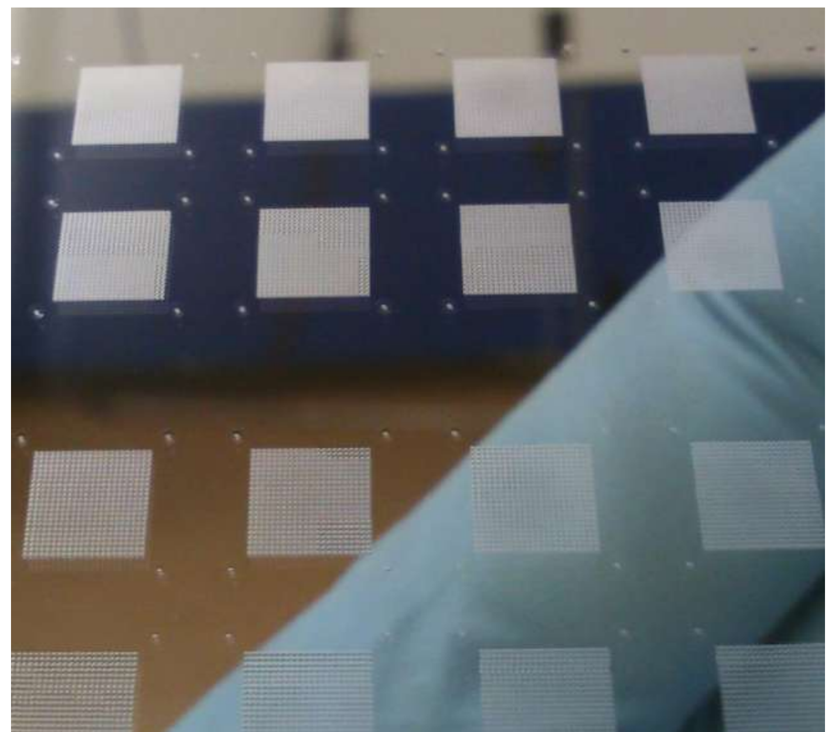
On-axis diffractive microlens arrays for wavefront sensors



Lens diameter – 5-10000 microns
Aperture – до 0.2
Efficiency – 70-90%





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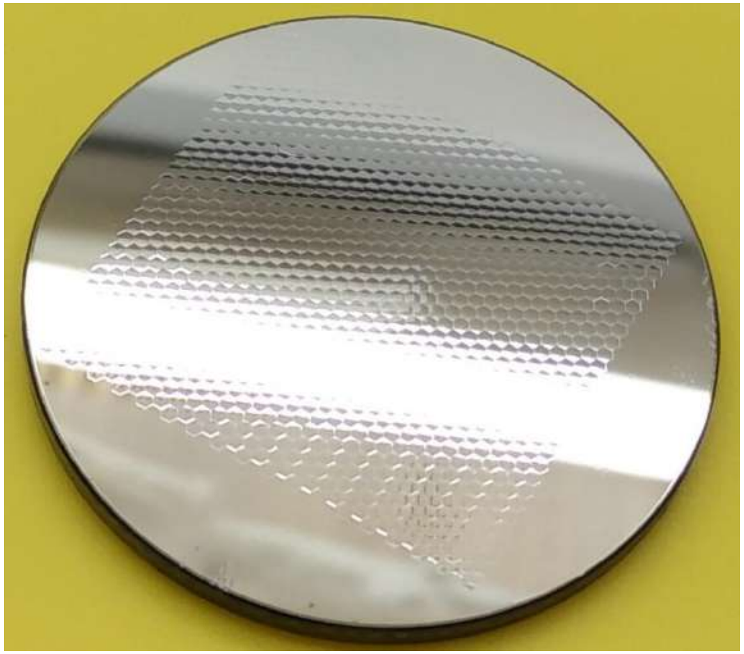
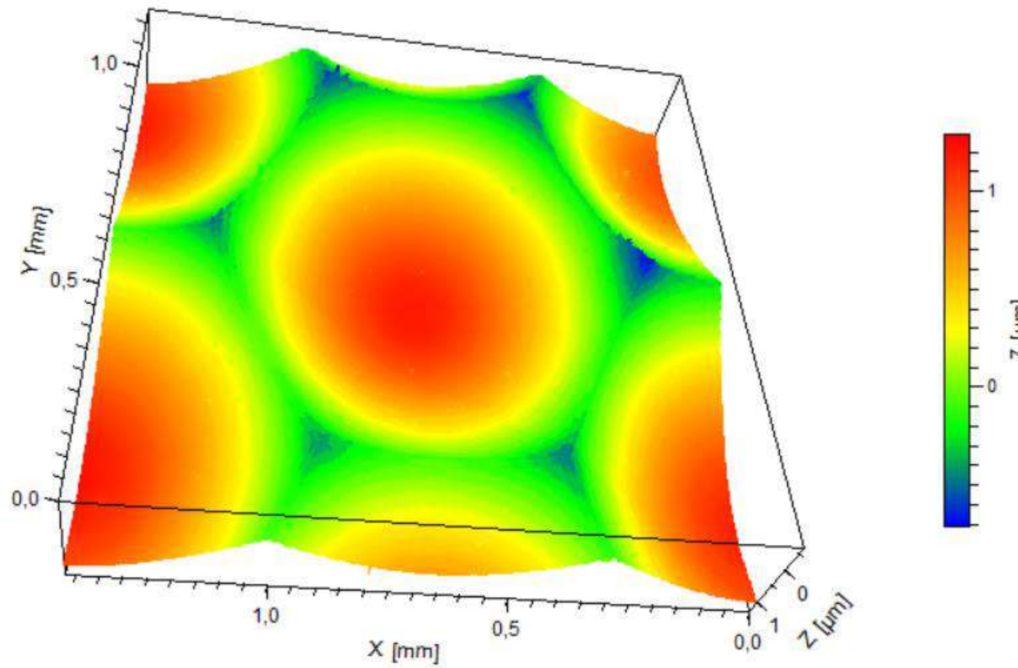
Silicon microlens arrays for wavefront sensors





Application of relief-phase optical elements for correction of wavefront

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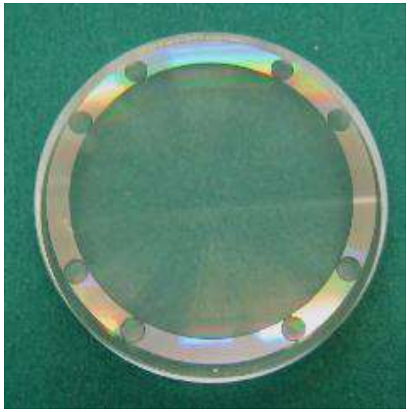
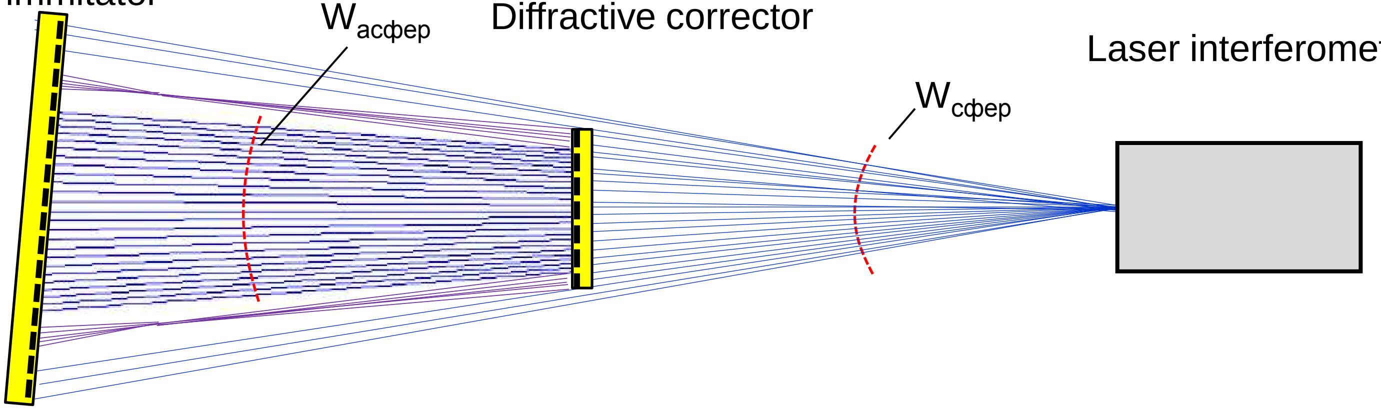
Binary diffractive correctors of wavefront

- Methods have been developed for the synthesis of diffraction correctors for converting plane and spherical wave fronts into aspherical ones with an error of the order of nanometers.
- ew methods for certifying the DCVF based on the use of combined DOEs and AVF simulators in combination with laser interferometers have been proposed and put into practice.
- It is shown that one of the main sources of errors is the error in the relative position in space of the interferometer, DOE, and simulator.



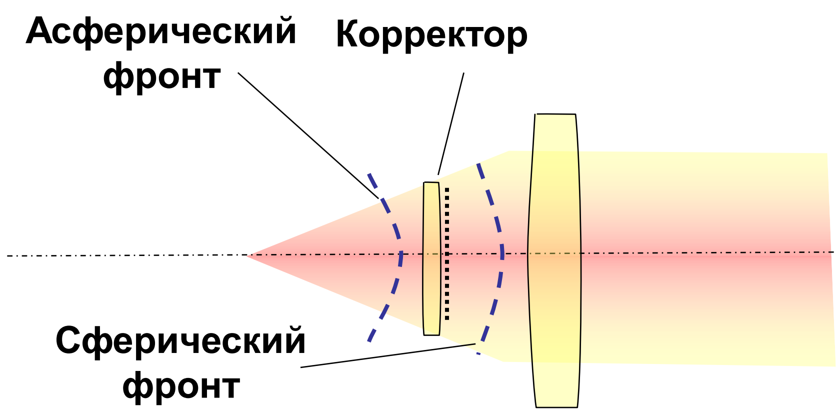


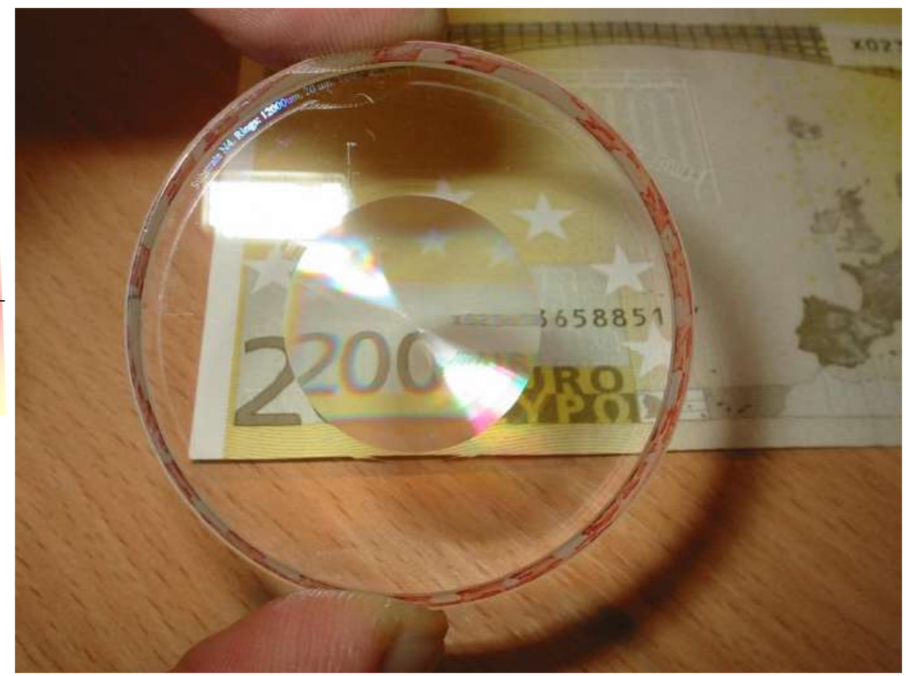
Optical system for certification of a diffractive wavefront corrector

IA&E SB RAS

High-efficiency diffractive correctors for wavefront

Diameter – < 100 mm
Minimal period – > 3 microns
Диапазон длин волн – 200-1100 нм
Материал подложки – плавленый кварц, кремний
Diffraction efficiency– 70-95% (depending on numerical aperture)





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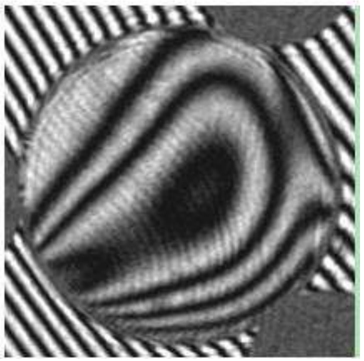
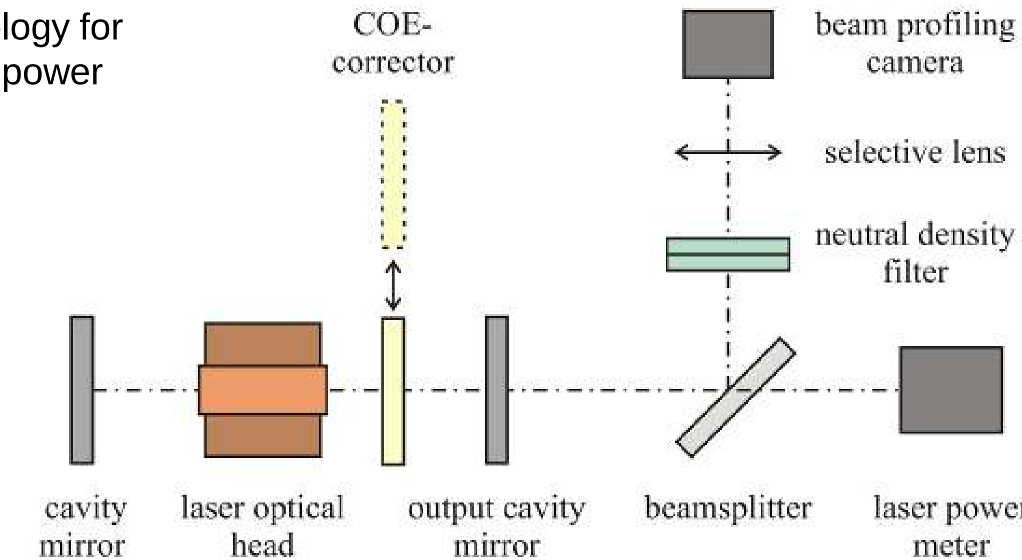
Conformal corrector

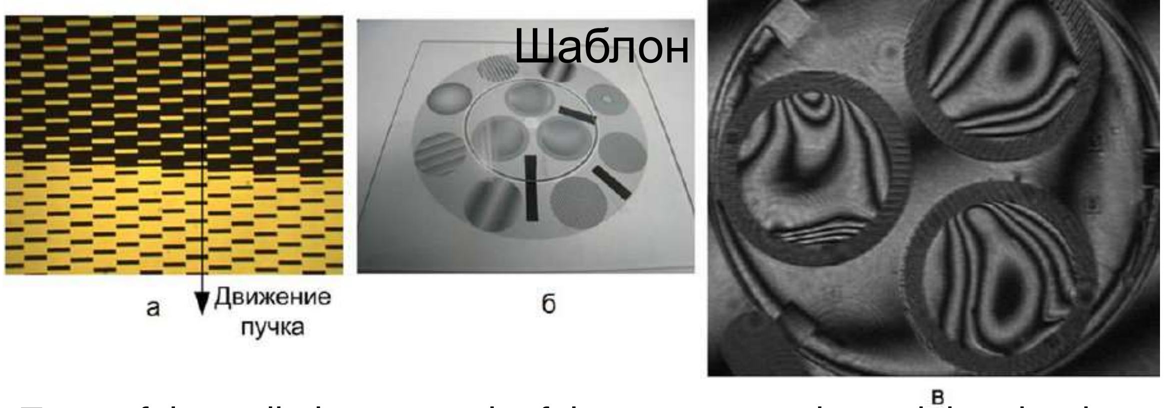
Objective: to develop a cost-effective technology for the manufacture of static correctors for high-power solid-state lasers.

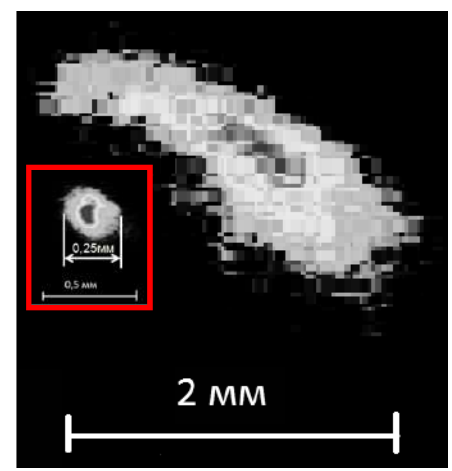


Phase map of active element with 20 mm diameter.



Фазовая карта трех корректоров





Tests of the radiation strength of the correctors showed that the damage threshold exceeds 17 J/cm2 at a wavelength of 1064 nm with a pulse length of 4 ns.

Spot in focus before and after correction

IA&E SB RAS

Conclusion

- Technology and precision laser equipment has been created for the manufacture of relief-phase optical elements with an arbitrary structure with a diameter of up to 240 mm have been developed .
- Calculation methods have been developed and the features of the use of synthesized DOEs for testing aspherical optics have been studied.
- Technology for manufacturing conformal correctors with a relief depth of up to 4–5 μm and a light field of up to 50 mm, which make it possible to reduce the radiation divergence of high-power lasers by a factor of 3–10 has been developed .
- Technology for custom fabrication of diffractive and refractive microlens screens on fused quartz and silicon substrates with a relief depth of up to 4-5 μm has been developed .
- If you need micro-optical elements that are optimal for your circuit, and not those that were “in stock”, we will make them a reality.