AdlOptica

foXXus 0.015-0.047_NA0.8

(L9388 + L9388.44)

Multi-focus objective
with protective window

Manual

October 17, 2021

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Fig. 1 foXXus 0.015-0.047_NA0.8 *(L9388 + L9388.44)* outlook

1. Specifications

Table 1

Items		Values
Description		Objective lens with multiple foci Supplied with replaceable Protective Window Design ver. L9388 + L9388.44 is completely compatible with ver. L9388 and L9322
Accessories		- Protective Window D12_1064 or D12_515/1030 - Adapter C-Mount Ext/Int 6 mm
ΔF, μm	air	2 foci: 15, 47 4 foci: 16-15-16
	Glass (x1.5)	2 foci: 24, 72 4 foci: 24-24-24
	Al_2O_3 (x1.76)	2 foci: 28, 86 4 foci: 29-28-29
Beam full diameter, mm		12.9
Numerical aperture (NA)		0.8
Focal length (F), mm		8.1
Working Distance, mm		Objective only: 1.1 Objective + Protective Window: 1.0
Spectral band, nm		_1064: 1020 - 1100 _532: 510 - 550 other wavelengths on request
2ω, μm waist in air, by Gaussian beam of $1/e^2$ diameter 9 mm	1064 nm	1.22
	532 nm	0.61
Angular field		± 1^O
Recommended max. pulse energy		25 mJ at 5 ns
Mounting		C-Mount (1”-32 UN 2A)
Diameter, mm		34.5
Length, mm		39.6 – 40.4 45.8 – 46.6 with Adapter C-Mount Ext/Int 6 mm (spacer)

2. Description

Important! Current version "L9388 + L9388.44" of **foXXus 0.015-0.047_NA0.8** is equipped with the Protective Window in Holder and is completely compatible with previous versions L9388 and L9322:

- the same optical design,
- near same overall dimensions with adapter installed, see below drawing in Fig. 3,
- the same mounting thread C-Mount,
- near same Working Distance (WD) as in L9388, even with the installed Protective Window.

Objective **foXXus 0.015-0.047_NA0.8**, hereinafter referred to as foXXus, can be used without or with the adapter extending the total length for compatibility with previous versions, see correspondingly Figs. 2, 3.
The foXXus presents a beam shaping optical device splitting the light beam in several beamlets in order to focus it in up to 4 separate focuses along optical axis. Operation principle is based on lossless beam transformation, independently from beam size within foXXus clear aperture and parameters of beam quality (any M^2 or BPP). The foXXus objectives are intended to be used with modern ultra-short pulse lasers - design of objectives presumes absence of focusing of partially reflected light ("ghosts") inside lenses, high resistance AR-coatings. This makes the foXXus objectives suitable in applications like cutting of glass, dicing of Al_2O_3, SiC and other brittle materials, where the foXXus provide simultaneous multi-layer processing.
Drawings of two foXXus implementations are presented in Figs. 2, 3.

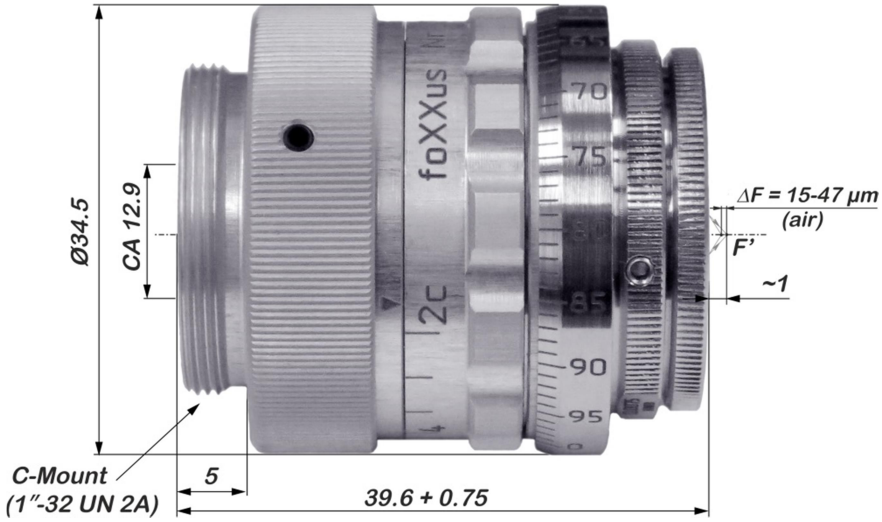


Fig. 2 foXXus with overall and mounting dimensions, adapter not installed.

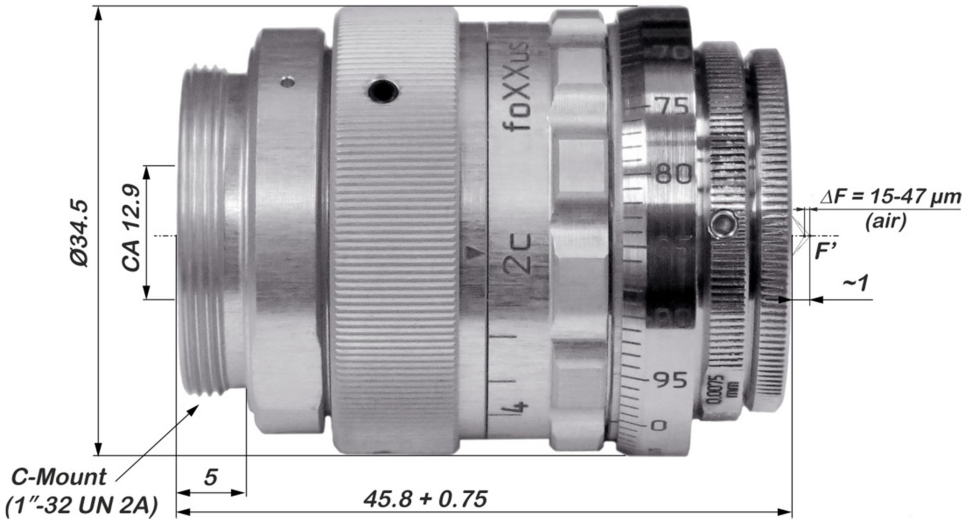


Fig. 3 foXXus with overall and mounting dimensions, with installed Adapter C-Mount Ext/Int 6 mm.

3. Controls and Adjustments

The controls and adjustment means are presented in Figs. 4, 5:

- Ring “Plate” with Scale “2c – 4 – 2d” to set required combination of foci,
- Collar “Aberration Correction” with Angular Scale, division value 0.0075 µm,
- Fixation Screws.

It is implied 3 steps of adjustment

the **1st step** is
Setting the Ring “Plate” in position “2c” or “4” or “2d” and locking by the Fixation Screw,

the **2nd step** is
Rotating the polarization plane of input beam using external wave plate; the foXXus objective is fixed,

the **3rd step** is
Rotating the Collar “Aberration correction” to compensate spherical aberration induced by deep focusing and fixing the Collar using three Fixation screws; the Reference Mark is used for readout.

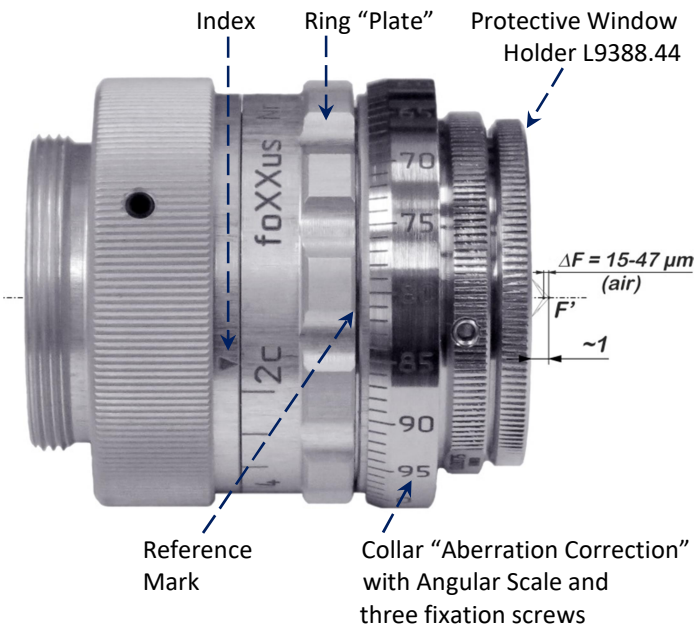


Fig. 4 Controls and adjustments.

Settings for foci layouts with even energy portions are presented in Fig. 7.

http://www.adloptica.com/pub/foxxus_na08_energy_distribution.xlsx is the Excel-program to calculate the energy portions in the characteristic and intermediate foci layouts

Energy portions are symbolically depicted by circles of different size.

Notation on the Scale of the Ring “Plate” corresponds to foci-combinations in case of unpolarized light:

- “2c” – 2 close foci,
- “4” – 4 foci,
- “2d” – 2 distant foci.

ΔF is proportional to refractive index of a medium where laser beam is focused.
Values of ΔF in air, glass (N-BK7), sapphire (Al_2O_3) and silicon carbide (SiC) are presented in insert of the “Table of Useful Layouts”, Fig. 7.

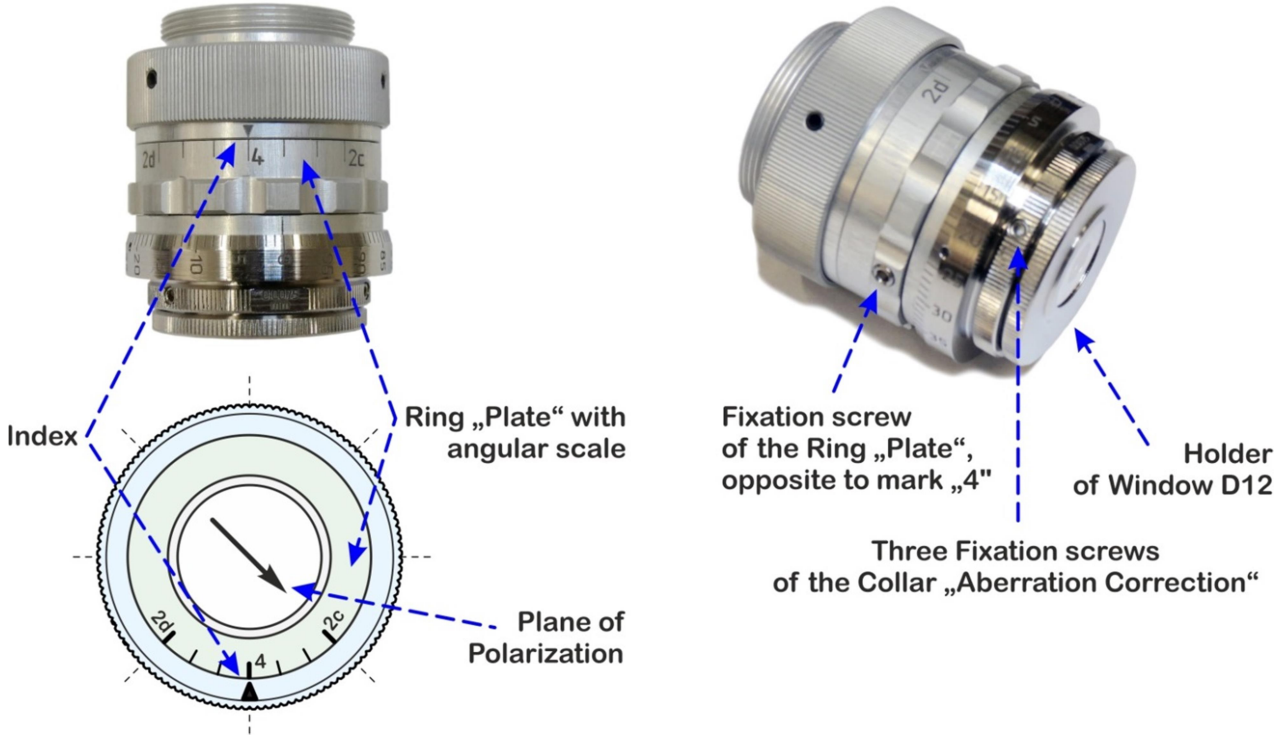


Fig. 5 Control and fixation means of foXXus.

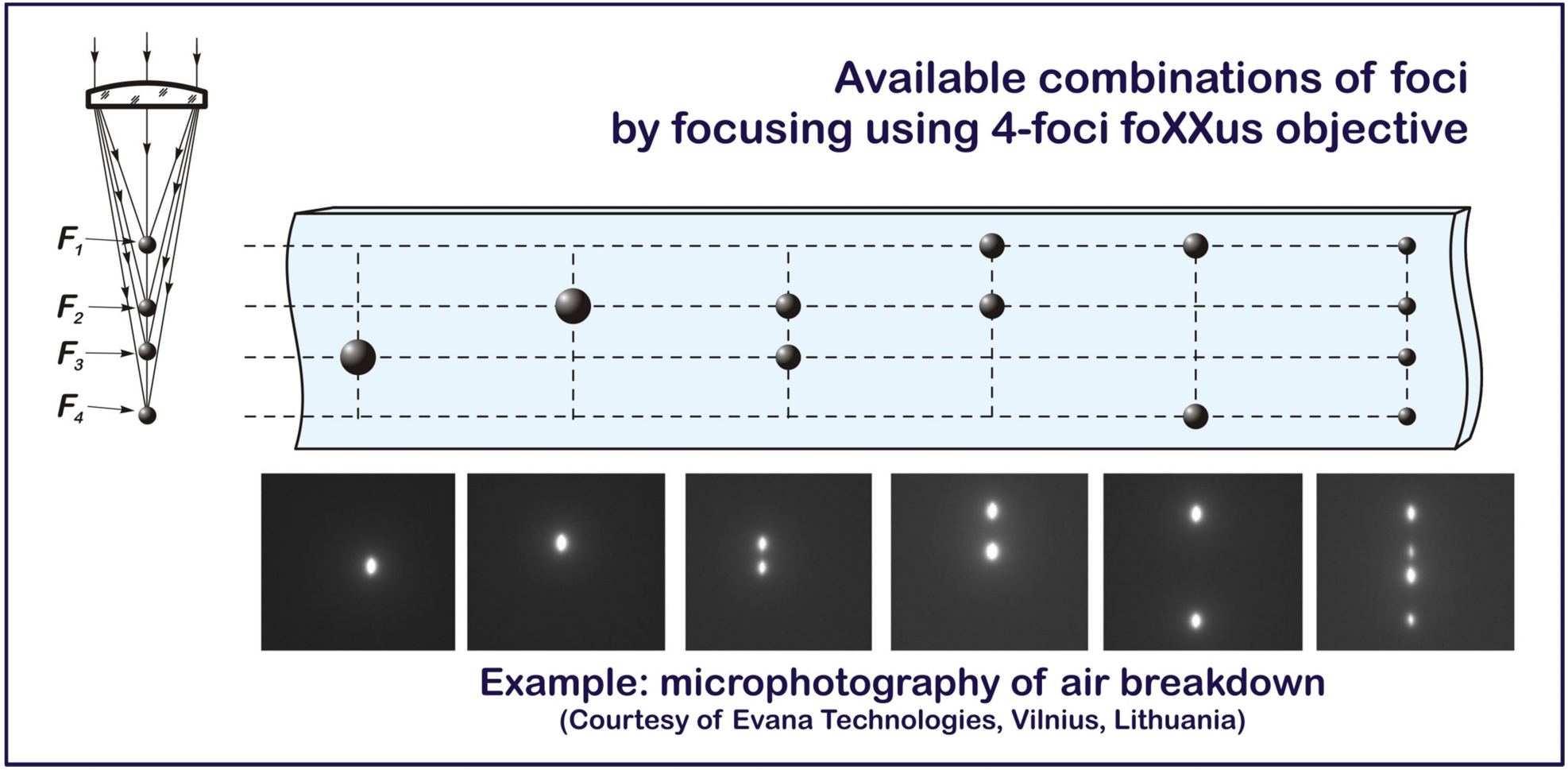
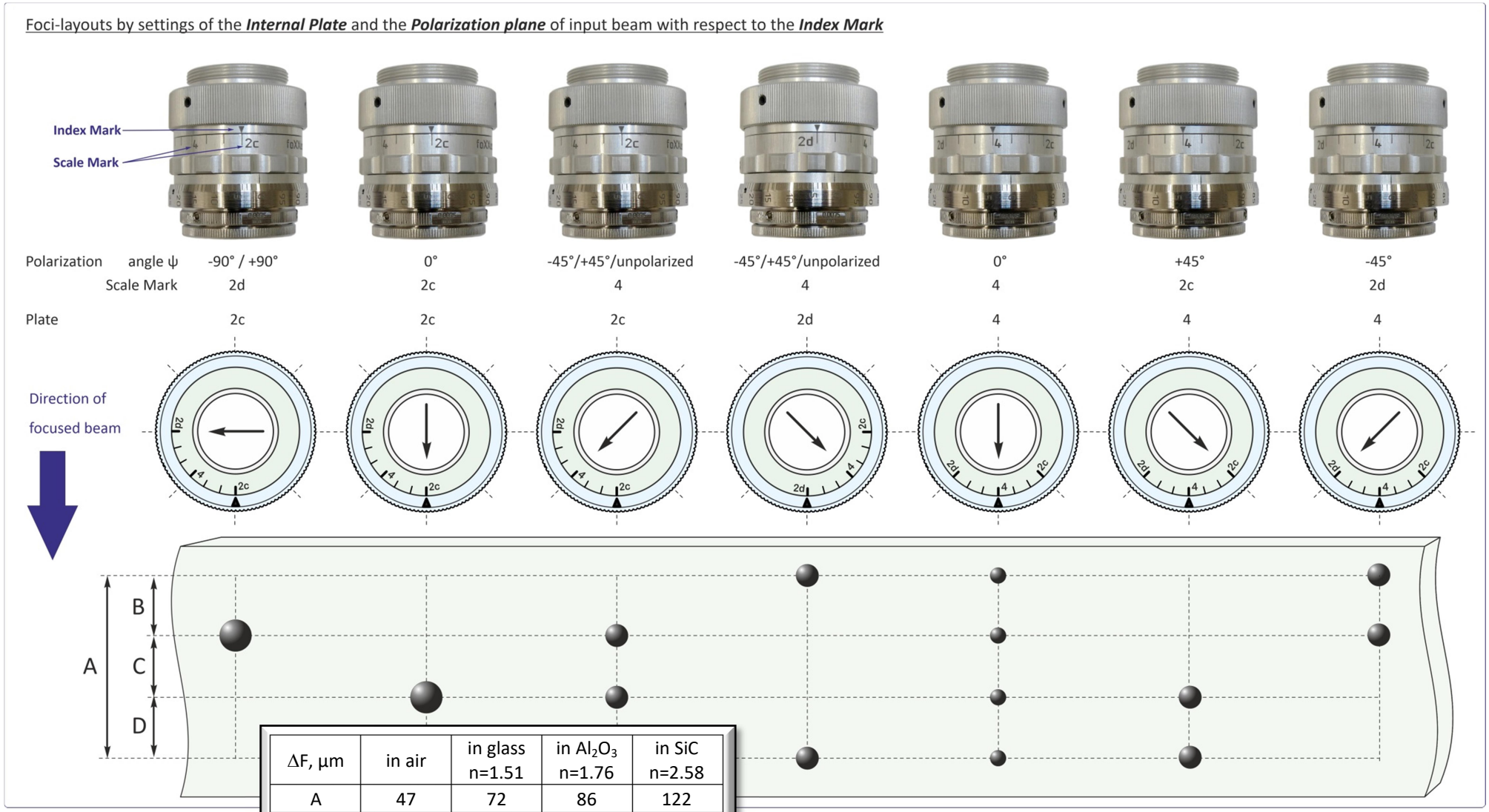


Fig. 6 Foci combinations and examples of view of zone of focuses with air breakdown by focusing fs pulses.

4. Table of foci-layouts with even energy portions

also in http://www.adloptica.com/pub/foxxus_na08_energy_distribution.xlsx

NA0.8



ΔF, µm	in air	in glass n=1.51	in Al_2O_3 n=1.76	in SiC n=2.58
A	47	72	86	122
B	16	24	29	42
C	15	24	28	39
D	16	24	29	42

Fig. 7 Settings of foXXus and external laser beam for various foci combinations.

5. Spectral properties

The optical design of the *foXXus* is optimized for operation in a specific working band, and the AR-coating of each *foXXus* model is optimized for the respective spectrum, detailed specifications are given in Table 2.

Table 2

foXXus 0.015-0.047_NA0.8	AR-coating	Optimum* spectrum, nm	Working band, nm (acceptable performance)
_1064	V-type @ 1040 nm	1020 - 1100	950 - 1150
_532	V-type @ 520 nm	510 - 545	500 - 560

Spectral transmission graphs are presented in Fig. 8.
These data are based on measurements of reflection of the optical surfaces with AR-coatings.
There may be deviations from the presented graphs in objectives of different production batches.

When operating in the Optimum spectrum, the total losses do not exceed 6%.

Using *foXXus* at a wavelength outside the optimal spectral band will affect the increasing in loss.

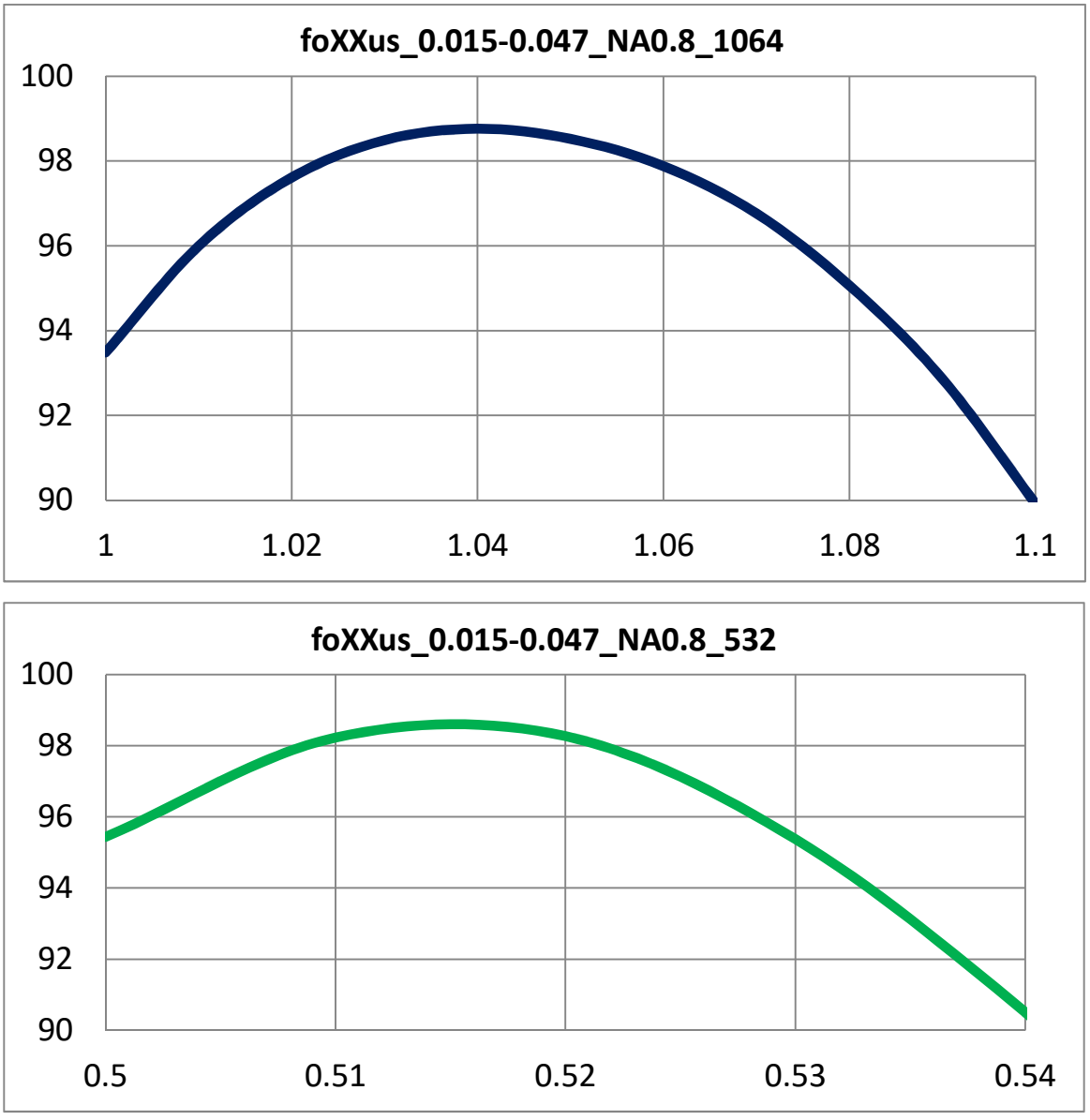


Fig. 8. *foXXus* Spectral transmission, %, versus wavelength, µm, other explanations in text.

NA0.8

6. Aberration correction by focusing inside transparent medium

foXXus 0.015-0.047_NA0.8 *(L9388 + L9388.44)*

Compensation of spherical aberration induced by processed transparent material is realized through rotation of the Collar "Aberration Correction", see the Figs. 4, 5:

- the pitch of the Collar thread is 0.75 mm,
- division value 0.0075 µm,
- rotating the Collar "Aberration Correction" results in longitudinal movement of optical component.

Recommended procedure to set aberration-free focusing inside transparent material

1) Setting the objective Collar in optimum for "0" depth corresponding to position of "0" mark of the Angular Scale against the Reference Mark – this is position installed by delivery of the foXXus objective.
2) Performing the focusing on a glass surface according to p. 8 "Recommendations to focusing procedure", and defining the settings for focus F_1 on the glass surface, corresponding to "0" Depth – this setting is initial one for further settings at different Depths inside various media presented in p.6, Tables 2-4.

   !! Important:
   While focusing procedure to move the objective DOWN to a workpiece, i.e. starting from longer distance!!
   To avoid focusing of reflected from a workpiece surface light inside the objective lens.

3) Setting the objective Collar in optimum position inside particular material using data of below Tables 2-4 in p.6:
   - Depth – focusing depth inside material, 1st focus closest to the objective,
   - Δ_1 – Collar shift towards rest part of the objective, to ***left*** in Fig. 4,
   - Δ_2 – Shift of complete objective, direction opposite to Δ_1, to ***right*** in Fig. 4,
   - WD - optimum Working Distance from the objective mechanical face to the medium surface,
   - NA - numerical aperture by input beam diameter 12.9 mm.
4) To shift the whole objective at value Δ_2 , thus providing optimum WD for the chosen Depth.
5) To do material processing and prove settings by stepwise variation of depth around the pre-determined value in range +/-10 µm and checking the processing result.
   If necessary, to correct position of Collar with checking processing result at the chosen depth.

!! Important:
!! By focusing in Al_2O_3, SiC, fused silica at depth 0 - 50 µm the working distances are practically constant,
therefore, for that range of focusing depths it is possible to apply alternative adjustment approach:
- after shifting the Collar "Aberration Correction" at distance Δ_1 according to below Tables 2-4 in p.6,
- to shift the whole objective in opposite direction at the same value,

then aberration-free focusing at required depth is provided.
Proving of optimum focusing according to above p. 5) is recommended to do anyway.

!! Important:
The closest position of the Collar to the rest objective part corresponds to ***maximum*** focusing depth in material under processing where total aberration compensation is provided.

!! Important:
While focusing procedure to move the objective DOWN to a workpiece, i.e. starting from longer distance!!
To avoid focusing of reflected from a workpiece surface light inside the objective lens.

7. Recommended design data of the Collar position, @1040 nm

here

- Depth – focusing depth inside material, 1st focus closest to the objective,
- Δ_1 – Collar shift towards rest part of the objective, to ***left*** in Fig. 4,
- Δ_2 – Shift of complete objective, direction opposite to Δ_1, to ***right*** in Fig. 4,
- WD - optimum Working Distance from the objective mechanical face to the medium surface,
- NA - numerical aperture by input beam diameter 12.9mm.

!! By setting the Collar and Objective positions it is recommended to prove focusing performance by stepwise variation of depth around the pre-determined value in range +/-10µm and checking the processing result. If necessary, to correct position of Collar with checking processing result at the chosen depth.

6.1 Without protective window

Fused Silica (SiO_2) Table 3

Depth, mm	Δ_1 , mm	Δ_2 , mm	WD, mm	NA
0 (air)	0	0	1.152	0.75
0 (SiO_2)	-0.088	0.108	1.172	0.76
0.01	-0.115	0.135	1.172	0.76
0.02	-0.142	0.161	1.171	0.76
0.03	-0.169	0.188	1.171	0.76
0.04	-0.195	0.213	1.170	0.77
0.05	-0.221	0.238	1.169	0.77
0.1	-0.346	0.358	1.164	0.77
0.15	-0.467	0.471	1.156	0.78

Sapphire (Al_2O_3) Table 4

Depth, mm	Δ_1 , mm	Δ_2 , mm	WD, mm	NA
0 (air)	0	0	1.152	0.75
0 (Al_2O_3)	-0.111	0.136	1.177	0.77
0.01	-0.137	0.163	1.178	0.77
0.02	-0.163	0.189	1.178	0.77
0.03	-0.189	0.216	1.179	0.77
0.04	-0.214	0.241	1.179	0.77
0.05	-0.239	0.266	1.179	0.77
0.1	-0.36	0.387	1.179	0.78
0.15	-0.476	0.502	1.178	0.79

Silicon Carbide (SiC) Table 5

Depth. mm	Δ_1 , mm	Δ_2 , mm	WD. mm	NA
0 (air)	0	0	1.152	0.75
0 (SiC)	-0.135	0.165	1.182	0.76
0.01	-0.154	0.185	1.183	0.76
0.02	-0.174	0.206	1.184	0.76
0.03	-0.194	0.227	1.185	0.77
0.04	-0.214	0.248	1.186	0.77
0.05	-0.233	0.267	1.186	0.77
0.1	-0.328	0.365	1.189	0.77
0.15	-0.418	0.458	1.192	0.78
0.2	-0.506	0.547	1.193	0.78

6.2 With protective window D12

!! Important: ***Initial position of the Collar Δ_1 = -0,394 mm, corresponding to compensation of the window thickness.***

Fused Silica (SiO_2)					Table 6
Depth, mm	Δ_1 , mm	Δ_2 , mm	WD, mm	NA	D_{beam}, mm
0 (air)	-0.394	0	0.939	0.79	12.9
0 (SiO_2)	-0.494	0.12	0.959	0.791	12.9
0.01	-0.519	0.144	0.958	0.792	12.9
0.02	-0.544	0.1675	0.9565	0.793	12.9
0.03	-0.569	0.191	0.955	0.794	12.9
0.04	-0.594	0.215	0.954	0.795	12.9
0.05	-0.619	0.239	0.953	0.796	12.9
0.1	-0.719	0.327	0.941	0.78	12.5
0.15	-0.744	0.325	0.914	0.68	10.9

Sapphire (Al_2O_3)					Table 7
Depth. mm	Δ_1 , mm	Δ_2 , mm	WD. mm	NA	D_{beam}. mm
0 (air)	-0.394	0	0.939	0.79	12.9
0 (Al_2O_3)	-0.494	0.12	0.959	0.791	12.9
0.01	-0.519	0.145	0.959	0.792	12.9
0.02	-0.544	0.17	0.959	0.793	12.9
0.03	-0.569	0.195	0.959	0.794	12.9
0.04	-0.594	0.22	0.959	0.795	12.9
0.05	-0.619	0.245	0.959	0.795	12.8
0.1	-0.719	0.339	0.953	0.78	12.5
0.15	-0.744	0.343	0.932	0.68	11.0

Silicon Carbide (SiC)					Table 8
Depth. mm	Δ_1 , mm	Δ_2 , mm	WD. mm	NA	D_{beam}. mm
0 (air)	-0.394	0	0.939	0.79	12.9
0 (SiC)	-0.494	0.12	0.959	0.791	12.9
0.01	-0.514	0.1406	0.9596	0.791	12.9
0.02	-0.534	0.161	0.96	0.792	12.9
0.03	-0.554	0.182	0.961	0.793	12.9
0.04	-0.574	0.2026	0.9616	0.794	12.9
0.05	-0.594	0.223	0.962	0.795	12.9
0.1	-0.694	0.3263	0.9653	0.8	12.9
0.15	-0.744	0.3696	0.9586	0.78	12.5
0.2	-0.744	0.352	0.941	0.68	11.0

8. Comments to view of processing results

The Collar position relates to the situation when the induced by material spherical aberration is totally compensated for the ***given*** focusing depth. In case of deviation of working depth from the given value the aberration is:

- overcompensated for smaller depth, and
- undercompensated for bigger depth.

Longitudinal spherical aberration induced by deep focusing inside material is ***positive***, and then peripheral rays of a beam intersect the optical axis ***after*** the paraxial focus (i.e. further from the objective) and certain portion of laser energy from the beam periphery is transferred and concentrated in elongated area *after* the focus.

When taking into account aberration effects only and omitting effects of interaction of laser energy and the material under processing, typical views of the processed area around a focus in different cases are:

- when uncompensated or undercompensated aberration there are observed a void in focus and a stroke-like volume of processed material ***after*** the void along optical axis,
- when totally compensated aberration the only void is observed,
- when overcompensated aberration there are observed a void in focus and a stroke-like volume of processed material ***before*** the void.

9. Recommendations to focusing procedure

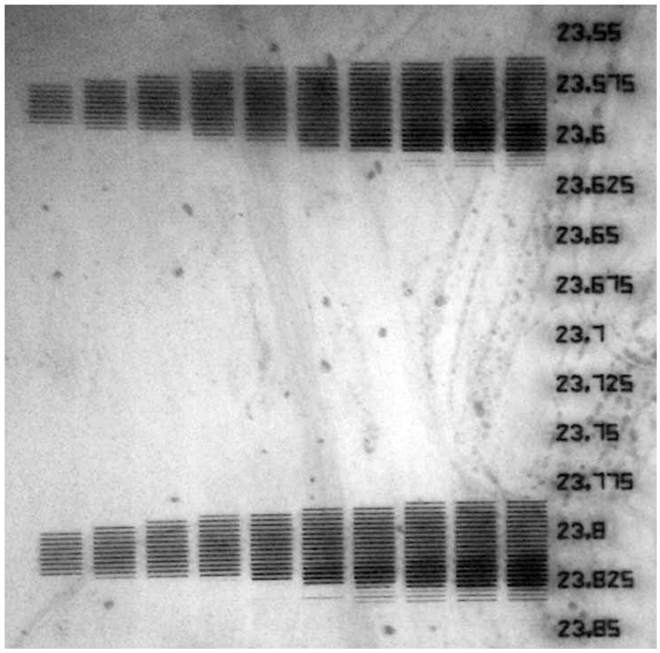
!! Important:

While focusing procedure to move the objective DOWN to a workpiece, i.e. starting from longer distance!!

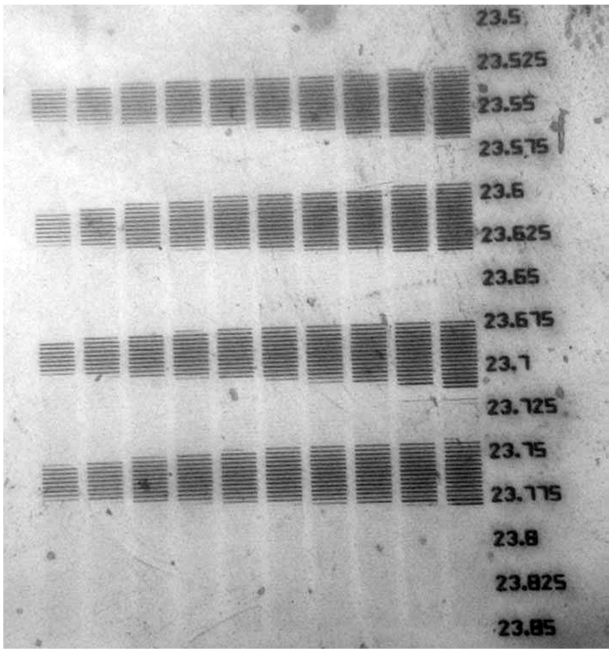
To avoid focusing of reflected from a workpiece surface light inside the objective lens.

- to do focusing procedure by processing the surface of glass or another material where traces of focused spot are visible,
- step-wise recording of test pattern, for example in form of a short line,
- focusing step 2.5 µm,
- to do focusing procedure using 2 - 3 pulse energy levels, when no essential material damage happens,
- to use 2 basic configurations: 2-distant foci, 4-foci,
- to analyse the processing results by a microscope.

Examples of focusing procedure for foXXus objective with NA0.38 are presented in below microphotographs by processing of glass surface.



2-distant foci
"Plate" - "2d" Polarization "4"



4-foci
"Plate" - "4" Polarization "2c"

Fig. 9 Settings Examples of focusing procedure with variation of pulse energy.

10. Window in Holder L9388.44

Current version “L9388 + L9388.44” of **foXXus 0.015-0.047_NA0.8** is equipped with the Protective Window in Holder “L9388.44” used to mount the replaceable Protective Window D12 (Ø12 mm, Thickness 0.17 mm).

Owing to high NA, foXXus has small working distance. Therefore the Holder, shown in Figs. 4, 5, is mounted using a thread on the Collar “Aberration Correction” and retains the Protective Window D12 which is inserted in the hollow of the Collar face.

In general, the procedure for replacing a Window is as follows:

- hold the foXXus vertically,
- twist off and dismantle the Holder L9388.44 from the foXXus,
- replace the Window D12, it is recommended to use plastic tweezers for careful handling,
- make sure that the new Window D12 is inserted in the hollow on the face of the Collar “Aberration Correction”,
- mount the Holder L9388.44 by turning.

Fig. 10 To replacement of the Protective Window D12.

11. Data for communication with a supplier

By the communication with a supplier for evaluation of the optics performance, it is recommended to present following data measured beforehand:

- Input beam
  - wavelength ,
  - CW or pulse,
  - M^2,
  - $1/e^2$ diameter,
  - power specifications,
  - pulse energy,
  - pulse width,
  - polarization state,
  - orientation of the polarization plane in the case of linearly polarized light,
  - astigmatism and ellipticity,
- Results of focusing procedure according to section 9. “Recommendations to focusing procedure”

  for example, in form of microphotographs by processing surface glass or another material,
- All data relating to the focusing procedure and material processing to be supplied with information about settings of the foXXus and orientation of the polarization plane.

!! Important:

Data with material processing are considered ONLY when the results of focusing procedure are presented.