AdlOptica

aplanoXX NA0.8_D20

(L9844)

High NA objective
with protective window,
with compensation of spherical aberration by focusing
inside transparent materials

Manual

October 15, 2021

Fig. 1 Objective outlook, without protective window.

aplanoXX NA0.8_D20

1. Specifications

Table 1

Items	Values
Description	Objectives of aplanatic design with • function of compensation of spherical aberration that occurs when focusing laser radiation in transparent media • replaceable protective window
Accessories	• Window in Holder L9333.06 • Protective Window D12_515/1030, D12_800, D12_1064 • Spanner Wrench K-26-0.4x0.4
Clear aperture	19.8 mm
Numerical Aperture (NA)	0.8
Focal length, mm	12.5
Working Distance, *with* the Window in Holder (distance from last *holder* mech. surface to a workpiece)	0.1 - 1.6 mm (depends on the focusing depth, see Chapter 5)
Working Distance, *no* Window (distance from last *objective* mech. surface to a workpiece)	0.7 - 2.5 mm (depends on the focusing depth, see Chapter 5)
Range of focusing depth in fused silica*, µm	0...4000
Spectral band, nm	_1030: 1020 – 1100 _800: 770 – 900 _515: 510 – 545 _800 / 1030: 770 – 900 / 1020 – 1100
Angular field of view (FOV) *	± 0.3° (by NA0.8)
Recommended maximum pulse energy	100 mJ at 5 ns 300 µJ at 1 ps
Mounting	C-Mount (1”-32 UN 2A), external other threads available on request
Diameter, mm	44
Length with window holder, mm	54.1

* - by diffraction limited focusing.

2. Description

The objective **aplanoXX NA0.8_D20_4**, hereinafter referred to as *aplanoXX*, is

- an objective of NA0.8, when the input beam diameter is 19.8 mm,
- aplanatic optical design ensures no spherical and coma aberrations by NA0.8 in the angular FOV ±0.3°, which reduces the sensitivity to misalignments when focusing laser radiation inside transparent materials,
- the function of compensation of spherical aberration that occurs when focusing in transparent media ensures diffraction limited high NA focusing of light at depths up to 4 mm in fused silica, sapphire and other transparent brittle materials,
- replaceable protective window prevents damage of the last outer optical surface caused by the particles ejected during the material processing.

The *aplanoXX* objectives are developed for use with modern ultra-short pulse lasers – the design of objectives assumes no focusing of partially reflected light ("ghosts") inside lenses, high resistant AR-coatings. This makes the *aplanoXX* objectives suitable for applications such as glass cutting, dicing of Al_2O_3, SiC and other brittle materials.
Drawings of two *aplanoXX* implementations, without and with the protective window, are presented in Fig. 2.

Applications:

- Microprocessing sapphire, fused silica, glass, Si, SiC,
- 3D micro- and nanofabrication,
- Nanostructuring in optical data storage and recording polarization converters,
- Selective Laser Etching,
- Waveguide recording,
- Dicing,
- Microscopy.

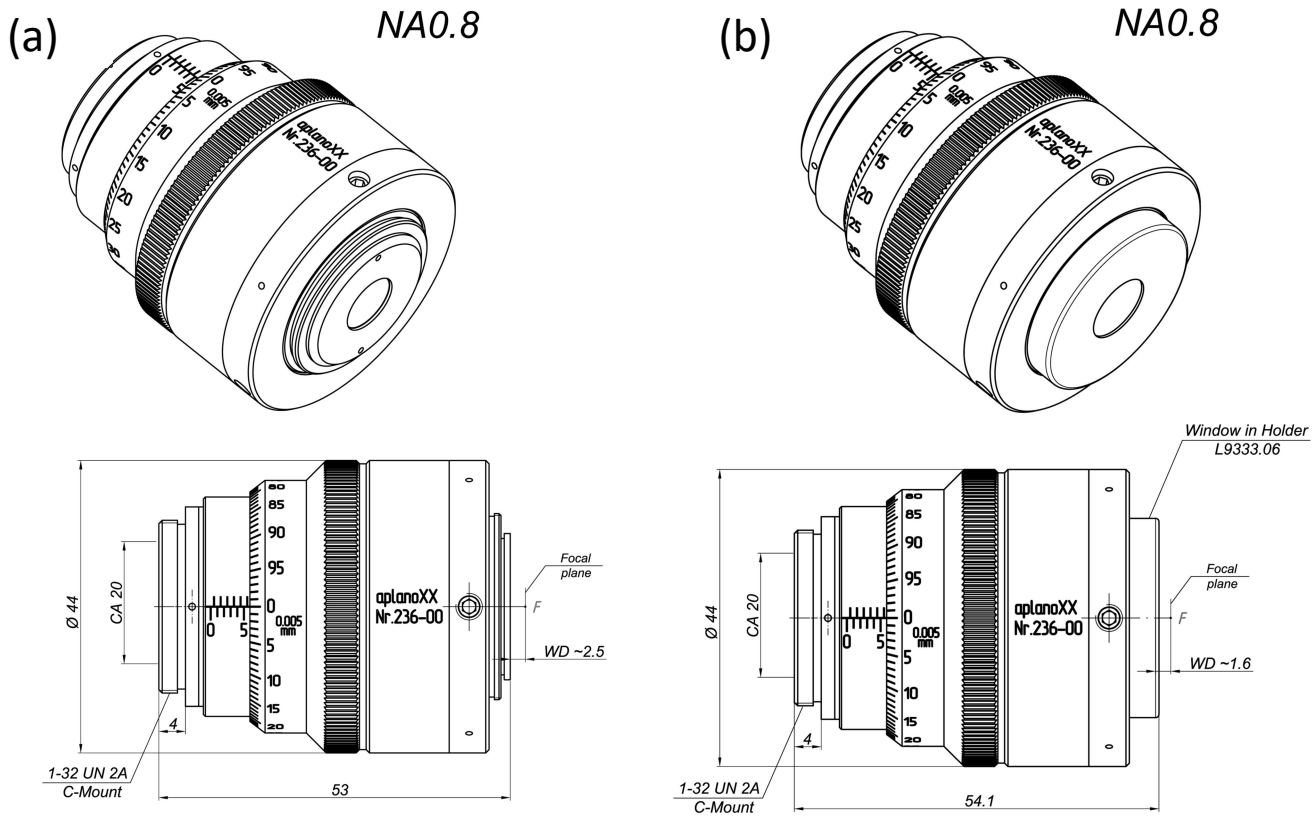

Fig. 2 aplanoXX NA0.8_D20 with overall and mounting dimensions:
(a) without protective window, (b) with protective window,
Working Distance (WD) in air.

3. Controls and Adjustments

The controls and adjustment means are presented in Fig. 3:

- Focusing Collar with Angular and Linear Scales,
  the mechanism of rotation and movement of the Focusing Collar is similar to that used in micrometer instruments,
  the thread pitch is 0.5 mm,
- Fixation Screws, to fix settings of the Focusing Collar,
- Replaceable Window D12 in Holder L9333.06,
- Mounting thread C-Mount.

Details of the adjustment procedure and tables of settings for different materials and focusing depths are described in the Chapter 5 “Settings for the diffraction limited in-depth focusing”.

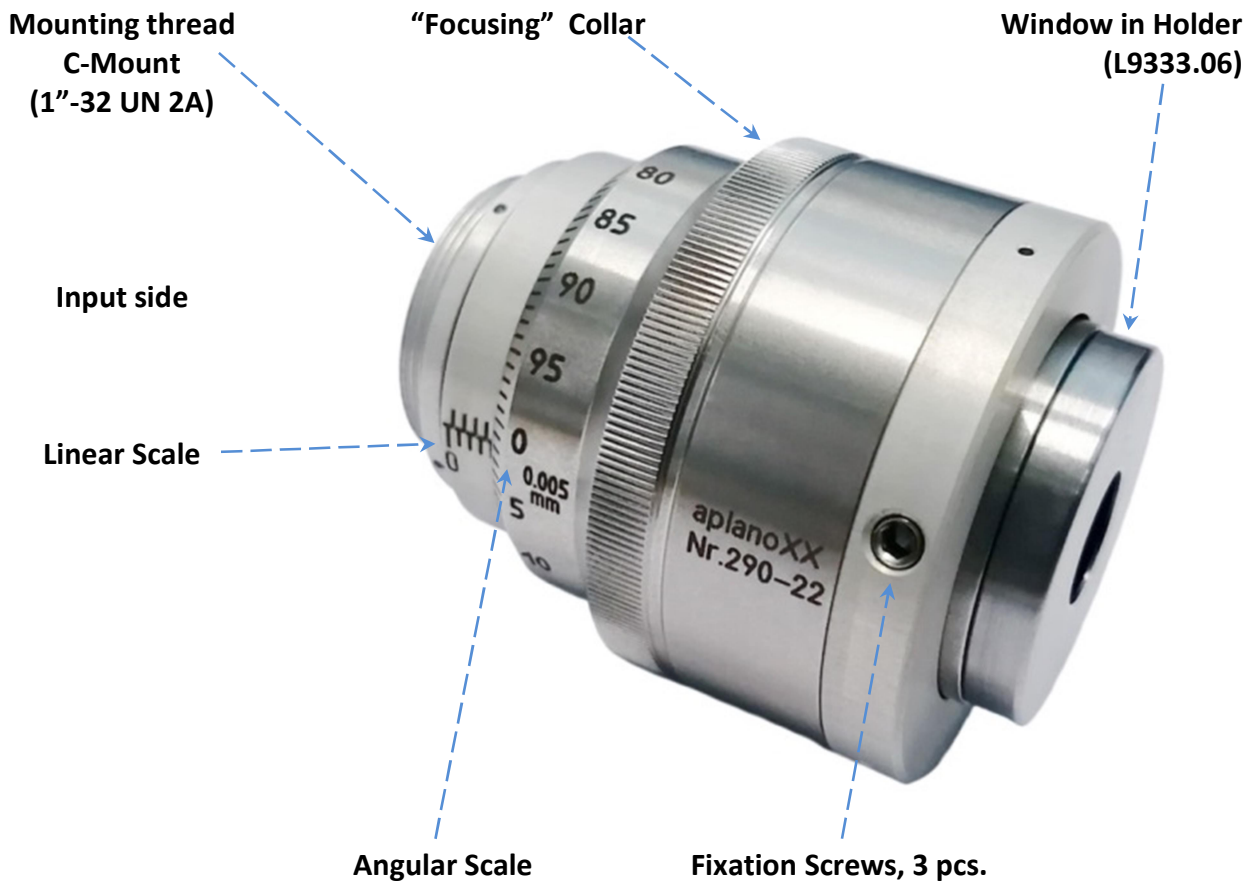

Fig. 3 aplanoXX NA0.8_D20 controls and adjustments.

4. Window in Holder L9333.06

The Holder L9333.06 is intended for mounting the Protective Window D12 (Ø12, Thickness 0.17 mm), Fig.4. The Window is fixed in the deepening on the back of the Holder using a Thread Ring, yellow detail in Fig.4.

For convenience, the Thread Ring is rotated using the Wrench shown on the left in Fig.4.

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

- twist off the Window in Holder L9333.06 to dismantle it from the *aplanoXX*, see Figs.2, 3,
- twist the yellow Thread Ring off using the Wrench,
- replace the Window D12, it is recommended to use plastic tweezers for careful handling,
- make sure that the new Window D12 is located inside the deepening on the back of the Holder,
- mount the Thread Ring by turning using the Wrench,
- mount the assembled new Window in Holder L9333.06 on the *aplanoXX*.

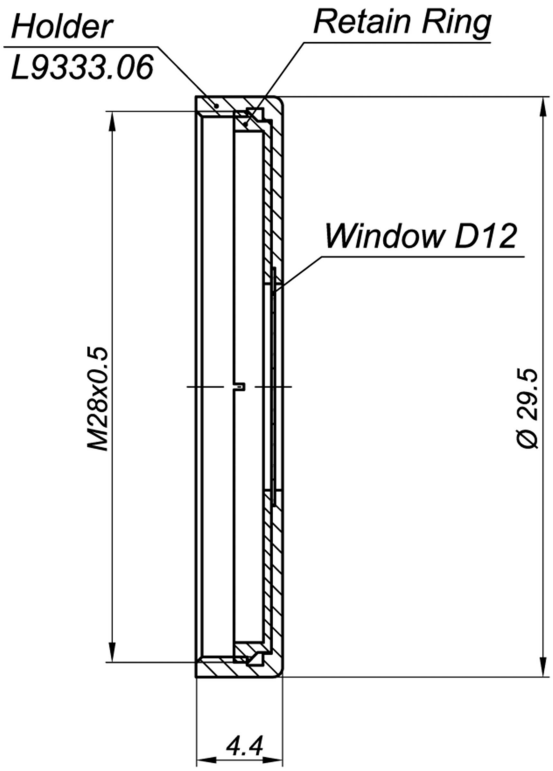

Fig. 4(a) Window in Holder L9333.06
with the installed Protective Window D12.

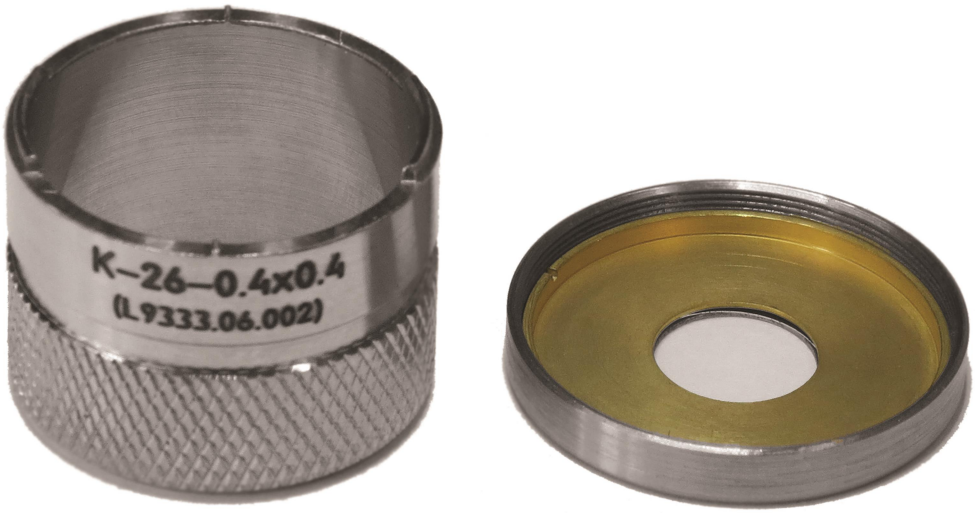

Fig. 4(b) Window in Holder L9333.06 with Wrench K-26-0.4x0.4.

5. Spectral properties

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

Table 2

aplanoXX NA0.8_D20_	AR-coating	Optimum* spectrum, nm	Working band, nm (acceptable performance)
_1030	V-type @ 1030 nm	1020 - 1100	950 - 1150
_800	Broadband	770 - 900	750 - 950
_515	V-type @ 515 nm	510 - 545	500 - 560

Spectral transmission graphs are presented in Fig. 5. 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 *aplanoXX* at a wavelength outside the optimal spectral band will affect the increasing in loss.

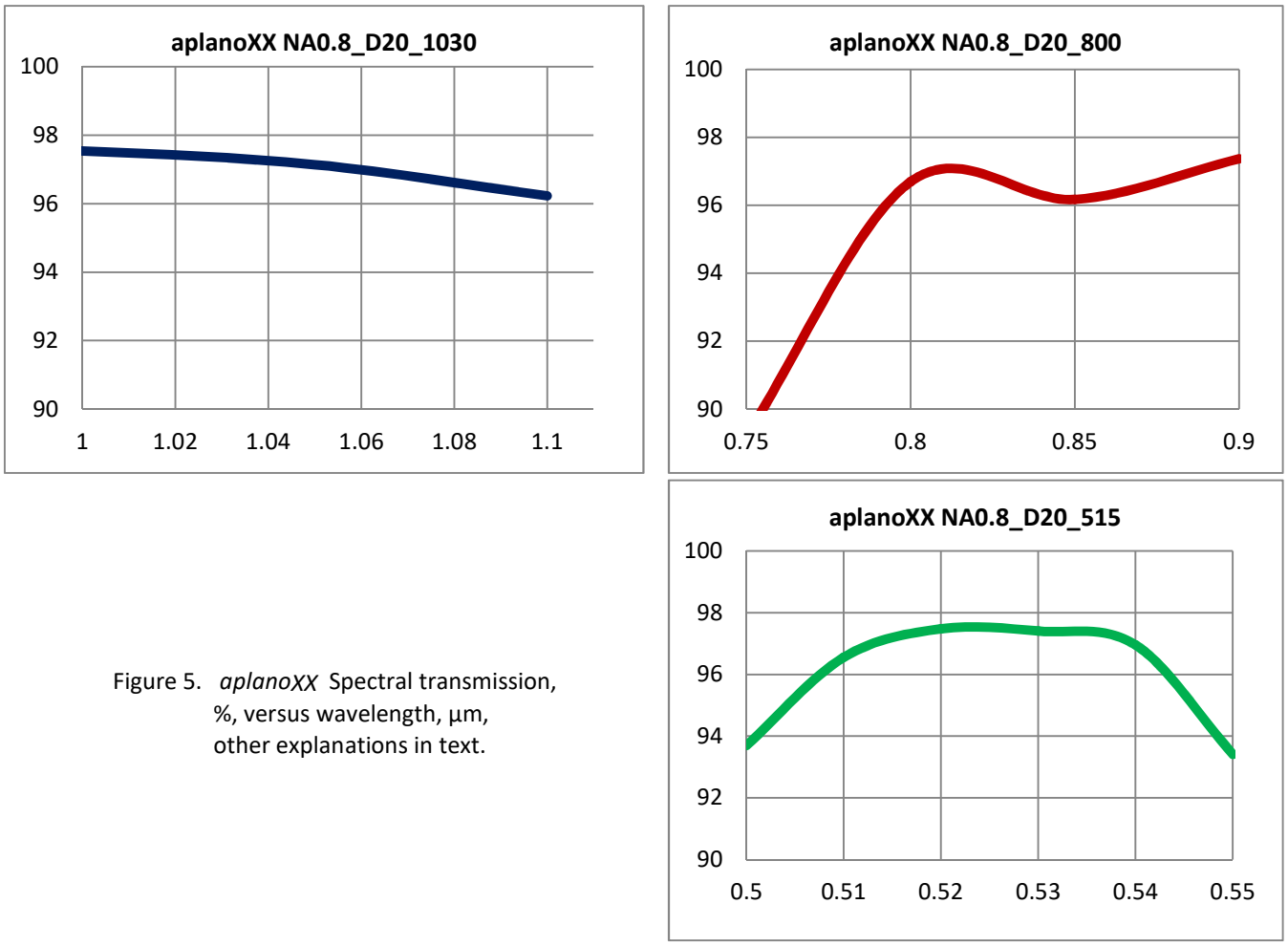

Figure 5. *aplanoXX* Spectral transmission, %, versus wavelength, µm, other explanations in text.

Protective Windows D12 are made of optical glass D263 (Schott), thickness 0.17 mm, are optimized for operation in a specific working band, detailed specifications are given in Table 3.

Table 3

Protective Window D12_	AR-coating	Optimum* spectrum, nm	Working band, nm (acceptable performance)
_515/1030	W-type @ 515 and 1030 nm	510 – 535 1020 - 1100	500 – 560 950 - 1150
_1064 (_1030)	V-type @ 1030 nm	1020 - 1100	950 - 1150
_800	V-type @ 800 nm	770 - 900	750 - 950

Spectral transmission graphs are presented in Fig. 6. 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 2%.

Using Protective Windows D12 at a wavelength outside the optimal spectral band will affect the increasing in loss.

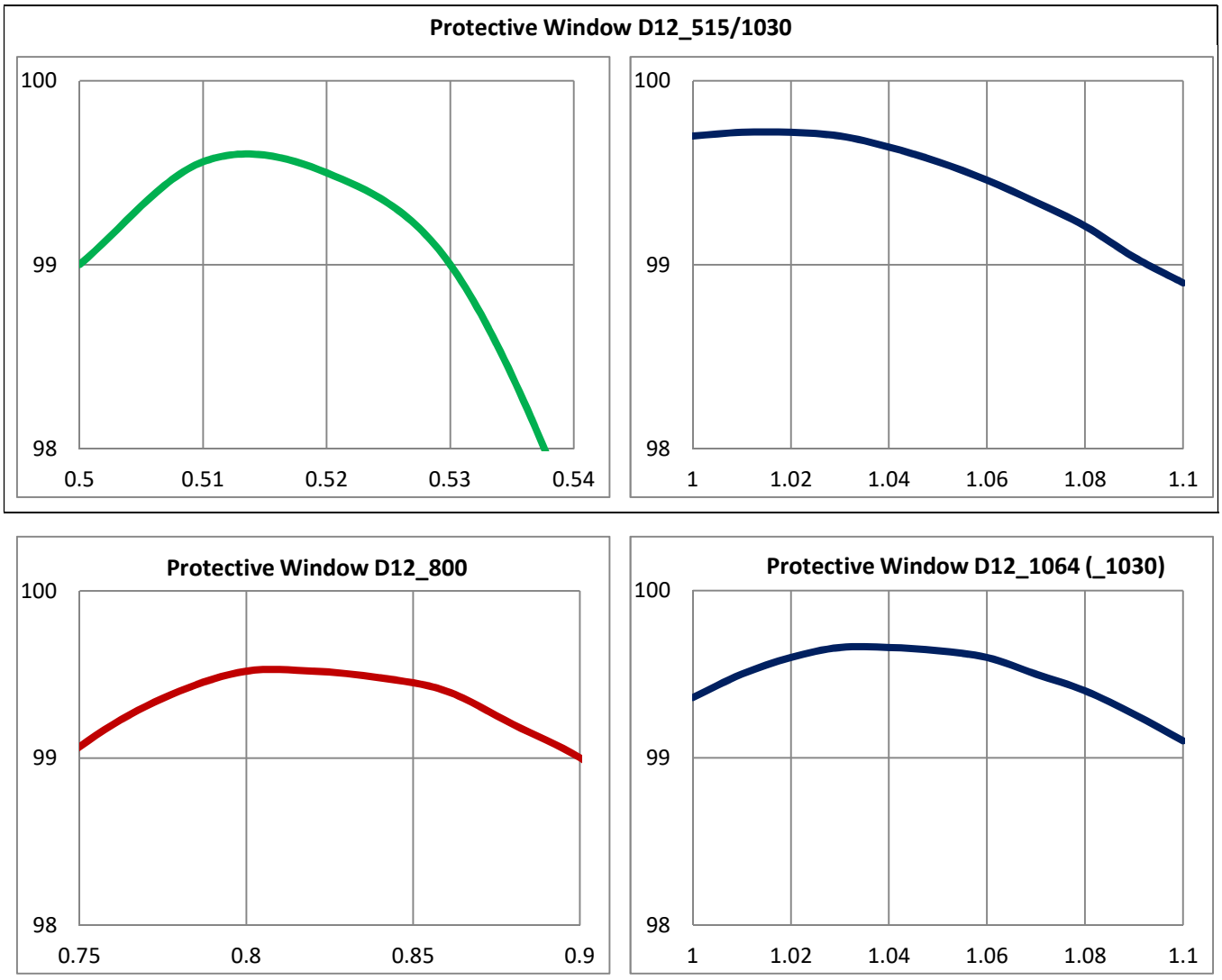

Figure 6. Spectral transmission of Protective Windows D12 , %, versus wavelength, µm, other explanations in text.

6. Settings for the diffraction limited in-depth focusing

This chapter presents the tables of optimal settings of the Focusing Collar and the entire *aplanoXX* objective when focusing inside transparent media under the following basic conditions:

- compensation of spherical aberration to ensure diffraction-limited focusing:
  RMS wavefront aberration <λ/14 according to the Maréchal criterion, which is optimal for efficient use of laser,
- various materials,
- variable depths,
- different wavelengths,
- with and without protective windows,
- no beam clipping on the lens holders,
- determining the optimum input beam diameter for each particular case.

!! Important:
Exceeding the diameter of the input beam results in appearing the spherical aberration, the acceptability of which should be analysed in a specific application.

Spherical aberration induced by focusing inside a transparent material is automatically compensated simultaneously with setting the processing depth when rotating the Focusing Collar and setting the Working distance according to the tables below. The mechanism of rotation and movement of the Focusing Collar is similar to that used in micrometer instruments.

Recommended procedure to set aberration-free focusing inside a transparent material

1) Set the Focusing Collar for "0" depth: marks "0" on the Linear Scale and Angular Scale, this setting also corresponds to aberration-free focusing in air.
2) Perform the focusing procedure, for example on a glass surface, and confirm the initial Working Distance.

!! Important:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!! To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

3) Set the Focusing Collar and Working Distance for the chosen depth using data fromFig.7 and the Tables below:
   - Depth — focusing depth inside material,
   - Δ_1 — longitudinal displacement of the Focusing Collar by its rotation, to ***right*** in the Drawing in Fig.3,
   - Δ_2 — longitudinal displacement of the entire objective using equipment movement tools, "0" corresponds to focus in air, to be defined using the focusing procedure, negative value means direction opposite to the direction of Δ_1,
   - WD — optimal Working Distance from the mechanical face of the Objective or the Window Holder to the flat surface of a workpiece,
   - D_{in} — beam diameter corresponding to NA_{dlf} when diffraction limited focusing,
   - NA_{dlf} — numerical aperture with ensured diffraction limited focusing (RMS wavefront aberration <λ/14), with taking into account: depth, wavelength, window, beam clipping on the lens holders.

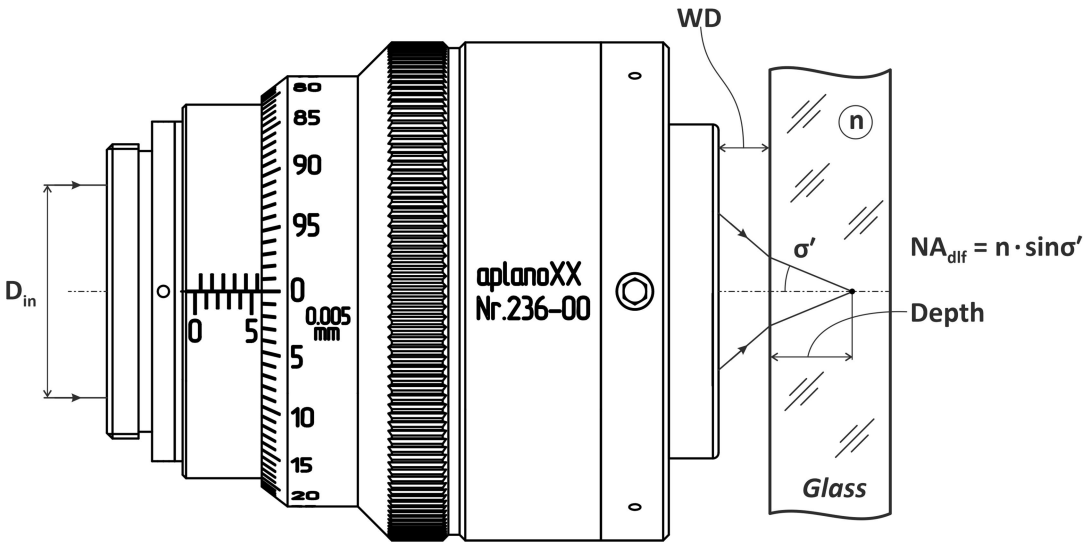

Figure 7 Focusing inside transparent media.

4) Carry out material processing and confirm the settings by stepwise variation of the depth around the pre-determined value in the range ±10 µm and checking the processing result.
If necessary, correct the setting of the Focusing Collar and Working Distance.

!! Important:
!! Longitudinal displacement Δ_2 less than ~10µm is practically negligible,
therefore, processing at depths, where Δ_2 is in the range from -10 µm to +10 µm, can be performed with constant WD and only rotation of the Focusing Collar, then spherical aberration is automatically compensated for the chosen processing depth. These settings are highlighted ***in green*** in the Tables below.
Checking the optimal focusing conditions according to above p. 4) is recommended in any case.

!! Important:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Comments to view of processing results

The Focusing Collar setting refers to a situation when the spherical aberration, induced by material, is totally compensated for a ***given*** focusing depth. If the working depth deviates from the specified value, the aberration is:

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

The longitudinal spherical aberration induced by in-depth focusing inside the transparent material is positive, therefore, the peripheral rays of the beam cross the optical axis after the paraxial focus (i.e. further from the objective), and a certain portion of the laser energy from the periphery of the beam is transferred and concentrated to an elongated area after the focus.

Considering the aberration effects only and not taking into account the effects of interaction of laser energy and the material under processing, typical types of the processed area around a focus in different cases are:

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

Fused Silica @1027 nm Table 6.1

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0	0	2.581	19.8	0.78	0	0.427	0	1.67	19.8	0.8
0.05	0.129	0.003	2.578	19.8	0.79	0.05	0.544	0.007	1.663	19.8	0.8
0.1	0.255	0.008	2.573	19.8	0.79	0.1	0.659	0.015	1.655	19.8	0.81
0.2	0.496	0.020	2.561	19.8	0.8	0.2	0.88	0.033	1.637	19.6	0.81
0.3	0.723	0.037	2.544	19.6	0.8	0.3	1.09	0.054	1.616	19.3	0.8
0.4	0.941	0.056	2.525	19.4	0.8	0.4	1.293	0.078	1.592	19.1	0.8
0.5	1.149	0.077	2.504	19.2	0.8	0.5	1.489	0.103	1.567	18.9	0.8
0.75	1.63	0.143	2.438	18.4	0.79	0.75	1.952	0.174	1.496	18.4	0.8
1	2.053	0.223	2.358	17.3	0.75	1	2.353	0.26	1.41	17.3	0.77
1.25	2.445	0.311	2.27	16.5	0.73	1.25	2.722	0.354	1.316	16.4	0.74
1.5	2.812	0.406	2.175	15.85	0.71	1.5	3.062	0.455	1.215	15.6	0.71
1.75	3.15	0.508	2.073	15.2	0.69	1.75	3.393	0.56	1.11	15.1	0.69
2	3.467	0.615	1.966	14.6	0.67	2	3.702	0.67	1	14.5	0.67
2.25	3.771	0.726	1.855	14.1	0.65	2.25	3.984	0.785	0.885	13.9	0.65
2.5	4.065	0.84	1.741	13.7	0.64	2.5	4.257	0.903	0.767	13.4	0.63
2.75	4.356	0.955	1.626	13.4	0.63	2.75	4.538	1.021	0.649	13.1	0.62
3	4.634	1.074	1.507	13.1	0.62	3	4.806	1.142	0.528	12.8	0.61
3.25	4.899	1.195	1.386	12.8	0.61	3.25	5.063	1.265	0.405	12.5	0.6
3.5	5.146	1.32	1.261	12.45	0.6	3.5	5.273	1.396	0.274	12.3	0.6
3.75	5.273	1.465	1.116	12.1	0.58	3.75	5.273	1.562	0.108	11.4	0.55
4	5.273	1.632	0.949	11.1	0.53	3.9	5.273	1.663	0.007	10.8	0.51

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing
  (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Fused Silica @800 nm Table 6.2

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0.196	0.044	2.537	19.8	0.79	0	0.645	0.04	1.63	19.8	0.81
0.05	0.333	0.046	2.535	19.8	0.795	0.05	0.768	0.046	1.624	19.8	0.81
0.1	0.465	0.049	2.532	19.8	0.8	0.1	0.888	0.053	1.617	19.8	0.82
0.2	0.716	0.06	2.521	19.6	0.8	0.2	1.118	0.07	1.6	19.6	0.82
0.3	0.953	0.075	2.506	19.4	0.8	0.3	1.338	0.09	1.58	19.4	0.82
0.4	1.178	0.093	2.488	19.1	0.8	0.4	1.55	0.112	1.558	19.2	0.82
0.5	1.393	0.114	2.467	18.9	0.8	0.5	1.75	0.137	1.533	18.8	0.81
0.75	1.898	0.176	2.405	18.4	0.8	0.75	2.211	0.21	1.46	17.8	0.79
1	2.338	0.253	2.328	17.3	0.77	1	2.623	0.294	1.376	16.8	0.754
1.25	2.733	0.342	2.239	16.3	0.73	1.25	2.999	0.388	1.282	15.9	0.72
1.5	3.107	0.437	2.144	15.6	0.71	1.5	3.353	0.488	1.182	15.2	0.7
1.75	3.451	0.539	2.042	14.9	0.69	1.75	3.687	0.592	1.078	14.6	0.68
2	3.775	0.645	1.936	14.3	0.67	2	3.996	0.703	0.967	14	0.66
2.25	4.086	0.756	1.825	13.8	0.65	2.25	4.304	0.814	0.856	13.6	0.644
2.5	4.387	0.869	1.712	13.4	0.64	2.5	4.595	0.93	0.74	13.2	0.63
2.75	4.672	0.986	1.595	13	0.62	2.75	4.87	1.049	0.621	12.8	0.62
3	4.955	1.104	1.477	12.7	0.613	3	5.145	1.17	0.5	12.5	0.607
3.25	5.226	1.225	1.356	12.4	0.603	3.25	5.373	1.298	0.372	12.1	0.59
3.5	5.373	1.367	1.214	11.9	0.58	3.5	5.373	1.464	0.206	11.1	0.535
3.75	5.373	1.534	1.047	10.8	0.52						
4	5.373	1.702	0.879	9.8	0.47						

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Fused Silica @515 nm Table 6.3

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0.732	0	2.391	19.8	0.82	0	1.257	0	1.496	19.5	0.83
0.05	0.895	-0.002	2.393	19.8	0.82	0.05	1.397	0.004	1.492	19.3	0.83
0.1	1.051	-0.003	2.394	19.8	0.83	0.1	1.535	0.009	1.487	19.3	0.83
0.2	1.34	0.003	2.388	19.3	0.82	0.2	1.795	0.022	1.474	19	0.83
0.3	1.609	0.013	2.378	18.9	0.82	0.3	2.038	0.039	1.457	18.5	0.82
0.4	1.862	0.028	2.363	18.5	0.81	0.4	2.261	0.061	1.435	17.8	0.8
0.5	2.1	0.047	2.344	18.1	0.8	0.5	2.47	0.086	1.41	17.1	0.77
0.75	2.623	0.11	2.281	16.5	0.75	0.75	2.954	0.159	1.337	15.8	0.73
1	3.097	0.185	2.206	15.5	0.72	1	3.392	0.243	1.253	14.8	0.69
1.25	3.525	0.272	2.119	14.6	0.69	1.25	3.803	0.334	1.162	14.1	0.67
1.5	3.924	0.365	2.026	13.9	0.66	1.5	4.186	0.432	1.064	13.5	0.65
1.75	4.298	0.466	1.925	13.3	0.64	1.75	4.54	0.536	0.96	12.9	0.63
2	4.643	0.572	1.819	12.7	0.62	2	4.877	0.645	0.851	12.4	0.61
2.25	4.973	0.682	1.709	12.2	0.6	2.25	5.203	0.756	0.74	12	0.6
2.5	5.273	0.798	1.593	11.9	0.59	2.5	5.273	0.91	0.586	10.7	0.53
2.75	5.273	0.964	1.427	10.1	0.5	2.75	5.273	1.078	0.418	9.1	0.44
3	5.273	1.132	1.259	8.7	0.42	3	5.273	1.247	0.249	8	0.39

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing
  (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Sapphire (ordinary) **@1027 nm** Table 6.4

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0	0	2.581	19.8	0.78	0	0.427	0	1.67	19.8	0.8
0.05	0.127	-0.002	2.583	19.8	0.79	0.05	0.542	0.001	1.669	19.8	0.8
0.1	0.249	-0.003	2.584	19.8	0.79	0.1	0.653	0.004	1.666	19.8	0.81
0.2	0.484	-0.001	2.582	19.8	0.8	0.2	0.869	0.011	1.659	19.7	0.81
0.3	0.707	0.004	2.577	19.6	0.8	0.3	1.076	0.021	1.649	19.5	0.81
0.4	0.92	0.012	2.569	19.4	0.8	0.4	1.275	0.033	1.637	19.2	0.81
0.5	1.125	0.022	2.559	19.2	0.8	0.5	1.465	0.047	1.623	18.8	0.8
0.75	1.875	0.057	2.524	18.7	0.8	0.75	1.922	0.089	1.581	18.4	0.8
1	2.054	0.101	2.48	18.3	0.8	1	2.352	0.139	1.531	18	0.8
1.25	2.477	0.154	2.427	17.9	0.8	1.25	2.742	0.199	1.471	17.2	0.78
1.5	2.857	0.216	2.365	17	0.77	1.5	3.103	0.267	1.403	16.4	0.75
1.75	3.208	0.286	2.295	16.15	0.74	1.75	3.435	0.341	1.329	15.6	0.72
2	3.543	0.36	2.221	15.5	0.72	2	3.757	0.418	1.252	15	0.7
2.25	3.86	0.438	2.143	14.9	0.7	2.25	4.066	0.499	1.171	14.5	0.68
2.5	4.165	0.52	2.061	14.4	0.68	2.5	4.358	0.584	1.086	14	0.67
2.75	4.452	0.606	1.975	13.9	0.66	2.75	4.644	0.671	0.999	13.6	0.65
3	4.745	0.692	1.889	13.6	0.65	3	4.927	0.759	0.911	13.3	0.64
3.25	5.014	0.783	1.798	13.2	0.64	3.25	5.199	0.85	0.82	13	0.63
3.5	5.273	0.876	1.705	12.9	0.63	3.5	5.273	0.972	0.698	12.2	0.59
3.75	5.273	1.011	1.57	11.8	0.57	3.75	5.273	1.109	0.561	11	0.52
3.9	5.273	1.094	1.487	11	0.52	3.9	5.273	1.193	0.477	10.3	0.49
4	5.273	1.149	1.432	10.6	0.5	4	5.273	1.248	0.422	9.9	0.47

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Medium after a Glass Plate @1027 nm **! WD > 0.7 !** Table 6.5

Multi-layer structure, Fig. 8:
Glass Plate + Medium,
focusing inside the Medium,
no Window in Holder L9333.06 applied.

The transparent Medium:
- refractive index $n'_d = 1.376$,
- Abbe number $v_d = 56$;

the Glass Plate:
- N-BK7 (Schott),
- refractive index $n_d = 1.5168$,
- Abbe number $v_d = 64.2$,
- thickness $t = 2$ mm.

Legend, Fig. 8:
- Depth focusing depth inside the Medium,
- Δ_1 longitudinal shift of the Focusing Collar by rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing
  (RMS wavefront aberration <λ/14, the Maréchal criterion).

Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	3.539	0	2.032	15	0.69
0.05	3.6	0.024	2.008	14.9	0.69
0.1	3.66	0.049	1.983	14.8	0.69
0.2	3.777	0.098	1.934	14.6	0.68
0.3	3.892	0.148	1.884	14.4	0.67
0.4	4.003	0.199	1.833	14.2	0.66
0.5	4.111	0.251	1.781	14	0.66
0.6	4.216	0.303	1.729	13.8	0.65
0.7	4.33	0.354	1.678	13.7	0.65
0.8	4.43	0.407	1.625	13.5	0.64
0.9	4.54	0.459	1.573	13.4	0.64
1	4.635	0.513	1.519	13.2	0.63
1.1	4.741	0.566	1.466	13.1	0.63
1.2	4.846	0.619	1.413	13	0.62
1.3	4.941	0.674	1.358	12.9	0.62
1.4	5.034	0.729	1.303	12.7	0.61
1.5	5.133	0.784	1.248	12.6	0.61
1.6	5.231	0.838	1.194	12.5	0.61
1.7	5.273	0.902	1.13	12.4	0.6
1.8	5.273	0.972	1.06	12.1	0.58
1.9	5.273	1.043	0.989	11.7	0.56
2	5.273	1.114	0.918	11.3	0.54

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! Important:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

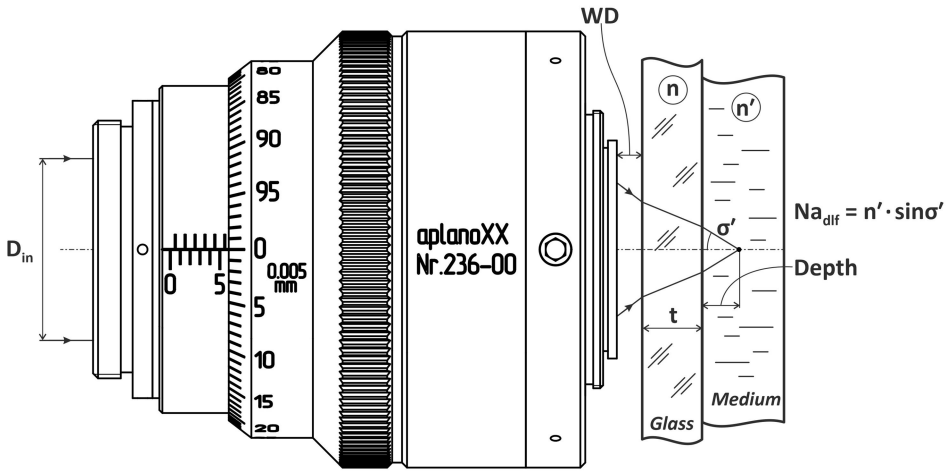

Figure 8 Focusing inside a transparent Medium with refractive index n' after a Glass Plate of refractive index n and thickness t .

PMMA @800 nm Table 6.6

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0.196	0.044	2.537	19.8	0.79	0	0.645	0.04	1.63	19.8	0.81
0.05	0.333	0.045	2.536	19.8	0.8	0.05	0.768	0.045	1.625	19.8	0.81
0.1	0.466	0.048	2.533	19.8	0.8	0.1	0.888	0.051	1.619	19.8	0.82
0.2	0.718	0.057	2.524	19.6	0.8	0.2	1.119	0.067	1.603	19.6	0.82
0.3	0.956	0.07	2.511	19.4	0.8	0.3	1.34	0.084	1.586	19.4	0.82
0.4	1.181	0.086	2.495	19.1	0.8	0.4	1.549	0.106	1.564	19	0.81
0.5	1.396	0.106	2.475	18.8	0.8	0.5	1.749	0.129	1.541	18.6	0.8
0.75	1.905	0.163	2.418	18.4	0.8	0.75	2.225	0.195	1.475	18	0.8
1	2.347	0.236	2.345	17.3	0.77	1	2.634	0.277	1.393	16.8	0.76
1.25	2.747	0.32	2.261	16.3	0.73	1.25	3.013	0.366	1.304	15.9	0.72
1.5	3.085	0.41	2.171	15.6	0.71	1.5	3.371	0.461	1.209	15.2	0.7
1.75	3.48	0.506	2.075	15	0.69	1.75	3.708	0.562	1.108	14.6	0.68
2	3.8	0.61	1.971	14.3	0.67	2	4.021	0.668	1.002	14	0.66
2.25	4.114	0.716	1.865	13.8	0.65	2.25	4.332	0.775	0.895	13.6	0.65
2.5	4.419	0.825	1.756	13.4	0.64	2.5	4.626	0.886	0.784	13.2	0.63
2.75	4.707	0.938	1.643	13	0.62	2.75	4.905	1.001	0.669	12.8	0.62
3	4.993	1.052	1.529	12.7	0.62	3	5.182	1.117	0.553	12.5	0.61
3.25	5.266	1.169	1.412	12.4	0.61	3.25	5.373	1.248	0.422	12.1	0.59
3.5	5.373	1.313	1.268	11.7	0.57	3.5	5.373	1.41	0.26	11	0.53
3.75	5.373	1.476	1.105	10.6	0.51						
4	5.373	1.641	0.94	9.6	0.46						

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing
  (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

PMMA @1027 nm Table 6.7

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0	0	2.581	19.8	0.78	0	0.427	0	1.67	19.8	0.8
0.05	0.13	0.002	2.579	19.8	0.79	0.05	0.545	0.006	1.664	19.8	0.8
0.1	0.256	0.006	2.575	19.8	0.79	0.1	0.66	0.013	1.657	19.8	0.81
0.2	0.497	0.017	2.564	19.8	0.8	0.2	0.883	0.029	1.641	19.8	0.82
0.3	0.726	0.031	2.55	19.6	0.8	0.3	1.096	0.048	1.622	19.6	0.82
0.4	0.944	0.049	2.532	19.4	0.8	0.4	1.298	0.07	1.6	19.2	0.81
0.5	1.153	0.069	2.512	19.2	0.8	0.5	1.495	0.094	1.576	19	0.81
0.75	1.647	0.128	2.453	18.8	0.81	0.75	1.959	0.161	1.509	18.4	0.8
1	2.103	0.197	2.384	18.3	0.8	1	2.378	0.24	1.43	17.6	0.78
1.25	2.496	0.282	2.299	17.2	0.77	1.25	2.754	0.329	1.341	16.7	0.75
1.5	2.865	0.372	2.209	16.4	0.74	1.5	3.102	0.425	1.245	15.9	0.72
1.75	3.202	0.471	2.11	15.6	0.71	1.75	3.436	0.525	1.145	15.3	0.71
2	3.536	0.572	2.009	15.1	0.7	2	3.756	0.629	1.041	14.8	0.69
2.25	3.848	0.677	1.904	14.6	0.68	2.25	4.055	0.738	0.932	14.3	0.67
2.5	4.141	0.788	1.793	14.1	0.66	2.5	4.347	0.849	0.821	13.9	0.66
2.75	4.427	0.9	1.681	13.7	0.65	2.75	4.624	0.963	0.707	13.5	0.65
3	4.698	1.016	1.565	13.3	0.64	3	4.886	1.081	0.589	13.1	0.63
3.25	4.969	1.133	1.448	13	0.63	3.25	5.149	1.2	0.47	12.8	0.62
3.5	5.228	1.252	1.329	12.7	0.62	3.5	5.373	1.325	0.345	12.5	0.61
3.75	5.373	1.39	1.191	12.3	0.6	3.75	5.373	1.487	0.183	11.6	0.56
4	5.373	1.553	1.028	11.3	0.54	4	5.373	1.651	0.019	10.6	0.5

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Silicon Carbide, n_o (SiC-o) @1027 nm Table 6.8

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0	0	2.581	19.8	0.78	0	0.427	0	1.67	19.8	0.8
0.05	0.099	-0.005	2.586	19.8	0.79	0.05	0.517	-0.002	1.672	19.8	0.8
0.1	0.196	-0.009	2.590	19.8	0.79	0.1	0.604	-0.003	1.673	19.8	0.81
0.2	0.383	-0.014	2.595	19.8	0.8	0.2	0.775	-0.004	1.674	19.8	0.81
0.3	0.561	-0.018	2.599	19.8	0.81	0.3	0.939	-0.004	1.674	19.7	0.82
0.4	0.732	-0.019	2.600	19.8	0.81	0.4	1.099	-0.002	1.672	19.6	0.82
0.5	0.898	-0.019	2.600	19.6	0.81	0.5	1.254	0.002	1.668	19.4	0.82
0.75	1.291	-0.012	2.593	19.3	0.81	0.75	1.626	0.015	1.655	18.9	0.81
1	1.662	0.002	2.579	18.7	0.81	1	1.978	0.035	1.635	18.5	0.81
1.25	2.013	0.022	2.559	18.4	0.81	1.25	2.317	0.058	1.612	18.1	0.81
1.5	2.348	0.046	2.535	18.1	0.81	1.5	2.636	0.087	1.583	17.7	0.8
1.75	2.670	0.075	2.506	17.7	0.8	1.75	2.948	0.119	1.551	17.4	0.8
2	2.976	0.107	2.474	17.1	0.78	2	3.251	0.153	1.517	17.1	0.8
2.25	3.276	0.143	2.438	16.8	0.78	2.25	3.545	0.191	1.479	16.8	0.79
2.5	3.567	0.181	2.400	16.5	0.78	2.5	3.814	0.233	1.437	16.2	0.77
2.75	3.844	0.222	2.359	16.1	0.77	2.75	4.070	0.279	1.391	15.6	0.75
3	4.100	0.268	2.313	15.5	0.74	3	4.318	0.327	1.343	15.1	0.73
3.25	4.355	0.314	2.267	15.1	0.73	3.25	4.563	0.376	1.294	14.7	0.71
3.5	4.600	0.364	2.217	14.7	0.72	3.5	4.797	0.427	1.243	14.3	0.7
3.75	4.835	0.415	2.166	14.3	0.7	3.75	5.032	0.479	1.191	14.0	0.69
4	5.051	0.47	2.111	13.8	0.68	4	5.253	0.534	1.136	13.7	0.67
4.25	5.286	0.523	2.058	13.6	0.67	4.25	5.373	0.605	1.065	13.1	0.65
4.5	5.373	0.599	1.982	12.9	0.63	4.5	5.373	0.696	0.974	11.9	0.57
4.75	5.373	0.69	1.891	11.6	0.56	4.75	5.373	0.789	0.881	10.7	0.51
5	5.373	0.783	1.798	10.5	0.5	5	5.373	0.883	0.787	9.8	0.46

Legend, Fig. 7:

- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing
  (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Silicon (Si) @1070 nm Table 6.9

No protective window ! WD > 0.7 !						With protective window, D263 thickness 0.17 mm					
Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}	Depth, mm	Δ_1, mm	Δ_2, mm	WD, mm	D_{in}, mm	NA_{dlf}
0	0	0	2.594	19.8	0.78	0	0.394	0	1.676	19.8	0.8
0.05	0.046	0.002	2.592	19.8	0.78	0.05	0.462	-0.002	1.678	19.8	0.8
0.1	0.12	-0.001	2.595	19.8	0.79	0.1	0.529	-0.003	1.679	19.8	0.8
0.2	0.263	-0.008	2.602	19.8	0.79	0.2	0.66	-0.006	1.682	19.8	0.81
0.3	0.402	-0.012	2.606	19.8	0.8	0.3	0.787	-0.007	1.683	19.8	0.81
0.4	0.536	-0.016	2.61	19.8	0.8	0.4	0.911	-0.008	1.684	19.8	0.82
0.5	0.665	-0.018	2.612	19.8	0.81	0.5	1.032	-0.008	1.684	19.7	0.82
0.75	0.976	-0.02	2.614	19.7	0.82	0.75	1.325	-0.004	1.68	19.3	0.82
1	1.272	-0.017	2.611	19.4	0.82	1	1.605	0.004	1.672	18.9	0.81
1.25	1.555	-0.01	2.604	19	0.81	1.25	1.873	0.015	1.661	18.6	0.81
1.5	1.826	0.001	2.593	18.7	0.81	1.5	2.133	0.029	1.647	18.3	0.81
1.75	2.087	0.014	2.58	18.4	0.81	1.75	2.384	0.046	1.63	18	0.8
2	2.341	0.03	2.564	18.1	0.81	2	2.628	0.064	1.612	17.8	0.8
2.25	2.586	0.048	2.546	17.8	0.8	2.25	2.866	0.085	1.591	17.55	0.8
2.5	2.826	0.069	2.525	17.6	0.8	2.5	3.099	0.107	1.569	17.3	0.8
2.75	3.059	0.091	2.503	17.3	0.8	2.75	3.327	0.131	1.545	17.1	0.8
3	3.289	0.114	2.48	17.1	0.8	3	3.548	0.157	1.519	16.8	0.79
3.25	3.513	0.139	2.455	16.9	0.8	3.25	3.767	0.184	1.492	16.6	0.79
3.5	3.734	0.166	2.428	16.7	0.8	3.5	3.983	0.212	1.464	16.4	0.79
3.75	3.951	0.193	2.401	16.5	0.79	3.75	4.178	0.244	1.432	15.9	0.77
4	4.159	0.223	2.371	16.2	0.79	4	4.371	0.276	1.4	15.5	0.75
4.25	4.354	0.255	2.339	15.75	0.77	4.25	4.564	0.309	1.367	15.15	0.74
4.5	4.548	0.288	2.306	15.4	0.75	4.5	4.744	0.345	1.331	14.8	0.72
4.75	4.731	0.323	2.271	15	0.74	4.75	4.925	0.381	1.295	14.5	0.71
5	4.916	0.359	2.235	14.7	0.73	5	5.101	0.418	1.258	14.2	0.7
5.25	5.09	0.396	2.198	14.35	0.71	5.25	5.281	0.455	1.221	14	0.7
5.5	5.268	0.433	2.161	14.1	0.7	5.5	5.373	0.505	1.171	13.5	0.67
5.75	5.373	0.481	2.113	13.7	0.68	5.75	5.373	0.57	1.106	12.5	0.61
6	5.373	0.547	2.047	12.6	0.61	6	5.373	0.637	1.039	11.4	0.55
6.25	5.373	0.614	1.98	11.5	0.55	6.25	5.373	0.705	0.971	10.5	0.5
6.5	5.373	0.682	1.912	10.6	0.5	6.5	5.373	0.774	0.902	9.8	0.46

Legend, Fig. 7:
- Depth focusing depth inside material,
- Δ_1 longitudinal shift of the Focusing Collar by its rotation,
- Δ_2 longitudinal shift of the entire objective,
  "0" corresponds to focus in air, to be defined using the focusing procedure,
- WD optimum Working Distance,
- D_{in} full beam diameter corresponding to NA_{dlf} when diffraction limited focusing (RMS wavefront aberration <λ/14, the Maréchal criterion).

!! Important:
After setting the Focusing Collar and the Objective, it is recommended to check the performance of material processing by stepwise variation of the depth around the pre-determined value in the range ±10 µm .
If necessary, correct the settings.

!! *Important*:
During the focusing procedure, move the Objective DOWN to the workpiece, i.e. starting from greater distance!!
To avoid focusing the light reflected from the workpiece surface inside the Objective lenses.

Keep the Working Distance > 0.7mm
when working WITHOUT Protective Window in Holder L9333.06,
to avoid focusing the light reflected from the workpiece surface inside the Objective lenses.