Lens spacing of a 3× beam expander used at 1030, 515 and 343 nm

Fused-silica singlets against CaF2 / fused-silica doublets for the three harmonics of a Yb laser, with the collimation read on the Gaussian beam at each line

Application

A micromachining station that switches between the fundamental, green and UV lines of a Yb laser needs a collimated, three times wider beam at each line. In the UV, fused silica and calcium fluoride are the lens materials. The buyer asks whether one expander can serve the three lines, and how far it must be adjusted.

Modelling approach

Two designs of the same 3× expander were compared. Each was optimized on the three wavelengths at once, one variant per wavelength: the singlets keep their own lens spacing at each line, the doublets share one geometry. A Gaussian beam was then propagated through each case while the lens spacing was scanned.

1 The two designs and the collimation at each line

PARAMETER	VALUE
Laser lines	1030 / 515 / 343 nm
Input beam	4 mm diameter (1/e²), M² 1.2
Magnification	3×, fixed, Galilean (no internal focus)
Singlet design	two fused-silica lenses
Doublet design	two air-spaced CaF2 / fused-silica doublets
Housing length	singlets 170 mm at 1030 nm, 160 mm at 343 nm; doublets 170 mm

Table 1. Main parameters. The input aperture holds 99 % of the beam power.

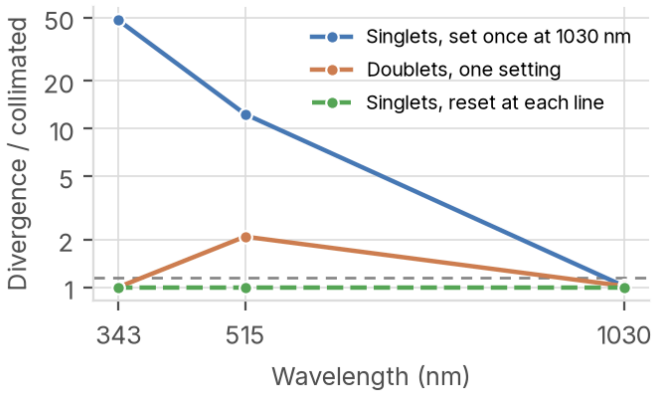


Figure 1. Divergence of the output beam divided by that of a perfectly collimated beam of the same diameter, at each line. The dashed line is the acceptance limit, 1.15.

2 The lens spacing each line needs

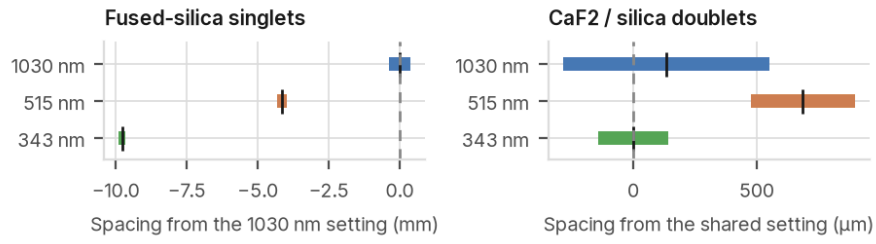


Figure 2. Range of lens spacing that keeps the collimation within the limit at each line; the tick marks the best setting. Left, singlets, counted from the 1030 nm setting. Right, doublets, counted from the setting shared by 1030 and 343 nm.

9.8 mm
How much closer the two singlets must be at 343 nm than at 1030 nm (4.1 mm at 515 nm).

±115 µm
Spacing tolerance of the singlets at 343 nm, the tightest of the three lines.

687 µm
Extra spacing the doublets need at 515 nm; one setting serves 1030 and 343 nm.

Acceptance

A line is accepted when the magnification is within 1 % of 3, the divergence ratio stays below 1.15, and the wavefront error, focus removed, stays below λ/14 RMS [4]. The 1.15 limit applies the same Maréchal criterion to the focus error alone; behind a focusing lens it keeps the focus within 0.56 Rayleigh lengths of its nominal position [3].

Doublets cut the spacing travel from 10 mm to 0.7 mm

Magnification within 0.05 % in every collimated case; wavefront below λ/21 in every case.

Table 2. Each design at each line

Design	Line (nm)	Spacing (mm)	Magnification	Divergence / collimated	Divergence (µrad)	Wavefront RMS	Optical spec
Singlets, set once at 1030 nm	1030	163.00	3.000	1.02	67	λ/126	pass
	515	163.00	3.030	12.35	401	λ/56	fail
	343	163.00	3.071	48.20	1029	λ/30	fail
Singlets, reset at each line	1030	163.00	3.000	1.02	67	λ/126	pass
	515	158.86	3.000	1.06	35	λ/62	pass
	343	153.24	3.000	1.13	25	λ/40	pass
Doublets, one setting	1030	153.67	2.999	1.02	69	λ/43	pass
	515	153.67	2.997	2.08	71	λ/35	fail
	343	153.67	2.999	1.00	23	λ/22	pass

Spacing: air gap between the lens groups. Divergence: half angle of the output Gaussian beam. Doublets at the spacing shared by 1030 and 343 nm.

Singlets

With one glass, both focal lengths shrink together towards the UV. The magnification stays at 3, but at 343 nm the beam diverges 48 times more than a collimated one. Moving the lenses 9.8 mm closer restores it, held to ±115 µm.

Doublets

Calcium fluoride and fused silica correct the colour between the two ends of the band, 1030 and 343 nm, but not in the middle. At the shared setting the green beam diverges 2.1 times more than a collimated one. Opening the spacing by 687 µm brings it back.

Recommendation

Doublets replace a 10 mm motorized focus with two fixed stops 0.7 mm apart. Singlets need three calibrated positions over 10 mm.

In etendue

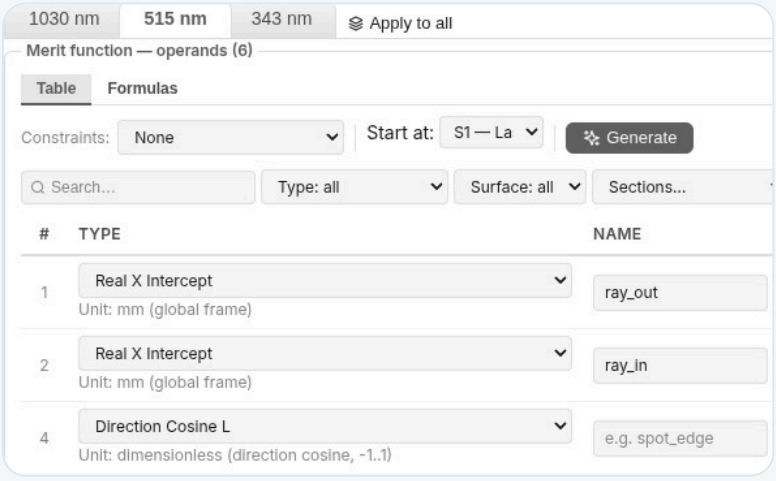


Figure 3. The merit function of the coupled optimization, variant 515 nm. Each wavelength is a variant with its own tab. The two named rows read the height of one real ray at the output and at the input; further down, a formula divides them and asks for a magnification of 3. The direction-cosine rows ask for a collimated output. Library project: « LAS12 - Beam Expander for the 1030, 515 and 343 nm Harmonics ».

References. [1] I. H. Malitson, Interspecimen comparison of the refractive index of fused silica, J. Opt. Soc. Am. 55, 1205 (1965). [2] I. H. Malitson, A redetermination of some optical properties of calcium fluoride, Appl. Opt. 2, 1103 (1963). [3] A. E. Siegman, Lasers, University Science Books (1986), ch. 17. [4] M. Born, E. Wolf, Principles of Optics, 7th ed., Cambridge University Press (1999), § 9.3 (Maréchal criterion).
Limits. Same input beam at the three lines; collimation read on the paraxial Gaussian beam. Aberration moves the best setting by 0.1 to 0.3 mm: a wave-optics propagation of the singlets at 343 nm gives a divergence ratio of 1.00 at the aberration-balanced setting and 1.15 at the paraxial one. Coatings and UV absorption not modelled.

Gaussian beam propagated through each variant; spacing scanned at each line.