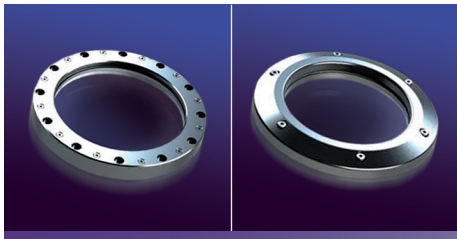


## Calcium Fluoride for Femtosecond High Power Lasers

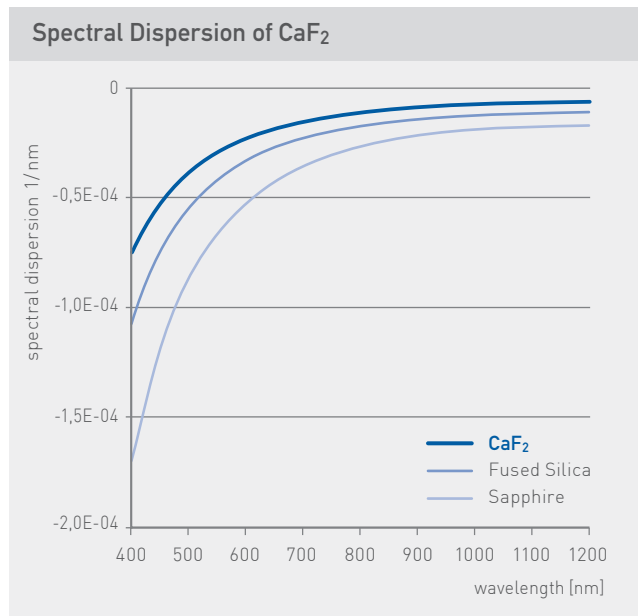
Low Dispersion, Low B-Integral CaF<sub>2</sub> Vacuum Windows  
Yb<sup>3+</sup>:CaF<sub>2</sub> Laser Crystals



## Low Dispersion, Low B-Integral CaF<sub>2</sub> Vacuum Windows

Calcium fluoride features a very low spectral dispersion, a low non-linear refractive index and is available in sizes up to 440 mm diameter. These advantages make it a superior optical material for vacuum windows for spatial filters, target and compressor chambers.

| Calcium Fluoride properties   |  |
|---|--|
| Nonlinear refractive index [cm <sup>2</sup> W <sup>-1</sup> ] @ 1064 nm   | 1.9 x 10 <sup>-16</sup>                    |
| Refractive index @ 1064 nm  | 1.42848                                    |
| Abbe number $v_d$   | 95.23                                      |
| Thermal conductivity [W m <sup>-1</sup> K <sup>-1</sup> ]   | 9.71                                       |
| Thermal expansion coefficient [K <sup>-1</sup> ]  | 18.41 x 10 <sup>-6</sup>                   |
| Modulus of rupture [MPa]  | 36.5                                       |
| Sellmeier dispersion formula  |  |
| $n^2 - 1 = B_1 \lambda^2 / (\lambda^2 - C_1) + B_2 \lambda^2 / (\lambda^2 - C_2) + B_3 \lambda^2 / (\lambda^2 - C_3)$ |  |
| B <sub>1</sub> 6.188140 x 10 <sup>-1</sup>  | C <sub>1</sub> 2.759866 x 10 <sup>-3</sup> |
| B <sub>2</sub> 4.198937 x 10 <sup>-1</sup>  | C <sub>2</sub> 1.061251 x 10 <sup>-2</sup> |
| B <sub>3</sub> 3.426299   | C <sub>3</sub> 1.068123 x 10 <sup>3</sup>  |



| Products      |   |
|---------------|---|
| Delivery form | fine ground blanks / polished windows (flatness up to $\lambda/10$ , scratch/dig 20-10) |
| Crystallinity | monocrystalline (<111> orientation / others upon request) or oligocrystalline           |
| Diameter      | max. 440 mm (oligocrystalline), max. 250 mm (monocrystalline)                           |
| Thickness     | max. 250 mm (oligocrystalline), max. 150 mm (monocrystalline)                           |

| Thickness calculation of vacuum windows                                 |                  |   |
|---|------------------|---|
| $th = \sqrt{\frac{\Delta p * \left(\frac{d}{2}\right)^2 * SF * K}{MR}}$ | th [mm]          | minimum thickness of vacuum window                              |
|   | $\Delta p$ [bar] | pressure differential between both sides of the window          |
|   | d [mm]           | free diameter of window   |
|   | SF               | safety factor (typically 4 for standard operating conditions)   |
|   | K                | empirical constant (1.1 for unclamped, 0.75 for clamped window) |
|   | MR [bar]         | Modulus of rupture (365 bar for CaF <sub>2</sub> )              |

| Example: Vacuum windows for 1.01325 bar pressure differential |               |                           |  |
|---|---------------|---------------------------|--|
|   | Diameter [mm] | Calculated thickness [mm] | $n_2$ [cm <sup>2</sup> W <sup>-1</sup> ] @ 1064 nm |
| CaF <sub>2</sub>  | 254           | 14.0                      | 1.9 x 10 <sup>-16</sup> [1]                        |
| Fused Silica  | 254           | 12.3                      | 2.6 x 10 <sup>-16</sup> [2]                        |
| Sapphire  | 254           | 4.0                       | 2.8 x 10 <sup>-16</sup> [3]                        |

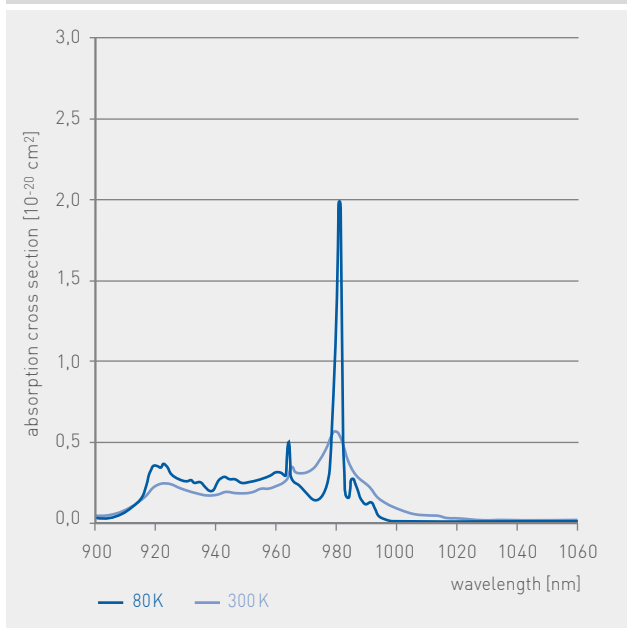
## Yb<sup>3+</sup>:CaF<sub>2</sub> Laser Crystals

Long fluorescence lifetime and broad absorption bands turn Yb<sup>3+</sup>:CaF<sub>2</sub> into an ideal material for laser diode pumping. The material exhibits a low linear and non-linear refractive index and shows a broad fluorescence bandwidth supporting ultra short pulses less than 100 fs .

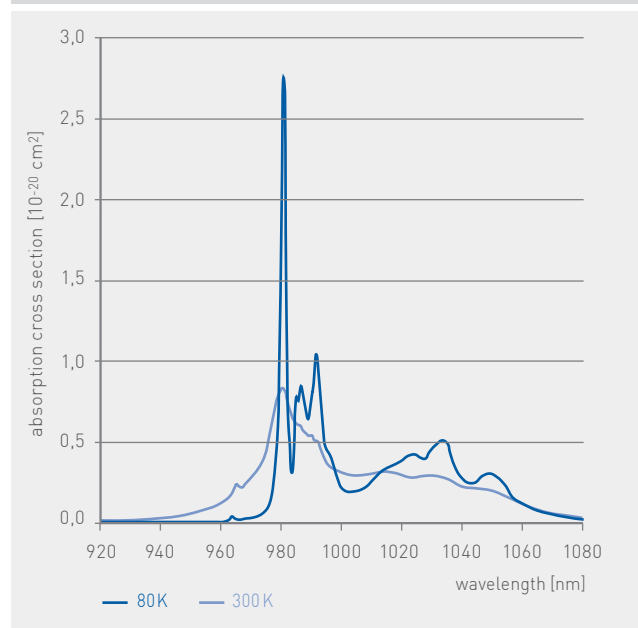
| Properties of Yb <sup>3+</sup> :CaF <sub>2</sub>                                  |                                |
|---|--------------------------------|
| Dopant concentration [at%]  | 1 – 3                          |
| Absorption peak wavelength [nm]   | 980                            |
| Absorption cross section @ 980 nm [cm <sup>2</sup> ]                              | 5.4 x 10 <sup>-21</sup>        |
| Emission cross section @ 1035 nm [cm <sup>2</sup> ]                               | 2.3 x 10 <sup>-21</sup>        |
| Fluorescence lifetime [ms]  | 2.2                            |
| Refractive index @ 1035 nm  | 1.42866                        |
| Nonlinear refractive index [CaF <sub>2</sub> ] [cm <sup>2</sup> W <sup>-1</sup> ] | 1.9 x 10 <sup>-16</sup> [1]    |
| Density [CaF <sub>2</sub> ] [g/cm <sup>3</sup> ]                                  | 3.18                           |
| Thermal conductivity [CaF <sub>2</sub> ] [W m <sup>-1</sup> K <sup>-1</sup> ]     | 9.71                           |
| Thermal expansion coefficient [K <sup>-1</sup> ]                                  | 18.41 x 10 <sup>-6</sup>       |
| Crystal structure   | cubic,<br>(111) cleavage plane |

| Products                     |  |
|------------------------------|--|
| Delivery forms               | cut / fine ground blanks,<br>polished / AR coated discs,<br>rods                   |
| Surfaces                     | polished: surface figure 3/0.2,<br>surface quality 5/3 x 0.16<br>(per ISO 10110-3) |
| Antireflective coating       | 1000-1070nm R < 0.15% AOI<br>0-10° s/p pol<br>(others upon request)                |
| Diameter                     | max. 250 mm (monocrystalline)<br>max. 440 mm (oligocrystalline)                    |
| Refractive index homogeneity | 15 ppm (for 110 mm diameter)   |
| Stress birefringence         | 3 nm/cm RMS<br>(for 110 mm diameter)   |

Absorption spectrum of Yb<sup>3+</sup>:CaF<sub>2</sub>



Emission spectrum of Yb<sup>3+</sup>:CaF<sub>2</sub>



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- [1] D. Milam, et. al, "Nonlinear refractive index of fluoride crystals," Appl. Phys. Lett. 31, 822-824 (1977)
- [2] D. Milam, „Review and Assessment of Measured Values of the Nonlinear Refractive-Index Coefficient of Fused Silica“, Appl. Opt. 37, 546-550 (1998)
- [3] A.Major et al, "Dispersion of the nonlinear refractive index in sapphire", Opt. Lett. 29, 602-604 (2004)

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