9. Polarizers

All polarized light is to some degree elliptical in nature. Basic states of polarization like linear and circular are actually special cases of elliptically polarized light which is defined by three physical parameters: handedness (right or left handed), degree of ellipticity and orientation of major axis of ellipse.

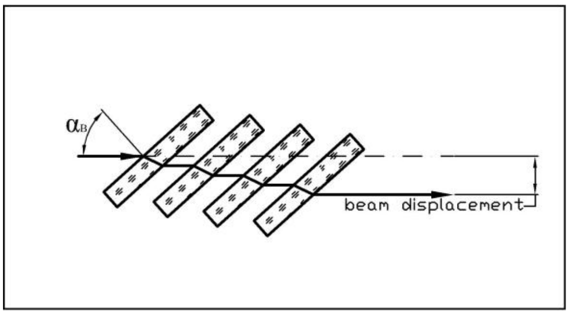
Optical components, which modify the state of polarization of optical beam are very important elements commonly used in optics, and especially in laser technique. Construction of these elements is based on two fundamental phenomena – polarization by reflection, and polarization by double refraction. We produce polarizers both of the phenomena listed above.

9.1. Stacked plate polarizers

There is one particular angle of incidence at which no light is reflected from optical surface when the E vector is parallel to the plane of incidence ("P"-polarisation):

This angle is called a ***Brewster angle*** (α_B).

For incidence of light from air to glass:



$\mathrm{tg}\,\alpha_B = n$

n – refraction index,

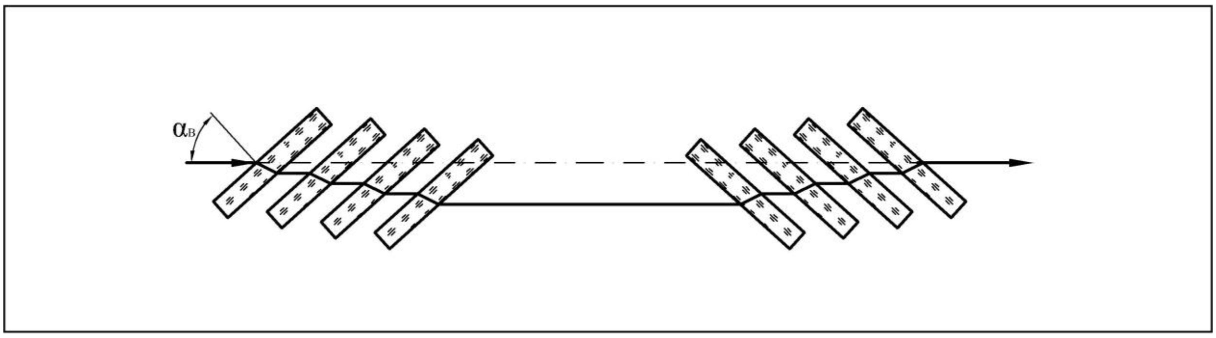
and coefficients of reflection for "P" and "S" components are as follows:

$r_S = \sin^2 (2\alpha_B - 90°)$

$r_P = 0$

Material	Wavelength (λ)	Index of refraction (n)	Brewster angle	Coefficient of reflection r_S
N-BK7	589.3 nm	1.5167	56.6°	15.5%
CaF_2	5000 nm	1.3991	54.4°	10.5%
Fused silica	193 nm	1.5608	57.4°	17.5%

Examples of r_S – coefficient and Brewster angles for different materials



Degree of polarization resulting from a single surface reflection is relatively small, and in practical solutions a number of plates are stacked parallel one to another.

The contrast ratio of the polarizer (K) consisting of N plates is defined in the case of perfectly polarized beam as the ratio of transmitted intensities with the polarizer axis parallel (T_P) and perpendicular (T_S) to the beam polarization axis.

$$K = \frac{T_P}{T_S} = \left(\frac{n^2+1}{2n}\right)^{4N}$$

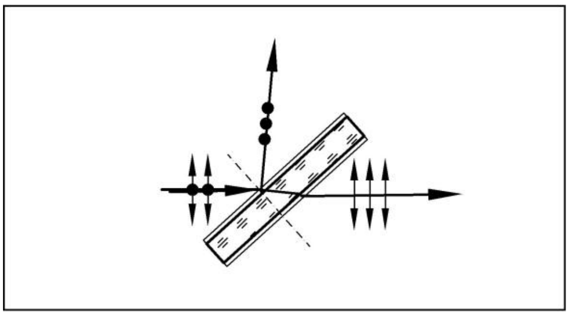
We offer development and production of stacked plate polarizers according to the requirements.

9.2. Dielectric polarizers

9.2.1. Polarizing beam splitter plate

Plate dielectric polarizer is a plane parallel glass plate with multilayer dielectric coating on the optical surface. It is adjusted in optical beam at Brewster angle. Multilayer dielectric coating is constructed so, as to obtain the biggest difference between coefficients of reflection for polarization “P” and “S” for specified wavelength. These polarizers can also operate at high power densities as stacked plate polarizers and typical contrast ratio is about 500:1.

We produce Brewster’s dielectric plate polarizers for specified wavelength of the laser.



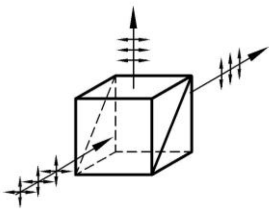
Technical specification – plane dielectric polarizers	
	Standard
Spectral range	500 nm ÷ 1500 nm
Size	5 mm ÷ 50 mm
R_S	> 99.8%
R_P	< 10%
T_P	> 90%
T_S	< 0.2%
Contrast ratio	500:1
Max. power density	500 MW/cm^2
Mounting	on requested

According to customer specification, we can deliver non-standard plane dielectric polarizer with higher optical parameters.

9.2.2. Polarizing beam splitter cubes

Cube dielectric polarizers consist of two cemented right angle prisms with dielectric multilayer coating inside. The polarizer transmission for the „P" component is very high, but „S" component is reflected. Dielectric layers are always made of materials with such refraction indexes so as to obtain incidence at Brewster angle. Right angle prisms are made of flint glass. Since they are cemented, this kind of polarizers can be used only at lower power densities, but they can operate in a broad range of wavelengths.

We produce dielectric cube polarizers for the visible range and near infrared.



Technical specification- cube dielectric polarizers	
	Standard
Spectral range	500 nm ÷ 1500 nm
Size	(10 x 10 x 10) mm ÷ (50 x 50 x 50) mm
R_S	> 99.8%
R_P	< 10%
T_P	> 90%
T_S	< 0.2%
Contrast ratio	500:1
Max. power density	20 MW/cm^2
Mounting	on requested

According to customer specification, we can deliver non-standard cube dielectric polarizer with higher optical parameters.

9.3. Birefringent polarizers

In anisotropic crystalline materials, whose optical properties are different in different directions, incident beam is split into two orthogonally polarized components propagating in a crystal with different velocities. These components are called ***ordinary*** and ***extraordinary*** rays, and they characterize different indexes of refraction:

n_o – for ordinary ray
n_e – for extraordinary ray

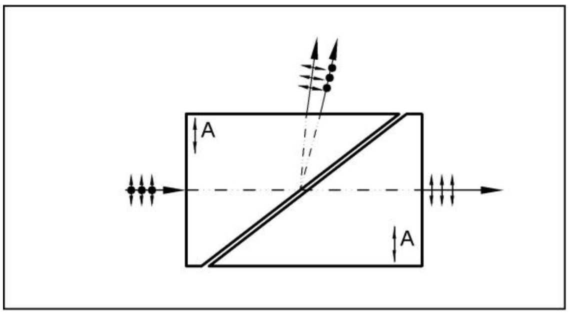
If some means can be founded to separate one ray from the other, a doubly refracting crystal may be used as a polarizer.

Material	n_o	n_e	$n_e - n_o$	Kind of birefringence
Calcite	1.65845	1.4864	–0.1720	negative
Quartz	1.5442	1.5533	+0.0091	positive
Lithium Niobate	2.3002	2.2147	–0.0855	negative
Magnesium Fluoride	1.3780	1.3890	+0.0110	positive

Birefringence of commonly used crystals for λ = 589,3 nm.

9.3.1. Glan – Taylor polarizers

This kind of polarizer consists of two right angle prisms made of calcite ($n_e < n_o$) with internal surfaces cut at the angle which exceeds the critical angle for one of the rays, but not for the other. Optical axis in both prisms is oriented in the same direction and is parallel to the base. Prisms are separated by an air space (about 0.05mm). Glan – Taylor polarizer is usually designed in such a way, that both the entrance and exit faces are normal to the incident beam. Internal faces are cut at such angle that ordinary ray is totally internal reflected at the first face. Acceptance angle for these polarizers is about 8^o.

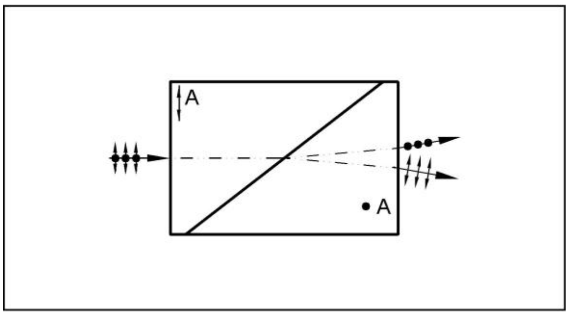


We produce Glan – Taylor polarizers with one or two escape windows on request. The polarizers are particularly useful in application requiring a high degree of polarization, high transmission, and low to medium power requirements.

Technical specification – Glan – Taylor polarizers		
Material	Calcite	
Spectral range	300 nm ÷ 2500 nm	
Outer dimension of the faces	(5 x 5) mm ÷ (20 x 20) mm	
Surface finish	60-40	
Dimensional tolerances	+/– 0.1 mm	
Clear aperture	90%	
Parallelism of the faces	< 5 arcmin	
Surface accuracy	$\lambda/4$ (633 nm)	
Contrast	10^5	
Max power density:	CW lasers	< 100 W/cm^2
	Pulse lasers (10 ns)	< 200 MW/cm^2
Mounting	on requested	

9.3.2. Wollaston polarizers

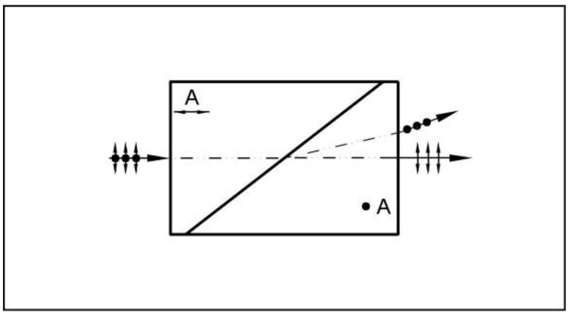
These polarizers consist of two right angle cemented prisms which transmit both linearly polarized beams. The beams are polarized in perpendicular planes and after passing through the polarizer they travel in different directions. Optical axis in first and second prism are perpendicular and as result the ordinary ray in the first prism becomes extraordinary in the second one. Separation angle between two orthogonally plane polarized output beams depends on the angle between the entrance and the inner faces and on the wavelength as well.



Technical specification – Wollaston polarizers				
Material	Calcite	Quartz		MgF_2
Spectral range	350 nm ÷ 2500 nm	200 nm ÷ 2800 nm	350 nm ÷ 2800 nm	140 nm ÷ 6000 nm
	optical contact	optical contact	cementing	optical contact
Outer dimension of the faces	(5x5) mm ÷ (20x20) mm	(5x5) mm ÷ (25x25) mm		(5x5) mm ÷ (15x15) mm
Surface finish	60 – 40	60 – 40		60 – 40
Exit angle	1^o ÷ 20^o	0.1^o ÷ 2^o		0.1^o ÷ 2^o
Clear aperture	90%			
Parallelism of the faces	< 5 arcmin			
Surface accuracy	$\lambda/4$ (633 nm)			
Contrast	10^5			
Max power density	CW lasers < 20 W/cm^2			
	Pulse lasers (10 ns) < 100 MW/cm^2			
Mounting	on requested			

9.3.3. Rochon polarizers

These polarizers are similar to Wollaston ones. They consists of two right angle cemented prisms. Prisms are cut in such a way – with respect to optical axis, that after passing through the polarizer the ordinary ray does not change its direction, but the extraordinary ray is deviated. To obtain this effect, optical axis in the first prism (input) is perpendicular to the entrance optical surface (parallel to the input beam). In this direction there is only one index of refraction n_o Upon entering the second prism the ordinary beam has still the same index of refraction and propagates undeviated. The extraordinary beam has another index of refraction (n_e) and is deviated. This deviation is further increased at the exit from crystal to air.



Technical specification – Rochon				
Material	Calcite	Quartz		MgF_2
Spectral range	350 nm ÷ 2500 nm	200 nm ÷ 2800 nm	350 nm ÷ 2800 nm	140 nm ÷ 6000 nm
	optical contact	optical contact	cementing	optical contact
Outer dimension of the faces	(5x5) mm ÷ (15x15) mm	(5x5)mm ÷ (25x25)mm		(5x5)mm ÷ (15x15)mm
Surface finish	60 – 40	60 – 40		60 – 40
Exit angle	$1^o \div 10^o$	$0.1^o \div 1^o$		$0.1^o \div 1^o$
Clear aperture	90%			
Parallelism of the faces	< 5 arcmin			
Surface accuracy	λ/4 (633 nm)			
Contrast	10^5			
Max power density	CW lasers < 20 W/cm^2			
	Pulse lasers (10 ns) < 100 MW/cm^2			
Mounting	on requested			

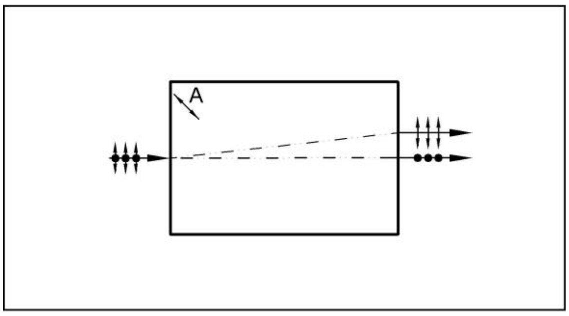
9.3.4. Beam displacing polarizers

These polarizers provide two parallel orthogonally polarised output beams from one unpolarised input beam. Operation of these polarizers is based on the deviation effect the extraordinary ray in the crystal when the angle between optical beam and optical axis is different than 0^o or 90^o. If the angle is 45^o, the deviation angle for the extraordinary ray equals:

$$\varphi\left(\frac{\pi}{4}\right)=\frac{1}{2}\left(1-\frac{n_e^2}{n_o^2}\right) \text{ [rad]}$$

The ordinary beam passes undeviated.
Beam displacement polarizers are made of calcite, crystalline quartz or MgF_2 just like plane parallel plates with optical axis meeting optical surfaces at the angle of 45°.

Beam displacement in this polarizers is dependent on the wavelength and thickness of the plate. We produce beam displacement polarizers from calcite, crystalline quartz or MgF_2.



Beam displacing polarizers

Material	Calcite	Quartz	MgF_2
Spectral range	300 nm ÷ 2500 nm	200 nm ÷ 2800 nm	140 nm ÷ 6000 nm
Aperture	(5 x 5) mm ÷ (20 x 20) mm	(5 x 5) mm ÷ (20 x 20) mm	(5 x 5) mm ÷ (20 x 20) mm
Beam displacement	0.1 mm ÷ 4.0 mm	5 μm ÷ 100 μm	5 μm ÷ 100 μm
Parallelism	≤ 3 arcsec	≤ 3 arcsec	≤ 3 arcsec
Mounting	on requested		

9.3.5. Retardation plates

While polarizers operate on the basis of space separation of the ordinary and extraordinary rays, retardation plates (or phase shifters) operates on the basis of velocity difference between the ordinary and extraordinary beams, without space separation. Retardation plates operate as elements changing the state of polarization of optical beams.

Because the ordinary and the extraordinary beam pass the plate with different velocities, the phase difference Γ is obtained, between these beams which is proportional to the plate thickness t:

$$\Gamma = \frac{2\pi}{\lambda}\left(n_e - n_o\right)t$$

where: λ — wavelength,

If the plate thickness is such that the phase difference is λ/4, the plate is called “0” order quarter wave plate. Thickness of this plate equals:

$$t = \frac{\lambda}{4\left(n_e - n_o\right)}$$

For $\Gamma = \lambda/2$ the plate is called a “0” order half-wave plate. Thickness of the plate is:

$$t = \frac{\lambda}{2\left(n_e - n_o\right)}$$

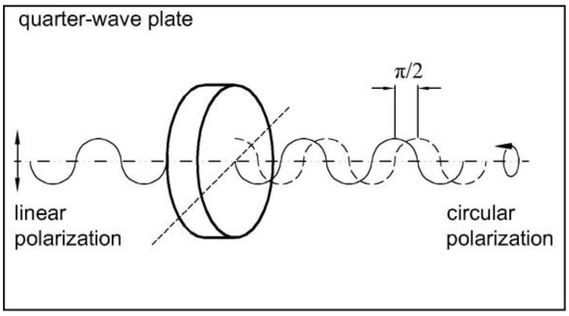
For phase difference of some multiple of λ/4 or λ/2, the plate is called multi-order plate, and its thickness is equal respectively:

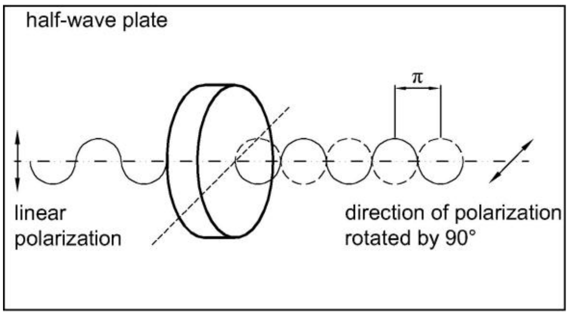
$$t_m = \frac{m\lambda}{n_e - n_o} + \frac{\lambda}{4\left(n_e - n_o\right)} \text{ for quarter-wave plate}$$

and

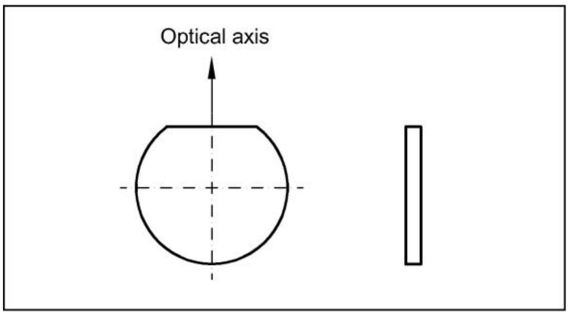
$$t_m = \frac{m\lambda}{n_e - n_o} + \frac{\lambda}{2\left(n_e - n_o\right)} \text{ for half-wave plate}$$

Retardation plates are used for changing and analysis of different states of polarisation. They are especially useful in construction of optical isolators and electro-optic modulators.

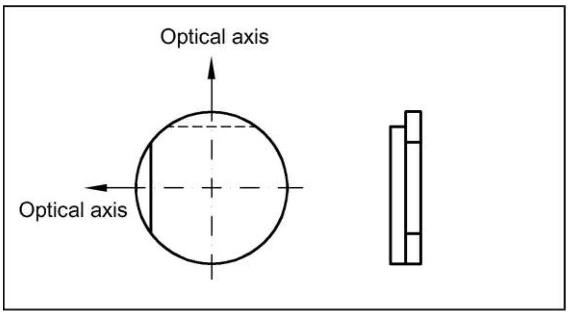




We produce retardation plates of „0” and multiple-order.



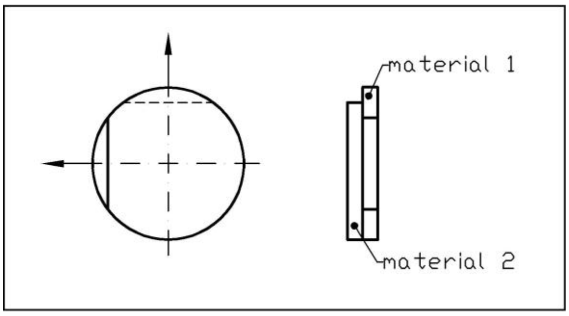
zero-order retarder



multiple-order retarder

We produce retardation plates from crystalline quartz and MgF_2. We offer also achromatic retardation plates. They are combination of quartz and MgF_2 retardation plates.

Achromatic wave plates characterized low sensitivity to wavelength change so they can be used in wide bandwidth.



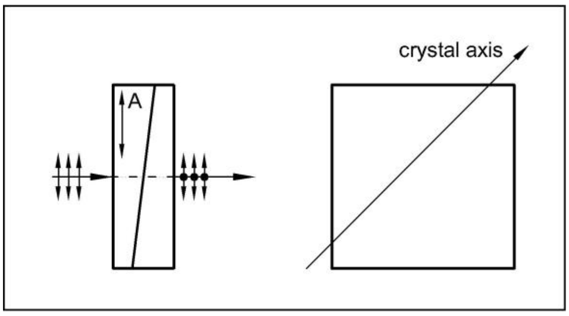
achromatic retarder

Technical specification – retardation plates λ/4 (quarter wave) and λ/2 (half-wave)		
Material	Quartz	MgF_2
Spectral range	200 nm ÷ 2800 nm	140 nm ÷ 6000 nm
Retardation	λ/4, λ/2	λ/4, λ/2
Retardation tolerance	λ/100 ÷ λ/300	λ/100 ÷ λ/300
Outer dimensions	10 mm ÷ 50 mm	10 mm ÷ 50 mm
Clear aperture	80%	80%
Parallelism	< 3 arcsec	< 3 arcsec
AR Coatings ($R < 0.2$ %)	on request	
Mounting	on request	

Technical specification – Achromatic retardation plates	
Material	Quartz + MgF_2
Spectral range	460 nm ÷ 680 nm
Retardation	λ/4, λ/2
Retardation tolerance	λ/50
Outer dimensions	10 mm ÷ 50 mm
Clear aperture	80%
AR Coatings (R < 0.2 %)	on request
Mounting	on request

9.3.6. Wedge depolarizers

A depolarizer is an optical device used to convert a polarized beam of light into a pseudo-random polarized beam of light. It consists of a pair of wedges. The first component is birefringent. The fast axis of this element is generally at 45 degrees to the wedge. The second component is used to correct the angular deviation. It is made of material, which has a very similar refractive index to first, but is not birefringent.



Technical specification - Wedge depolarizers	
Spectral range	200 nm ÷ 2800 nm
Outer dimensions	10 mm ÷ 50 mm
Parallelism of the faces	< 5 arcmin
Surface finish	60-40
Clear aperture	90%
Parallelism of the faces	< 5 arcmin
Surface accuracy	λ/4 (633nm)