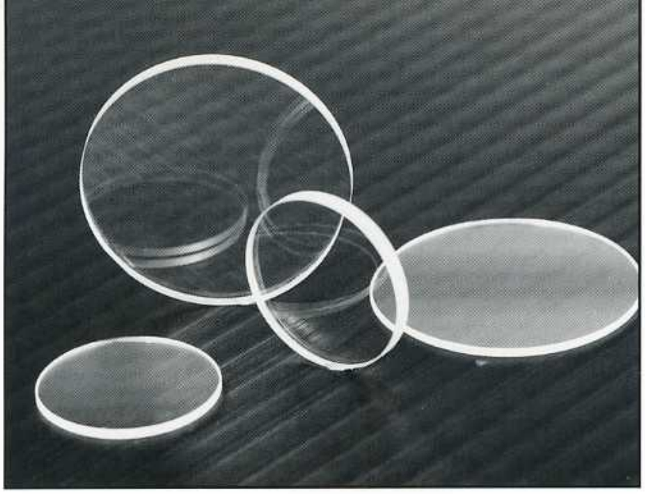


Retardation Plates

Retardation plates, or phase shifters, including quarter- and half-wave plates, are elements primarily used for synthesis and analysis of light in various polarization states. The quarter-wave plate is especially useful for isolators used in laser interferometry, multi-stage traveling wave laser amplifiers (to prevent stages from behaving as oscillators), and electro-optic modulators.

The simplest retardation plate is a uniaxial crystal cut to include the crystalline optic axis direction. The velocity difference between ordinary and extraordinary beams, from an unpolarized beam, within the plate is therefore maximized. As O and E beams traverse the plate, a phase difference accumulates between these beams proportional to the distance traveled within the plate. At emergence, the O and E beams recombine to form a second, unpolarized beam.

Within the retarder plane, the crystalline optic axis and another axis normal to it are often called fast or slow axis, depending on whether the uniaxial crystal is positive or negative. By rotating the retarder slightly about one of these axes, it is possible to adjust retardation amount.

Rotation around the crystalline optic axis increases effective plate thickness. However, it does not affect velocity difference between O and E rays, thus accumulated retardation is increased. Rotation around the other axis increases effective plate thickness and reduces velocity difference between O and E rays. The latter effect dominates for small rotations, reducing accumulated retardation. A narrowband retarder (or combination of retarders) may be tuned over a limited retardation range at fixed wavelength, or over a limited range of wavelengths at fixed retardation.

If plate thickness is such that the phase difference (retardation of the slow ray by comparison with the fast ray at emergence) is a quarter wavelength, the plate is called a first-order quarter wave plate. If the phase difference at emergence is one half wavelength, the plate is called a first-order half-wave plate. If the phase difference at emergence is some multiple of one quarter- or one half-wavelength, the plate is called a multi-order or higher-order plate. Notice that that these names refer to phase difference, not physical thickness.

Since O and E ray refractive indices of most materials are wavelength dependent, retardation which accumulates within a plate of specified thickness is also wavelength dependent. A particular value of retardation can be precisely achieved for normal incidence at only one specified wavelength.

Mica is exceptional in that its principal refraction indices vary slowly across the visible spectrum. Thus a retarder made for 550 nm and normal incidence will produce approximately the same retardation at other visible wavelengths, ideal for broadband visible applications.

Crystalline quartz is recommended for higher power applications. It exists in left- and right-handed forms, each causing polarization to rotate in opposite directions. Polarization of the O and E rays in quartz rapidly changes from circular to elliptical even for directions which depart only slightly from the optical axis. For the ellipse to be even approximately circular, much smaller angles are required. For this reason, devices which depend on circular polarization are effective only in highly collimated light propagating nearly parallel to the optic axis direction.

The retarder applications which follow assume that monochromatic incident light is collimated and normally incident upon the plate. They describe typical functions and uses for retardation plates.

POLARIZER HOLDERS

Melles Griot holders, on page 385, provide an ideal mount for retardation plates. They are intended for use with post-mountable rotators on page 457.

APPLICATION NOTE

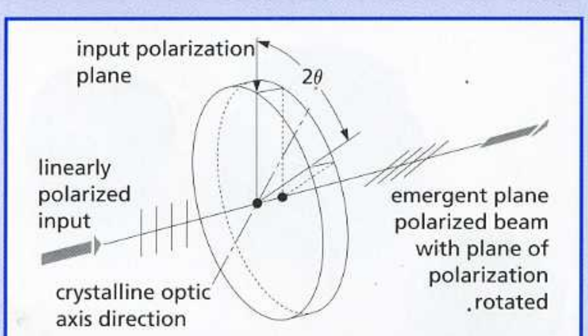
Half-Wave Plate Applications

If the retarder is a half-wave plate (either first- or multiple-order), and the angle between the electric field vector in a plane or linearly polarized incident beam and the retarder principal plane is θ (acute), the emergent beam (also plane or linearly polarized) will make an acute angle θ with the retarder principal plane. Thus the half-wave plate rotates the polarization plane through an angle 2θ.

Half-wave plates are used in laser-line rotators which allow the polarization plane of a laser beam to be continuously adjusted without moving the laser. This can also be accomplished by placing a pair of quarter-wave plates, identically oriented, back-to-back.

A half-wave plate followed by a polarizing cube will make a variable ratio beamsplitter for monochromatic linearly polarized inputs. The half-wave plate will convert left circularly polarized light into right circularly polarized light, or vice versa by reversing the direction of propagation. It will also convert left elliptically polarized light into right elliptically polarized light, or vice versa.

A pair of half-wave plates, identically oriented and back to-back, make up a full-wave or tint plate as used in photoelastic stress analysis. Similarly, half-wave plates can be assembled from quarter-wave plates.

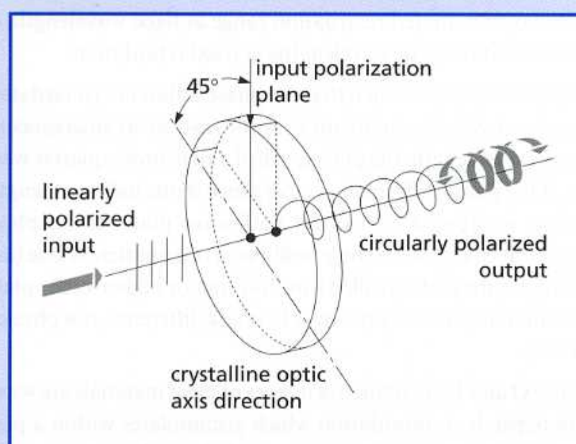


Half-wave retardation plate

APPLICATION NOTE

Quarter-Wave Plate Applications

If the retarder is a quarter-wave plate, and the angle θ between the electric field vector of the incident linearly polarized beam and the retarder principal plane is +45 degrees, the emergent beam is circularly polarized as shown in the figure below. Reversing θ to -45 degrees reverses the sense of circular polarization. A quarter-wave plate will also transform circular polarized into linear polarized light by reversing the direction of propagation.

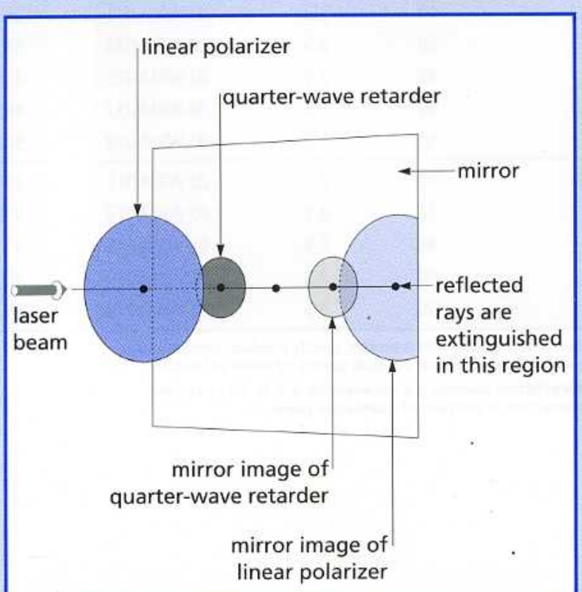


Quarter-wavelength retardation plate

APPLICATION NOTE

Optical Isolator

When θ is ±45 degrees and the direction of propagation of the circularly polarized beam is reflected at normal incidence, the circular polarization sense is reversed before the second transformation into linear polarization. Therefore, linear polarization of the reflected beam, as it finally emerges from its second trip through the retarder, is orthogonal to the incident linear polarization with which we began. A suitably oriented polarizer will now extinguish the reflected beam. This combination of a polarizer and a quarter-wave plate, with θ equal to either ±45 degrees, is opaque to specularly reflected radiation and is called an isolator. Isolators are used to prevent feedback from interferometers into lasers, which create troublesome mode-pulling and de-tuning. Similarly, quarter-wave plates are often used to suppress unwanted reflections in laser illuminated Twyman-Green interferometers.

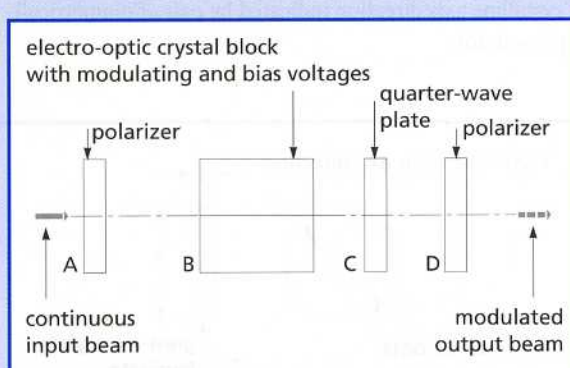


Quarter wavelength retarder isolator construction

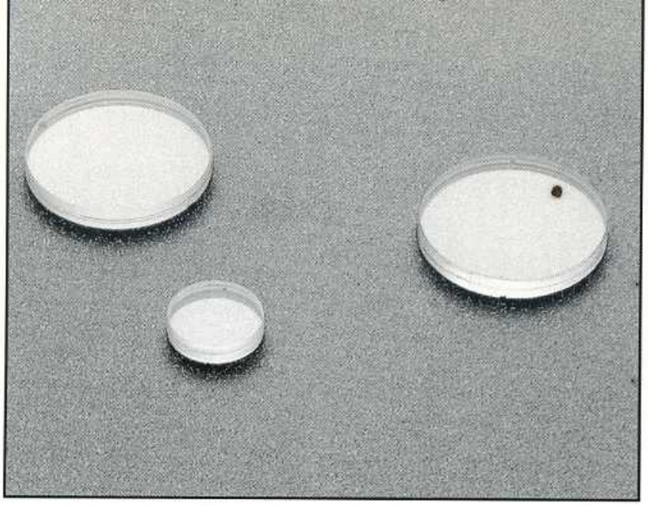
APPLICATION NOTE

Electro-Optic Modulator

If θ has some value other than ±45 degrees, a quarter-wave plate transforms linearly polarized light into elliptically polarized light. Again the transformation is reversed by reversing the direction of propagation. As such, quarter-wave plates also find application in electro-optic modulators for laser beams. The figure shows a continuous linearly polarized input beam(A). A block of electro-optic material, such as KDP (B), is either rendered birefringent or its state of birefringence is altered by an external electric field. In either case, the electro-optic block can be made equivalent to a quarter-wave plate by appropriate block length and a DC bias voltage. The angle θ between radiation electric field vector and retarder principal plane can be modulated to about 45 degrees. The beam which emerges from it is approximately elliptical and variably polarized. It can be transformed into linear and variable polarization by a suitably oriented quarter-wave plate (C). The linearly polarized beam must pass through a second polarizer (D) to achieve about 50% transmission of the incident linearly polarized beam with zero modulation voltage at element (B). Small variations in modulation voltage are transformed into amplitude modulation of the final output beam.



Quarter-wave plate used with electro-optic modulators



Mica Retardation Plates

Mica retardation plates are recommended for low power applications such as tint plates in microscopes, visual stress analyzers, and helium neon lasers, because of their relatively high absorption coefficient and occasional homogeneities.

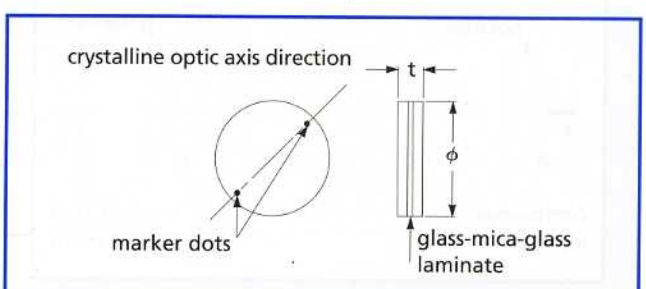
Melles Griot offers two types of mica retardation plates:

- Broadband mica retarders (Type 1), suitable for use in the visible spectrum (400–700 nm), centered at 550 nm.
- Laser-line mica retarders (Type 2), made for any specific wavelength between 400–2500 nm. They are exactly quarter-wave or half-wave at the specific wavelength for which the retardation tolerance will be λ/50. The most common laser wavelengths are available directly from stock.

Each mica sheet is cemented between protective glass discs for increased strength.

SPECIFICATIONS: MICA RETARDATION PLATES

Wavelength Range:
Type 1: 400–700 nm
Type 2: Specific wavelength between 400–2500 nm
Wavefront Distortion: 2λ at 550 nm
Material: Selected mica sheet
Mounting: Cemented between protective glass discs
Retardation Tolerance:
Type 1: λ/20
Type 2: λ/50
Diameter Tolerance: ±0.25 mm
Optic Axis:
Crystalline axis direction indicated by pair of diametrically opposed dots.



02 WRM mica retardation plates

Broadband Mica Retarders (Type 1)

Retardation	Diameter ϕ (mm)	Thickness t	PRODUCT NUMBER	PRICE US $
λ/2	10	2.5	02 WRM 021	114
	20	2.5	02 WRM 023	140
	30	2.5	02 WRM 025	210
	40	3.5	02 WRM 027	264
	50	3.5	02 WRM 029	282
λ/4	10	2.5	02 WRM 001	114
	20	2.5	02 WRM 003	140
	30	2.5	02 WRM 005	210
	40	3.5	02 WRM 007	264
	50	3.5	02 WRM 009	282

Laser-Line Mica Retarders (Type 2)*

Retardation	Diameter ϕ (mm)	Thickness t	PRODUCT NUMBER	PRICE US $
λ/2	10	2.5	02 WRM 031	295
	20	2.5	02 WRM 033	337
	30	2.5	02 WRM 035	416
	40	3.5	02 WRM 037	466
	50	3.5	02 WRM 039	580
λ/4	10	2.5	02 WRM 011	295
	20	2.5	02 WRM 013	337
	30	2.5	02 WRM 015	416
	40	3.5	02 WRM 017	466
	50	3.5	02 WRM 019	583

When ordering laser-line retarders, specify product number **and wavelength required (for example specify 02 WRM 011/632.8).*

Antireflection coatings are not available due to the cemented construction of this type of retardation plate.