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Ealing Technical Note
Waveplates

In this article we will compare and contrast different aspects of waveplates used in laser application. A Waveplate, or Retardation Plate, resolves a beam of polarized light into two orthogonal components, retards the phase of one component relative to the other and then recombines the components into a single beam with new polarization characteristics.
Applications for Half Waveplates include rotating the plane of polarization (e.g. in a laser), electro-optic modulation and as a variable ratio beamsplitter (when used in conjunction with a polarizing cube).

Waveplates are made from materials which exhibit birefringence. The velocities of the extraordinary and ordinary rays through the birefringent material vary inversely with their refractive indices. For the case of crystal quartz the extraordinary beam has a higher refractive index and therefore a slower velocity. For this reason its direction is known as the 'slow' axis. Likewise, the direction of the ordinary beam is known as the 'fast' axis and is indicated by the marked lines on the mount.

The difference in velocities gives rise to a phase difference when the two beams recombine. In the case of an incident linearly polarized beam this is given by

$$\theta = \frac{\pm 2\pi d\,(n_e - n_o)}{\lambda}$$

where:

θ = phase difference
d = thickness of waveplate in mm
n_e, n_o = refractive indices of extraordinary and ordinary rays respectively
λ = wavelength in nm

At any specific wavelength the phase difference is governed by the thickness of the retarder. Quarter and Half Waveplates are two specific cases of this.

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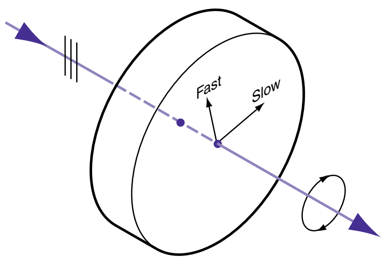
QUARTER WAVEPLATES



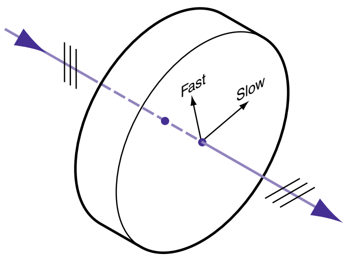
The construction of a Quarter Waveplate is such that the fast axis lies in the surface at 45° to the input polarization. The input beam is therefore resolved into two components of equal amplitude but varying velocities.

A Quarter Waveplate is used to convert linearly polarized beams into circularly polarized beams (and vice versa). This occurs when the thickness of the Quarter Waveplate is such that the phase difference is $\pi/2$ (zero order) or $3\pi/2$, $5\pi/2$, $7\pi/2$, etc (multiple orders). In practice the thickness required to produce a phase difference of $\pi/2$ is only approx 17µm, which is too thin to manufacture. For this reason, Multiple Order Waveplates often provide a convenient means of producing the required retardation.

Application

There are many applications for Quarter Waveplates. These include creating circular polarization from linear or linear polarization from circular, ellipsometry, optical pumping, suppressing unwanted reflections (when used in conjunction with a polarizer) and optical isolation (when used with a Polarizing Beamsplitting Cube).

HALF WAVEPLATES



The thickness of a Half Waveplate is such that the phase difference is π (zero order) or 3π, 5π, 7π, etc (multiple orders). A linearly polarized beam incident on a Half Waveplate emerges as a linearly polarized beam but rotated such that its angle to the optic axis is twice that of the incident beam. It is usual to have the fast axis lying in the surface of the retarder at 45° to the input polarization. The Half Waveplate therefore introduces a 90° rotation of the plane of polarization.

Like Quarter Waveplates, Half Waveplates are available as Multiple Order or Zero Order for a variety of wavelengths.

Application

Applications for Half Waveplates include rotating the plane of polarization (e.g. in a laser), electro-optic modulation and as a variable ratio beamsplitter (when used in conjunction with a polarizing cube).

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MULTIPLE OR ZERO ORDER WAVEPLATES - TECHNICAL CONSIDERATIONS

A Multiple Order Waveplate is simpler in construction and hence lower in cost. However, there are a number of parameters which can seriously affect the retardation value if they are not controlled very tightly.

Temperature

The temperature dependence of waveplates is directly proportional to the retardation value and hence the thickness. Typical temperature sensitivities are 1 degree change in retardance per °C for the Multiple Order and 0.1 degree for the Zero Order. For situations where temperature stability cannot be guaranteed, a Zero Order Waveplate should therefore be chosen.

Wavelength

For a Multiple Order Waveplate, the design wavelength must be specified very accurately - even a 0.2nm change in wavelength will produce a 10% change in retardation. A Zero Order Waveplate offers much more tolerance in wavelength variations. (A change of approx. 15nm in wavelength results in a 1% retardation change.)

Angle of Incidence and Degree of Collimation

For any beam which does not pass through the waveplate at normal incidence, there will be an increase in path length, increasing as the waveplate becomes thicker. This produces greater changes in retardation. It is particularly important to have a collimated input beam when using a Multiple Order Waveplate. If this cannot be ensured, a Zero Order Waveplate should be considered.

Multiple Order Waveplates

Ealing Multiple Order Waveplates are available for a stock range of wavelengths. Mounted in a 25.4mm diameter mount, these crystal quartz waveplates are manufactured to exacting standards. They are suitable for a wide variety of applications. However, the retardation value of a Multiple Order Waveplate is strongly dependent on temperature, wavelength, angle of incidence and degree of collimation. Where these are important, a Zero Order Waveplate will usually solve the problem. Non-standard wavelengths available on request.

Zero Order Waveplates

Ealing Zero Order Waveplates have been designed for those applications where a thickness is required which corresponds to a zero order phase difference. This is achieved by constructing the waveplate from two halves with their fast axes crossed. The thicknesses of these two halves are chosen so that the difference in retardation between them is equivalent to the zero order required. Any variation in temperature, wavelength, angle of incidence and collimation, affects both plates similarly and hence these effects are largely cancelled out. Non-standard wavelengths available on request.

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