PHOTOELASTIC MODULATORS

PEM TECHNICAL OVERVIEW

PRODUCT BULLETIN

The PEM200 photoelastic modulator is an instrument used for modulating or varying (at a fixed frequency) the polarization of a beam of light.

The basic PEM system includes the PEM-200 controller and the optical head (Figure 1).

By varying the material, size, and shape of optical element, and coupling closely-matched drive and control circuits to the PEM optics, Hinds Instruments has developed a range of photoelastic modulators for a variety of applications in a wide spectral region (UV to far-IR).

OVERVIEW OF FEATURES

- High sensitivity
- A resonant device generating a sinusoidal retardation at a fixed frequency
- USB or optional ethernet communication
- A reputation for stable, trouble-free performance
- CE approval and FCC certification

PEM APPLICATIONS

- Chopping a light beam (20 - 84 kHz)
- Birefringence Measurements
- Stokes Polarimetry
- Optical Rotation Polarimetry
- Linear and Circular Dichroism in UV-Vis and IR
- Magnetic Circular Dichroism
- FTIR Double Modulation Spectroscopy (VCD, VLD, IRRAS, etc.)
- Ellipsometry
- Fluorescence Polarization
- Waveplate Measurement

OPTICAL HEAD FEATURES

- Common isotropic optical material
- Wide useful aperture (1.5 - 3.0 cm for standard models)
- Wide acceptance angle (±25°)
- Retardation range: 130 nm - FIR
- High retardation performance
- Selection of optical materials and designs
- High quality and low residual birefringence optics

OPTIONS AND ACCESSORIES

- Wide frequency range (20 - 84 kHz)
- Anti-reflective coatings
- Laser non-interference option
- Strong magnetic field option
- Vacuum compatibility
- Rack mount option
- Low birefringence option, on Series I PEM

PRINCIPLES OF OPERATION

The phenomenon of photoelasticity is the basis for operation of the PEM. If a sample of transparent solid material is stressed by compression or stretching, the material becomes birefringent, that is, different linear polarizations of light pass through the material at slightly different speeds.

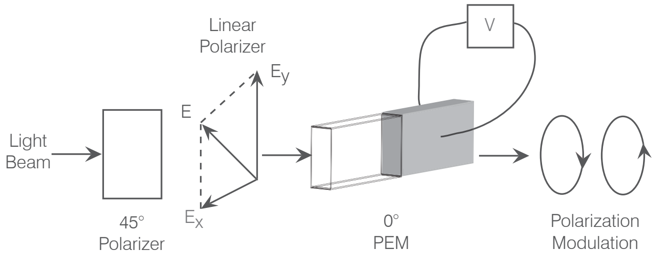

Figure 2a.

If the optical element is relaxed, the light passes through with the polarization unchanged. If the optical element is stressed, the polarization components parallel or perpendicular to the modulator axis travel at slightly different speeds. The parallel component then either "leads" or "lags" the perpendicular component after passing through the modulator. The phase difference thus created between the two components oscillates as a function of time and is called the retardation or retardance.

An important condition occurs when the maximum (peak) retardation reaches exactly one-fourth of the wavelength ($\lambda/4$) of light. When this happens, the PEM acts as an oscillating quarter-wave plate. At the peak, the polarization vector traces a right-handed spiral about the optical axis. Such light is called "right circularly polarized." The polarization oscillates between right circular and left circular, with other polarization states between (See Figure 2b).

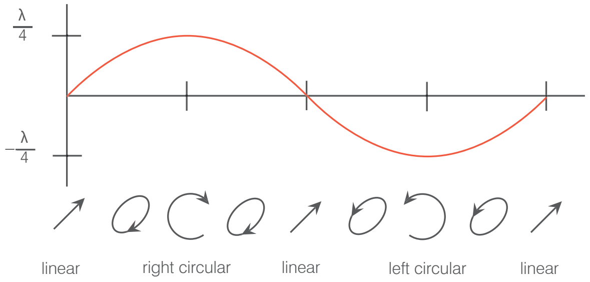

Figure 2b.

Another important condition occurs when the peak retardation is one-half the wavelength ($\lambda/2$) of the light. When this happens, the PEM acts as an oscillating half-wave plate. The polarization is modulated between two orthogonal linearly polarized states at twice the PEM's frequency (2f).

The PEM may be used in two basic modes: as a modulator, to produce polarization modulation of a light beam, or as an analyzer, to determine the polarization states of a light beam.

In a circular dichroism (CD) experiment, the PEM is used in the modulator mode of operation. The incoming light is linearly polarized at 45 degrees with respect to the optical axis of the modulator. At $\lambda/4$ PEM peak retardation, the result is a modulation between left and right circularly polarized light at the modulator frequency (1f). The differential absorption between right and left circular polarization ($\Delta A = A_L - A_R$) is measured with phase-sensitive detection.

When the PEM 100 is used as an analyzer, as in a Stokes polarimeter, a net circular polarization component will produce an electrical signal in the detector at the modulator frequency (1f). A net linear polarization component at 45 degrees with respect to the modulator axis will produce an electrical signal in the detector at twice the modulator frequency (2f). Thus, the polarization characteristics of a light source can be determined.

SERIES I AND II MODULATORS

Series I modulators use rectangular optical elements and are useful in the ultraviolet, visible and infrared to 1 or 2 microns.

Series II modulators use symmetrical or octagonal optical elements and are primarily intended for use in the visible and infrared (to far-IR) spectral regions. Special models have been used in the ultraviolet.

Modulators are offered with optical elements made of various optical materials. The choice of optical material is made primarily on the basis of the spectral transmission requirements of the instrument. A list of commonly available materials is given in Table 1.

TABLE 1 – HEAD ASSEMBLIES

Spectral Region	Series	Material
Vacuum UV, UV	I	Lithium Fluoride
Vacuum UV to mid-IR	I, II	Calcium Fluoride
Vacuum UV to near-IR	I, II	Fused Silica
Mid-visible to mid-IR	II	Zinc Selenide
Near to mid and far-IR	II	Silicon

Compared to the Series II octagonal optical elements, the rectangular optical elements used in Series I modulators provide lower levels of peak retardation for a given optical element thickness. This is a drawback when working in the infrared, but an asset when working in the UV, especially the vacuum UV.

Octagonal (Series II) optical elements are much more efficient for a given thickness, and thus have a significant advantage in the infrared. Operation of Series II modulators at low retardation levels (e.g. the deep UV) may present some problems.

When a PEM is used with a laser, modulated interference effects may occur. These can produce spurious optical/electronic signals which may hamper certain measurements. Hinds engineers should be consulted for techniques to eliminate or minimize such signals in applications where laser light sources are used with PEMs.

Antireflection coatings may be used to increase the throughput of light through the modulator, to reduce interference effects, and to reduce the fraction of light which passes through the modulator at an undesired peak retardation. In particular, zinc selenide and silicon modulators benefit from antireflection coatings because of their high indices of refraction. (Note: An antireflection coating may significantly reduce the usefulness of the modulator outside the spectral band of the coating.)coating may significantly reduce the usefulness of the modulator outside the spectral band of the coating.)

EXAMPLES OF APPLICATIONS

Chopping a Light Beam

The PEM is a polarization modulation device. However, it can also be used as an intensity modulator when placed between crossed polarizers. This device has no moving mechanical parts and provides a modulation frequency on the orders of 20 and 100 kHz.

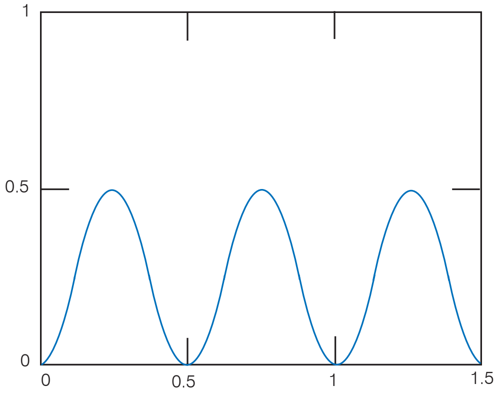

Figure 3a.

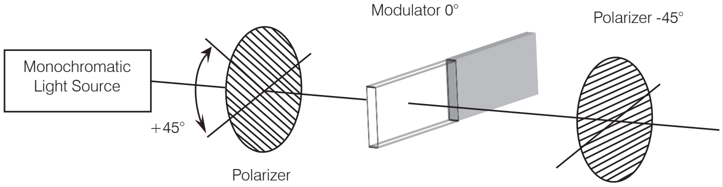

Figure 3b.

Polarimetry

PEMs may be used for measuring the polarization characteristics of a light beam (Stokes polarimetry) or measuring the rotation of the plane of linear polarization (optical rotation) induced by an “optically active” sample. An experimental setup for measuring optical rotation is shown in figure 4.

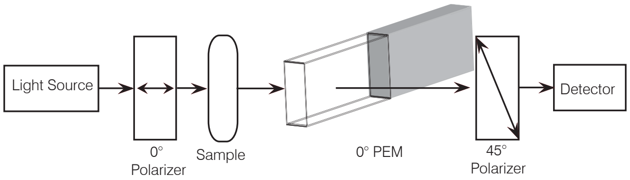

Figure 4.

Birefringence Measurement

In this set-up, the orientation (θ) of the linear birefringence of a sample should either be known or be measured by rotating the sample until a maximum signal is observed. The magnitude of the birefringence (B) can then be determined from the lock-in outputs (1f and 2f) and the average signals.

The set-up can be used for measuring small residual birefringence of optical materials and for determining accurately the retardance of a wave-plate.

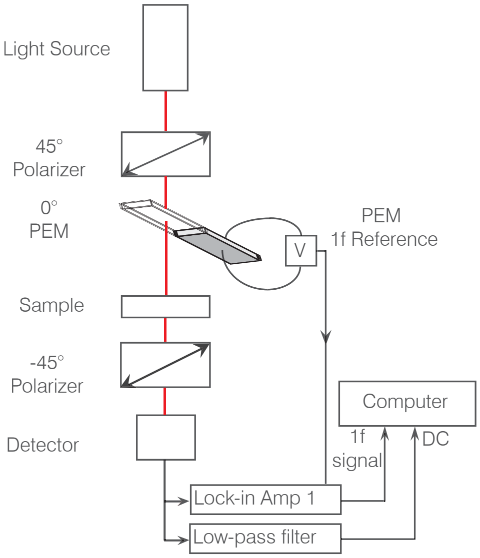

Figure 5.

OPTIONS

Antireflective Coating

Hinds offers several standard coating options for both the visble and IR regions. Our standard coatings are:

I/FS50 modulators: 633nm, 450-650nm, 800nm, and 633 - 1000nm

II/ZS37 or II/ZS50: 3-12μm and 9-12μm

Antireflective Coatings can be provided on a custom basis for any of our modulator optical elements. Both narrow and broadband coatings are available.

Non-interference Option

This option deflects internally reflected beams from the primary beam path, thereby eliminating modulated interference (see PEM Newsletter #8).

Magnetic Field Compatible

The Optical Head is manufactured without any ferromagnetic materials. This option is recommended for magnetic fields exceeding 100 Gauss.

Vacuum Operation

PEM optical heads may be operated in a vacuum. Hinds offers a custom vacuum head option or several custom flanges. Hinds' CaF2 modulator in our custom vacuum chamber is rated for e^{-10} torr with a maximum bakeout temperature of 120 degrees C.

ADDITIONAL INSTRUMENTS

Detectors

Hinds Instruments also produces a series of photodiode detectors for the UV-Vis and near IR spectral regions.

Our DET-200 silicon and germanium photodiode detectors are specifically designed for polarization modulation experiments.

The APD-100 Avalanche Photodide Detector Module is for use in very low light experiments, especially for circular dichroism and fluorescence applications.

Lock-in Amplifiers

Hinds' Signaloc 2100 is a dual-phase, analog lock-in ampifier designed to work at the Photoelastic Modulator's resonant frequency (1f). There are two configurations: one provides maximum sensitivity at 1f using a band pass filter; in the second configuration (without the band pass filter) both the 1f and 2f signals can be amplified.

PEM200 OPTICAL HEAD SPECIFICATIONS[1]

Model	Optical Material	Frequency, nominal	Retardation Wavelength Range		Useful Aperture[2]
			Quarter Wave	Half Wave	
I/FS50	Fused Silica	50 kHz	170 nm - 2 μm	170 nm - 1 μm	16 mm
I/FS20	Fused Silica	20 kHz	170 nm - 2 μm	170 nm - 1 μm	22 mm
I/CF50	Calcium Fluoride	50 kHz	130 nm - 1 μm	130 nm - 500 nm	16 mm
II/FS20[3]	Fused Silica	20 kHz	170 nm - 2 μm	170 nm - 1 μm	56 mm
II/FS42[3]	Fused Silica	42 kHz	170 nm - 2 μm	170 nm - 1 μm	27 mm
II/FS47[3]	Fused Silica	47 kHz	170 nm - 2 μm	170 nm - 1 μm	24 mm
II/FS50[3]	Fused Silica	50 kHz	170 nm - 2.6 μm	170 nm - 2.5 μm	22 mm
II/FS84[3]	Fused Silica	84 kHz	170 nm - 2.5 μm	170 nm - 2.5 μm	13 mm
II/IS42[3]	Infrasil	42 kHz	210 nm - 3.5 μm	210 nm - 3 μm	27 mm
II/IS84[3]	Infrasil	84 kHz	210 nm - 3.5 μm	210 nm - 3 μm	13 mm
II/CF57	Calcium Fluoride	57 kHz	2 μm - 8.5 μm	1 μm - 5.5 μm	23 mm
II/ZS37	Zinc Selenide	37 kHz	2 μm - 18 μm	1 μm - 9 μm	19 mm
II/ZS42	Zinc Selenide	42 kHz	2 μm - 18 μm	1 μm - 10 μm	17 mm
II/ZS50	Zinc Selenide	50 kHz	2 μm - 18 μm	1 μm - 10 μm	14 mm
II/SI40	Silicon	40 kHz	28 μm - 57 μm		36 mm
II/SI50	Silicon	50 kHz	28 μm - 57 μm		29 mm

[1] *Specifications for models purchased after April 1, 2019*
[2] *For a full discussion, consult the Useful Aperture Technical Note*
[3] *Please contact Hinds Instruments with your wavelength range for optical calibration*