PEM-90™ PHOTOELASTIC MODULATORS

STATE-OF-THE-ART POLARIZATION MODULATION

For High-Sensitivity Measurements In:
- Circular Dichroism
- Linear Dichroism
- Birefringence
- Optical Rotation
- Ellipsometry
- Polarimetry

HINDS INSTRUMENTS™
Founded in 1971, Hinds Instruments, Inc. is the world’s leading supplier of photoelastic modulators. For over 25 years we have been committed to developing this method of polarization modulation as a basic tool of optical analysis in applications ranging from laboratory research and development to industrial process monitoring.

The latest result of this ongoing commitment is the new D-Series of the PEM-90™, a unique photoelastic light modulator system which permits unprecedented levels of sensitivity in polarized light measurements — to the order of $10^{-6}$.

Beginning with a single PEM model designed for use in the visible spectrum, Hinds has developed modulators which extend from the vacuum UV to the mid-IR. Our unique self-resonating electronic drive design results in a system which is stable, reliable, and easy to use.

We offer more than a dozen basic PEM models for use either as stand-alone instruments or in integrated systems, as well as several modular accessory instruments that permit PEM users to quickly develop custom configurations.

Custom PEM models have been built for use with on-board rocket instruments, laser microscopes, vacuum chambers, and tokamak fusion experiments, and as standard components in systems for semiconductor manufacture and process monitoring in a chemical extraction environment.

Dedicated to serving the scientific and engineering community, our select team of highly qualified technical professionals has over 65 years combined experience to help you apply PEM polarization modulation technology to your specific application.
The PEM-90 photoelastic modulator is an instrument used for modulating or varying (at a fixed frequency) the polarization of a beam of light. Hinds photoelastic modulators are used for measurement of circular and linear dichroism, birefringence, optical rotation, and for ellipsometry, polarimetry, reflection difference spectroscopy, and FTIR double modulation.

The PEM-90 principle of operation is based on the photoelastic effect, in which a mechanically stressed sample exhibits birefringence proportional to the resulting strain. Photoelastic modulators are resonant devices, each producing oscillating birefringence at a fixed frequency in the low frequency ultrasound range (20 kHz to 100 kHz). These factors result in a number of very useful advantages which are unique to the PEM including wide acceptance angle, large aperture, and high modulation “purity.”

In its simplest form the PEM-90 consists of a rectangular bar of a suitable transparent material (fused silica, for example) attached to a piezoelectric transducer (Figure 1b). The bar vibrates along its long dimension (Figure 1a) at a frequency determined by the length of the bar and the speed of a longitudinal sound wave in the optical element material. The transducer is tuned to the same frequency and is driven by an electronic circuit which controls the amplitude of vibration. The oscillating birefringence effect is at its maximum at the center of the fused silica bar.

**Figure 1. Modulator Optical Assembly for Model I/FS50.**

By carefully varying the type, size, and the shape of optical material, and coupling closely matched drive and control circuits to the PEM-90 optics, we have developed a range of photoelastic modulators for a variety of applications. In addition to the information provided in this technical guide, Hinds engineers are available for free consultation to help you design your specific application setup.
Thin Film Growth

PEM-based reflectance difference spectrometers are being used to monitor in real time the growth of gallium arsenide thin films.

The PEM-90 line of photoelastic modulators incorporates many design features, including:

- RS-232 interface, allowing computer control and monitoring of all PEM functions.
  (IEEE-488 interface capability is available through a National Instruments™ converter unit.)
- Digital set-up and display of retardation and source wavelength in user-selectable units, with automatic adjustment of retardation for varying wavelengths.
- A range of models which spans the spectrum from vacuum UV to mid-IR.
- A retardation function with high sinusoidal accuracy which results in noise-free modulation or chopping.
- Optional ultra-low residual birefringence optics.
- A documented reputation for stable, trouble-free performance.

Figure 2 details features of the three basic PEM-90 components: the Controller, the Electronic Head, and the Optical Head.
The phenomenon of photoelasticity is the basis for operation of the PEM-90. If a sample of transparent solid material is stressed by compression or stretching, the material becomes birefringent, that is, different linear polarizations of light have slightly different speeds of light when passing through the material.

PEM-90 Series I modulators use a rectangular shape for the modulator optical element. In the Model I/FSSQ, a fused silica bar is made to vibrate with a natural resonant frequency of about 50 kHz. This vibration is sustained by a quartz piezoelectric transducer attached to the end of the bar, as shown in Figure 1 (page 3).

At the center of the bar an oscillating birefringence occurs at a frequency of about 50 kHz. The magnitude of the birefringence is controlled electronically with the PEM-90 Controller.

**Retardation Effects of Compression and Extension**

The effect of the modulator on a linear polarized monochromatic light wave is shown in Figure 3. The plane of polarization is at 45° to the modulator axis before passing through the modulator. If the optical element is relaxed (Figure 3a) the light passes through with the polarization unchanged.

If the optical element is compressed, the polarization component parallel to the modulator axis travels slightly faster than the vertical component. The horizontal component then "leads" the vertical component after light passes through the modulator (Figure 3b).

If the optical element is stretched, the horizontal component "lags" behind the vertical component (Figure 3c).

The phase difference between the components at any instant of time is called the retardation or retardance. The peak retardation is the amplitude of the sinusoidal retardation as a function of time.

The retardation (in length units) is given by

\[ A(t) = z[n_x(t) - n_y(t)] \]

where \( z \) is the thickness of the optical element and \( n_x(t) \) and \( n_y(t) \) are the instantaneous values of refractive index along the x and y directions. Common units for retardation include distance (nanometers, microns), waves (quarter-wave, half-wave), and phase angle (radians, degrees). As shown in Figure 2 (page 4), the PEM-90 Controller can display retardation in waves or phase angle.

**Quarter-Wave Retardation**

An important condition occurs when the peak retardation reaches exactly one-fourth of the wavelength of light. When this happens, the PEM acts as a quarter-wave plate. Figure 4a shows this condition at the instant retardation is at its maximum.
The polarization vector traces a right-handed spiral about the optic axis. Such light is called “right circularly polarized.” For an entire modulator cycle, Figure 4b shows the retardation vs. time and the polarization states at several points in time. The polarization oscillates between right circular and left circular, with linear (and elliptical) polarization states in between.

**Figure 4. Quarter-Wave Retardation**

![Figure 4](image)

The polarization vector traces a right-handed spiral about the optic axis. Such light is called “right circularly polarized.” For an entire modulator cycle, Figure 4b shows the retardation vs. time and the polarization states at several points in time. The polarization oscillates between right circular and left circular, with linear (and elliptical) polarization states in between.

**Half-Wave Retardation**

Another important condition occurs when the peak retardation reaches one-half of the wavelength of the light (Figure 5a). When this happens, the PEM acts as a half-wave plate at the instant of maximum retardation and rotates the plane of polarization by 90°.

**Figure 5. Half-Wave Retardation**

![Figure 5](image)

Figure 5b shows retardation vs. time for a modulator cycle and indicates polarization states at several different times during a cycle. At maximum retardation, the polarization states are linear, rotated by 90°.

The half-wave retardation condition is particularly important for calibration of the PEM-90°.

**Symmetric Optical Element**

PEM-90 Series II modulators use a unique symmetric or “octagonal” shape for the modulator optical element (Figure 6). This utilizes a “two-dimensional” standing wave which approximately doubles the retardation available with a given drive voltage. Series II modulators are particularly useful in the infrared spectrum.

**Figure 6. Symmetric Optical Assembly for Model II/ZS37**

![Figure 6](image)
The PEM-90 may be used in either of two basic modes: as a modulator, to produce polarization modulation of a light beam, or as an analyzer, to determine the polarization state of a light beam. More specific applications are discussed in detailed application notes.

Use as a Modulator
The PEM-90 may be used to modulate a beam of light. One frequently used condition of operation occurs when the peak retardation corresponds to a quarter of the wavelength of the light being used. This setup is shown in Figure 7.

As shown in Figure 7, the incoming light is linearly polarized in a plane which is at 45˚ with the long axis of the modulator. The result is light which oscillates between left and right circularly polarized light, with elliptically polarized light between these extremes. The optical oscillation frequency is at the modulator frequency (1f). This experimental setup is used for studies of circular dichroism.

Use as an Analyzer
The PEM-90 may also be used to analyze the state of a polarized beam of light. Figure 8 shows a setup for the measurement of the circular and linear polarization of a beam of light.

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˚ with respect to the modulator axis will produce an electrical signal in the detector at twice the modulator frequency (2f). Use of the reference signals from the PEM-90 Controller with lock-in amplifiers enables the simultaneous measurement of these two polarization components.

Used as a polarimeter, the PEM-90 is capable of detecting polarization components weaker than 1 part in 10^6 of the total intensity. For complete details on use of the PEM-90 as a polarimeter, consult the Stokes Polarimetry Application Note.
There are several important factors to consider in selecting a PEM-90. These include the wavelength of the light to be used, the retardation requirement, use of an antireflection coating, and the aperture required.

Spectral Range Considerations

The two primary considerations in the selection of a PEM-90 are the spectral region in which the modulator must operate and the range of retardance required. In general, Series I modulators are designed for use in UV and visible applications, but they may also be used for many IR laser diode applications. Model I/CF50 is specifically intended for the vacuum UV region.

Series II modulators are primarily intended for the near- and mid-IR regions, but some may be used in the visible spectrum. Consult the specifications table in the Modulator Head Data Bulletin for details regarding transmission limits and available retardation.

Retardation Requirements

A PEM-90 intended for both half-wave and quarter-wave applications should be capable of providing half-wave retardation throughout the spectral region of interest. Standard linear dichroism setups require half-wave operation, and it should be possible to achieve half-wave operation at any wavelength where calibration of the retardation is required.

Many modulator applications require only quarter-wave retardation. These include circular dichroism, optical rotation, polarimetry, birefringence, and amplitude modulation or chopping.

Some advanced techniques use a third modulator setting: the first retardation setting at which the Bessel Function \( J_0(\eta) = 0 \). This occurs at a retardation setting of \( \eta = 2.405 \) radians or 0.383 waves. For this setting, the average DC signal may be used for signal normalization.
Optical Considerations

**Aperture.** Hinds can supply custom modulators with special size apertures. For a given optical element material, the aperture (and optical assembly size) is inversely proportional to the operating frequency. Standard apertures range from 1.5 to 3.0 cm.

**Use with lasers.** Laser light sources are monochromatic and have high spatial coherence, which can lead to undesirable interference effects. Reflections between the optical element surfaces may cause spurious detector signals at the fundamental and other harmonic frequencies. Use of antireflective coatings, tilting the modulator, or a special patented “non-interference” option which deflects internally reflected beams can reduce or eliminate this problem. Contact Hinds engineers for assistance with laser applications.

**Antireflection coatings.** Antireflection coatings may be used to increase the throughput of light through the modulator, to reduce the 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 will significantly reduce the usefulness of the modulator outside the spectral band of the coating.*

Detector Considerations

The detector and its associated electronics should receive careful consideration. If oscilloscope calibration of the system is required, the detector and amplifying electronics should have a frequency bandwidth several times the fundamental modulator frequency. Many applications require that a low-pass DC signal component be derived from the detector signal. For many applications the lock-in amplifier should be able to operate at the second harmonic of the modulator frequency.

Hinds offers several modular accessories including a Photodiode/Preamplifier Assembly for detecting modulated light signals. This detector module is specially designed for the requirements of systems which use PEM-90 photoelastic modulators.

Modular Components and Engineering Support

The RS232 serial interface is standard with the PEM-90 controller. If IEEE-488 operation is desired, this may be obtained using a National Instruments™ Model GPIB-232CV-A converter. A signal conditioner is available which derives from the detector signal a low-pass (DC) signal and a wide-band AC signal.

Please call to discuss your application and experimental setup with our engineers before ordering. Our toll-free number in the United States and Canada is 1 800 688-4463. (Find our address and other contact information on the back cover.)

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