SUMMER 1998

HINDS INSTRUMENTS, INC.

PEM™

APPLICATIONS NEWS FOR USERS OF PHOTOELASTIC MODULATORS

Modulated Interference Effects in Photoelastic Modulators

by Theodore Oakberg, Ph.D.

If lasers are used as light sources for polarization modulation experiments using a photoelastic modulator (PEM), special problems can arise. Strong coherent noise at the modulator oscillation frequency and harmonics arise due to interference between the primary laser beam passing directly through the PEM and beams which undergo multiple reflections between the PEM optical element surfaces (Figure 1). The intensity of this modulated interference can easily be greater than the polarization modulation signals being studied in an experiment.

Modulated interference has been investigated by myself,[1] and by Ernst Polnau and Hans Lochbihler.[2]

RECTANGULAR PEMS (SERIES I)

In my paper I proposed that the modulated interference effects arise from the periodic variation in thickness between the optical element surfaces. Based on this theory, an upper limit for the peak-to-peak amplitude of the modulated interference is given in equation 1,

$$\frac{V_{AC}}{V_{DC}} = 4R \qquad (1)$$

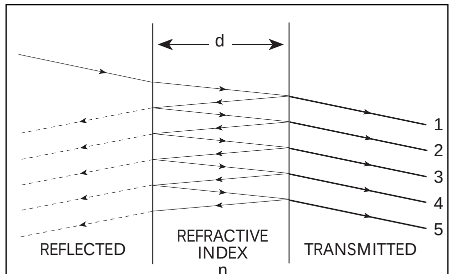

Fig. 1. Light propagation in a PEM optical element.

where V_{AC} is the peak-to-peak amplitude of the modulation, V_{DC} is the average intensity and R is the single surface reflectance of the optical element material. (If V_{AC} is expressed as RMS, as would be measured by a lock-in amplifier, the relationship is $V_{AC}/V_{DC} = 1.41R$.) For fused silica at 633 nm (refractive index = 1.457) the maximum V_{AC}/V_{DC} would be 0.138, which was verified using a rectangular PEM (Hinds Model I/FS50).

The strength of modulated interference, however, will usually be considerably less than the maximum intensity indicated by the relationship given above. The amplitude of the modulated interference depends on a number of factors, including the parallelism of the optical element surfaces, the beam diameter and the amplitude of the PEM oscillations. Users should expect that the effect will be of the order of 10 percent of the limit given above if no corrective action is taken. *(continued on page 2)*

NEW PRODUCT – THIN II/ZS50

MODIFICATION EXTENDS IR RANGE

A new version of the II/ZS50 model is now available which allows increased and extended transmission out to 19 microns (525 cm-1). Known as the II/ZS50-ER, the unit was developed in response to a user's need for a ZnSe range PEM-90 that offered extended range transmission into the far-IR.

The spectral range extension was achieved by decreasing the PEM's optical path length. (With ZnSe, partial transmission losses beyond 14 microns are due to absorption.) However, decreasing the thickness of the optics required redesign of the optical assembly interface and mounting system. The new version unit met the requirements of this particular customer at a price that is very comparable to the standard version II/ZS50. This new unit will be of interest to customers with II/ZS50 applications that require increased and/or extended transmission at longer wavelengths.

Specifications: PEM Model II/ZS50 Comparison

Model	Optical Material	Nominal Frequency	Transmission Limits	Retardation Range 1/4 Wave	Retardation Range 1/2 Wave	Useful Aperture
II/ZS50-ER	Zinc Selenide	50 kHz	550 nm - 19 µm	550 nm - 14 µm	550 nm - 7 µm	14 mm
II/ZS50	Zinc Selenide	50 kHz	550 nm - 18 µm	550 nm - 18 µm	550 nm - 10 µm	14 mm

SYMMETRIC OR OCTAGONAL PEMS (SERIES II)

In their *Optical Engineering* paper, Polnau and Lochbihler suggested that the time dependent variation of the orthogonal refractive indices n_x and n_y along the birefringent axes of the PEM must also be considered for explaining modulated interference.[2] The time dependent refractive indices are given by the equations

$$n_x(t) = n_0 + \Delta n_x \sin(\Omega t) \qquad (2)$$

$$n_y(t) = n_0 - \Delta n_y \sin(\Omega t) \qquad (3)$$

where the modulation amplitudes of the refractive indices are designated by Δn_x and Δn_y and the modulation angular frequency is $\Omega = 2\pi f$.

Polnau and Lochbihler showed that at the center of a symmetric PEM optical element, there is no relative motion of the optical element surfaces. Variations in the refractive indices n_x and n_y must therefore be solely responsible for modulated interference effects. They also showed that for modulated interference effects at the PEM oscillation frequency f, the light intensity at the detector has the form

$$I(t) = I_{ave} + I_{\Omega}\cos(2\Phi)\sin(\Omega t) \qquad (4)$$

where I_{Ω} is the amplitude of the modulated interference, I_{ave} is the average intensity and Φ is the angle between the plane of polarization of the light incident on the PEM and a birefringent axis of the PEM.

Of particular interest is the case where Φ = 45 degrees. For this angle, modulated interference at the PEM frequency vanishes. This is fortuitous since the majority of PEM applications require linearly polarized light incident on the optical element at 45 degrees!

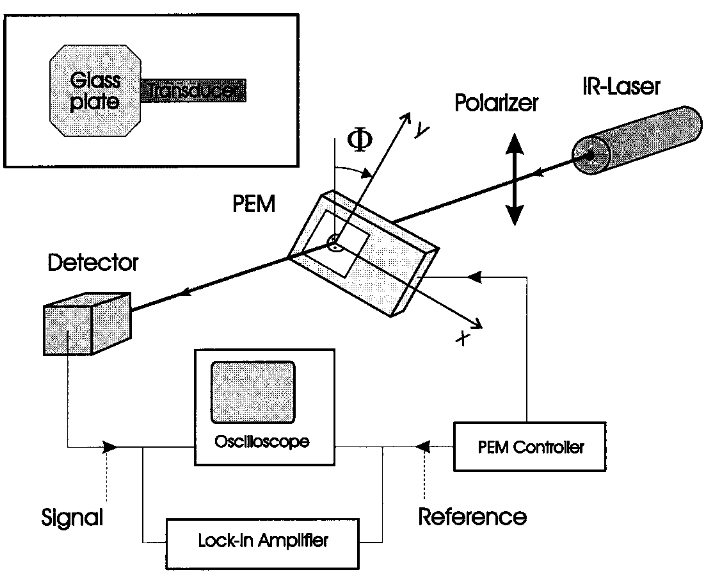

Fig. 2. Sketch of the experimental setup: Photoelastic modulator (PEM), IR HeNe laser, Ge detector, oscilloscope, and lock-in amplifier. The inset shows the geometry of the optical element, consisting of an octagonal glass plate and a piezoelectric transducer.

Fig. 3. Measured lock-in signal as a function of angle Φ at normal incidence for a retardation $\delta=\lambda/4$.

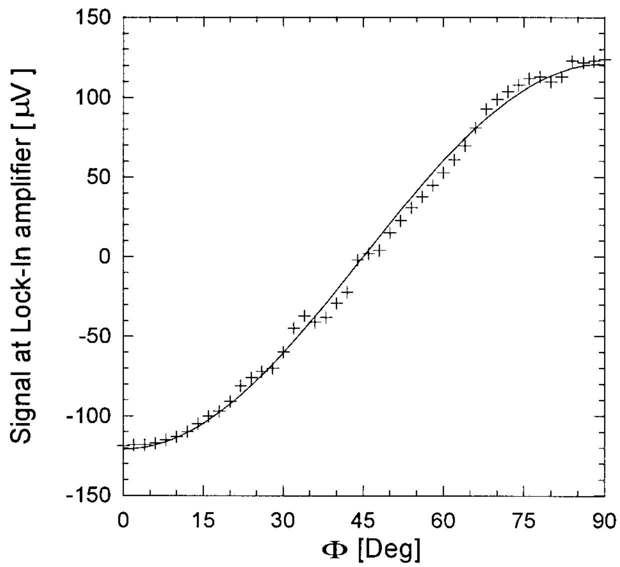

Figure 2 shows the experimental setup used by Polnau and Lochbihler to examine the intensity of the modulated interference vs. the angle Φ. This experiment used a Hinds Model II/IS42 PEM, a HeNe laser with a wavelength of 1.52 microns and a germanium detector (Hinds Model DET-90.007). The PEM peak retardation was set at quarter-wave.

Figure 3 shows the lock-in amplifier signal vs. the angle Φ. The graph clearly shows that the modulated interference vanishes at Φ = 45 degrees, as predicted by theory.

Experiments at Hinds Instruments indicate that the modulated interference at the PEM oscillation frequency f and odd multiples (3f, 5f, etc.) vanishes for polarized light incident on the PEM at 45 degrees everywhere across the optical element, and not just at the center. There is, however, no similar relationship which applies to modulated interference at frequencies which are even multiples of the PEM frequency f (2f, 4f, etc.).

SUPPRESSION OF MODULATED INTERFERENCE

Some reduction of modulated interference effects can be achieved by careful lateral (x or y) or rotational positioning of the PEM optical head.[1] The idea is to change the optical path length through the PEM optical element so that interference at odd multiples of f, or even multiples of f, may be suppressed. However, this method cannot be used to suppress both odd and even frequencies simultaneously. These adjustments are likely to be sensitive to such factors as changes in laboratory ambient temperature, flexures of the optical bench setup, etc. The following methods do not have these problems.

1. Tilting the PEM optical head (Series I and II)

If the diameter of the laser beam is sufficiently small (e.g.1 mm) tilting the PEM optical head may reduce or eliminate interference. In this case, the primary beam and secondary beams are laterally displaced from each other (see Figure 4). If the displacement is sufficient so that the beams do not overlap at the detector, modulated interference will be greatly reduced

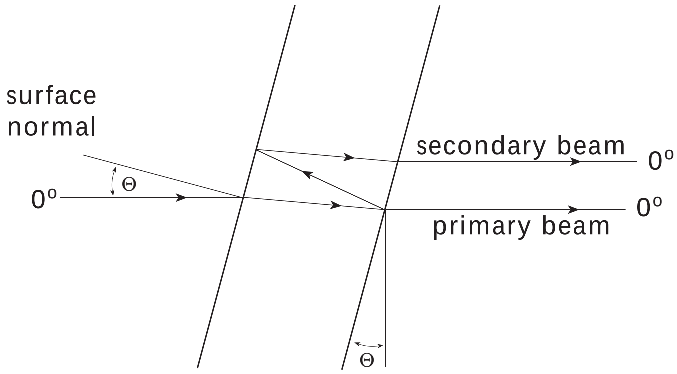

Fig. 4. Separation of primary and secondary beams by tilting the modulator.

or eliminated. (For a Hinds Model I/FS50 and a 1 mm beam diameter, a 10 to 15 degree tilt is sufficient.) This method has the advantage that it may be used with existing PEMs without modification. Note that following tilt adjustment, care should be taken to check the PEM retardation calibration and correct it if necessary.

2. Anti-reflective (AR) coatings (Series I and II)

Since the magnitude of the modulated interference depends directly on surface reflectance, AR coatings on the optical element surfaces may be used to reduce modulated interference. This is particularly useful if a single wavelength of laser light will be used exclusively in a PEM setup. A good V-coat type of AR coating on fused silica will give a typical reflectance of less than 0.1 percent per surface, compared with a surface reflectance of about 3.7 percent for HeNe laser light.

AR coatings may be used with tilted PEM optical heads. For angles of incidence of 10 to 15 degrees from the normal, the effectiveness of a V-coat AR coating should not be seriously compromised.

3. Wedge-shaped optical element (Series I)

For rectangular PEMs (Series I), constructing the PEM optical element so that the optical surfaces have a slight wedge angle to each other (e.g. ½ to 1 degree) will result in the primary and all secondary beams being deflected at different angles.[3] See Figure 5.

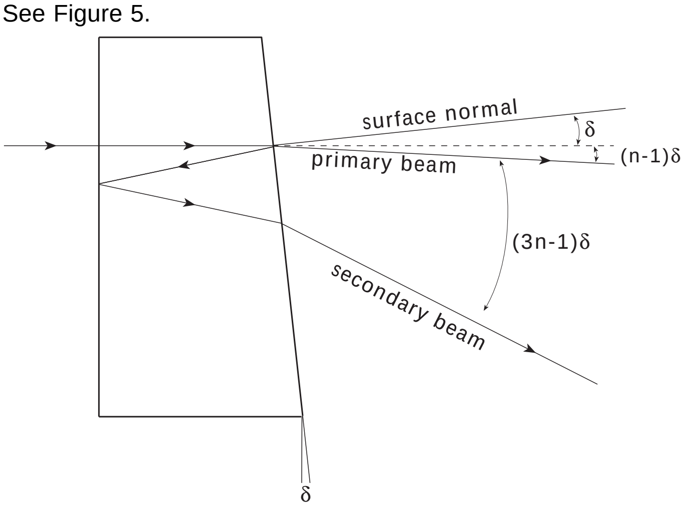

Fig. 5. Primary and secondary beam paths in a wedge modulator.

For a wedge angle of 1 degree, a few centimeters distance following the PEM will be sufficient to give a lateral beam separation of 2 to 3 mm.

Using a wedge-shaped optical element has two advantages:

- It is achromatic, good for different wavelengths of laser light.
- The magnitude of the modulated interference can be reduced to arbitrarily low levels by increasing the distance between the PEM and the detector.

PEMs with wedge-shaped optical elements have the following disadvantages:

- The beam is deflected slightly. For a wedge angle of 1 degree, the deflection angle will be about ½ degree.
- The peak retardation of the PEM depends on the thickness of the optical element where the beam passes. Calibration in situ is therefore recommended.

4. Orientation of the polarization direction of incoming linear polarized light (Series II)

If the primary signal of interest is at the modulator frequency f, symmetric or octagonal PEMs may take advantage of Polnau and Lochbihler's results. For an angle of 45 degrees between the plane of polarization of linear polarized light and the PEM axis, the modulated interference vanishes at the modulator frequency and odd multiple frequencies. Fortunately, this configuration is used in the majority of PEM applications. In some other applications (e.g. where a waveplate precedes the PEM) a judicious rearrangement of components may make it possible to achieve the above condition.

For modulated interference at even multiples of f, suppression may be achieved by using an AR coating, tilting the PEM optical head with respect to the beam, and/or careful rotational or lateral positioning of the optical head.

SUMMARY

Modulated interference can be a serious problem when photoelastic modulators are used with laser light sources. Fortunately a number of methods can be used to reduce the interference to acceptable levels.

Hinds Instruments is very grateful to Ernst Polnau and Hans Lochbihler for their contributions to our understanding of modulated interference.

REFERENCES

1. T.C. Oakberg, "Modulated interference effects: use of photoelastic modulators with lasers," *Opt Eng.* **34,** 1545-1550 (1995).
2. E. Polnau and H. Lochbihler, "Origin of modulated interference effects in photoelastic modulators," *Opt. Eng.* **35,** 3331-3334 (1996).
3. T. C. Oakberg, "Elimination of Modulated Interference Effects in Photoelastic Modulators, U.S. Patent 5,652,673, Hinds Instruments, July 29, 1997.

HINDS INSTRUMENTS
3175 NW Aloclek Drive
Hillsboro, OR 97124 USA

Address correction requested.

BULK RATE
US POSTAGE PAID
Hillsboro, OR
Permit No. 76

INSIDE PEM

Printed in USA. 5M/06-98

NEWS & EVENTS

- Ted Oakberg presented a paper titled **"An Instrument for Measuring Retardation in Optical Materials and in Waveplates"** at the OPTO 98 conference in Erfurt, Germany on May 19. Please contact us for a copy of this paper.
- Mid-July is the scheduled launch date for our Web site: www.hindspem.com. We look forward to providing fast and efficient customer service using the Web.
- Stop by our booth #1027 at SPIE's 1998 Optical Science, Engineering and Instrumentation Show in San Diego, July 19 - 24, where we will be demonstrating the PEM. Bob Wang will present a paper describing an improved method of measuring low-level birefringence during the Monday morning segment of the Inorganic Optical Materials session July 20.
- Hinds Instruments will be well represented in Europe during September. Members of the Sales Engineering and Application Scientist groups will staff the PEM booth (#202), at CLEO/Europe in Glasgow, Scotland, September 14 - 17. Also, Ted Oakberg will attend the "193 at the Peak" conference, September 14-17 in Telfs, Tyrol, Austria. We are looking forward to the opportunity of meeting with European customers and representatives during these conferences.
- Later in the fall, come see us at the Materials Research Society's 1998 fall meeting November 30 - December 4 in Boston, Massachusetts.

ABOUT THE SCIENTISTS

Ernst Polnau received his diploma in physics from the Technical University of Munich. His thesis work was on the alignment of transmission gratings using a photoelastic modulator at the Max-Planck-Institut für Extraterrestrische Physik, Garching.

In 1995 he joined the Physikalisches Institut at the University of Bern in Switzerland, where he is working toward his Ph.D.

His work has provided experience in many areas including optical metrology, polarimetry, laser technology, image processing, mass spectrometry, vacuum technology, electronics, and computer programming.

Hans Lochbihler received his diploma and Ph.D. degrees in physics from the Technical University of Munich. He worked with the x-ray astronomy group at the Max-Planck-Institute für Extraterrestrische Physik, Garching near Munich.

Currently, he is with OHB-SYSTEM Co., Bremen, as a research engineer for optical systems. His research interests include diffractive optics, gratings, electromagnetic problems, optical surface excitations, polarimetry, image processing, and x-ray optics.