

INFRARED POLARIZERS – Theory and Applications

Polarizers are valuable tools used for spectroscopic analysis of sample orientation and for measuring thin films on reflective surfaces. This overview presents basic polarization theory and highlights some useful polarization applications.

For the purposes of discussing polarizers, light is considered an electric field with a magnitude oscillating in time. Light propagating along the z axis can be described as a combination of electric vectors in x and y axis. Linearly polarized light may be thought of as consisting of an x and a y component with different relative magnitudes. For example if the y component is close to zero, the light is considered fully polarized in the x direction.

Polarizers are devices that split unpolarized light into two orthogonal components; one of the linearly polarized components is transmitted, the other is reflected, redirected or absorbed. The most important features of a good polarizer are brightness, contrast and durability. Brightness and contrast can be described by two main parameters; K_1 and K_2 .

K_1 = Transmission efficiency for normally incident polarized light whose electric field vector is perpendicular to the wire direction.

K_2 = Transmission efficiency for normally incident polarized light whose electric field vector is parallel to the wire direction.

For a ‘perfect polarizer’ $K_1 = 1$, which means full transmission of polarized light whose electric field

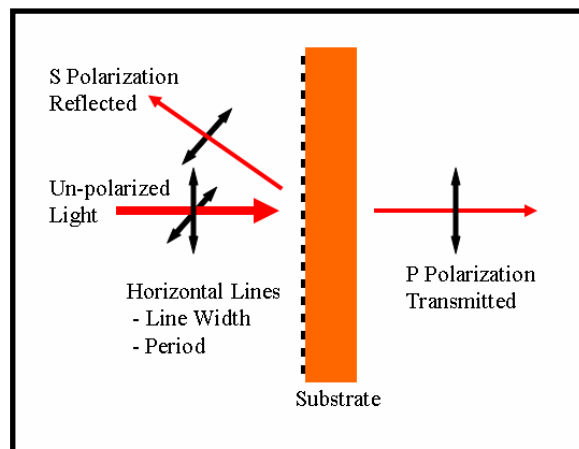
vector is in the preferred direction and $K_2 = 0$, which means complete blockage of a beam of polarized light whose electric vector is perpendicular to the former. Other measures of performance deduced from K_1 and K_2 are

$$\text{Degree of polarization} = \frac{(K_1 - K_2)}{(K_1 + K_2)}$$

$$\text{Extinction Ratio} = \frac{K_1}{2K_2}$$

$$\text{Principal transmittance ratio or contrast} = \frac{K_1}{K_2}$$

Polarizers may be made from very fine conducting parallel elements or grid placed upon a suitable transparent base material. When the grid spacing is much smaller than the wavelength of light, the light with the electric vector parallel with the grid will be reflected and only the component with perpendicular electric vector will be transmitted (shown graphically below).



The overall transmission characteristic of the polarizer depends upon the substrate, but the polarization

efficiency depends upon the period, line width and other design parameters of the polarizer.

In the mid-infrared range the most practical and commonly used polarizers are ruled or holographic wire grid structures. The polarization effect comes from the same principle as the free standing wire grid, except the fine wires are formed on the surface of an infrared transmitting optical window material. Polarization efficiency depends on smaller grid spacing than the wavelength and on the conductivity of the wires. In the case of a ruled polarizer, the surface of the optical element is created by a diamond needle to form very fine parallel lines, such as 1200 lines/mm, on the surface. The optical element is then placed into a vacuum chamber and this pattern is partially coated with aluminum or other evaporated metallic layer. The spacing between the evaporated thin lines has to be very small, typically a fraction of the wavelength. Ruled polarizers have good performance and are durable at

high laser powers, but can only be made on hard, non-granular materials that can be ruled, such as ZnSe.

Holography is another method used to form the fine metallic wire pattern on the surface of the polarizer element. Two coherent laser beams are directed onto the surface of the optical element which is coated with a very thin layer of photo resist. The pattern formed at the intersection of the two beams is

interference

allowed to expose the photo resist. The lines in between the exposed photo resist are removed and then coated in a vacuum chamber similar to the ruled grating type. The advantage of holographic polarizers is that a wider variety of materials can be used such as the softer KRS-5. As mentioned earlier, the efficiency of the polarizer depends on the grid spacing formed among the wires. Holographic techniques allow more uniform grid patterns because the spacing is produced optically. Light scatter due to imperfections of ruled grooves are also reduced. If the grid spacing is smaller, the polarizer is more efficient. The spacing errors have also much less effect on the efficiency if the grid is much smaller than the wavelength. The trade-off with tighter grid is the reduction of the optical throughput. These parameters are carefully optimized in the design of the polarizer elements and the right polarizer can be selected for specific experimental conditions.

Specifications and performance characteristics of polarizers offered by PIKE Technology are shown in the following table;

Polarizer Type <i>Application</i>	Wavelength Range, cm-1	Transmission Efficiency, K1	Undesired Transmission, K2	Degree of Polarization, (K1-K2)/(K1+K2)
ZnSe <i>Mid-IR, general purpose</i>	15000 - 460	70%	1%	97%
KRS-5 <i>Mid-IR, wide-range</i>	17900 - 200	75%	0.25%	99%
Ge <i>Mid-IR, highest efficiency</i>	5500 - 430	90%	0.25%	99%
Polyethylene <i>Far-IR, widest range</i>	500 - 10	80%	4%	93%
Polyester <i>Far-IR, highest efficiency</i>	200 - 10	90%	3%	93%
CaF2 <i>NIR applications</i>	79500 - 1025	85%	1%	98%

Notes: Efficiency values reported at 1000 cm-1 for mid-IR, at 3300 cm-1 for NIR and 100 cm-1 for far-IR

The optical material substrate used to create the polarizers determines the wavelength range of the polarizer –

such as ZnSe or KRS-5. The table above shows the K₁ values of our polarizers. The maximum transmitted light is affected by the transmission of the materials and the scattering of the ruled and evaporated surfaces. Fresnel losses are determined by the refractive index and the performance of the anti-reflection coating on the element. The maximum transmission compared to a fully depolarized open beam is typically less than 50%. However, FT-IR spectrometers produce slightly polarized beams which in most cases are oriented in the vertical direction in the sample compartment. Thus the apparent transmission of a single polarizer oriented vertically and compared to open beam, can be over 50%.

The other critical parameter of polarizers, the contrast, can be measured by crossing two polarizers and recording the throughput signal. For efficient polarizers in a practical spectroscopy setting, such as using a converging infrared beam in the sample compartment of an FT-IR spectrometer, it is expected that the light level should be less than 1%, for selected high performance ones better

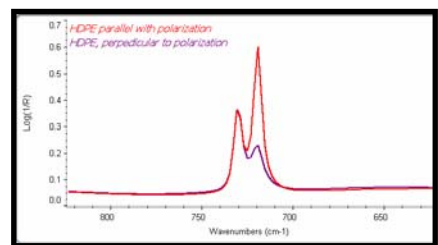
than 0.5%.

Polarizers are usually mounted in a plastic disc and placed in a rotating

holder with an angle scale. This way the angle of the polarizer orientation can be positioned with approximately 1 degree repeatability. Motorized polarizers are available with much better angular accuracy and precision. The automated polarizers are also very useful for conducting a series of experiments with different angle settings under complete computer control.

One of the main uses of infrared polarizers is to monitor molecular orientation in samples such as films and fibers. During manufacture polymers tend to orient along the axis of the mechanical stretching and this preferred orientation is retained after the material stops flowing. In some cases polymers are a mixture of crystalline, more polarized, and amorphous, less polarized, forms of the material. In order to study orientation, polarized light is directed on the film or fiber. The polarized light electrical vector coinciding with the dipole of the infrared active moiety increases in absorption intensity, thereby revealing the band assignment and the orientation of the molecular group. Single crystals placed in the focus of polarized light also absorb selectively, depending on the orientation of the crystal.

Spectra for high density polyethylene (HDPE) with parallel and perpendicular polarization demonstrate that this sample is oriented.



Polarizers can also be used in conjunction with attenuated total

reflection (ATR). Even without polarizers, for any ATR that retains the orientation relative to the incoming infrared beam, there could be spectral differences noted when an oriented sample is placed with its direction along the optical axis or perpendicular to it. The phenomenon is related to penetration depth differences for the light components polarized parallel or perpendicular with the reflective surface (see ATR Theory and Applications).

Another important application of polarizers is the enhancement of the signal measuring thin films on polished semiconductors, metallic mirrors and other reflective surfaces.

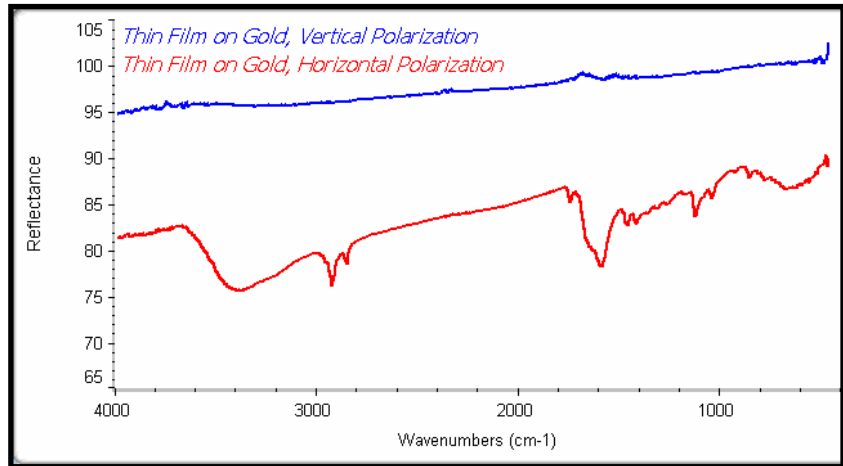
Using large angle reflectance optics, the grazing angle reflectance of the thin films can be measured. Substantial signal enhancement can be achieved by using polarized light in conjunction with a grazing angle accessory. As an example, a thin oily deposit on a gold mirror can be measured with good signal-to-noise ratio by using polarized light with a

specular reflectance accessory set at 80 degrees. Background spectra for each result were collected at the identical polarization angle as the sample. As seen in the spectra below, the light polarized such that the electric vector is perpendicular to the

measurements, showing a signal with less contrast than the red trace.

Summary

Polarizers are highly useful spectroscopy sampling tools for the



metallic mirror surface is enhanced. The spectrum measured with the polarization perpendicular to the surface (electric vector parallel with the surface) is not detected. The non-polarized light measurement is a combination of the two polarized

measurement of samples with molecular orientation, for measuring thin films on reflective surfaces and for molecular spectroscopic research.