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PHOTONICS SPECTRA

Polarizers and polarizing beamsplitters are available in many shapes and sizes to meet performance, bandwidth and spatial requirements.

Perplexed by Polarizers?

A practical look at polarizers reveals their suitability for various applications.

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When engineers, chemists and physicists discuss polarization, they could be talking about anything from the diffraction efficiency of a hologram to the precision of a micromachining laser to the brightness of an LCD system. With such diverse applications, it is critical to understand polarization and how it affects the project at hand.

Polarization is the direction in which the electric field of a light wave oscillates. Because lightwaves are transverse waves, the electric field is always perpendicular to the direction of the propagation of the beam (the Z-direction, for example). Plane-polarized or linearly polarized light is characterized by the electric field always remaining parallel to the X- or Y-direction, or to some angle in between. Light rays from the sun, a lightbulb or a candle flame are classified as unpolarized because the direction of polarization varies continuously and randomly.

In the fields of optics and photonics, polarization direction is defined relative to the plane of incidence where P-polarized light is parallel (P = parallel) to the plane of incidence and S-polarized light (S from senkrecht, the German word for perpendicular) is perpendicular to it (Figure 1). In a typical optical setup, S-polarized light also is referred to as transverse-electric (TE) or vertically polarized because the electric field direction of the wave is perpendicular to the horizontal plane along the direction of propagation.Alternatively, P-polarized light often is called transverse-magnetic (TM) or horizontally polarized because the electric field direction of the wave is in the horizontal plane along the direction of propagation.

To transform unpolarized light into polarized light, one or more polarizers are used to absorb, reflect or refract the unwanted polarization state, depending on the level of polarization purity required. There are many varieties of polarizers and polarizing beamsplitters, from crystal calcite prisms to wire grids. The right one for a specific application is generally a compromise that accomodates mechanical constraints,

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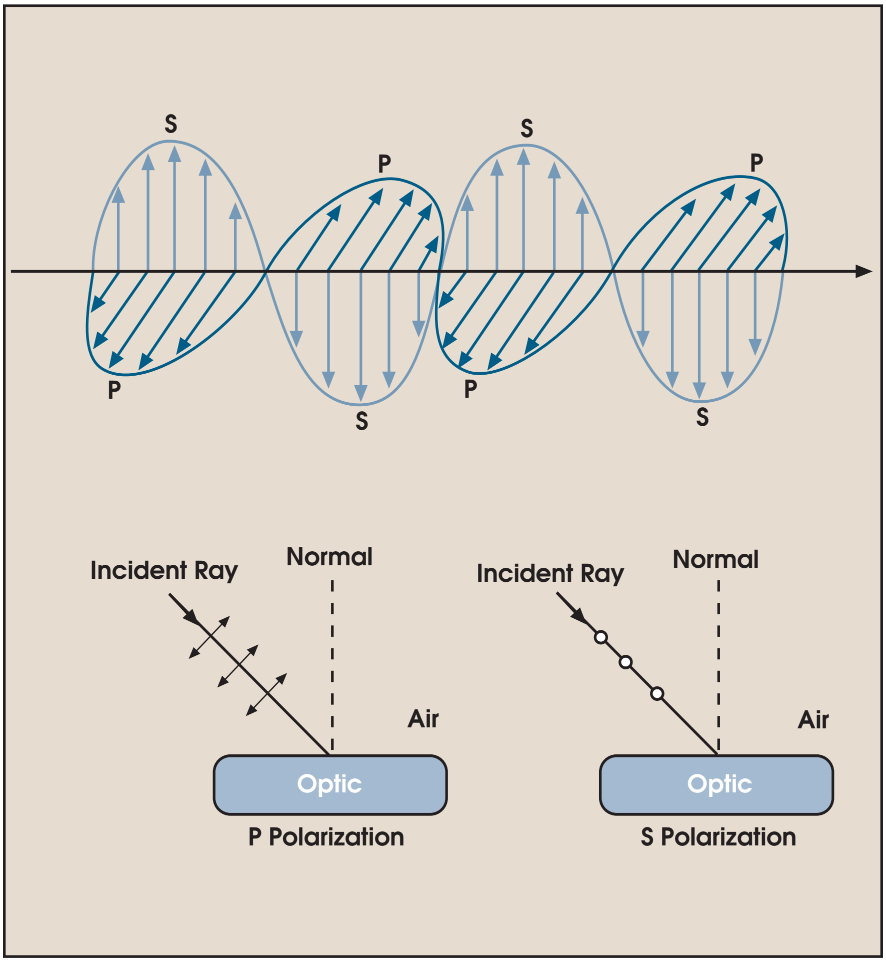

Figure 1. *Polarization direction is defined by its relation to the plane of incidence. P-polarized light is parallel — and s-polarized, perpendicular to — this plane.*

technical requirements and the available budget.

Dichroic polarizers absorb one polarization component while transmitting the other; a perfect linear polarizer will transmit 50 percent of unpolarized input light. A polaroid filter or plastic-sheet polarizer is the most common type of dichroic polarizer. First invented in 1928 by Edwin H. Land, this type of linear polarizer is composed of a thin anisotropic polymer film that is stretched until the molecules align, forming a polarization axis perpendicular to the molecular chain. Electromagnetic waves parallel to this axis are transmitted while those perpendicular to it are blocked or absorbed. Polarizing filters are used extensively in LCDs, microscopy, 3-D movies and other low-energy imaging applications.

Corning's Polarcor® and Hoya's CUPO are dichroic glass polarizers that are similar in concept to polymer polaroid filters but comprise elongated and axially aligned silver and copper particles, respectively. These linear polarizers have very high extinction ratios and operate over broader bandwidths and wider acceptance angles than most dichroic sheet polarizers. Because they are solid glass, they also are durable and thermally stable, with lower transmitted wavefront distortion than many other types of polarizers. Their transmission efficiencies are highest in the near-infrared, making them particularly suitable for liquid crystal switches, for fiber optic devices and as low-energy fiber laser polarizers.

Wire grid polarizers use reflection to remove the unwanted polarization component; therefore, they can withstand higher energy levels than absorptive sheet polarizers. They also have a wider field of view than thin-film polarizers, making them suitable for use with noncollimated beams. The thin metal wires can be either freestanding or imparted onto a suitable glass substrate via mechanical "ruling" with a diamond needle or via a holographic technique.

Polarization efficiency is maximized when the dimensions and spacing of the lines are very small compared with the wavelength of incident light; consequently, wire grid polarizers are most often used in the mid-to-far-IR where wavelengths are relatively long (2 to 50 µm). However, grid spacing of less than 1 µm can be achieved using semiconductor nanofabrication techniques, producing polarizers for use at wavelengths down to 200 nm. Bandwidth and transmission efficiency are limited primarily by the host material, an infrared transmitting glass substrate such as ZnSe, KRS-5, Ge or CaF_2 onto which fine parallel lines of aluminum or gold are coated. Structured in the same way as sheet polarizers, wire grids transmit light that is polarized in the direction perpendicular to the wires, reflecting or absorbing the parallel component of the electric field.

For high-energy lasers and for applications requiring both polarization components, absorption is undesirable. In these cases, a polarization beamsplitter is used to split the input beam into two beams with opposite polarizations, both of which can be used. The splitting can be done by reflection or refraction of one of the polarization states.

The amount of reflection off an uncoated optic depends on the wavelength and angle of incidence. At Brewster's angle, P-polarized light fully transmits through a component while S-polarized light is partially reflected. A series of windows or plates set at this angle eventually will polarize the light completely.

This setup often is known as a "pile of plates" and has been in use since 1812. It is simple to design and is functional at any wavelength from the deep-UV to the far-IR, wherever optical materials transmit. The drawback to this design is that the S-polarized light is spread out among many beams, so it may not be very practical if used as a beamsplitter.

Adding a multilayer coating to the concept of the Brewster's angle polarizer makes a more compact and efficient design, whether it is on a plate or within a cube structure. Thin-film plate polarizers use the interference effects within the coating layers to mimic the pile-of-plates design in a fraction of the space. Transmission efficiencies greater than 95 percent and extinction ratios (Tp/Ts) typically exceeding 100:1 can be achieved with a single front-surface coating. The reflection of P-polarized light off the uncoated back surface is minimal because of the nearness to Brewster's angle, making antireflection coating of the second side unnecessary.

Historically, plate polarizers have been available for use only at or beyond Brewster's angle. Recent advances in coating design and technology, however, have made 45° plate polarizer designs more manufacturable. Highly accurate techniques can produce dense dielectric coatings impervious to the wavelength shift inherent in most thin-film polarizers. Consequently, transmission efficiencies of greater than 97 percent can be maintained without the need for angle tuning. Also, because the incident angle is 45°, the reflected and transmitted beams are separated by 90° and orthogonally polarized, thus reducing the need for intricate beam paths and time-consuming alignments.

In 1946, Stephen MacNeille took the Brewster's angle thin-film polarizer one step further by modifying the coating design for an internal glass-to-glass interface. The MacNeille prism polarizer forms the basis for the many varieties of polarizing beamsplitter cubes currently available. Each polarizer consists of a pair of right angle prisms with a multilayer coating at the cemented interface and antireflection coatings on the legs to increase overall transmission. Cubes of this type are available in many sizes, materials and wavelengths but generally have a limited field of view and low reflected extinction ratios (Rs/Rp). Despite these shortcomings, cemented cubes are a widely used, low-cost alternative for low- to medium-energy applications from the UV to the near-IR.

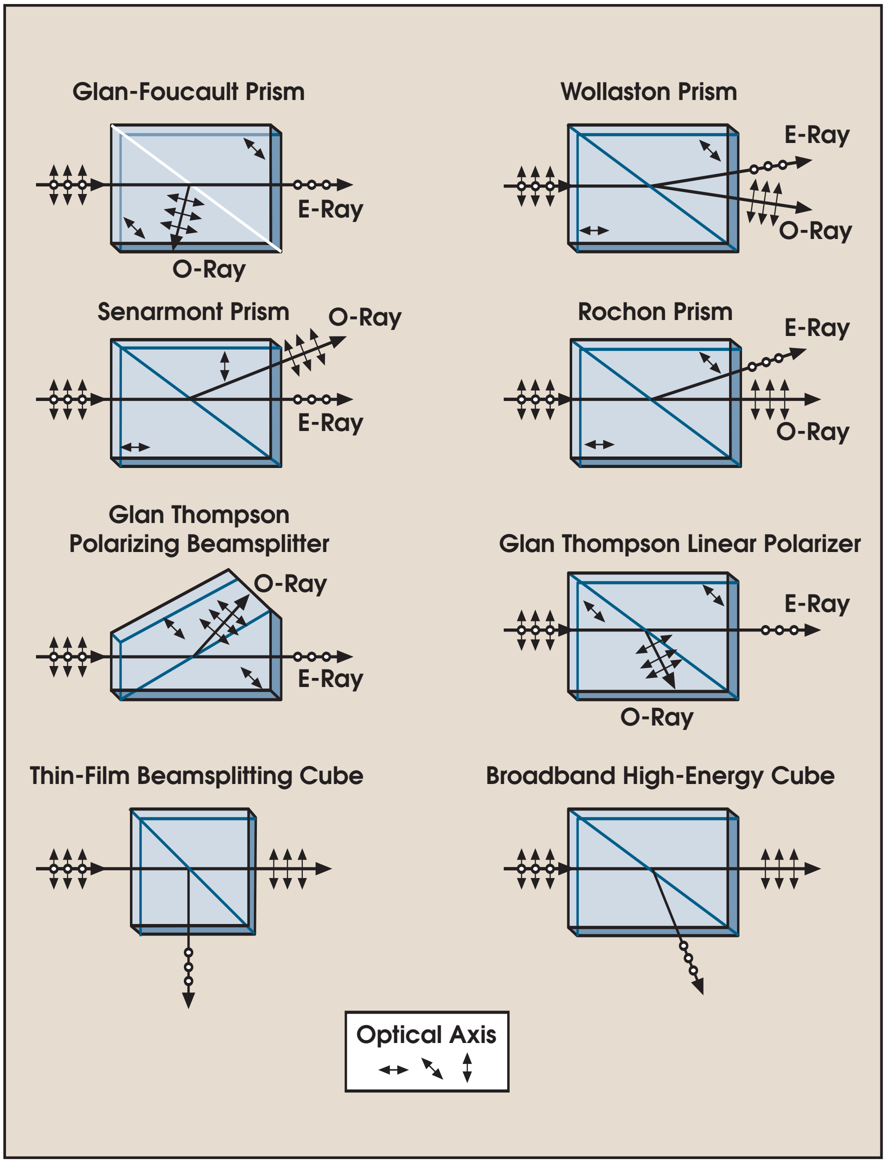

Figure 3. *These examples show how various polarizing prism designs affect the lightpaths of introduced beams. Each design provides specific options for the beam outputs.*

The cubes are available in narrowband and broadband versions with damage thresholds of up to 1 J/cm² and transmitted extinction ratios of up to 1000:1, depending on the wavelength and spectral bandwidth. For wavelengths below 300 nm, and for high-fluence lasers and vacuum applications, cement and other epoxies are undesirable. Absorption, scatter and outgassing can all occur within the cement layer, resulting in laser damage, contamination of other components in the system or loss of energy.

Optically contacted polarizing cubes do not exhibit any of the aforementioned negative characteristics. Optical contacting is a room-temperature epoxy-free bonding process that results in optical paths that are 100 percent transparent with negligible scattering and absorptive losses at the interfaces. Consequently, beamsplitter cubes assembled with this process introduce very little wavefront distortion or optical path variance between the output beams, and they can be used with energies exceeding 5 J/cm^2. Narrowband laser line cubes separate the S- and P-polarized beams by 90° and are available at many wavelengths from 193 to 2200 nm.

By modifying the prism angles away from 45°, coating designs have been adjusted to produce broadband and multiple-wavelength polarizing cubes without compromising the damage threshold or transmitted extinction ratio. The larger internal angle of incidence allows design variations using the same coating materials —without cement — to generate high-energy asymmetric cubes with extinction ratios of greater than 10,000:1 over bandwidths of 50 to 250 nm.

Birefringent polarizers and polarizing beamsplitters feature extinction ratios of greater than 10,000:1 through the use of optically anisotropic crystals such as calcite, quartz, YVO_4 and magnesium fluoride. When unpolarized light enters a birefringent crystal in a direction other than parallel to the optic axis, each of the polarization components experiences a different index of refraction and, therefore, follows a different path through the crystal, splitting the beam into two orthogonally polarized rays.

The original linear polarizer, devised by William Nicol in 1828, has evolved into several variations. These include the Glan-Thompson, Wollaston and Rochon prism polarizers, which are cemented, and the Glan-Taylor, Glan-Foucault or Glan-air and Senarmont prisms, which are air-spaced. Altering the orientation of the optic axis, the crystal material and/or the mechanical construction of the polarizer has allowed designers to adapt the divergence angle, damage thresh-old, degree of polarization, acceptance angle and functional wavelengths for many different uses. Applications requiring the high extinction ratios or extreme polarization purity of birefringent polarizers are telecommunications isolators, microscopy, spectroscopy and Q-switched lasers.

Polarizers come in many types, shapes and sizes. Single elements can cost tens of dollars for a polarizing sheet to hundreds of dollars for birefringent crystals, and each one can last from hours to years, depending on the application and environment.

Even within a certain group of polarizers, whether absorptive, reflective or refractive, researching the available benefits and limitations of each component is a worthwhile effort that will greatly affect the final result and the out-put of the system around it. Selection guides are available online that allow comparison of extinction ratios, wavelengths and laser damage threshold. ☐

Meet the author

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