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HIGH POWER POLARIZERS

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Polarization has many important applications across engineering and science, including Liquid Crystal Displays (LCDs), laser radar (LADAR) and Quantum Cryptography. With such diverse applications, it is critical to understand polarization and how it affects the project at hand.

Polarization refers to the direction in which the electric field of a light wave oscillates. Since light waves are transverse, the electric field is always oriented perpendicular to the direction in which the wave is traveling—typically referred to as the Z-direction. In the case of plane-polarized or linearly polarized light, the electric field maintains a constant orientation, remaining aligned with either the X- or Y-direction, or at some fixed angle between the two. In contrast, light emitted from sources like the sun, a lightbulb, or a candle flame is considered unpolarized, as the direction of polarization in such light varies randomly and continuously over time.

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 convert unpolarized light into a polarized form, optical systems make use of polarizers, which function by selectively absorbing, reflecting, or refracting certain polarization components, depending on the level of polarization required. Polarizers and polarizing beamsplitters come in many forms, such as calcite crystal prisms and wire grid designs. However, not all types are suitable for high energy applications like Directed Energy and Aerospace.

In scenarios involving high-power laser systems or applications where both polarization components must be retained, and absorption minimized, polymer sheet polarizers, birefringent prism polarizers and wire grid polarizers are not ideal. 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 light reflected by an uncoated optical surface varies with both the light's wavelength and the angle at which it strikes. At Brewster's angle, P-polarized light transmits entirely through the material, whereas S-polarized light is partially reflected. Arranging multiple glass plates at this specific

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angle will eventually yield fully polarized light—a configuration historically known as the "pile of plates." Though in use since 1812 and functional across the entire optical spectrum—from deep ultraviolet to far-infrared—this design spreads the S-polarized component across multiple beams, making it less effective as a true beamsplitter.

By incorporating multilayer coatings, the pile-of-plates concept has been miniaturized and made more efficient, whether implemented on optical plates or within cube geometries. Thin-film plate polarizers take advantage of interference effects in these coatings to replicate the function of a pile of plates in a far more compact form. These designs can achieve transmission rates exceeding 99%, with extinction ratios (the ratio of P-polarized to S-polarized transmission) over 5,000:1 using just a single coating on the front surface. Because the design already operates near Brewster's angle, reflections from the uncoated rear surface are minimal, often eliminating the need for antireflective coatings.

More recently, innovations in coating design and technology, have made 45° plate polarizer designs more manufacturable. These advanced coatings are highly stable against wavelength shifts typical in thin-film beam splitters and polarizers, achieving transmission efficiencies above 98% without requiring angle adjustments. The 45° geometry also simplifies optical layouts: reflected and transmitted beams emerge at 90° angles and are naturally orthogonally polarized, streamlining alignment and beam path configuration.

In 1946, Stephen MacNeille enhanced the Brewster-based thin-film polarizer by adapting the coating for use at an internal interface between two pieces of glass. This led to the MacNeille prism, which laid the groundwork for today's polarizing beamsplitter cubes. These cubes consist of two right-angle prisms joined at a coated interface, with antireflective coatings on the entry and exit faces to optimize transmission. Cubes of this type are available in many sizes, materials and wavelengths but generally have a limited field of view and lower reflected extinction ratios (Rs/Rp) than plate polarizers. Despite these limitations, cemented cube designs are widely used as economical solutions for low- and medium-power applications, particularly at visible and near-infrared wavelengths.

Conversely, epoxy bonding is typically not recommended for wavelengths below 300 nm, or where high laser fluence or vacuum compatibility is needed. The adhesives can introduce absorption, scattering, and/or outgassing, which may damage the system, degrade components, or reduce energy efficiency. Optically contacted cubes eliminate these risks by using a room-temperature epoxy-free bonding process, resulting in highly transparent optical paths with minimal scattering or absorption at the interfaces. These cubes offer improved beam quality and can handle energies exceeding 5 J/cm^2. Narrowband laser line cubes using this method can split orthogonally polarized beams at 90° across wavelengths ranging from 193 nm to >2200 nm.

For even higher power applications or those requiring additional environmental and thermal stability, like optics for space-flight and biocompatible optics, chemically bonded beamsplitter cubes with ionbeam-sputtered (IBS) coatings are the most robust option. As with optically contacted cubes, there is no scattering or absorptive losses at the interfaces and no outgassing. The chemically activated, solution based process forms covalent bonds which are chemically resistant, extremely uniform and durable, resulting in polarizing beamsplitter cubes with very low absorption, damage thresholds over 20J/cm^2 at 1064nm.

By adjusting the internal prism angles beyond the typical 45°, manufacturers have developed coating designs that support multiple wavelengths or broad wavelength ranges without sacrificing durability or extinction performance. This allows for high-power asymmetric cube polarizers with extinction ratios over 10,000:1 and operational bandwidths between 50 and 300 nm, all without the use of adhesives or epoxies.

Polarizers come in many shapes and sizes, with single units costing from tens to thousands of dollars depending on the wavelength and detailed specifications, so researching the benefits and limitations of each different type is a worthwhile effort. Selection guides are available online that allow comparison of extinction ratios, wavelengths, typical costs and laser damage threshold of the various available options. Or contact us at Perkins Precision Developments to discuss the best solution for your application.

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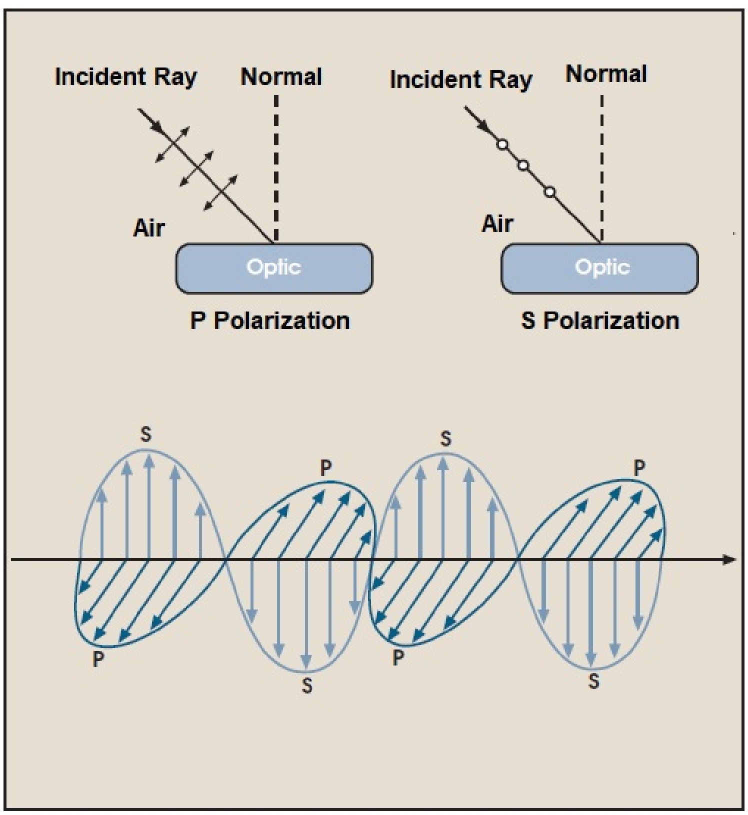
Summary Table

Polarizer Type	**Wavelength Range**	**Damage Threshold**	**Key Applications**
Wire Grid	200 nm – 50 µm	>5 J/cm²	Defense IR, Aerospace imaging
Thin-Film Plate	193 nm – 2.5 µm	5–20 J/cm²	High-power optics, Fiber-lasers
Adhesive free Cubes	193 – 2200 nm	5–20 J/cm²	Quantum, Directed energy, Space-flight, Nd:YAG & fiber lasers
Asymmetric Polarizing Cubes	355 – 1550 nm (typical)	5–20 J/cm²	High-energy beamlines, femtosecond systems
Brewster Angle Plates	180 nm – >10 µm	~1–5 J/cm²	Legacy laser systems



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