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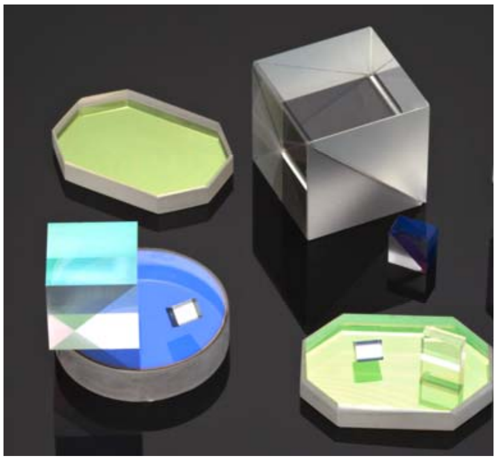
# A Preference for High Power Polarizers

By E. Kubacki and N. Traggis, Precision Photonics Corporation



As laser energies have increased throughout the years, the selection of appropriate polarization components has become increasingly limited. Until recently, if a system was running greater than about a joule per square centimeter, the only options available were air-spaced beamsplitter cubes or Brewster angle plate polarizers, both of which required fairly complicated beam paths and alignment. Fortunately, as coating technologies and assembly techniques have improved, so has the selection and quality of available high energy polarizers. Using new designs and advanced techniques in both assembly and thin film coating, three types of components have become available for high energy applications from the ultraviolet (UV) through the visible and near-infrared (NIR): epoxy-free beamsplitter cubes, single element crystal polarizers and non-shifting thin film plate polarizers.

For high damage threshold applications requiring the optical path lengths of the orthogonally polarized beams to remain equal, polarizing beamsplitter cubes are the obvious choice. An idyllic cube would separate the polarized beams by 90 degrees for easy alignment, and would be manufactured without the use of epoxies or optical cement which can outgas, absorb or scatter input light, resulting in separation of the components or catastrophic laser damage. Fabrication of high energy cubes meeting these criteria can be accomplished through epoxy-free bonding techniques such as optical contacting and chemically-activated direct bonding. Although more costly up front, the advantage of epoxy-free components for high energy applications is clear.

Optical contacting is a room-temperature process dating back to the 1930's by which two well-polished right angle prisms are coated and then physically pressed together to achieve an adhesive-free bond. Although typically performed using clean, dry glass or coated components, a small amount of isopropyl alcohol can also be used at the interface to allow for minor adjustments to the alignment of the components while the alcohol evaporates. The assembly is optically transparent and is usually edge-sealed along oversized bevels in order to increase the overall strength and life-time of the bond. Beamsplitter cubes, waveplates and mirror assemblies utilizing this production method have been successfully manufactured throughout the photonics industry using fused silica, Zerodur, crystal quartz and other optical glasses. Typical specifications for various types of polarizing beamsplitter cubes are shown in Fig A. optical properties (scattering, absorption, index mismatch, and power handling), thermal properties, and chemical properties, along with the simplicity and manufacturability of the process itself.

Chemically activated direct bonding™ (CADB) is one alternative to optical contacting which results in more robust bonds and manufacturing flexibility. Unlike more elaborate processes like diffusion bonding which utilizes pressure along with highly elevated temperatures applied in a protected atmosphere, chemically activated direct bonding is a robust, adhesive-free process that requires only a clean room environment and a skilled technician. After chemical activation, the two surfaces are brought into contact and annealed at material-specific temperatures to form covalent bonds between the atoms of each surface, resulting in structures which can exhibit bulk strength and a zero-thickness bond line at the interface. A primary advantage of a technique like

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this over optical contacting is that the increased strength of the bond allows for processing after assembly, meaning that the bonded parts can be cut, shaped, polished or coated to create highly toleranced or multi-component assemblies (Fig B) without the temperature constraints or threat of delamination exhibited by other assembly techniques. Because there is no epoxy, the finished units are compact and thermally stable, exhibiting insignificant levels of absorption or scattering loss at the optical interface.

| Specification | Cemented | Optically Contacted | Optically Bonded (CADB™) |
|---|---|---|---|
| LDT at 1064nm | 0.2-1J/cm$^2$ | 3-10J/cm$^2$ | 12-15J/cm$^2$ |
| LDT at 355nm | 0.1-0.5J/cm$^2$ | 1-2J/cm$^2$ | 2-3J/cm$^2$ |
| Transmitted Wavefront Distortion | $\lambda$/2-$\lambda$/4 p-v at 633nm | $\lambda$/4 p-v at 633nm | $\lambda$/10 p-v at 633nm |
| Extinction ratio Tp/Ts | 500-1000:1 | 200-500:1 | > 1000:1 |
| Dimensional Tolerance | ± 0.25-0.50mm | ± 0.25mm | ± 0.125mm |
| Avg Price | $100-200 | $700-800 | $700-800 |

Fig A) Typical specs for ½" polarizing beamsplitter cubes

Optically contacted and chemically bonded cubes are designed for single laser-line wavelengths from 193nm to 2200nm using multi-layer dielectric coatings within fused silica glass. They are intended primarily for narrowband laser applications where optical path lengths must remain equal, transmitted and reflected wavefront quality must be maintained and/or laser energies exceed about 1J/cm$^2$.

By modifying the design of a fused silica cube to have an internal angle closer to Brewster's angle, broadband and multi-wavelength polarization can be achieved without compromising wavefront, transmission efficiency or damage threshold. The larger internal angle results in a less-than-ninety degree separation in the output beams, but also expands the possible coating design options to produce cubes with bandwidths of 200nm or more.

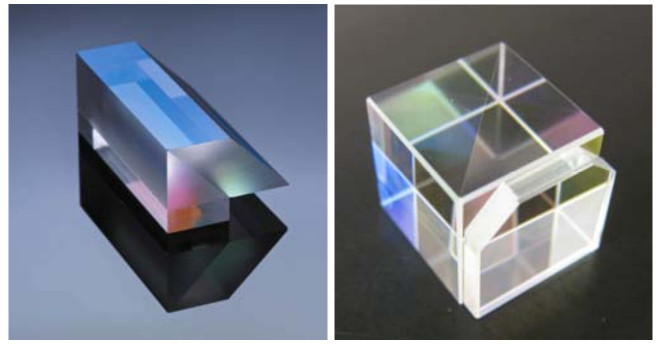

Figure B) Multi-component adhesive-free assemblies manufactured via chemically activated direct bonding™

Another way to increase bandwidth of the polarizing coating is through the use of a higher index glass substrate such as SF10 or SF11. The higher index glass, in combination with standard dielectric coating materials, yields similar results as achieved with the broadband cubes mentioned above, but without the disadvantage of having to align additional optical components in the system at odd angles. Because they are epoxy-free, these beamsplitter cubes still withstand high laser energies of at least 4J/cm$^2$ over bandwidths of greater than 300nm in the visible or near-infrared wavelength regions, while exhibiting high extinction ratios and good transmitted wavefront properties.

Single element crystal polarizers are not yet widely available, but initial designs demonstrate attributes which indicate their potential as high energy, broadband polarizers. Anisotropic crystals such as alpha-barium borate α-BBO, yttrium vanadate YVO4, rutile TiO2, and lithium niobate LiNbO3 can be used alone for small beam diameters or in combination of two to three prisms for lasers with beam diameters up to 10mm. By utilizing total internal reflection and altering the direction of the optic axis within the crystal, the mechanical angles of the prism components can be designed in multiple ways to optimize the divergence angle and separation of the exiting polarized beams. Employing Brewster angle epoxy-free designs makes non-linear crystal polarizers promising as low-loss replacements for standard cemented or air-spaced calcite polarizers in many mid-to-high energy laser applications.

Although more difficult to process than optical glasses such as BK7 and fused silica, the crystal design

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removes any dependence on thin film coatings or optical assembly, possibly reducing the overall cost of manufacturing them to equal or even below the cost of other high energy polarization components. Final performance parameters and specifications have yet to be established, but without cement or complicated coating stacks, laser damage thresholds are limited only by the bulk material itself.

Plate polarizers are used in situations where high laser damage thresholds are required but the size, performance or cost of a beamsplitter cube is undesirable. Coated thin film plate polarizers exploit the interference effects within the coating layers to reproduce a pile-of-plates Brewster angle design in a single component design. Because the coating can be done on any shape or thickness substrate, plate polarizers can be designed to minimize pulse dispersion and reflected or transmitted wavefront distortion without sacrificing clear aperture or transmission efficiency. A laser-quality plate polarizer designed for 1064nm can withstand greater than 10J/cm$^2$ of pulse energy in the transmitted beam (P-polarization, with transmission greater than 97%) and as much as 20J/cm$^2$ in the reflected beam (S-polarization), with typical transmitted extinction ratios exceeding 1000:1.

Plate polarizers are currently available throughout the ultraviolet to near-infrared wavelength regions at either Brewster's angle (56°) or at 45 degrees, as shown in figure C. The 45° design is ideal for easy set-up and alignment, creating orthogonally polarized beams separated at right angles. However, although more complicated to align, Brewster angle polarizers achieve higher transmission efficiency and extinction ratios over a broader acceptance angle than the 45° plates.

Historically, thin film plate polarizers required angle tuning during usage. Because of the porous nature of electron-beam deposited coating stacks, environmental changes to humidity and temperature cause a wavelength shift within the coating which can alter the spectral performance of the polarizer at any given wavelength. Recent advancements in ion beam sputtering (IBS) coating processes have eliminated this effect, making the plate polarizer a more stable and functional component. During the IBS process, a high-energy ion beam is used in vacuum to deposit dielectric materials onto a substrate. Unlike evaporative or ion-assisted processes, the coating materials in an IBS coating chamber are deposited at a high average energy, approximately 10 eV, or 100 times their thermal energies. This allows the molecules to form covalent bonds, resulting in thin films with extremely densely packed micro-structures. Consequently, IBS films are nearly impervious to water vapor, resulting in insensitivity to changes in heat and humidity, even in a vacuum environment.

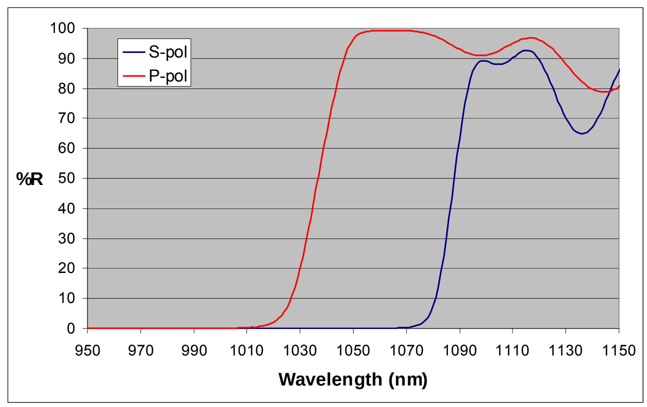


Figure C) Spectral Trace of Plate Polarizer for 1064nm 45°

Throughout the industrial laser, semiconductor and aerospace industries, increased laser energies have continued to push the optical component marketplace to new and higher thresholds. Polarizing beamsplitters have not been excluded from this development; instead they have utilized innovative designs and techniques to improve and expand upon the products available. Higher damage thresholds, increased transmission and improved functionality are all features of current coating designs and readily available optics and optical assemblies for use in today's applications.


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precisionphotonics
3180 Sterling Circle
Boulder, CO 80301