DESIGN CONSIDERATIONS FOR POLARCOR™ MICRO-POLARIZERS

Mark P. Taylor
Corning Incorporated SP-DV-1-5
Corning, New York, USA 14831

1. INTRODUCTION: A NOVEL POLARIZING GLASS

Polarized light is electromagnetic radiation confined to oscillate in one plane. It is one of the most technologically useful phenomena of nature, allowing light to be controlled with simple devices such as calcite prisms, glass polarizing beamsplitters, wire grid polarizers, microcrystalline polarizers and molecular sheet polarizers. Detailed discussions of polarized light and description of the devices are available in several texts.[1,2]

Dichroic polarizers are among the most useful because they can be made in sheet or strip form and do not require precise alignment or assembly. In the 1920's, E.H. Land observed that microcrystals of dichroic materials[3] produced polarization effects when they were oriented by stretching in a sheet of polymeric material. He later used oriented organic molecules made dichroic by staining with iodine. Polarization effects in glass were first observed by Corning scientists in the mid-1960's.[4] They noticed that by stretching glass containing dispersions of metal particles, one polarization component could be transmitted and the other absorbed, thus producing an optical polarizer. Moreover, the wavelength of the absorption could be adjusted by changing the aspect ratio of the particles: long thin particles absorbed at longer wavelengths whereas shorter thicker particles absorbed at shorter wavelengths. Polarizers could thus be optimized for specific wavelength ranges.

Corning introduced this new glass innovation under the trade name Polarcor™ in 1987 for use in the near infrared region of the spectrum.[5] This region, from about 700 nm to 2000 nm, was poorly served by the existing molecular sheet and wire grid polarizer technology. More recently, high performance polarizers have been introduced with performance similar to calcite prism polarizers.[6,7] Polarcor has found application in six market segments: optical isolators, optical data storage, instruments, fiber optic sensors, military systems and research.

Polarcor replaced existing polarizer technology because of six main advantages: high transmittance, high contrast, thin profile, large acceptance angles, heat resistance and high durability. New applications of Polarcor will use these advantages to produce small, rugged optical devices.

The purpose of this paper is to share some of the design considerations that have been effective in making best use of these advantages. I will conclude with some suggestions of future applications for Polarcor.

2. CONTRAST RATIO SELECTION

Contrast ratio is the ratio of the intensity of the transmitted polarization component, k_1, (aligned perpendicular to the silver particles) divided by the intensity of the absorbed component, k_2, (aligned parallel to the silver particles). The higher the contrast ratio, the higher the performance of the polarizer. Figure 1 shows the k_1 and k_2 transmittance curves for polarizers processed for two different contrast ratios. It can be seen that the high contrast process does not significantly reduce k_1, so there is no transmittance penalty paid for polarizers with high contrast.

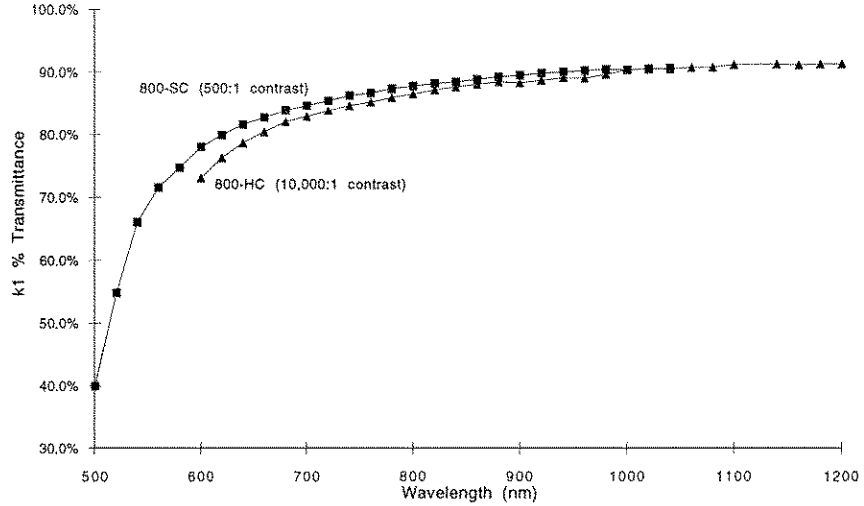

Fig. 1. 1 Transmittance curves perpendicular (kl) to silver particles for high and standard contrast ratio designs.

High contrast (HC) Polarcor has contrast ratios in excess of 10,000:1. HC polarizers provide performance similar to calcite prisms and are used in the most demanding applications such as optical isolators. Enhanced contrast (EC) polarizers provide contrast ratios of 1000:1. EC polarizers have performance similar to glass polarizing beam splitters (PBS) and rutile birefringent polarizers. They are used in applications such as Kerr effect optical data storage devices and optical instruments where relatively high performance is required, but cost constraints limit the use of high performance polarizers. Standard contrast (SC) polarizers provide contrast ratios of 500:1. They are used in high volume applications such as glare reduction and polarization clean-up from diode lasers. Typical applications include optical data storage devices and range finders. These polarizers provide better infrared performance than organic molecular sheet polarizers because they have higher transmittance and are more suitable to hostile environments.

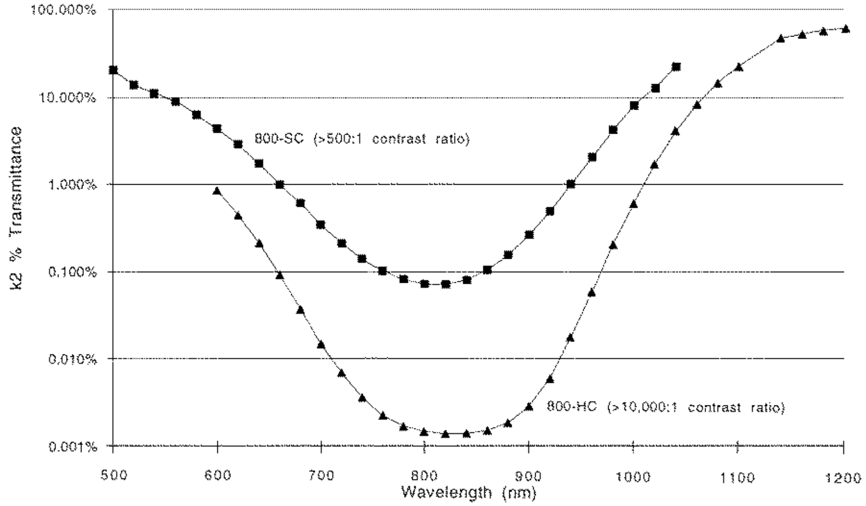

Fig. 1.2 Transmittance curves parallel (k2) to silver particles for high and standard contrast ratio designs.

Figure 1 also shows that higher contrast polarizers cover a broader band than lower contrast polarizers. This allows high contrast polarizers to be substituted in applications where a low or intermediate contrast is required over a broad bandwidth. For example, 900-HC polarizers may be used to supply 100:1 contrast over much of the near-infrared spectrum used by silicon detectors (700-1100 nm).

3. WAVELENGTH SELECTION

The absorption wavelength is controlled by the silver particles' aspect ratio, making it possible to optimize the glass for use at wavelengths corresponding to commercial lasers and other light sources. Figure 2 shows the k_1 and k_2 transmittance curves for polarizers optimized for use at 800, 900, 1060, 1300 and 1550 nm. The absorbance bands broaden at higher wavelengths, although all are about the same width at half maximum if displayed in electron volts rather than wavelength. The asymmetry of the absorbance band probably reflects an asymmetric distribution of aspect ratios of silver particles present in the glass.

The width of the absorption band allows the polarizers to be used at a variety of wavelengths. For example, 800 nm polarizers may be used with 750, 780, 825 and 840 nm diode lasers. These polarizers are typically used in low cost systems such as optical data storage and compact disks. Another formulation is optimized for use at 1060 nm (Nd:YAG or Nd:glass lasers), but can be used at the 1083 nm He line, the 1150 HeNe laser line, and the 980 nm line associated with diode lasers used to pump fiber optic amplifiers. Two popular wavelengths are 1300 and 1550 nm since they correspond to the diode lasers used for optical telecommunications.

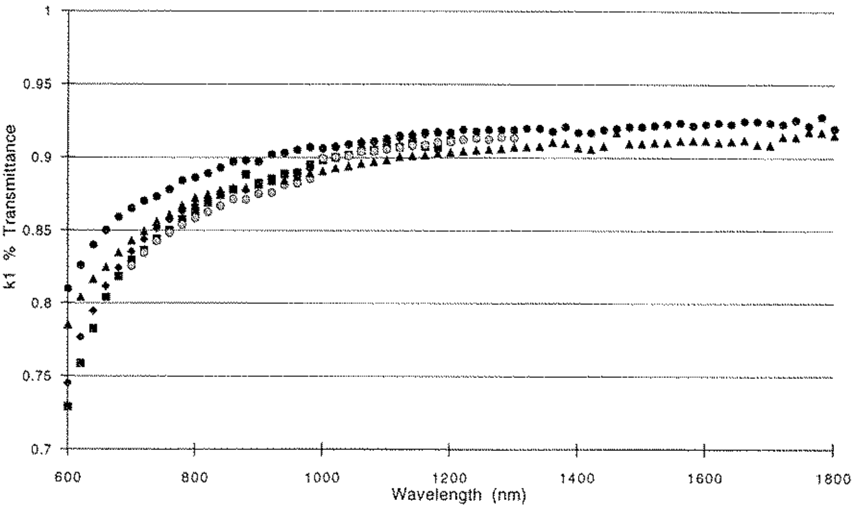

Fig. 2. 1 Transmittance curves perpendicular to silver particles for five different wavelength designs.

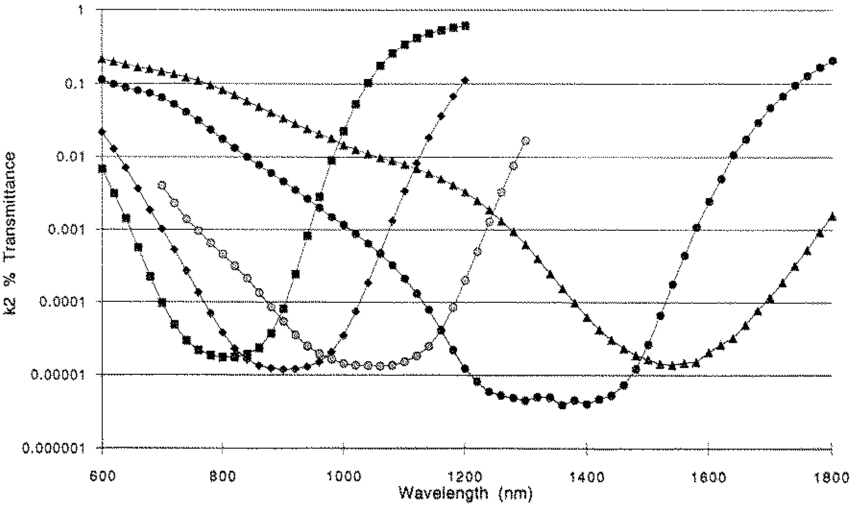

Fig. 2. 2 Transmittance curves parallel to silver particles for five different wavelength designs.

4. TRANSMITTANCE AND ANTI-REFLECTION COATINGS

Polarcor's principle transmittance, k_1, is greater than 84% throughout the near-infrared region of the spectrum. This transmittance is substantially higher than organic sheet and wire grid polarizers which have transmittances in the 57-65% range. Figure 1 shows that Polarcor's k_1 transmittance is not substantially affected by changes in contrast ratio. Figure 2 shows that absorption by metallic silver gradually reduces the transmittance in the red and visible portions of the spectrum, limiting the usefulness of the Polarcor technology for visible regions. The transmittance above 1200 nm is limited primarily by surface reflections, with only very slight absorption.

The transmittance in the near-infrared can be improved substantially through the use of anti-reflective coatings. About 4% of the energy of an incident light beam is lost at each surface the beam encounters. Normally the beam encounters two surfaces, so the maximum transmittance is about 92%. Anti-reflection coatings consist of several thin layers of dielectric material that cause reflected beams to interfere destructively, thereby increasing the transmittance. Polarcor can be treated like any optical glass using conventional coating techniques. Dielectric materials such as SiO_2, TiO_2 and ZrO_2 are used, providing a durable coating that resists peeling.

Several types of coatings can be designed. A single wavelength coating[8] is the most efficient, providing reflectivities under 0.25% per surface. The single wavelength coating should used if the light source is a single wavelength laser. Its performance should be specified over the expected emission range of the laser. Single wavelength coatings can usuallv be designed to provide less than 0.25% reflectivity over a ±20 nm range.

Double wavelength coatings provide minimum reflection at two specified wavelengths. For example, if the polarizer is to be used with both a 1550 nm and a 1310 nm diode laser, it would be appropriate to specify a double wavelength coating (often called a "Double V"). These coatings can usually be designed to provide less than 0.35% reflectivity over ±20 nm ranges centered on each of the two characteristic wavelengths.

Broadband coatings provide low reflectivity over several hundred nanometers. These are used when the incident light covers a broad spectrum. For example, a coating might be designed to provide low reflectivity over the 700-1200 nm range of a silicon detector. Broadband coatings have also been designed to work over the fiber optic amplifier wavelengths (1450-1600 nm). These are usually specified at less than 0.5% reflectivity over the wavelength range, but better performance can often be obtained if the range is not too broad.

5. THICKNESS

Polarization effects in Polarcor arise from a 20-50 μm layer at both surfaces of the glass (Figure 3). As a result, it is possible to make the polarizer very thin without sacrificing performance or available aperture. This allows Polarcor to be used in micro-optic components where thickness must be severely limited to allow the device to be used in a small space. For example, 0.2 mm thick polarizers can be incorporated directly into a diode laser package.

Three thicknesses have been established as standards. One mm thick material should be selected for best mechanical strength and applications where wavefront distortion must be limited. Aperture dimensions of up to 30 mm in the pass direction and 75 mm in the absorption direction are possible with this thickness when used with 800 and 1060 nm polarizers. Optical isolators typically use 0.5 mm thick polarizers which combines ease of production with a more compact format. It is best limited to apertures of 10 mm or less. When space is at a premium, the most demanding applications use 0.2 mm thick Polarcor. This thickness can be provided in dimensions up to 10 mm widths, but it is preferable to limit the aperture to a few millimeters.

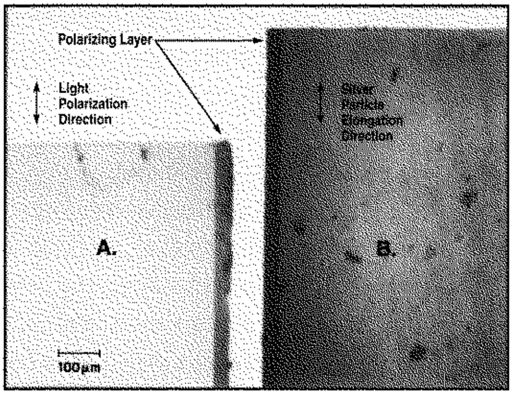

Fig. 3 Polacor polarizers viewed on edge in polarized light.

6. SHAPE AND SIZE

Flexibility with respect to shape and size is one of the most important considerations in designing with Polarcor. While traditional disk shapes can be produced, most applications use straight-edged shapes such as squares or rectangles which lend themselves to high volume production. Straight-edged shapes have an additional advantage: the polarization direction can be aligned at any angle to a given edge within 0.1°. This can be an aid in assembly since the polarizer does not have to be oriented.

Shapes other than squares and rectangles can be produced to meet specific design needs. In general, best yields come from symmetric shapes that are based on two sets of parallel lines (parallelograms) or objects with three-fold or six-fold symmetry (triangles and hexagons). Very sharp acute angles should be avoided as they may break during handling.

Maximum dimensions parallel to the k_1 transmission direction (pass direction) should be limited to 30 mm for 800, 900 and 1060 nm polarizers and 10 mm for 1300 and 1550 nm polarizers. Dimensions parallel to the k_2 transmission direction (blocking direction) may be as much as 75 mm for 800, 900 and 1060 nm polarizers and 10 mm for 1300 and 1550 nm polarizers.

Length and width dimensions can be very small in straight-edged designs. Care must be taken in designing the clear aperture to allow for edge chips of up to 0.1 mm. It is also prudent to observe at least a 2:1 ratio between the minimum surface dimension and the thickness. The smallest polarizers produced to date have been 0.6 mm squares.

Disk polarizers are generally one millimeter thick and 4-30 mm in diameter. Nevertheless, diameters as small as 1.8 mm have been produced.

The ability to produce very small polarizers is an important design advantage. Organic sheet polarizers often delaminate when they are cut very small. Difficulties in handling and alignment limit the minimum size of prism polarizers to 1-2 mm.

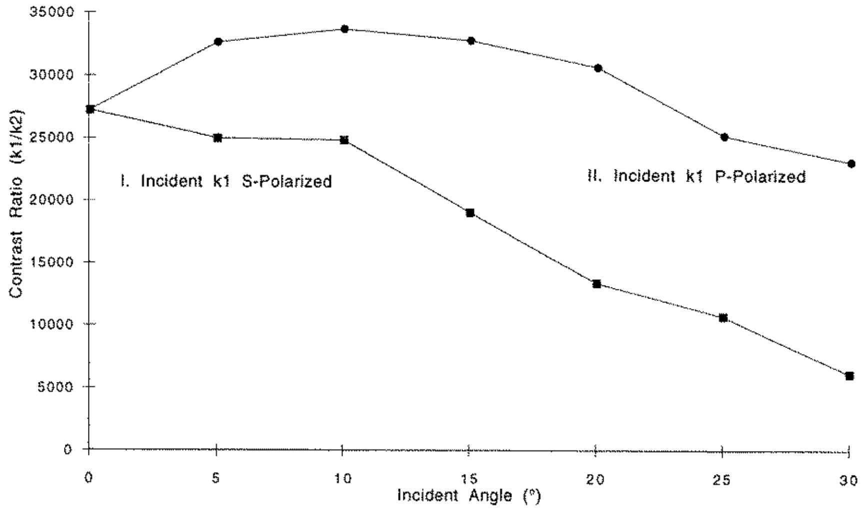

Fig. 4 Contrast ratio for off-normal incident angles.

7. ACCEPTANCE ANGLE

Acceptance angle is the angle over which the polarizer will provide specified polarization and is generally twice the maximum incident angle. The absorption mechanism in Polarcor is not strongly dependent on the incident angle (Figure 4), resulting in a polarizer with a wide acceptance angle (30-40°). This contrasts with calcite prism polarizers which require a length to aperture ratio of 3.0 to provide an acceptance angle of 20-25° in the near-ir. Polarizing beam splitters have an acceptance angle of about 10°.

A wide acceptance angle means that the optical engineer can use the polarizer in designs that require converging or diverging beams. For example, Polarcor can interface directly to the facet of a diode laser, thereby eliminating the need for collimating optics. The polarizer can be tipped off normal incidence in applications which are sensitive to back reflections, such as optical isolators.

8. THERMAL AND ENVIRONMENTAL STABILITY

The host glass for Polarcor is a durable alkali borosilicate. It can be cleaned with a variety of materials such as alcohol, acetone or trichloroethylene. The best cleaning procedure is to scrub with soap and water followed by rinsing with high resistance deionized water and spin drying in a nitrogen atmosphere.

Coated Polarcor polarizers have been exposed to thermal cycles between -55 and 125°C (2 hour cycle, 500 repetitions) and 1000 hour 85°C, 90% relative humidity storage tests without significant loss of performance. Polarcor may also be exposed to temperatures of up to 400°C for short durations (1 hour). Higher temperatures may cause some loss of contrast ratio.

High chemical and thermal durability recommends Polarcor for use in applications which are too hostile for organic dichroic polarizers or cemented prism polarizers.

9. LASER DAMAGE

Laser damage has not been a problem in diode laser applications since power levels are generally low. Loss of contrast ratio has been observed in some pulsed Nd:YAG applications where intensities are much higher. Polarization arises by the absorption of the energy of one polarization component by the elongated silver particles. The resultant local heating around the particles may cause the particles to loose their needle shape resulting in a loss of contrast ratio and visible darkening of the polarizer.

Laser damage in the blocking direction should be limited to about 25 watts per square centimeter in continuous wave operations. In the pass direction, intensities should be limited to about 100 watts per square centimeter. In pulsed applications, it is best to test prototypes carefully, since damage appears to be very sensitive to pulse duration and intensity. For example, damage thresholds are much higher for a 120 microsecond pulse than for a 13 nanosecond pulse.

10. FUTURE APPLICATIONS

Future applications can be expected in designs which take advantage of Polarcor's unique characteristics. In the past, Polarcor competed primarily with calcite prism and glass polarizing beam splitters in high performance applications, the primary advantage being low thickness, low cost and ease of alignment. As fiber optic and diode laser technology becomes more commonplace in large volume products, we can expect to see Polarcor's characteristics put to wider use.

For example, automobile manufacturers are using optical technology in a number of navigational, sensing and measurement systems. These components must be able to withstand long use at engine temperatures in environments rich in dust and hydrocarbons. Polarcor's high chemical durability and temperature resistance make it an attractive alternative in environments that are too hostile for organic sheet polarizers.

Miniaturization and integration of optical devices is an important trend, especially in optical data storage and fiber optic sensors. These applications require tiny, low cost optical subcomponents that are rugged and easy to assemble. Polarcor's ability to be cut into submillimeter components and bonded to other components makes it an ideal candidate for these applications. For example, Polarcor can be combined with quarter-wave plates to produce circular polarizers used to reduce glare from specular reflections in various fiber optic sensors. It can also be bonded to molded optic lenses and lens arrays to mass-produce polarizing optics.

Finally, mass customization[9] - the ability to produce custom shapes and optical performance specifications at mass production prices and delivery times - is a critical advantage to system suppliers who are faced with short development cycles in highly competitive environments. The design considerations outlined in this paper allow rapid production of low volume prototypes at initial prices that are already well down the learning curve. These rules thus provide users of Polarcor a unique competitive advantage: time.

11. FIGURES

Figure 1 - Transmittance curves perpendicular (k_1, Figure 1.1) and parallel (k_2, Figure 1.2) to silver particles for high and standard contrast ratio designs. Notice that the transmittance curve, k_1, is only slightly reduced in the high contrast form. k_1 is plotted against the linear scale in Figure 1.1 and k_2 is plotted against the logarithmic scale in Figure 1.2.

Figure 2 - Transmittance curves for five different wavelength designs. Figure 2.1 shows that the absorption wavelength has relatively little effect on the k_1 transmittance curve. Changes in the aspect ratio of the silver particles change the wavelength of the absorption band in the k_2 curve (Figure 2.2).

Figure 3 - Polarcor polarizers viewed on edge in polarized light. Surface zone (30 μm) contains metallic silver particles that selectively absorb the polarization component oscillating parallel to the long axis. In orientation A, the silver particles are pointing out of the plane of the photograph, so no extinction occurs, only partial light absorption. In orientation B, the silver particles are aligned parallel to the direction of polarization of the light and extinction occurs.

Figure 4 - Contrast ratio for off-normal incident angles. Curve I represents an incident beam which is polarized perpendicular to the plane of incidence (S-polarization). Curve II represents an incident beam which is polarized parallel to the plane of incidence (P-polarization). Performance is better for the P-polarized transmitted component because surface reflectivity of the k_2 component increases with angle, thereby assisting the polarization action. The polarizer is an 800-HC (high contrast). The calculated acceptance angle is twice the maximum incident angle.

References

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[2] *Optics Guide #4*, Melles Griot Corporation. Irvine, California. 1988

[3] The transmittance spectrum of dichroic materials is dependent on the orientation of the crystal. Dichroic crystals produce polarized light by preferentially absorbing the polarization component oscillating parallel to one axis while transmitting the other.

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[8] Often called a V coating because of the V shape of the reflectivity curve when plotted against wavelength.

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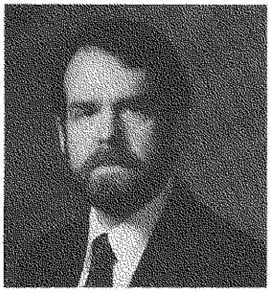
Author's Profile



Mark P. Taylor holds a BA in chemistry from Carleton College, a Ph.D. in geology from Stanford University and an SM in Management of Technology from MIT's Sloan School. Dr. Taylor has been an employee of Corning for thirteen years serving as Research Associate in Research and Development and Business Development Manager in the Advanced Products Department. He is currently the Portfolio Manager for Corning Asahi Video, a television glass joint venture between Corning and Asahi Glass. He holds 20 U.S. Patents and has been an author or co-author of over 30 scientific papers.

和文抄録

コーニングインターナショナル株式会社
総合営業部
川口 輝夫

コーニングの偏光板ガラスPolarcor™（コーニング社商標）は，長く延伸させた金属銀をガラス自身の中に一方向に配列させることにより，偏光特性を持たせたガラスで，金属銀の配向条件により使用波長帯域，消光比パラメータが制御可能である．従来の有機物偏光膜と異なり，耐熱性，耐湿性，耐化学薬品性及びレーザに対する耐性に優れている．

消光比10,000：1以上，1300 nm～1550 nm波長帯のPolarcor™が開発可能になり，主に光通信用光アイソレーターの偏光子(検光子)として，偏光ビームスピリッタ(PBS)にかわり，広く使われてきている．これは，Polarcor™がサイズ的に小さくできること，光学特性が優れ取り扱いが簡単であることなど，光アイソレーターのコンパクトデザイン化のニーズに合致するためであり，一般的な偏光子（検光子）用のPolarcor™の厚さは0.5 mmである．また最近では，極薄の0.2 mmのものが作製できるようになり，使われだしている．

最近，特に注目されているのは，800 nm～900 nm波長帯付近の光センサー用途で，Polarcor™が有機物偏光膜のかわりに検討されてきていることである．例えば，自動車用光センサー，機器用センサーなどであり，耐熱性，耐久性が要求される分野である．消光比は，100：1～1000：1程度であるが，量産による低価格化が今後の課題といえよう．