LightingAnswers

Multilayer Polarizer Panels

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NATIONAL LIGHTING PRODUCT INFORMATION PROGRAM

Background

Fluorescent lamp luminaires with multilayer polarizer panels produce partially *polarized light**, which can increase the contrast of a visual task under some viewing conditions. In principle, a decrease in *illuminance* can accompany an increase in task *contrast* without affecting *visual performance*. Because a reduction in illuminance implies a reduction in the electric power used for lighting, multilayer polarizer panels have been promoted as energy-saving devices. This issue of *Lighting Answers* discusses the effectiveness of multilayer polarizer panels as a means of maintaining visual performance at reduced illuminances and, thus, as energy-saving devices in typical commercial spaces.

Introduction

Visual performance is affected by the amount of illuminance on the task and the contrast of the objects, or targets, being illuminated. Contrast is a quantitative expression of the visual distinctness of a target against its background. A typewritten letter on white paper is an example of a high-contrast target; the same letter typed on dark gray paper is a low-contrast target. In principle, contrast and illuminance can be traded off against each other while maintaining a constant level of visual performance; a low-contrast task will require a higher illuminance than a high-contrast task, and vice versa.

Light distribution also affects the contrast of a task. Mirror-like, *specular reflections* from a task surface will reduce contrast. For example, reading a glossy magazine often requires that the magazine be repositioned to avoid specular reflections from the page. Lighting systems that limit the amount of specular reflections will increase task contrast and, therefore, allow lower illuminances to maintain the same level of visual performance.

Under certain conditions, polarized light will reduce specular reflections. Multilayer polarizer panels are commercially available, flat lenses that are specifically designed to be used with ceiling-mounted fluorescent lamp luminaires. Light emitted from luminaires that are equipped with these panels is partially polarized and can improve the contrast of the visual task to a greater or lesser degree depending upon several factors that are discussed on p. 4.

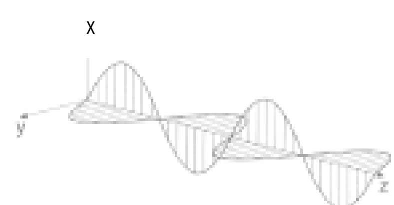
The Illuminating Engineering Society of North America (IESNA) recommends illuminance levels for different visual tasks in an effort to ensure acceptable levels of visual performance in typical applications such as offices, schools, and libraries (IESNA 1993). In general, recommended illuminance levels are relatively high where the visual task is difficult to see (for example, of low contrast) or where the speed and accuracy of the task are critical.

There is no question that polarized light can improve contrast. However, the important practical question that faced the National Lighting Product Information Program (NLPIP) was, "For typical applications, is the contrast improvement from multilayer polarizer panels of sufficient magnitude to justify a reduction in recommended illuminances and, thus, to justify lower lighting power densities?" To answer this question, NLPIP addressed several other questions regarding polarized light and the use of multilayer polarizer panels.

What is polarized light?

Like waves in the ocean, light travels as a transverse wave. This means that as light moves in a particular direction the frequency (and wavelength) of the light vibrations (or waves) is measured in a given plane centered along the light path (Figure I).

Figure 1
Transverse Wave



A transverse light wave travelling along the z axis. The frequency of the wave can be measured along any plane perpendicular to the z axis; two such planes are shown above.

* All terms in italics are defined in the glossary on p. 5.

If the light is completely polarized, all vibrations occur in just one plane along the direction of travel; for unpolarized light (see Figure 2a) these vibration planes will occur randomly at every angle perpendicular to the direction of travel. The vibration planes of partially polarized light will be more concentrated about a particular direction. Figures 2b and 2c illustrate completely and partially polarized light, respectively. The vibration planes are denoted by double-ended vectors, which represent the light oscillations.

All of the vibration planes in any beam of light can be resolved into x and y component vectors, as shown in Figure 2d. The average of the x component vectors and the average of the y component vectors yield overall component vectors, x and y in both directions (Figure 2e). These values are then used to calculate the *degree of polarization* expressed as a percentage. The formula is:

$$\frac{\bar{y}-\bar{x}}{\bar{y}+\bar{x}} \times 100$$

where y is the larger of the two vectors.

When resolving the vectors (vibration planes) of polarized light, horizontal and vertical directions are used most often because these represent planes of interest within architectural spaces like desk tops, video display terminal (VDT) screens, and walls. Thus, one often refers to “horizontally” and “vertically” polarized light.

What are multilayer polarizer panels?

Multilayer polarizer panels are commercially available products consisting of several laminated plastic layers that partially polarize the light following the principle described below. They typically are manufactured in panels that replace the plastic prismatic or diffusing panels in standard 2-foot by 4-foot (0.6-meter by 1.2-meter fluorescent lamp luminaires; however, they may assume other sizes or be used in a luminous ceiling.

How do multilayer polarizers work?

There are several ways to polarize light, including the method of reflection/transmission shown in Figure 3. By this method, as light passes through several layers of a material, some of the light is reflected at each layer interface, and some is transmitted. The reflected light is more polarized in the plane of the layer interface; the transmitted light is more polarized perpendicular, or normal, to the layer interface. Multilayer polarizers are almost always installed horizontally in ceiling-mounted luminaires. Thus, light emitted from a horizontally positioned luminaire with a multilayer polarizer will be characterized as partially vertically polarized.

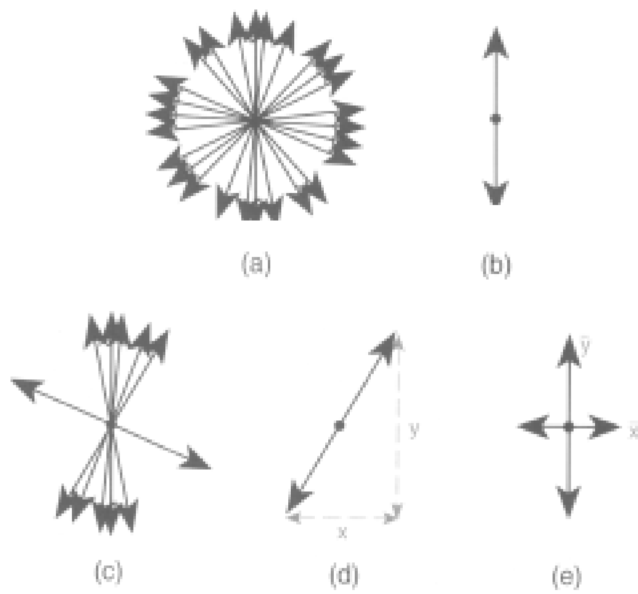
Whether the transmitted light is referred to as horizontally or vertically polarized light depends upon the relative magnitudes of the x and y vectors. As light travels through more and more layers, the transmitted light becomes more and more polarized. Thus, the degree of polarization of light emitted from a luminaire equipped with a multilayer polarizer panel will depend upon the number of layers in the panel material.

The degree of polarization also depends upon the *incident angle* of the light reaching the layer interface. Light striking the material normal to the plane of the layer interface will be transmitted without being polarized. As the incident angle increases, the degree of polarization increases until an angle of maximum polarization, known as *Brewster's angle* is reached; larger incident angles produce lower degrees of polarization. The exact value of Brewster’s angle depends upon the refractive index of the materials.

Multilayer polarizer panels and video display terminals (VDTs)

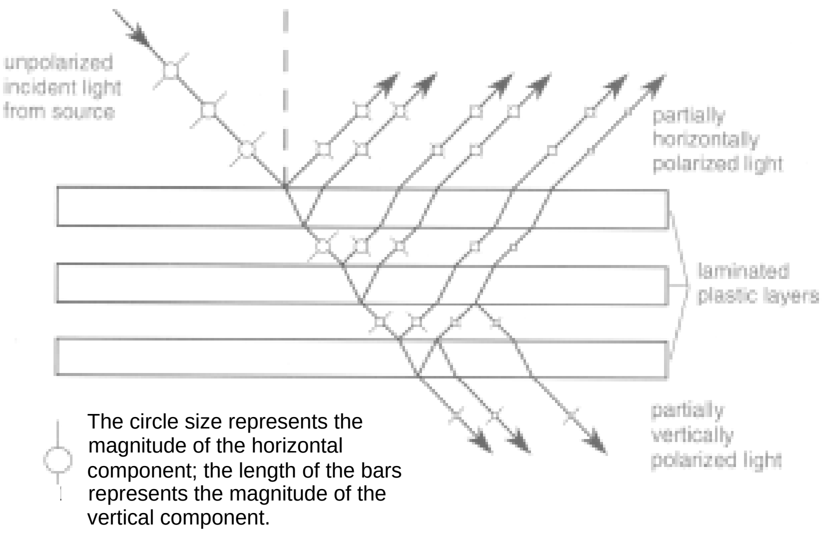
Light reflected from a vertical surface becomes vertically polarized, and vertically polarized light incident on a vertical surface is reflected with little or no attenuation. Therefore, ceiling-mounted multilayer polarizer panels that emit partially vertically polarized light provide little or no reduction in reflected glare from vertical surfaces such as VDT screens.

Figure 2
Describing Polarized Light with Vectors



The center dot in each of these figures represents a beam of light travelling out of the page toward the reader.
(a) Unpolarized light vibrates randomly at every angle perpendicular to the direction of travel.
(b) Completely polarized light vibrates in a single plane.
(c) Partially polarized light consists of many waves clustered about a particular orientation.
(d) Any double-ended vector can be described by two perpendicular, double-ended component vectors, called here x and y.
(e) The x and y component vectors in (d) for each wave are averaged to produce these overall component vectors, x and y.

Figure 3
How Multilayer Polarizers Produce Partially Polarized Light



To what degree is the illumination polarized with multilayer polarizer panels?

As discussed above, the transmitted component of the light becomes more polarized as it passes through each successive lamination of a multilayer polarizer panel. As the light passes through each layer, however, less light is transmitted, and the reflected light is more likely to be absorbed by materials within the luminaire. Thus, there is a trade-off between the amount of light transmitted through the panel and the degree to which the light is polarized.

For this study, NLPIP measured the degree of polarization for light transmitted through a commercially available multilayer polarizer panel, a 1/8-inch (3.2-millimeter) translucent, white plastic flat-bottom diffuser, and a prismatic lens. The results are summarized in Figure 4. The data for the multilayer polarizer panel are consistent with results from two other studies of multilayer polarizer panels, which are described in the sidebar on p. 5.

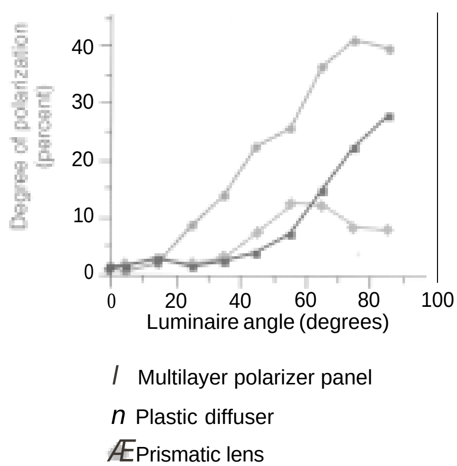
Figure 4 shows the degree of polarization measured for 0° to 85° vertical (altitude) angles for a multilayer polarizing panel, a prismatic lens, and a white diffuser. For each material, NLPIP found that as the *luminaire angle* increased up to about 60° the degree of polarization increased, but by different amounts. In every case, light is essentially unpolarized directly beneath the luminaire (between 0° and 20°). For the multilayer polarizing panel, the maximum degree of polarization was measured to be approximately 40 percent at a luminaire angle of about 75°

How efficient are luminaires equipped with multilayer polarizer panels?

It is difficult to accurately measure the *luminaire efficiency* of polarizing lenses with mirror photometers, the most common type available for making luminaire efficiency and luminous intensity measurements, because the reflecting mirror interacts with the incident polarized light and affects the amount of light reaching the detector.

NLPIP estimated the efficiency of a 2-foot by 4-foot two-lamp luminaire equipped with a multilayer polarizer. *Luminance* measurements were obtained for luminaire angles between 0° and 85° for a fluorescent lamp luminaire fitted with a multilayer polarizer panel. These measurements were roughly equivalent to those obtained at the same angles from the same luminaire equipped with a 1/8-inch translucent, flat, white plastic diffuser instead of the multilayer polarizer panel. These data suggest that the efficiency of the luminaire equipped with the multilayer polarizer panel and that with the 1/8-inch white diffuser were roughly the same. According to the IESNA *Lighting Handbook* a typical 2-foot by 4-foot two-lamp luminaire equipped with a flat-bottom diffuser has an efficiency of about 60 to 65 percent. (The same luminaire equipped with a common prismatic lens typically has an efficiency of about 65 to 70 percent.)

Figure 4
Degree of Polarization of Light Transmitted Through Three Materials



Can multilayer polarizers be used at lower illuminances without changing visual performance?

Increased contrast can allow reduced illuminance without affecting visual performance, and multilayer polarizers can increase contrast in some applications. However, the degree to which contrast improvements can be realized with multilayer polarizer panels depends upon several factors, which are listed below. Figure 5 summarizes these points.

1. **Task orientation.** For ceiling-mounted multilayer polarizer panels, contrast is not substantially improved for vertically positioned tasks such as VDT screens. The greatest improvement in contrast occurs for horizontally positioned tasks. Tasks in other planes will be influenced less.

2. **Task specularity.** Matte materials, such as typing paper, are not greatly affected by multilayer polarizer panels mounted in any position. Multilayer polarizer panels reduce specular reflections from glossy materials, such as glass or drafting film.

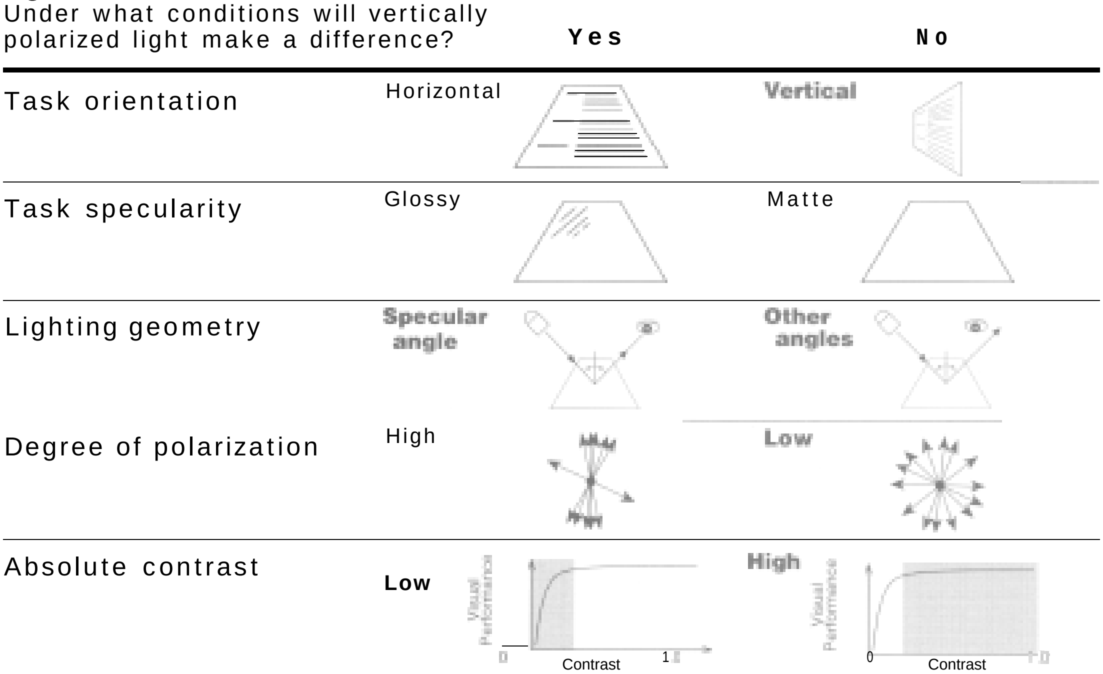
3. **Lighting geometry.** The incremental benefits of illumination from multilayer polarizer panels compared with that from more conventional luminaire lenses are maximized when the task is positioned so as to form a specular reflection between the observer and the luminaire. Little or no contrast benefits result from multilayer polarizer panels when specular reflections are not present. For example, no significant contrast benefits occur from the use of multilayer polarizer panels after tilting the task or moving the head position to avoid the specular reflections.

4. **Degree of polarization.** The benefits of polarized light emitted from a multilayer polarizer panel are angle dependent, even at the *specular angle* Directly beneath a luminaire fitted with a multilayer polarizer panel, the light is essentially unpolarized (see Figure 4). As the specular angle increases, the degree of polarization in the incident illumination increases, and therefore, specular reflections are reduced and contrast is increased.

Typical viewing angles for horizontal reading tasks are between 10° and 30° (Crouch and Kaufman 1963; Rea *et al.* 1985). The degree of polarization of light emitted from multilayer polarizer panels between these angles was measured to be less than 15 percent. Because the degree of polarization is so small, multilayer polarizer panels of the type tested by NLPIP would have little effect on reducing specular reflections for typical task geometries.

5. **Absolute contrast** Illuminance recommendations by the IESNA are based explicitly upon visual performance. As shown in the bottom condition of Figure 5, visual performance is nearly constant for medium to high contrasts at a given background luminance. Contrast improvements within this range have very little effect on visual performance. One study (Dillon *et al.* 1987) showed that low-contrast materials rarely are used in typical office tasks. Nevertheless, where low-contrast tasks, such as pencil writing on paper, are performed, slight improvements in contrast can result in significant improvements in visual performance.

Figure 5
Under what conditions will vertically polarized light make a difference?



The contrast improvements of multilayer polarizer panels are greatest when all of the conditions addressed in the five statements above are met simultaneously. If one or more of these conditions is not met, the contrast improvements will be minimal or nonexistent. Thus, for multilayer polarizer panels to be very effective relative to conventional luminaires, an office would need to use horizontally positioned, low-contrast, specular task materials under fixed lighting geometries seen at extremely large specular angles. These conditions are not likely to be common in typical commercial environments.

Can multilayer polarizer panels be used to save energy?

Illuminance recommendations that are made by such bodies as the IESNA are based on a consensus view of practical and economic considerations as well as the scientific literature. The IESNA recommends, for example, reduced illuminances when other compensatory factors such as high contrast offset a loss in visual performance. To answer the major question asked in the Introduction, NLPIP believes that there is little basis for the IESNA to change its recommended illuminances for spaces with multilayer polarizer panels. This belief is based on the evidence that is available about these panels, on consideration of typical tasks that are performed in actual commercial spaces, and on the observed modest improvements in contrast for these tasks using these panels. Therefore, NLPIP does not consider multilayer polarizer panels to be energy-saving devices.

Two studies using multilayer polarizer panels

The theoretical properties of polarized light are well understood. Two studies (Rea 1981; Boyce et al. 1992) have been published to confirm the theory experimentally in settings using multilayer polarizer panels and simulated realistic task materials. Recognizing the theoretical aspects of polarized light, both studies were designed as "sensitivity tests" to establish the maximum and minimum expected effects of multilayer polarizer panels on the performance of selected visual tasks.

As expected, small improvements in performance were found with multilayer polarizers under ideal conditions (that is, for low-contrast, specular targets positioned in a horizontal plane at the specular angle). Again, as expected, no significant benefits were found under other conditions. Because the benefits of multilayer polarizers are limited to a narrow set of visual conditions, which were considered uncommon in commercial spaces, the authors of both studies concluded that this technology demonstrates little benefit in improving visual performance over more conventional luminaires in most office settings.

Glossary

Brewster's angle The incident angle of light upon the surface of a medium for which the reflected and transmitted light are perpendicular (90°) to each other. This angle is dependent on the refractive index of the medium. It defines the angle of maximum polarization for a medium.

contrast (luminance contrast) The relationship between the luminances of an object and its immediate background, equal to $|L_1 - L_2|/L_1$, or $\Delta L/L_1$, where L_1 and L_2 are the luminances of the background and object, respectively.

degree of polarization A measure of the amount of light polarization ranging from 0 to 100 percent.

illuminance The density of luminous flux incident upon a surface; it is the luminous flux divided by the area of the surface when the surface is illuminated uniformly.

incident angle The angle between a ray of light reaching a surface and a line normal (perpendicular) to that surface. See Figure 6.

luminaire angle The vertical (altitude) angle used in luminaire photometry to express the direction of the light output being measured. The "straight down" light is at 0° (the nadir).

luminaire efficiency The ratio of luminous flux, in lumens, emitted by a luminaire to that emitted by the lamp or lamps within it.

luminance The photometric quantity most closely associated with one's perception of brightness, measured in units of luminous intensity (candelas) per unit area (ft^2 or m^2).

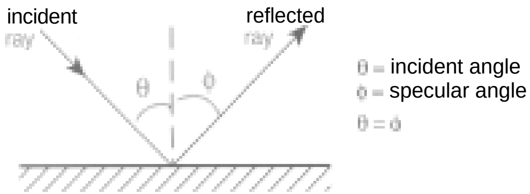
polarized light Light whose vibrations are oriented in (or around, for partially polarized light) a specific plane.

specular angle The reflected angle of light striking a surface, which is equal to and in the same plane as the incident angle. See Figure 6.

specular reflection Light incident upon a surface that is redirected at the specular angle. See Figure 6. Glossy or shiny surfaces exhibit a high degree of specular reflection.

visual performance The quantitative assessment of the performance of a visual task, taking into consideration speed and accuracy.

Figure 6
Specular Reflection



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Lighting Answers is a serial publication that is designed to complement the National Lighting Product Information Program's (NLPIP) other serial publication, *Specifier Reports.* In each issue of *Specifier Reports* NLPIP invites manufacturers to participate, performs extensive testing and reporting, and reports manufacturer-specific data. Each issue of *Lighting Answers* presents information about lighting technology in one of three formats: some issues present a summary of available information about a particular technology in an educational format with no testing; some issues present educational information about a specific topic that is of concern for lighting professionals; and other issues present information about a new or special technology on which NLPIP has performed some limited testing. For this issue of *Lighting Answers,* NLPIP performed limited testing and summarized available information on multilayer polarizer panels.