Perro’s Achromatic Polarization-Preserving Beam Displacer

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Abstract
A new achromatic polarization-preserving beam displacer is found in the simple Perro’s two-prism image erecter system. Full analyses of mechanism (compensating-phase-shifting principle), tilting tolerance and the influence of material are presented.

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Polarization-preserving optics is crucial for coherent optical systems and it is also important for investigation on the optical properties of biological tissues, etc. In many circumstances, it is necessary to displace light beam with a preservation of polarization. To displace a light beam, the simplest solution is to use a two-mirror configuration beam displacer. But there is a serious problem in this type of beam displacer, that is, there appears phase difference of $s$- and $p$-polarization under total reflection. To achieve the preservation of polarization in displacement, many methods, including special coating treatment on the mirrors have been developed [1]. Since the films coated for preserving polarization are all depend on wavelengths, these mirrors are not workable achromatically. In addition, these mirrors require special preparation and, thus, are inconvenient. Recently, Galvez demonstrated that compensating phase shifting (CPS) [2], i.e., to compensate the phase shift in $s$- and $p$-polarization, could be utilized to maintain the polarization state after beam displacement based on a four-prism or four-mirror configuration [3]. Here we extend the CPS principle to the Perro image erector system and show that the Perro’s two-prism configuration can be a good choice for achromatic polarization-preserving beam displacer. A full simulation analysis of tilting tolerance and materials is also presented.

Referring to Fig. 1, it can be seen that the two-prism beam displacer is corresponding to the classical Perro image erector system [4]. If the vector of input beam is $(0,0,1)$, vectors after each reflection become $(1,0,0)$, $(0,0,-1)$, $(0,-1,0)$ and $(0,0,1)$. If the beam polarization at the first and the second surfaces is $s$-polarization (or $p$-polarization), then it will become $p$-polarization (or $s$-polarization) on the third and the fourth surfaces. Therefore, the phase differences of $s$- and $p$-polarization created by total reflection at the first and the second surfaces will be compensated by the differences generated at the third and the fourth surfaces. In exploring biological system, circular polarization is usually required. One can verify that this CPS scheme is applicable.

![Fig. 1 The schematic of the Perro’s beam displacer](image)

where (a) shows the orientation of the first prism, 1, and the second prism, 2. The tilting in the coordinate system is also provided; the tilting about the x-axis is denoted as TLX; for the y-axis, TLY; and for z-axis, TLZ. (b): 3D layout of the system.
Next, let us present the tolerance analysis of the Perro’s two-prism configuration to show the performance. First, let us take two prisms, which have properties with typical BK7 material, 10, 14 and 10 mm of size A, B and C, 1/4 MgF\(_2\) at 550 nm AR-coating, be cemented together with 0.1 mm reflective index-matching epoxy. We evaluate the two-prism beam displacer by the OSLO software, which is available from the Lambda Research Corporation [5]. The initial polarized beam is under the wavelength at 632.8 nm and with polarization axis being oriented at 45 degrees to the x-axis of the beam displacer. We considered the ellipticity \(e\) of a linearly polarized beam and computed \(e^2 = \frac{I_{\min}}{I_{\max}}\), where \(I_{\max}\) and \(I_{\min}\) are the maximum and minimum intensities of the optical beam. Since the square of ellipticity after emerging from the two-prism beam displacer will remain less than \(10^{-33}\) even in different wavelengths, the polarization state can be preserved after displacing beam. If there is a source misalignment in the system, could the polarization state still be preserved? The answer is YES. As seen from Fig. 2, the simulation reveals that \(e^2\) is less than \(3 \times 10^{-5}\) even with a misaligned angle \(\pm 60\) arc min, no matter the incident beam misalignment is corresponding to x-axis or y-axis (as shown by the TLX and the TLY in Fig. 1 (a)). The values of \(e^2\) are so small that the linearly polarization state of initial beam remains almost unchanged after displacement.

If there exist tilting errors with the two prisms, do they seriously affect the polarization property of displaced beam? As shown by Fig. 3, the influences under tilting error of component 1 will be more significant than that of component 2, but the value of \(e^2\) of tilting angles at \(\pm 60\) arc min are all less than \(8 \times 10^{-4}\), which means the tilting errors of the two prism will not seriously affect the polarization state after displacement.

Now, let us consider the tilting error at each reflected surface in the two-prism beam displacer. We use a four mirrors arranged as like the Perro image erecter, as shown in Fig. 4. (a). The most
critical tilting tolerance value at each reflected surface is shown in Fig. 4 (b). We can find that the most critical tilting errors are TLY at the first and the second surface (Srf 1 and Srf 2) and TLX at the third and the fourth surface (Srf 3 and Srf 4). This result shows that a larger error will be produced by the change of incident angle at each reflected surface. But the values of $e^2$ are still less than $4 \times 10^{-5}$, which are so small enough that polarization property is almost preserved.

The performance beyond visible light can also be improved by using different material as shown in Fig. 5 (a) where CaF$_2$ is used. Furthermore, as shown in Fig. 5 (b), plastic materials can also be used in a wide range of wavelength and this is of commercial value.

In summary, we have shown that the Perro’s two-prism beam displacer is CPS and it can maintain the polarization state well after displacing light even with tilting errors. It is worthwhile to note that the performance of the Perro two-prism configuration is better than that of Galvez’s four-prism configuration [6] because the surfaces of compensating phase shifting form 90-degree conjugated pairs.

References: