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Scheme to polarization-correct a waxicon

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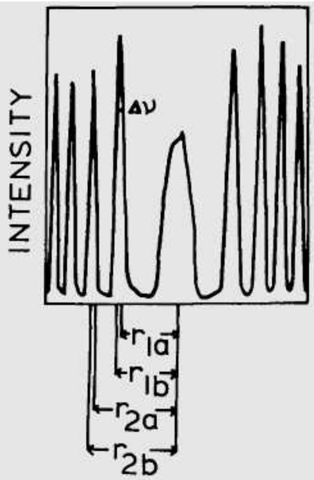

Fig. 4. Single-pulse spectral distribution of the laser output obtained as a microdensitometer trace of a photoplate.

65°, $d\beta_2/d\lambda = 9.2 \times 10^{-4}$ rad/Å. The two-grating combination has $d\theta/d\lambda = 1.3 \times 10^{-2}$ rad/Å and an angular acceptance $\Delta\theta = 7.6 \times 10^{-5}$ rad. The laser power was measured with a pyroelectric power meter and yielded a peak power of 1.4 kW for a 22-kV charging voltage of the flashlamp at the maximum of the power tuning curve at 595 nm of the 2×10^{-4}-M solution of Rh6G in ethanol. At typical operating parameters, namely, at a repetition rate of 50 Hz and a pulse length of 2 μsec, the corresponding average laser power is 140 mW.

The extension of the grazing incidence grating pulsed laser design described here to flashlamp-pumped dye lasers is a simple means to obtain a narrow spectral linewidth laser at relatively long pulse durations and with moderate power. Finally it is pointed out that a further reduction in bandwidth is possible by the addition of a plane mirror[5] to the Littrow mounted grating to increase the dispersion of the arrangement.

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Scheme to polarization-correct a waxicon

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The polarization problem of axicons and waxicons used in lasers with annular gain regions was first pointed out by Fink,[1] and a solution using multilayer dielectric coatings was subsequently suggested by Southwell.[2]

Recently[3,4] we showed that it is possible to equalize the net p (radial) and s (azimuthal) complex reflection coefficients (eigenvalues) of an axicon, hence preserve polarization, by coating the bare metal surfaces with a single dielectric film of appropriate thickness for each cone. Following the approach of Refs. 3 and 4, we have attempted to achieve a similar simple single-layer solution for the polarization problem of waxicons. For a waxicon to preserve polarization, its net complex eigenvalue for the p polarization must be made equal to the negative of that for the s polarization, because of the reversal of the direction of propagation of light after two reflections. No such solution could be found when the same film–substrate system is assumed for each cone, regardless of the cone semi-apex angle (or angle of incidence). Use of different film and/or substrate materials for each cone has not led to solutions either. Thus it appears that single-layer coatings would not produce polarization preservation in waxicons.

In this Letter we describe a hybrid scheme to make a waxicon preserve polarization. Specifically we propose to achieve polarization correction in two steps: (1) to equalize the radial and azimuthal complex eigenvalues by single-layer coatings as in the case of an axicon,[5] and (2) to introduce a 180° differential phase shift (minus sign) externally by using a transmissive radially birefringent halfwave retarder (RBHWR) in the path of the annular beam only.[6] This design scheme is shown in Fig. 1.

The annular RBHWR, Fig. 1(b), is an element that can be realized readily in practice. It may be made of a slab of an isotropic transparent material which is subjected to a radial stress pattern. Such stress can be applied by placing the element in a concentric-cylinder loading system and the birefringence is finely tuned to halfwave retardation using photoelastic methods. The correct stress can also be locked into the element as it is formed, so that no *in situ* stressing is required.

It is also conceivable that polarization correction can be achieved with uncoated (bare-metal) axicons and waxicons solely by using annular transmissive elements with combined linear birefringence and interference-induced apparent linear dichroism[7] whose principal axes coincide with the radial and azimuthal directions. If ρ_1, ρ_2 indicate the ratios of complex p and s reflection coefficients for the first and second reflections from the uncoated cone surfaces, respectively, and ρ_3 is the ratio of complex radial and azimuthal transmission coef-

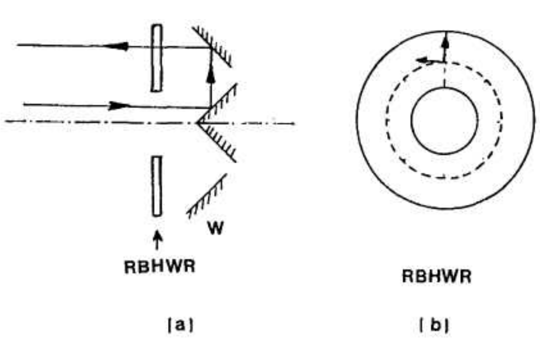

Fig. 1. (a) Scheme to make a waxicon preserve polarization. The radial and azimuthal complex eigenvalues (net p and s reflection coefficients) of the waxicon W are equalized by single-layer dielectric coating of appropriate thickness for each cone, as described in Refs. 3 and 4. The additional required 180° relative phase shift is introduced by an annular radially birefringent halfwave retarder (RBHWR). (b) Front view of the RBHWR showing radial and circular lines of principal birefringence axes.

ficients for the annular transmissive element, the condition of polarization preservation becomes

$$\rho_1\rho_2\rho_3 = \pm 1, \tag{1}$$

where the + and − signs are for the axicon and waxicon, respectively.

Before concluding, we note a polarization effect in bare-metal axicons and waxicons that appears to have been overlooked in earlier discussions, namely, that the reflectivity of the uncoated biconical element for incident linearly polarized light is azimuthally modulated. This would make the threshold gain of the laser medium depend on azimuth. To explain this effect, let $\mathcal{R}_p$ and $\mathcal{R}_s$ be the unequal radial and azimuthal reflectivities of the uncorrected axicon or waxicon. For incident linearly polarized light the reflectivity $\mathcal{R}$ is a function of the variable azimuth angle ϕ between the incident electric vector and the variable plane of incidence. This function is given by

$$\mathcal{R} = \mathcal{R}_p \cos^2\phi + \mathcal{R}_s \sin^2\phi$$
$$= \overline{\mathcal{R}} + \Delta\mathcal{R} \cos 2\phi, \tag{2}$$

where

$$\overline{\mathcal{R}} = \tfrac{1}{2}(\mathcal{R}_p + \mathcal{R}_s) \tag{3}$$

is the average reflectivity, and

$$\Delta\mathcal{R} = \tfrac{1}{2}(\mathcal{R}_p - \mathcal{R}_s) \tag{4}$$

is the amplitude of the azimuthal cosinusoidal reflectivity modulation. For silver surfaces at 10.6-μm wavelength and 45° angle of incidence, we have[8] $\mathcal{R}_p = 0.98$, $\mathcal{R}_s = 0.99$, and $\Delta\mathcal{R} = -0.005$.

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Automatic method for measuring simple lens power

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The purpose of this work is to study a method of evaluating, fast and automatically, the optical power of simple lenses using a Schottky-barrier surface position-sensitive detector to measure deviations of a laser beam produced by the lens. For the experimental setup, see Fig. 1.

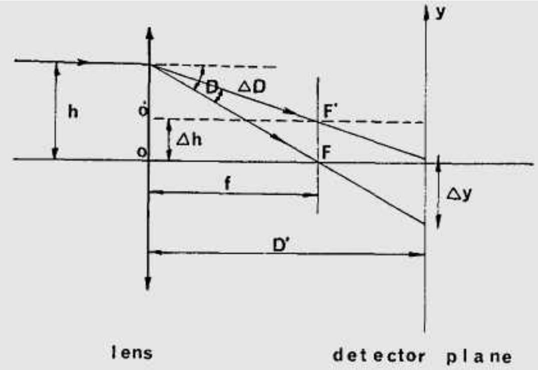

Fig. 1. Experimental setup scheme.

The deviation D of a ray due to a lens follows the geometric optics law: $D = -hC$, where C is the lens power. This linear relationship between D and h allows measurement of C using a differential method.

The displacement Δy is $\Delta y = CD'\Delta h$, and, therefore, $C = \Delta y / D'\Delta h$. As a source of light we used a Spectra-Physics 155 He–Ne 0.5-mW output power laser. Displacement Δy was measured using a Schottky-barrier SC 25 United Detector Technology position-sensitive detector. The range of application of our device is limited by the range of displacement Δy that could be measured. In our case the displacement Δy equivalent to the noise of the source–detector combination was nearly 0.05 mm, so we even measured displacements larger than 3 mm to make this source of error negligible. The lack of linearity we observed in our detector when measuring displacements between a 15-mm zone was <5%. Displacement Δh was provided by a set of gauges. We chose $D' = 500$ mm, and using two gauges 3 and 5 mm wide we were able to measure powers in the range $2\delta < [C] < 7.5\delta$ and $0.4\delta < [C] < 2\delta$, respectively, considering the above-mentioned limitations of our detector. Larger power values could be measured by choosing $D' = 150$ mm and using a 3-mm wide gauge ($6\delta < [C] < 25\delta$). The diameter of the laser beam (nearly 1 mm) and its widening due to the lens have been considered in this calculation. It is possible to measure convergent or divergent lenses with the same accuracy.

By using a standard lens it is also possible to calibrate the whole system, adjusting electronically the zero of the detector for the first measure and then adjusting the amplifier's detector gain to get an electrical output in δ units. By measurements of laser beam deviations over two perpendicular axes, which might be done with the same detector we have used, it is also possible to study glass defects.

From the above results we conclude that we developed a simple method that allows measurement of the optical power of lenses, with a wide range of application and an accuracy better than 5%. This method could be used, for example, for quality control in lens factories.