# Elimination of thermally induced modal distortions in Faraday isolators for high power laser systems

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**Abstract:** Two methods of eliminating thermal lensing in Faraday isolators are theoretically and experimentally investigated: use of an ordinary negative lens and use of a compensating glass element with negative induced thermal lensing.

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Recently, the average power of solid-state and fiber lasers has surpassed the kilowatt barrier [1]. Faraday isolators, a key component of high power laser systems, are strongly affected by thermal self-action since the absorption in magneto-optical media is relatively high. This self-action leads to loss in the initial spatial polarization mode of laser radiation. These loss $\gamma_t$ consist of three components: loss induced by isotropic thermal lens $\gamma_i$; polarization loss $\gamma_p$; and loss associated with amplitude-phase distortions due to depolarization $\gamma_a$ [2]

$$\gamma_t = \gamma_p + \gamma_a + \gamma_i \tag{1}$$

A significant portion of these distortions can be compensated by means of an ordinary lens or a telescope [2] (shown by a dashed line in Fig.1), which introduces additional curvature in the wavefront. This method is a point design, i.e., it will work at a fixed laser power. Alternatively, an adaptive method using a compensating glass with a negative *dn/dT* has recently been demonstrated [3]. Adaptive methods have the advantage that it will work at variable laser powers. The parameters of the compensating glass (e.g., FK51 Schott glass) are chosen so that the thermal lens has the same amplitude and shape as in Faraday isolator but has opposite sign.

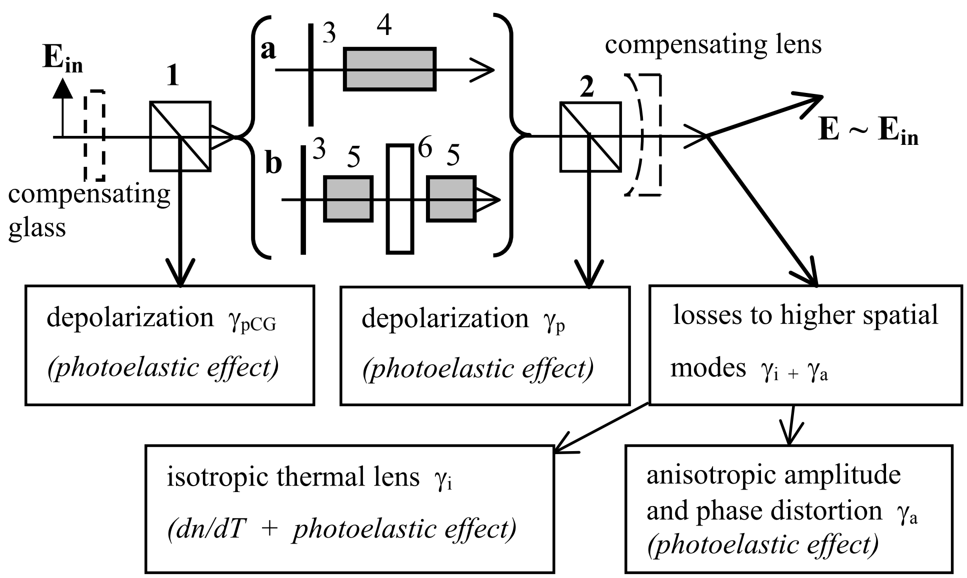


Fig.1. Power losses in the spatial polarization mode after pass through traditional (a) and depolarization-compensated (b) [4] Faraday isolator. 1,2 – polarizers, 3 – half wave plate, 4 – 45 degree Faraday rotator, 5 – 22.5 degree Faraday rotator, 6 – 67.5 degree reciprocal rotator

We present a detailed comparison of the two compensation methods considering all thermal effects both in the magneto-optic crystal and in compensating glass for two Faraday isolator designs – a traditional single magneto-optic-element Faraday isolator (Fig.1a) and a two-element design which compensates for internal depolarization in the magneto-optic crystal (Fig.1b) [4]. Analytical expressions for all of three terms in (1) have been derived for both methods and both designs. The critical parameters for determining $\gamma_t$ are the thermo-optic constants *P*, which determines isotropic loss $\gamma_i$, and *Q*, which determines anisotropic losses $\gamma_p+\gamma_a$ . We have measured these constants for TGG crystals and FK51 glass:

$P_{TGG}=(26\pm4)10^{-6}\ K^{-1}$ $\quad Q_{TGG}=-(2.6\pm0.4)10^{-6}\ K^{-1}$ $\quad P_{FK51}=-1.7\cdot10^{-6}\ K^{-1}$ $\quad Q_{FK51}=-0.63\cdot10^{-6}\ K^{-1}$

In earlier work, the optical path difference from *dn/dT* was considered to be the dominant effect [3]. However, for TGG, the contribution of the photoelastic effect to $\gamma_i$ is comparable in magnitude to the lens induced by *dn/dT*, and, because their contributions are additive, the actual thermal lens is stronger than the lens obtained when the photoelastic effect is neglected. For FK51 glass, the influence of the photoelastic effect is even higher. Thus, the contribution of the photoelastic effect in an isotropic thermal lens must be taken into account when the lens is compensated by an ordinary lens or by the adaptive method. In the latter case, the figure-of-merit of the compensating glass is a ratio *P/Q*.

We have experimentally verified the adaptive compensation method using a 40 W Nd:YLF laser beam. The radial distribution of phase measured by a scanning Hartmann sensor is presented in Fig.2a. The thermal lens averaged for two polarizations is almost totally compensated. At the same time, the astigmatism of the resulting lens is very large, because of the small ratio $P_{FK51}/Q_{FK51}$.

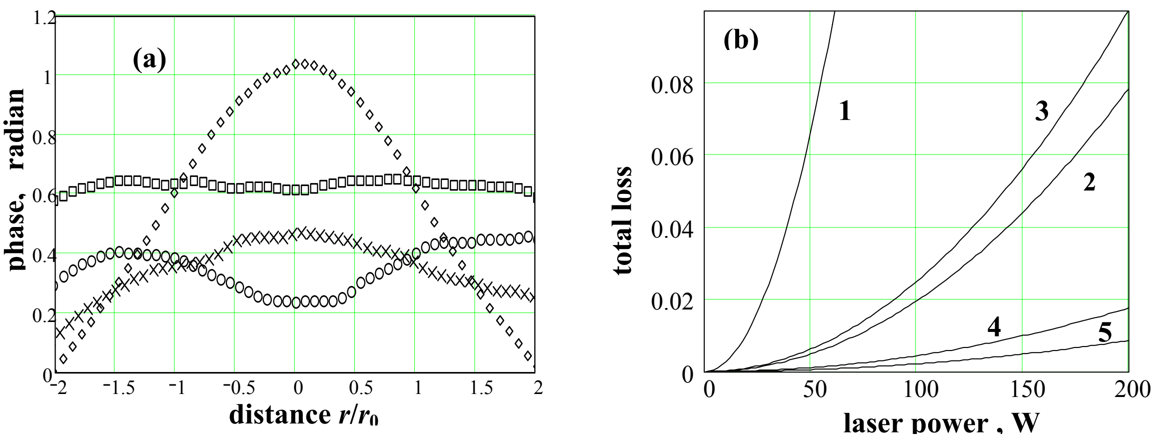


Fig. 2. (a) Probe laser optical path difference after propagating through the birefringence-compensated Faraday isolator (Fig.1b) without thermal compensation (diamonds) and with thermal compensation by means of FK51 glass: φ-polarization (circles), *r*-polarization (crosses), average between two polarizations (squares). The heating laser power is 38 W, $r_0$ – beam radius. (b) Theoretically predicted power losses $\gamma$ versus laser power $P_0$ for the Faraday isolator shown in Fig. 1b for no thermal compensation (curve 1), with telescopic compensation (curve 2), adaptive compensation by means of FK51 (curve 3), by means of glass with $P_{CG}/Q_{CG}=12$ (curve 4), by means of uniaxial crystal or gel (curve 5).

Fig. 2b shows the predicted performance up to 200 W for all of the cases we consider. In the absence of compensation, significant loss is seen at 50 W, increasing dramatically with higher powers. In addition, the efficiency of the adaptive method using FK51 glass is less than that for the ordinary lens. However, the efficiency of the adaptive method can be considerably enhanced by eliminating the anisotropy with a 90° polarization rotator or using a compensating glass with $P_{CG}/Q_{CG}>50$, a crystal with natural birefringence or a gel.

1.V. Gapontsev and W. Krupke, "Fiber lasers grow in power", Laser focus World **38,** 83-87, (2002).
2.E.A.Khazanov, "Characteristic features of the operation of different designs of the Faraday isolator for high average laser radiation power", Quantum Electronics, **30,** 147-151, (2000).
3.G.Mueller, R.S.Amin, D.Guagliardo, D.McFeron, R.Lundock, D.H.Reitze and D.B.Tanner, "Method for compensation of thermally induced modal distortions in the input optical components of gravitational wave interferometers", Classical and Quantum Gravity, **19,** 1793-1801, (2002).
4.E.A.Khazanov, "Compensation of Thermally Induced Polarization Distortions in Faraday isolators", Quantum Electronics, **29,** 59-64, (1999).