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A 45-dB Faraday isolator for 100-W average radiation power

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Abstract. It is demonstrated experimentally that at high average radiation power, the optical isolation in the recently proposed design of a Faraday isolator is substantially higher than in the conventional scheme. The Faraday isolator with the isolation of 45 dB at the radiation power of 100 W is implemented. The data obtained show that a 30-dB isolator for the average laser radiation power of 1 kW can be realised.

An increase in the average laser power with the conservation of the diffraction divergence of laser radiation is one of the most important problems of quantum electronics. In the development and operation of such lasers, one should take into account a heating of optical elements due to the laser radiation absorption. The problem of heating is especially important in Faraday isolators because of their high absorption coefficients (above 10^{-3} cm^{-1}) and the large length of a magneto-active medium (several centimetres). A deterioration of the isolation caused by the absorption of radiation was first studied in Refs [1 – 3]. In Ref. [2], two new designs of a Faraday isolator, which allow one to suppress substantially the effect of absorption, were proposed and theoretically calculated. Studies [2, 4, 5] demonstrated that the best design both for glass and crystal magneto-active media is a design consisting of two 22.5° Faraday rotators with 67.5° reciprocal quartz rotator (QR) placed between them. Hereafter, we will call this design the QR design.

In Ref. [5], both these designs were studied in model experiments. The 5-W second harmonic of a Nd : YAG laser was used. It was found that due to very high absorption (0.05 cm^{-1}) in magneto-active medium, the heating effects prevail in a conventional design, which consists of one 45° Faraday rotator, while they are suppressed substantially in the new designs. No studies of the new devices that would contain crystal magneto-active media of high thermal conductivity have been performed to date. Such a medium can be a crystal of terbium-gallium garnet (TGG). In this paper, we present the results of measurements of the so-called nonisolation γ of the Faraday isolators based on a TGG crystal with the [001] orientation. We studied Faraday isolators of both conventional and QR design at the radiation power up to 100 W.

The Faraday isolator consisted of two identical TGG crystals with the [001] orientation of diameter 10 mm and length 11 mm, a reciprocal QR and calcite wedges used as polarisers. We used in our experiments a 50-W, 1053-nm cw Nd : YLF laser with a Gaussian beam $1/\mathrm{e}^2$-diameter of 2.5 mm. The radiation passed through the isolator in direct and reverse directions, which is equivalent to doubling of the laser power from the point of view of heating. For correct comparison of the QR design with the conventional one, we used the same TGG crystals in the conventional design, but without QR.

The results of measurements of the nonisolation γ as a function of the radiation power are presented in Fig. 1. It was predicted in [2, 3] that the temperature dependence of the Verdet constant can be neglected compared to the effect of photoelasticity if γ is minimised by rotating polariser axis at each value of the power. The direction of the [100] crystallographic axis relative to the polarisation axis of radiation also was optimised in accordance with [2]. The experimental points in Fig. 1 show a minimal nonisolation, i.e., its value for optimal positions of the polariser and the crystallographic axis. The solid straight line in Fig. 1 shows the theoretical dependence for the conventional design:

$$\gamma = 0.014\left(\frac{L}{\lambda}\frac{\alpha Q}{\kappa}P_0\right)^2,$$

where

$$Q = \left(\frac{1}{L}\frac{\mathrm{d}L}{\mathrm{d}T}\right)\frac{n_0^3}{4}\frac{1+\nu}{1-\nu}(p_{11} - p_{12});$$

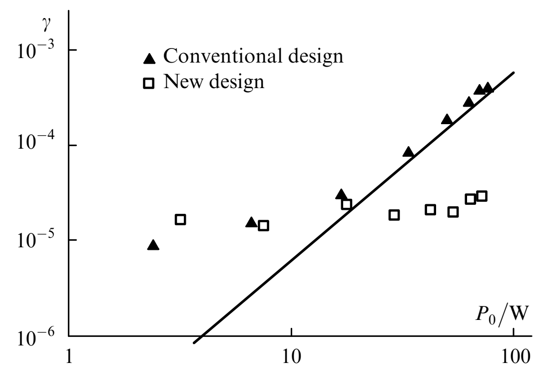

Figure 1. Experimental dependences of γ on the laser radiation power in the conventional and new designs of a Faraday isolator. The solid straight line is a theoretical dependence for a conventional design

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v is the Poisson coefficient; κ is the thermal conductivity; α is the absorption coefficient; n_0 is the refractive index; p_{ij} are the photoelasticity coefficients; L is the length of the magnetoactive medium, and P_0 is the laser radiation power [2, 3]. For the TGG crystal used, $Q\alpha = 7.7 \times 10^{-7}$ K^{-1} m^{-1} [6] and $\kappa = 7.4$ W K^{-1} m^{-1}.

At a low laser power, γ does not depend on P_0 because it is determined by the residual birefringence in TGG crystals, the imperfection of polarisers and the inhomogeneity of the magnetic field. In the conventional design at high powers, the nonisolation is mainly determined by thermal effects, the results being in good agreement with the theory (see Fig. 1). This confirms that the temperature dependence of the Verdet constant can be neglected when TGG is used [2, 3]. For glass, it was demonstrated experimentally in [5].

For a design with QR, the nonisolation does not depend on P_0 over the entire range of powers studied, which indicates that the thermal distortion of polarisation is compensated. Let us estimate the nonisolation in the isolator at high powers. For above values of $Q\alpha$ and κ, the formulas from [2] give $\gamma = 30$ dB at $P_0 = 450$ W. It was shown in [6] that TGG crystals exist with $Q\alpha = 3.2 \times 10^{-7}$ K^{-1} m^{-1}, for which $\gamma = 30$ dB at $P_0 = 1100$ W.

Our experiments confirmed that the Faraday isolators containing two TGG crystals with the [001] orientation, each of which rotates the polarisation plane by 22.5°, and 67.5° QR placed between them can provide the optical isolation that is substantially higher (by 15 times) compared to the isolation achieved in the conventional design at the 100 W radiation power. It was confirmed experimentally that, using TGG, the temperature dependence of the Verdet constant on the isolation can be neglected compared to the photoelasticity effect. These results indicate that a Faraday isolator with the 30 dB isolation at kilowatt powers can be realised.

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References

1. Khazanov E A, Kulagin O V, Yoshida S, Reitze D *Proc. CLEO'98* (San Francisco, 1998, p. CWF34)
2. Khazanov E A *Kvantovaya Elektron.* **26** 59 (1999) [*Quantum Electron.* **29** 59 (1999)]
3. Khazanov E A, Kulagin O V, Yoshida S, Reitze D, Tanner D *IEEE J.Quantum Electron.* **35** 1116 (2000)
4. Khazanov E A *Kvantovaya Elektron.* **30** 147 (2000) [*Quantum Electron.* **30** 147 (2000)]
5. Khazanov E, Andreev N, Babin A, Kiselev A, Palashov O, Reitze D *J. Opt. Soc. Amer B: Opt. Phys.* **17** 99 (2000)
6. Khazanov E, Andreev N, Palashov O, Poteomkin A, Sergeev A, Mehl O, Reitze D *Appl. Opt.* (to be published)