A Faraday isolator based on fused silica in a Herriott cell

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We demonstrated a multipass Faraday isolator based on fused silica. The polarization rotation angle of 45° was accumulated in a Herriott cell. The concept enables the use of magneto-optic materials with low Verdet constants in Faraday isolators.

Faraday isolators are widely used to protect sensitive optical setups like laser oscillators from the back reflections of optical radiation. They permit the transmission of optical radiation in one direction and suppress it in the opposing direction by employing the nonreciprocal Faraday polarization rotation in magneto-optic materials around the axis of an externally applied magnetic field. One of the most commonly used materials for lasers operating in the near infrared (NIR) spectral region is Terbium Gallium Garnet (TGG) due to its high Verdet constant [1,2]. At a wavelength of 1 µm, isolators for lasers with kW level average powers have been achieved [1]. But the use of TGG becomes impractical when going towards shorter wavelengths in the visible range. There TGG suffers from increased absorption [2], which limits the performance due to temperature induced depolarization effects [3]. In the ultraviolet range, TGG becomes eventually intransparent. Therefore, other materials with high transparency in the UV-vis range but low Verdet constants could be of interest. Towards longer wavelengths, TGG is limited in transmission to a wavelength of about 1.5 µm. Generally, at longer wavelengths it becomes challenging to achieve sufficient Faraday rotation due to the tendency of falling Verdet constants for magneto-optic materials. We present here a scheme to potentially enable the use of magneto-optic materials with low Verdet constants in Faraday isolators.

Materials with low Verdet constants require a correspondingly longer propagation length inside the magneto-optic material. It might not only be impractical and expensive to fabricate and use these materials. Relying on permanent magnets, it becomes also practically challenging to maintain a sufficiently strong and unidirectional magnetic field over the whole propagation length. Destructive superposition of magnetic dipole fields becomes a relevant consideration when scaling the length of the magnetic system surrounding the magneto-optic material without increasing its diameter. Therefore, we propose here to propagate the laser beam several times through the magneto-optic material by means of an optical multipass cell. As it has been demonstrated in the context of Faraday rotation spectroscopy, this scheme can be easily realized in a Herriott cell [4]. The Faraday rotation effect accumulates thereby for every path. For the purpose of an optical isolator, a much larger polarization rotation angle of 45° has to be acquired. Furthermore, it becomes crucial to minimize depolarization effects in the magneto-optic material to ensure a high isolation performance. Therefore, a material with low absorption and weak photoelastic effects is desirable [3].

In the visible range fused silica is a material with excellent transparency and weak thermal effects. In the UV range MgF_2 shows an exceptional transmission down to wavelengths about 200 nm. At a wavelength of 2 µm ZnSe has been employed in a Faraday isolator [5]. With multipass cells it might be possible to use ZnSe for even longer wavelengths. All three materials are easily available and could be potentially employed in a multipass cell Faraday isolator [6].

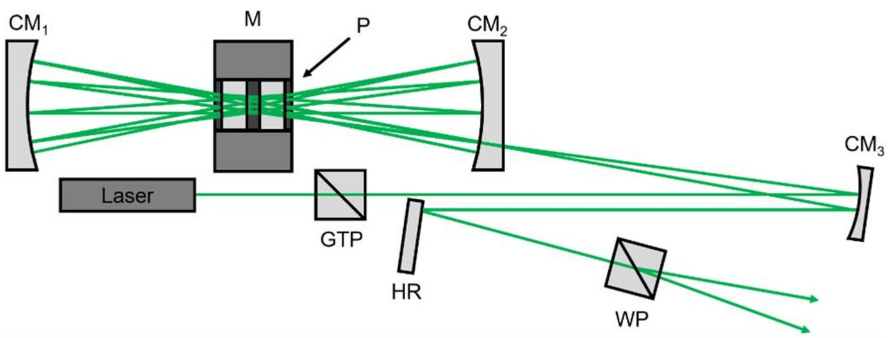

Figure 1 Scheme of a multipass Faraday isolator of materials with low Verdet constants. $CM_{1/2}$: curved cell mirrors, M: ring magnet, P: AR-coated fused silica plates of 6.35 mm thickness, GTP: Glan-Taylor polarizer, WP: Wollaston polarizer, HR: high reflective mirror, CM_3: coupling mirror.

To demonstrate the feasibility of the concept, we rotated the polarization of a laser beam about 45° in a Faraday medium made of fused silica. Fused silica is known for a low absorption from the UV to the NIR range. But the Faraday effect is weak due to its low Verdet constant of about 1.1 rad/(T·m) at a wavelength of 1 µm, which is about 35 times lower than that of TGG. To reduce the complexity of the setup, the experiment was carried out at a wavelength of 532 nm, where the Verdet constant is about five times higher. Two AR-coated plates of fused silica with a thickness of 6.35 mm were placed into a commercially available ring magnet with an axial orientation of the magnetic field [Figure 1]. The magnetic field inside the fused silica was estimated to be above 0.5 T. Inside a Herriott cell, the radiation of a 532 nm laser with an output power of 8 W was passed 30 times through the fused silica plates. Thereby, a total propagation length in the Faraday medium of 381 mm was realized and a polarization rotation angle of 45° was accumulated. The polarization of the transmitted beam was analyzed with a Wollaston prism. The power in the main polarization component was compared to the power in the orthogonal polarization component. From the ratio of both a depolarization of $1 – 2 \cdot 10^{-2}$ was usually measured. With careful alignment of the beams inside the Faraday medium, it was possible to decrease the depolarization to values of $2 \cdot 10^{-3}$, corresponding to an extinction ratio for the isolator of up to 27 dB.

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