Using Frustrated Total Internal Reflection for High-Power Lasers Monitoring

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Abstract: Two glass prisms are brought in close proximity. The evanescent field from the total internal reflection in one prism is used to obtain a beam with an irradiance tunable over 110 dB, with potential applications from medicine to materials processing. © 2019 The Author(s)

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1. Introduction

Complex high-power laser systems such as the one which is being commissioned at the Extreme Light Infrastructure - Nuclear Physics facility [1] comprise a large number of pump lasers with energies per pulse of several Joules and above and pulse duration in the nanosecond range. Owing to the high power involved, changes in beam properties like spatial profile or pointing could propagate and be amplified further in the chain, leading to possible damage of optical components. For this reason, permanent monitoring of the beam properties helps to achieve long operating life of the system.

In order to be monitored with CCD cameras or energy-meters, the beam needs first to be attenuated several orders of magnitude using optical components which reflect or absorb a part of the incoming beam. To achieve the required attenuation factor, several such components with fixed attenuation are placed in series.

The phenomenon of frustrated total internal reflection (FTIR) has been known for long [2]. The use of the evanescent field that appears at the reflection surface for building attenuators up to 105 dB for the far-infrared has been reported earlier [3–5]. Its use for the visible range was hampered at that time by limitations in the precision of the machining of optical surfaces and positioning of the components. Recently, an attenuator for the visible range with a tunable range of 70 dB has been reported [6].

2. Operating principle

Whenever a beam traveling in a medium is totally reflected at the interface with a lower refractive index medium, an evanescent field appears behind the reflecting surface. This field is known to decay exponentially with a characteristic length which is comparable with the wavelength of the beam. This fast decay can be exploited to sample a small and adjustable part of the incident beam by bringing a second medium within the range of the evanescent field. In practice, this can be achieved by using prisms as the propagation media for the beam, with an air gap between them. This is illustrated in Fig. 1 (a).

For a beam which is linearly polarized in the plane of incidence, the power transmitted through the prism-air-prism interfaces is given by [7,8]:

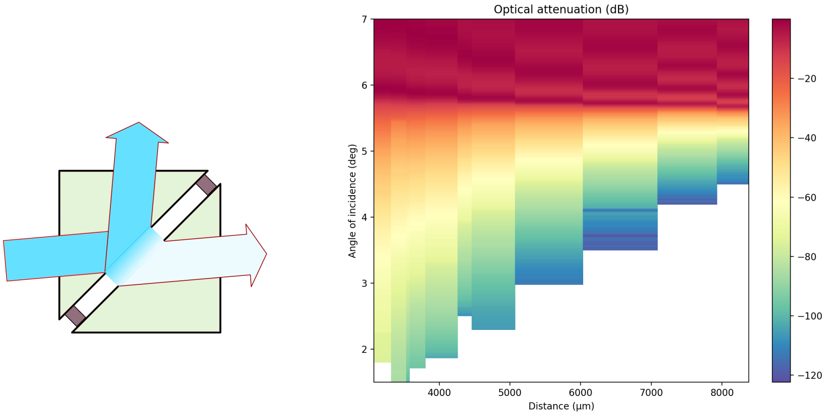
$$T_p = |T|^2 = 1 - \left| \frac{r_a^{\|}(1-e^{-2\alpha d})}{1-(r_a^{\|})^2 e^{-2\alpha d}} \right|^2 \tag{1}$$

where d is the separation between prisms and α is the attenuation coefficient:

$$\alpha = \frac{2\pi}{\lambda}(n_a^2 sin^2\theta - n_b^2)^{1/2} \tag{2}$$

and $r_a^{\|}$ is Fresnel's electric field amplitude coefficient for reflection at the first interface [7]:

$$r_a^{\|} = \frac{-in_a(n_a^2 sin^2\theta - n_b^2)^{1/2} - n_b^2 cos\theta}{-in_a(n_a^2 sin^2\theta - n_b^2)^{1/2} + n_b^2 cos\theta}\,. \tag{3}$$



(a)

(b)

Fig. 1: (a) Two prisms are brought in close proximity and separated by spacers. The evanescent field from the total internal reflection of a beam at a prism-air interface is transmitted through the second prism. (b) The attenuation coefficient for the transmitted beam (right handside in (a)) was measured as a function of (i) incidence angle at the entrance of the first prism, and (ii) prism separation.

In Eq. 2 and Eq. 3, n_a and n_b denote the refractive indices of the prism material and air, respectively, and θ is the incidence angle on the first prism-air interface.

3. Results and Outlook

Since the transmission coefficient from Eq. 1 depends on both incidence angle and prism separation, a complete characterization in this two-dimensional space was performed by fixing the distance between prisms with spacers and changing the incidence angle through rotation of the prisms assembly relative to the incoming beam. The measurement was then repeated for different gap widths. The results are shown in Fig. 1 (b). The present measurements were limited by the optical noise in the set-up. The preliminary analysis shows an excellent agreement between the measurement and the theory.

The high dynamic range of this FTIR-based attenuator for free space optics industrial applications will generate technological advance. The development of versatile metrology for high power lasers would allow to transform pump lasers used in PetaWatt class lasers from research-grade in industrial-grade, hence the production of industrial grade PW laser systems. Complementary, such attenuators would enhance the capabilities of lasers in medical applications, materials processing with high power lasers and in laser-based additive manufacturing.

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