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Application of tot'hema eosin sensitized gelatin as a potential eye protection filter against direct laser radiation

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ABSTRACT

The optical limiting properties of tot'hema and eosin sensitized gelatin layer (short TESG) under continuous second harmonic Nd:YAG laser light were investigated. In contrast to classical eye protection filters the microlens formation and carbonization in TESG are the main mechanisms for eye protection from direct laser radiation. Results have shown that safety goggles made on TESG can protect the eye from up to 10 W of incident laser power. Filters for other wavelengths can be manufactured by varying the sensitizer.

1. Introduction

The growing number of laser applications requires development of materials which protect against laser radiation. Special attention is dedicated to eye protection, due to focussing power of the eye lens. It is well known the eye lens produces high intensities at the retina surface [1–7] potentially leading to permanent vision impairment. Different parts of the eye can be damaged, depending on the laser wavelength and intensity. UV light (<400 nm) and part of IR light (>1400 nm) damage the cornea and the eye lens, while light at wavelengths between 400 nm and 1400 nm endanger the retina, which is the most sensitive part of eye [1–7].

The usual method of eye protection is based on different types of filters, (absorption, reflection, interference, or polarization) inside goggles or protective windows [8–11]. The majority of safety filters are plastic materials which protect human eye from scattered or otherwise diffusely reflected laser light. Some manufacturers offer glass-based filters, either as absorption or thin-film interference devices. A good quality laser eye protection goggles are characterized by a very small transmission for particular laser wavelength, and high transmission of visible light. According to European laser eye protection standards EN 207 [12] and EN 208 [13] a laser goggle must be able to protect the user for a minimum of 5 s (CW laser) or 50 pulses (pulsed laser) of direct laser radiation. The maximum permissible exposure (MPE), measured at the cornea of the human eye, is the highest laser power density or energy density that is considered safe for a given wavelength and exposure time [14]. In all cases, the protection level is limited by the laser energy absorbed within the material. Above certain threshold, the material absorbs enough energy to be melted and punctured, letting the full laser power to pass-through.

Here we report on the material exhibiting three different protective mechanisms. At low powers, absorption reduces the intensity of transmitted radiation below the MPE. In the intermediate range, microlens is produced which diverges the radiation, again reducing the eye irradiance below the MPE. Finally, at high powers the material carbonizes rather than melting, thus making the irradiated zone opaque.

This paper investigates the optical limiting behaviour of tot'hema and eosin Y sensitized gelatin layer (short TESG) as well as possible application as an eye protection filter against high-power direct laser beams. The tot'hema is a mixture of Fe(II)-, Mn(II)-

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and Cu(II) gluconates used in medicine for curing iron deficiencies. Eosin is an organic dye with absorption maximum about 532 nm, used in medicine, too. Previously, we have shown that TESG is an excellent optical material [15,16]. The microlens formation and dye bleaching occur simultaneously during laser exposure. Although the TESG layer is initially coloured due to presence of eosin and tot'hema, after irradiation with a 532 nm laser the dye bleaches leaving an irradiated layer with completely transparent microlenses. The process of microlenses formation is thermal as we have verified using a thermal camera [17]. The protection mechanism of the TESG layer is based on microlenses formation during the laser irradiation. The layer carbonization at higher laser power additionally protects an eye. As a result of all mentioned processes the TESG layer was able to reduce 10 W (CW operation at 532 nm) direct laser beam to the safe level.

The TESG layer is chemically stable (under the normal laboratory conditions), elastic [18] and not very sensitive to scratches and tearing. However, it is slightly sticky and dust and fingerprints may collect on the surface. In practice, the laser goggles require sandwiching of TESG between two transparent plastic plates (such as thin polycarbonate). This enables mechanical protection of the filter and goggle cleaning. Additional advantages of TESG such as easy manufacturability, low cost, non-toxicity and stability, make this layer very interesting for eye protection applications.

2. Material and methods

The layers were prepared as described in our previous papers [15,16]. The 5 g of gelatin powder (Gelatin from bovine skin gel strength ~225 g Bloom, Type B, Sigma) was swelled in 100 ml deionised water for 60 min. The gelatin is heated for 10 min in a water bath (Vela™, Cole Parmer) at 50 °C, with stirring. In order to prevent crystallization of the layer and keep elasticity, 1 g of sodium chloride (puriss. p.a. were purchased from Sigma–Aldrich) was added together with the 20 ml of tot'hema oral solution (Laboratorie Innotech International, France). At the end 0.3 ml of 1% water solution of eosin Y (5 wt.% in H_2O, Sigma–Aldrich) is supplemented. Eosin Y enhances absorption of TESG layer at 532 nm. The TESG solution is than centrifuged (Cole Parmer at 3400 rpm/min) for 30 min in order to remove impurities. In the next step the 10 ml of TESG solution is poured onto a precisely levelled and well-cleaned 2 mm thick polycarbonate (lexan) plate. The layer is dried in the dark, in relatively stable laboratory conditions. After drying, TESG layer thickness of 1 mm was obtained. The thickness of each deposited layer is an average of measurements at eight different points with a digital micrometre. The resulting layer is very elastic and sticky, and can be easily peeled and transferred to another substrate.

Protection filter prepared by adhering 1 mm thick layers of TESG on both sides of 2 mm thick transparent lexan plate was positioned 20 mm in front of a 5 mm diameter aperture, as shown in Fig. 1. The aperture is simulating the human pupil which normally opens about 2 mm in daylight, and 7 mm in the dark [19]. This configuration is analogous to laser protective goggles placed in front of eyes.

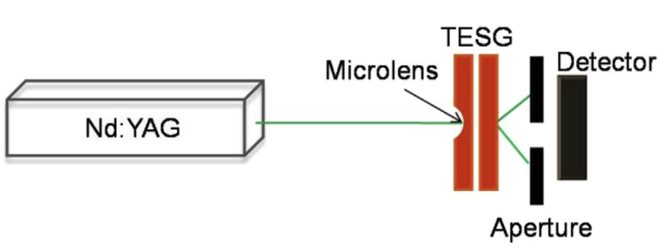

Fig. 1. Experimental setup: The transmitted power of CW laser light operating at 532 nm after passing an optical filter (made of a lexan plate sandwiched between two TESG layers) and aperture were measured by a power meter.

A 10 W, 532 nm Nd:YAG laser was used (Verdi V-10 manufactured by Coherent Inc.) to test the protective properties of TESG. The beam diameter was 2.3 mm. Transmitted laser power was measured by OPHIR power meter (NOVA II) with a photometric head placed close to the aperture (see Fig. 1). The laser power used to test TESG filter was varied between 100 mW and 10 W. Transmission spectra of TESG were analysed by a fibre-type spectrometer (Ocean Optics) with a tungsten-halogen light as illumination source. The morphology of the TESG layer and a plastic protective layer were investigated using a high resolution scanning electron microscope equipped with a high brightness Schottky field emission gun (FEGSEM).

3. Results and discussions

3.1. Power limiting and protective properties of TESG

At the beginning, we would like to emphasize the difference between TESG layer and classical plastic absorptive filters. TESG layer and one plastic filter were exposed with direct Nd:YAG laser beam at 532 nm wavelength, and power of 100 mW. After less than a second the plastic layer was perforated, as shown in Fig. 2a. In the case of TESG layer, after 10 s exposure, the microlens is formed (see Fig. 2b). The scanning electron microscopy images of a perforated hole and TESG microlens are shown in Fig. 2c and d, respectively. Important characteristic of the TESG layer is its property to bleach under the laser beam action. The bleaching (photochemical transition of eosin dye from pink to colourless state) and microlens formation occurs simultaneously during laser irradiation. The increased transmission due to bleaching is compensated by expansion of the laser beam by a microlens. As a result the irradiation level behind the microlens is constant. This is very important since bleaching prevents the layer overheating (within certain power levels) and perforating. The pink colour of TESG layer is due to eosin, but otherwise the visibility through the 1 mm thick layer is good.

3.1.1. A generic eye model and protection mechanism

To illustrate the eye protection principle, a generic model of the human eye is constructed (Fig. 3) and ray tracing is used to calculate the beam propagation through the eye [20,21]. In the case when the laser beam enters an unprotected eye (see Fig. 3a) the radiation is focused on the retina (0.17 mm spot diameter). The power density is high and retinal damage is possible.

If a protective filter, with the microlens (created under the influence of the beam) is placed in front of the eye the situation is changed. A microlens is an additional optical component between the laser beam and the human eye. It expands the beam, and only a small fraction of the radiation goes through the pupil of an eye. Even more, the radiation is not tightly focused (Fig. 3b) as in the previous situation (Fig. 3a). According to ray tracing calculation, the resulting spot on retina has 2.01 mm diameter, which is about 12 times larger compared to the direct laser beam spot size. As can be seen in Fig. 3b there are two effects– one is reduction of the amount of light transmitted through the eye pupil and another is increased size of the focused spot. The overall reduction of power density is approximately six orders of magnitude.

As we can see in Fig. 4 the protection mechanism is determined by the laser power and exposure time.

According to Fig. 4, the absorption of laser light dominates up to the laser power of 50 mW, and it doesn't affect the protective layer.