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Aging of laser protective filters concerning laser resistance

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Abstract

Various influencing factors concerning the laser resistance of laser protective filters have already been investigated, but the influence of the age of the filters has not been studied yet. Therefore, the focus of the experimental work was to determine the laser resistance of artificially aged laser protective filters and to compare the experimental results with new filters of the same product. The investigations were carried out on filters made of Polymethylmethacrylate (PMMA) to examine, whether aging has an effect on the protective properties of the filter material or not. The test samples were aged artificially by UV irradiation. On all filter samples the spectral transmittance (optical density), luminous transmittance and diffusion of light were first measured in the initial condition and afterwards in the aged state. The laser resistance was then tested by using Nd:YAG and CO_2 laser radiation. These laser resistance tests were carried out according to the certified scale numbers of the filters by the norm EN 207.

Keywords: Aging effects; laser resistance test; laser protective filter

1. Motivation

The correct selection of laser protective goggles is essential for safe experimental work in laser laboratories and for service works at laser systems in industry. The main task of filters is to keep the irradiation at the eye below the Maximum Permissible Exposure (MPE) [1]. When laser protective goggles are getting older, it gets more difficult to decide if they still can be used, which means whether they still fulfill the requirements to their protective function. In research work the influence of the beam diameter on the laser resistance of protective filter materials was investigated [2], but not yet the effects of aging.

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With the revision of the testing norm EN 207 [3] in the year 2010 a stability test to ultraviolet radiation was introduced for protective filters. This UV test means a standardized aging test which must be carried out in accordance with Clause 6 of the norm EN 168 [4] with an exposure time of 50 h. The optical properties of filters shall not change to such an extent that they can no longer satisfy the requirements of norm EN 207. Therefore, the spectral transmittance (optical density), luminous transmittance and diffusion of light are assessed by the certifiers before and after the exposure of the filters to ultraviolet radiation. But acc. to norm EN 207 it is not required to measure the resistance of the filters to laser radiation after being exposed to UV light, again. Thus, no information of the impact of ultraviolet radiation, i.e. of aging effects on the laser resistance of laser protective filters, is available. The consequence is that it belongs to the user of laser safety goggles to decide if googles after several years in use are still safe or should be replaced by new goggles. Even for the manufacturers of laser safety goggles it is difficult to give recommendation for the lifetime of their products.

Therefore, it is the aim of the study to get a more detailed knowledge about the resistance of aged laser protective filters to laser radiation in order to estimate the lifetime of laser safety goggles.

2. Experimental setup

Testing the resistance of laser protective filters to laser radiation is carried out following the current issue of norm EN 207. Irradiation of protective filters is performed with specified wavelengths, power (E) and energy densities (H) according to the scale number of the filters. The diameter d_{63} (in the case of a Gaussian beam, d_{63} corresponds to a distance where irradiance falls to 1/e of its central peak value [5]) of the laser beam during the resistance test is defined to 1.0 mm.

To determine the laser resistance time of laser protective filters two different laser types were used. First a cw lamp-pumped Nd:YAG laser “QY1000D” (wavelength 1064 nm) from the company Haas-Laser GmbH was utilized. Its experimental setup is shown in Fig. 1 and 2. The laser protective filter is placed according to the measured caustic of the laser beam, shown in Fig. 3, in such distance from the focusing optic that the required beam diameter d_{63} of 1.0 mm is realized on the surface of the filter. In this case the diameter d_{63} = 1.0 mm is identical with d_{86} = 1.4 mm, which is around 7 mm out of the focal point. Behind the filter, in a distance of 30 mm, a blackened photographic paper is placed to detect transmitting laser radiation. The required laser power is adjusted at the operation unit of the laser and controlled by using a power meter head LM 200 from Coherent. As the airflow has an influence on the laser resistance tests, the local exhaust ventilation is always placed 250 mm above the point of laser impact to have constant conditions for a high reproducibility of the tests. A shorter distance would cause a heavier reaction of the laser beam with the protective filters caused by feeding the reactive zone with fresh oxygen, which could result in shorter resistance time of the filters.

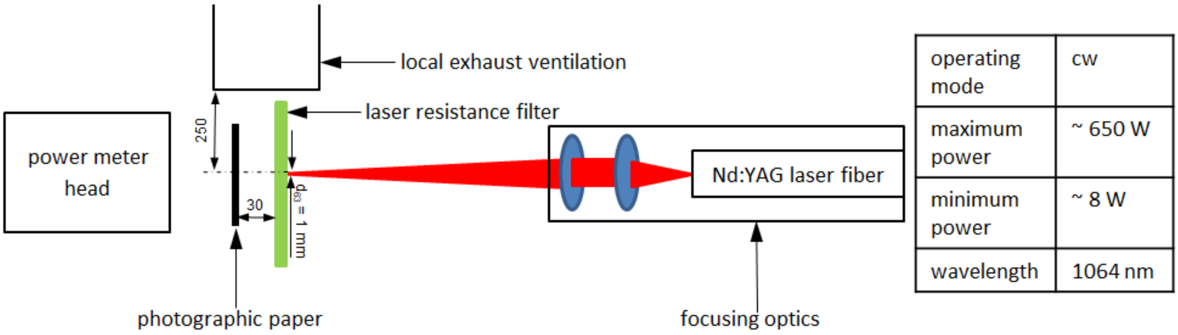


Fig. 1. Schematic setup for detecting the laser resistance time T of aged PMMA laser protective filters using a cw Nd:YAG laser.

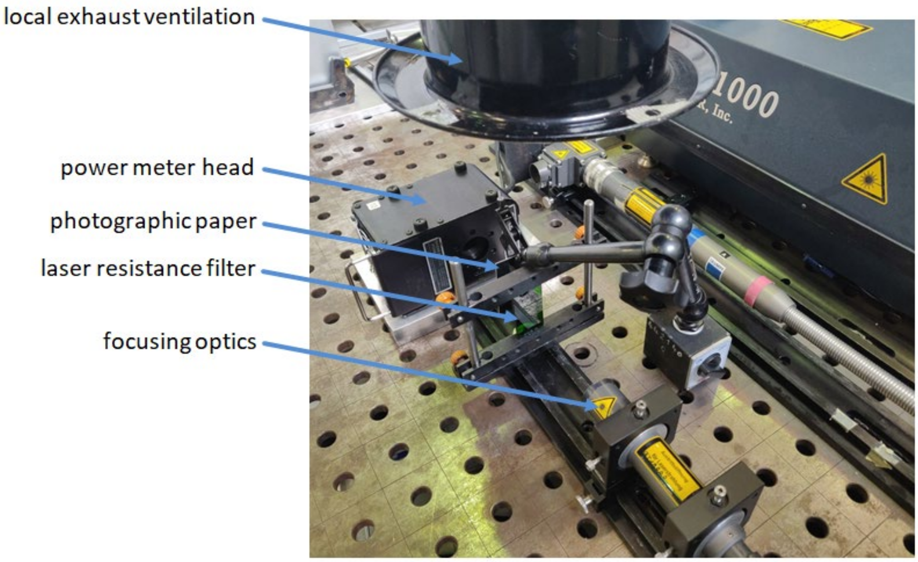


Fig. 2. Realization of the experimental setup for testing the laser resistance time of the PMMA filters with the Nd:YAG laser.

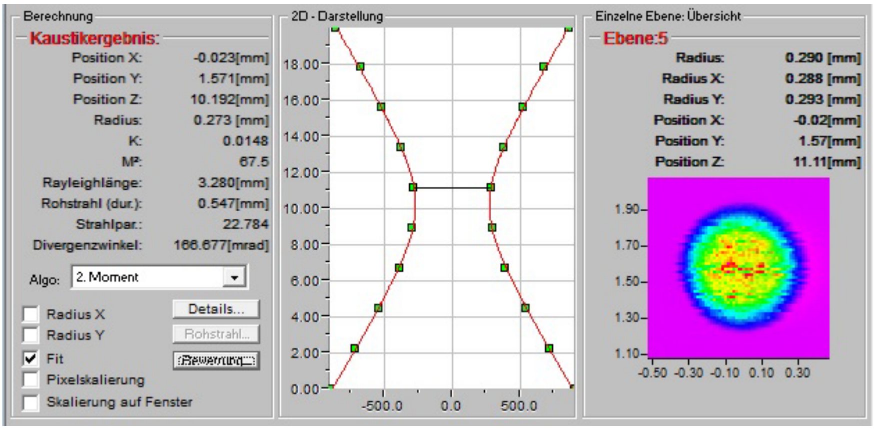
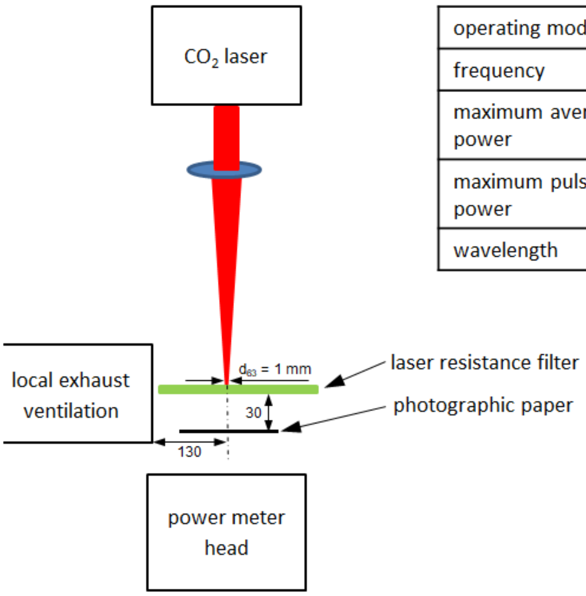


Fig. 3. Caustic measurement of the used Nd:YAG laser done with the caustic measuring device "FocusMonitor" (PRIMES GmbH).

The experiment starts with the laser beam switched on and a stopwatch being actuated. The time is stopped as soon as a visible effect on the blackened photographic paper placed behind the irradiated filter can be seen (failure criterion). This measured time between start and end of the experiment defines the laser resistance time T of the tested laser protective filter and is the comparison criterion for possible aging effects. The parameters for the laser resistance tests, i.e. the suitable laser power, which lead to reasonable laser resistance times, were determined in preliminary tests. When the laser power was set too high, the laser resistance time is too short to detect a clear result on the photographic paper. In this case the influence of the error by hand stopped time would be too high. On the other hand, if laser resistance time is too long, the reproducibility of the tests would also decrease because of the limited attention span of the experimenters. Therefore, with the Nd:YAG laser the laser power was set to 30 W to achieve a laser resistance time of around 30 s, which was found to be a good compromise between influence of hand stopped time and the attention span of the experimenters. At 30 s the failure from the hand stopped time is max. 5 %, since an inaccuracy of max. +/-1.5 s is empirically estimated.

The second laser for the experiments was a CO_2 laser "Microstorm" (wavelength 10600 nm) from the company FEHA LaserTec GmbH that was used in its cw mode. The experimental setup comparable to that of the Nd:YAG laser is shown in Fig. 4. The laser protective filter is placed in such a distance from the focusing optic that a laser beam diameter d_{63} of 1.0 mm is realized on the surface of the filter. The blackened photographic paper is placed 30 mm behind the laser resistance filter. According to the preliminary experiments with the Nd:YAG laser, the laser power was determined in prior measurements and set for the CO_2 laser to 1.6 W to get a suitable laser resistance time T of around 30 s. The local exhaust ventilation is placed in a distance of 130 mm from the point of laser impact. The experimental procedure to detect the laser resistance time at the aged filters was comparable to the tests with the Nd:YAG laser: Time was stopped by hand when the blackened photographic paper placed behind the filter showed a transmission of laser radiation.



operating mode	cw and pulsed
frequency	max. 150 kHz
maximum average power	~ 350 W
maximum puls peak power	~ 50 kW
wavelength	10600 nm

Fig. 4. Schematic setup for detecting the laser resistance time T of aged PMMA laser protective filters using a CO_2 laser.

The laser resistance tests described above with both lasers were done with laser protective filters based on PMMA with a laser absorptive dye for the near infrared range. The PMMA filters are certificated with a scale number of D LB6 at 1064 nm according to EN 207. The test samples have dimensions of 30 mm x 60 mm with a thickness of 3 mm. The samples were artificially aged under UV radiation following Clause 6 of the norm EN 168, with the UV lamp running at a power of 450 W. The first set of six samples was aged for 50 h. A second set of six samples was aged for 200 h. The third set of samples wasn't aged and was used for comparative tests. Aging for 200 h with ultraviolet radiation corresponds to several years of storing the filters permanently in direct sun light. With all samples in their initial status (i.e. in their unaged status) the spectral transmittance (optical density), the luminous transmittance and the diffusion of light were measured. These measurements were repeated after exposure of the first and second set of filters to ultraviolet radiation. The spectral and the luminous transmittance were measured with a spectral photometer Cary 6000i from Agilent Technologies in accordance with the norm EN 167 [6], Clause 6. The diffusion of light was detected with an appropriate measurement setup carried out in accordance with Clause 4 of the norm EN 167. After aging and detection of these optical properties all sets of samples were tested to their resistance to laser radiation until failure and the laser resistance time T was measured as described above.

3. Results and discussion of the experimental work

In Fig. 5 the PMMA test samples are shown after the laser resistance test at a wavelength of 1064 nm and 10600 nm.

Fig. 5. PMMA filters after laser resistance test at 1064 nm (left picture) and at 10600 nm (right picture): The filters on the left in both pictures are unaged, the filters in the middle are aged for 50 h under UV radiation, and the filters on the right are aged for 200 h.

Since the filters were tested until failure, i.e. until a thermal effect on the photographic paper was detectable, both lasers caused holes in the filters. Nevertheless, the appearance of the defects shows significant differences with respect to the wavelength of the lasers. There can be found melting and foaming of the filter material at 1064 nm compared to a pure drilling defect at 10600 nm. The different behavior of the filters during laser exposition can be explained by a wavelength dependent beam-matter-interaction. At 1064 nm the laser beam is absorbed within the dye which is solved in the polymer matrix as absorber material. The polymer matrix itself is transparent for this wavelength. If the dye will change the absorption due to the local heating of the filter material, this results in a deeper penetration of the filter and an absorption in the volume and not at the surface. This leads to an increase of temperature in the volume of the filter material and as a consequence to melting of the matrix material and a foaming effect because of gas formation due to the breakdown of the filter material. In contrast, at 10600 nm the laser energy is absorbed mainly at the surface of the filter by the PMMA matrix material itself. That means a melting and an evaporation of the filter material occurs always from the surface and the laser beam drills a hole through the filter. Within the same wavelength no differences in the appearance of the defects caused by the laser resistance tests at unaged, 50 h aged and 200 h aged PMMA filters are visible to the naked eye. This fact can be seen as an indication that aging by ultraviolet radiation has only a marginal effect on the laser resistance of PMMA filters.

The experimentally detected laser resistance time T versus the aged state of the filters is shown in Fig. 6 for 1064 nm and in Fig. 7 for 10600 nm.

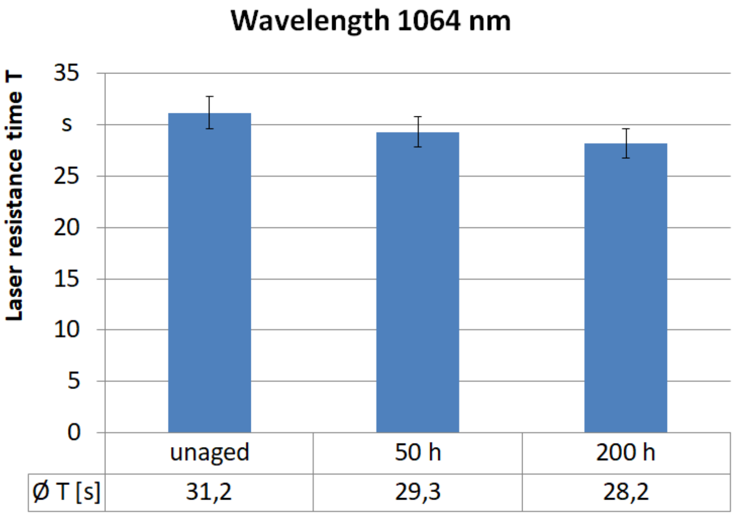


Fig. 6. Laser resistance time T versus aging state of the PMMA filters tested with Nd:YAG laser radiation at 1064 nm (average value out of six measurements).

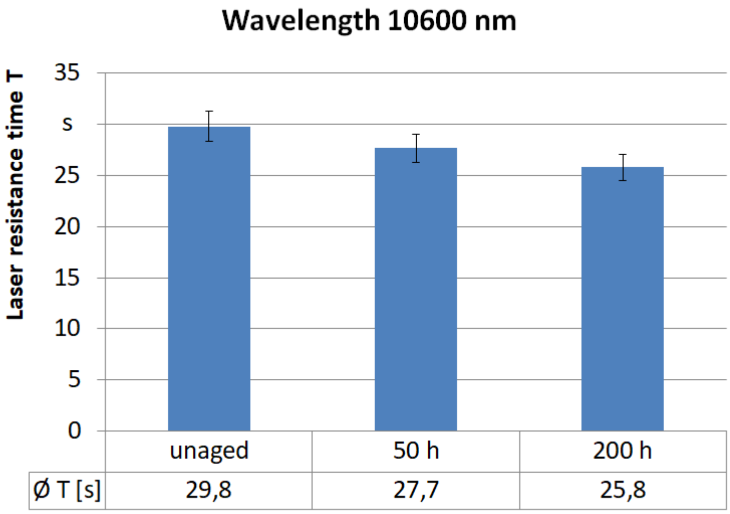


Fig. 7. Laser resistance time T versus aging state of the PMMA filters tested with CO_2 laser radiation at 10600 nm (average value out of six measurements).

The experimental results displayed in Fig. 6 and Fig. 7 show a similar correlation between the laser resistance time and the aging state for both wavelengths. It can be seen that artificial aging of PMMA filters by ultraviolet radiation leads to a moderate loss of laser resistance. For the Nd:YAG laser radiation at 1064 nm the laser resistance time decreased for around 10 % and for the CO_2 laser radiation at 10600 nm for around 13 %. For comparison, the used PMMA filters are certificated with a scale number of D LB6 at 1064 nm, which means that these filters withstood laser radiation at 7.9 W for at least 5 s. In our study we have shown that the real laser resistance of the tested PMMA filters at 1064 nm is even higher. The filters, even which were aged for 200 h, withstood laser radiation at 30 W for around 28 s. Thus, the detected decrease of laser resistance time of 10 % after aging for 200 h means a protection level, which is well beyond that of the certified scale number. Therefore, the loss of laser resistance seams not to be the limiting factor and is negligible for the investigated conditions. These results correspond well with the independence of the visible defects caused by the performed laser resistance tests (see Fig. 5) from the aging state of the filters. Since aging for 200 h with ultraviolet radiation corresponds to several years of storing the filters permanently in direct sun light, one can assume, that laser safety goggles with PMMA filters used within their certified range could withstand exposure to laser radiation even after years of use.

Although the laser resistance seams not to be the limiting factor, aging shows effects on the optical properties of the PMMA filters, which could make the use of the goggles critical. The measurements for the spectral transmittance show no measurable decreasing of the values by aging, because the values are still above the limitations for the used spectrometer. That underlines the results that laser resistance time is not decreasing significantly with the age of the filters. The situation differs for diffusion of light, where the limit value is 0.5 $cd/m^2/lx$. PMMA filters aged for 200 h by ultraviolet radiation show a diffusion of light around this limit value or slightly above it, what might be recognized by the user of the laser safety goggles. The maximum acceptable decreasing of the luminous transmittance after 50 h UV radiation concerning the norm is 10 %. The measured luminous transmittance on the PMMA filters aged for 200 h are just in the tolerance range given by the norm.

4. Conclusion

The data obtained from described experiments with Nd:YAG and CO_2 laser radiation at artificially aged PMMA filters have led to the result that aging time of the laser resistance filters shows an influence. But this influence is negligible low for the investigated PMMA filters. Furthermore the influence of the wavelength on the laser resistance of the aged filters is low, since the results at 1064 nm are quite comparable with that at 10600 nm. Even after an artificial aging process by UV radiation for 200 h the PMMA filters have a much higher protective level at 1064 nm than they need to have according to their certified scale number. Thus, the resistance to laser radiation seems not to be a limiting criterion with respect to aging processes if the manufacturer includes a safety surcharge for the laser resistance. On the one hand after aging for 200 h the measured luminous transmittance values are next to the limit values and on the other hand, diffusion of light is increased in a way the user may recognize. Because the measured spectral transmittance values are out of the limit of the spectrometer, further measurements on micro sections should follow. The investigations done so far do not yet prove a general causation. As a next step the laser resistance and the optical properties of “naturally” aged laser protective filters, which were used for many years in application, will be investigated in order to verify the results from the artificially aged protective filters.

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