M-Protection Levels for Safe Application of Shortpulse Lasers

Ultrashort Pulses Offer New Possibilities but also Inherent Hazards

In laser safety the letter M should not be mixed with a quick lunch at an American burger restaurant or with a racy Bavarian sports car. For a few years now, mode-locked lasers with pulses ranging from a few picoseconds to a few femtoseconds have been enjoying a continuously increasing market share. Fields of application can be found in research and development, industrial processes and also in medicine. The special properties of these lasers are well known and have been recognized since the 1980s and therefore have already gained much attention in the laser safety standards DIN EN 207 and DIN EN 208. According to this reliable laser protection is needed. Due to this requirement, manufacturers of laser safety products have certified laser safety goggles and other protection equipment for these types of lasers. In this article we present the challenges of laser safety filters against ultrashort pulse lasers.

The application of ultrashort pulse (USP) lasers established itself in many fields of material processing. Many applications have been introduced, ranging from ultra-precise material cutting of temperature-sensitive or hard materials to drilling sub-µ holes used for ventilation, injection or storage of liquids and straining of particles. Laser machining has also become a key technology in the production of photovoltaic modules. Here USP-lasers allow much finer structures resulting in higher efficiency and the ability to use new substrates. In R&D fs-lasers are used, for example, for time-resolved monitoring of fast running processes. Medical research projects like MIKAFEM investigate the therapy of caries.

So what is the difference between continuous laser systems and ultra short pulse laser systems?

Laser radiation of continuous wave (cw) lasers like Nd:YAG-material processing lasers is normally a narrow band emission (monochrome, single colored), which means it consists of only one wavelength or has a small emission line. It is relatively easy to find an absorption material or dielectric coating for this small line or bandwidth.

As opposed to continuous wave lasers, mode locked lasers emit pulsed radiation of extreme short pulses of light. These pulses were generated by Q-switching or mode synchronization.

But basic quantum physical principles of this pulse generation process lead to a spectral broadening of the emission line. So the filter material has to be adjusted to a significantly broader line width. USP-laser technology brings the ability to interact with photons at the femto- and picosecond time range and to use them as a tool to manipulate matter at that temporal dimension.

Normally machines using material processing laser technologies are completely enclosed. Nevertheless in some applications, e.g. medical applications, handheld systems are used where suitable eye protection is required. But also maintenance and adjustment operations require appropriate laser safety goggles as personal protective equipment (PPE). A suitable laser protection for all of these applications is mandatory and has to be marked with laser protection levels and operation modes. Laser protection equipment for USP-lasers has to be marked with the letter „M“ which designates the operation mode “short pulse/mode-locked”, the appropriate L-protection level (e. g. L7) and wavelength range.

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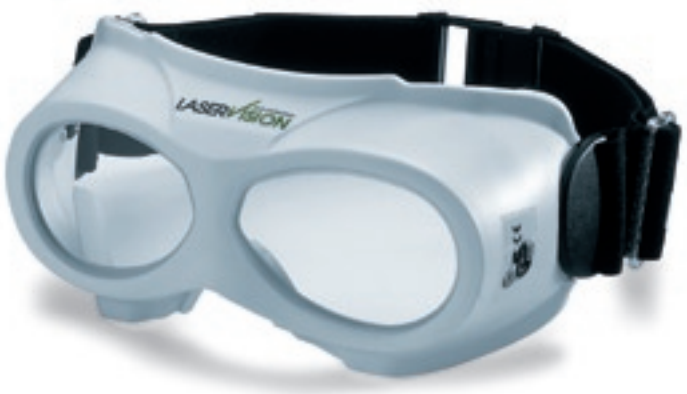

FIGURE 1: **The laser safety goggles PROTECTOR can be worn over corrective glasses and provides a stress-free wearing comfort as well as very high protection levels (up to M:L9).**

TABLE 1: **Overview of laser safety filters with M protection levels.**

Laser safety filter for USP–Laser (pulse length <1ns) by Laservision

Filter	315–532 nm	700–800 nm	800–1000 nm	1030–1100 nm
T27	M:L8			M:L9
T35				M:L9
T37	M:L8			M:L9
T39	M:L8	M:L 9 (750–1100 nm)		
T48		M:L8 (720–795 nm)/ M:L10 (795–805 nm)	M:L9 (805–1200 nm)	
T68		M:L8 (750–800 nm)	M:L9	M:L8 (1000–1064 nm)
P1006	M:L6			M:L6 (980–1065 nm)

Please remember that light would travel 7.5 times around the globe within one second, but would travel only a fraction of the width of a human hair within a femtosecond. In such a short time period a femtosecond light pulse concentrates the power of the total worldwide electricity network. USP-lasers concentrate a large amount of energy and emit this energy as an extremely short light pulse. In combination with the above-mentioned subject of emission line broadening this high peak power destroys nearly every material and it becomes a serious problem to design laser safety filters which fulfill the requirements of the laser safety standard of 10 seconds and 100 pulses durability against such laser radiation.

Challenges for Laser Safety Design

In addition to the high pulse peak power, a series of other effects, which are originally of interest or required for the application, have a negative influence on laser eye protection.

The most noticeable effect of ultra short pulse laser radiation in combination with laser safety filter material is designated as induced transmission. Here nonlinear physical interaction processes between light and matter affect the protection or blocking behavior of the laser filter. This interaction results in a momentary increase of the spectral transmission when the material is irradiated with short, high-energy laser pulses. Based on experiments about the behavior of commonly used laser safety filters with nanosecond laser pulse irradiation, this effect was also demonstrated in 2003 for much shorter femtosecond pulses in a study by the German federal agency of working protection and working medicine (BAuA). Based on the selected filters tested with femtosecond pulses it may be generally stated that absorbing glass filters seem to be less critical for applications with mode locked lasers than polycarbonate-based filters. However a generalization of this statement to all absorber materials for glass filters is not allowed. But based on the detected nonlinear behavior, polycarbonate filters seem to have an inherent potential risk. In particular the reversible process of induced transmission holds the risk that single laser pulses induce a high transmission leading to low attenuation by the filter material and dangerous impact of radiation on the eye. What does this mean for users? When improper or too low specified filters and/or goggles are used this „switch trough effect" causes a radiation impact to the eyes, which will be too high in some cases and result in damage to the eye. The remaining protection of filters showing this induced transmission effect and those which do not show this effect have been discussed in connection with the DIN EN 207 laser safety standard. As a result the corrective factors which are used to calculate laser protective levels have been modified for USP lasers. Here they will be higher due to the higher impact of energy during a very short time period.

The effect of induced transmission or switching-through effect observed primarily with polycarbonate absorber filters was not observed on laser safety filters based on glass tested by the BAuA.

However plastic absorbers with low M protection levels have been available for a long time. It is thought-provoking that plastic filters are preferred for pulse powers in the equivalent range of a medium-sized coal power station because they are of low weight and have general M protection certification, but insufficient protection in the event of an accident. In order to meet the growing requirements of wearing comfort and acceptance, laser protection manufacturers have undertaken great efforts to provide high M protection levels with plastic filters.

For the wavelength range of 315–532 nm and of 980–1065 nm Laservision was able to identify the material P1006 as a special, novel plastic absorbing filter material.

Within the certification process P1006 was the subject of real femtosecond-impact laser testing and has achieved a M:L6 protection level. Until now, this is unique for plastic absorbers. The P1006 is available in the DYNA GUARD OTG frame and it is particularly suitable for Nd:YAG lasers with their basic wavelength of 1064 nm and also for the harmonic wavelengths of 355 nm and 532 nm. Above that it covers the wavelength of 980 nm, which is typical for pump diodes.

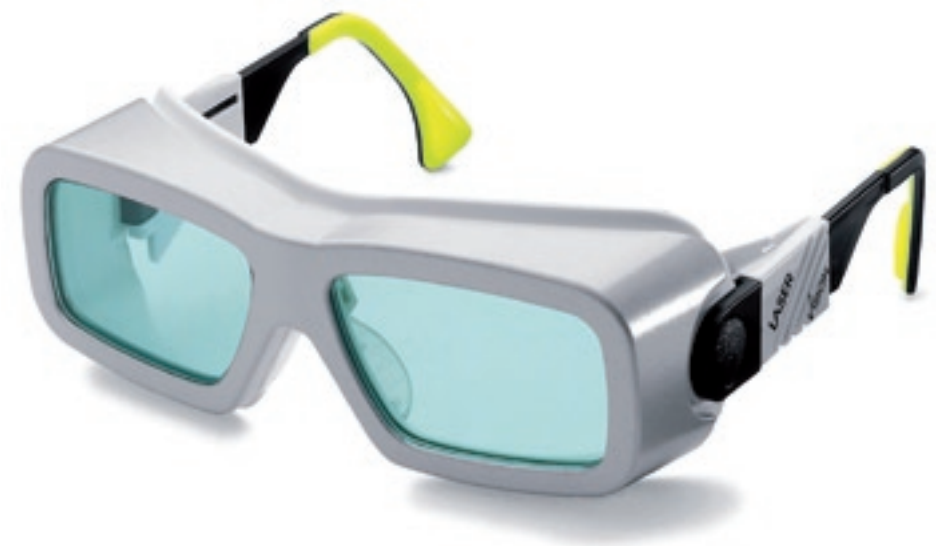

FIGURE 2: **The All STAR features a highly efficient outside reinforcement. This guarantees very high protection levels as well as additional mechanical protection against for e.g. scratches.**

Which Filter Fits?

For higher protection levels or if protection at other wavelengths is required, absorbing glass is the only appropriate filter material available until now.

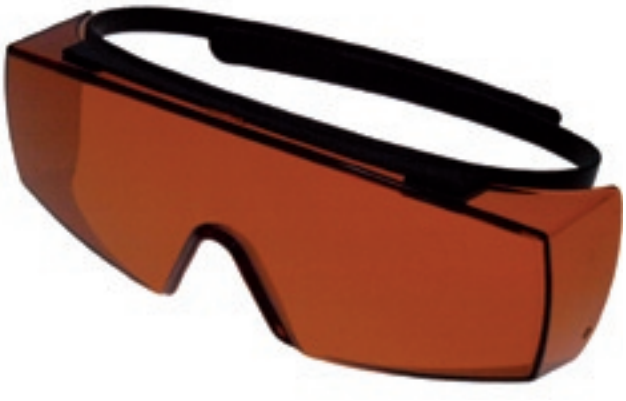

FIGURE 3: **The single shield of the DYNA GUARD OTG provides a broad field of view without any obstruction by the frame. The goggles features an extremely low weight and a nearly ideal fit to every shape of the head. In combination with the P1006 filter, it provides a M:L6 protection level.**

THE COMPANY

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Already in 1973 the company Rupp + Hubrach in Bamberg, Germany has built safety goggles against laser radiation. In 1987, Laservision was founded as a joint venture between Rupp + Hubrach and uvex-Arbeitsschutz GmbH and became one of the leading manufacturers in laser eye protection in no time. Since 2004 Laservision GmbH & Co. KG is 100% part of Uvex Safety Group.

Today Laservision is well positioned worldwide and with more than 30 employees characterized by a high level of innovation and the usage of different innovative technologies. Beside laser safety goggles laser protection windows, curtains and movable walls are offered as well.

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Laservision is aware of its responsibility for protection against increasing laser power and the expanding field of applications for USP lasers. Therefore we have also tested new and already existing absorbing glass filters and has gained M protection level certificates. With the new T39, which is equivalent to the P1006, an absorbing glass filter system was developed which reaches a M:L8 at the same wavelength range and even a M:L9 for 1064 nm. So it protects against the basic wavelength, as well as against the frequency doubled and tripled Nd:YAG wavelength. Included is also the range of a Titan-Sapphire-laser ranging 750–1100 nm.

Table 1 provides a complete overview of all filter materials with M protection level certification. Of course the ALL STAR and PROTECTOR frames also provide appropriate M-protection levels. Thus tailored M-laser protection according to each demand can be realized individually.

Yet Another Remark

In conclusion, it is important to remark to all laser safety officers that they use not only the relatively low average power of USP-lasers for calculating the required laser protection, but to take into consideration for a correct calculation the beam diameter, wavelength and also pulse energy, pulse length and pulse repetition rate. Only laser safety goggles with the appropriate L protection level and the correct operating mode (M for USP-lasers) provide reliable and safe protection for the users' eyesight.