Biuletyn WAT
Vol. LIX, Nr 3, 2010

Modern battlefield and new materials for eyes protection

MARCIN KLOSKE, STANISŁAW J. KŁOSOWICZ

Military University of Technology, Institute of Applied Physics,
00-908 Warsaw, 2 Kaliskiego Str.

Abstract. The paper presents an overview of the main threats for soldiers' sight in the modern battlefield. Such a problem is crucial for the proper action of pilots, drivers, and weapon operators. Even temporary lack of sight can be very dangerous in action. Amongst different possible threats two are of a special importance: lasers and nuclear blasts, however, special kinds of conventional blasts can be also dangerous. Possible means of eye protection are discussed with the special attention paid to prospective materials. The intelligent light valves based on liquid crystals are concerned as the best solution for contemporary air and land platforms as well as individual soldiers.

Keywords: sight protection, lasers, modern battlefield
Universal Decimal Classification: 681.73

1. Introduction

One of the most amazing features of human vision is its incredible intensity range. We can see in very bright sunlight and also in nearly total darkness. The intensity and wavelenght ranges that our eyes can detect come from three different parts of the eye [1, 2]:

1. The pupil, which contracts and expands depending on the amount of incident light and can physically block the amount of light entering the eye in bright situations, i.e. for too high light intensity.
2. The rod and cone cells in the retina — our eyes sense light with two different cell types: the rods and the cones; the cone cells can perceive color in bright light. The rod cells perceive black and white images and work best in low light.

3. The rhodopsin — the compound present in the rods being a key to night vision.

When a person is exposed to bright light, the rhodopsin breaks down into retinal and opsin. If then the person turns out to the dark, he/she cannot see. The cones need a lot of light so, they are useless and due lack of rhodopsin the rods are useless, too. During several minutes, however, the retinal and the opsin recombine back into the rhodopsin and the person can see well again.

The color-responsive compounds in the cones, called cone pigments, are very similar to those in the rods. The retinal portion of the compound is the same, however, the scotopsin is replaced with photopsins giving respective color-sensitive pigments:

a) red-sensitive pigment with the peak absorbance at 570 nm,
b) green-sensitive pigment with the peak absorbance at 535 nm,
c) blue-sensitive pigment with the peak absorbance at 445 nm.

The human eye can sense almost any color tint when red, green, and blue colors are mixed (up to several thousand of tints).

For people (especially soldiers), vision is the most important sense and in the modern battlefield, the threat from the unconventional means of war still increases (see Table 1).

Table 1

Hazards Caused by Various Light Wavelengths

Wavelength range	Effects on humans	
	Effect on eye	Effect on skin
Ultraviolet C 200-280 nm	Photokeratitis	Erthema (sunburn) Skin cancer Accelerated skin aging
Ultraviolet B 280-315 nm	Photokeratitis	Increased pigmentation
Ultraviolet A 315-400 nm	Photochemical cataract	Pigment darkening Skin burn
Visible 400-700 nm	Photochemical Thermal retinal injury	Pigment darkening Skin burn
Near-infrared 700-1400 nm	Cataract and retinal burn	Skin burn
Mid-infrared 1400-3000 nm	Corneal burn Aqueous flare, cataract	Skin burn
Far-infrared 3000-100 000 nm	Corneal burn	Skin burn

From: Ken Barat, Laser Safety Management, CRC Press Taylor & Francis Group, 2006.

The authors would like to present important threat for soldiers coming from the light emitted during nuclear weapon blast, blast of special conventional charges and especially non-lethal directed weapons (lasers) blinding soldiers during the battle. We also would like to discuss new materials designed for eye protection.

2. Sources of threat

2.1. Nuclear weapon effects

Depending on the design of the nuclear weapon and the environment in which it is detonated, the energy distribution can be significantly different. The blast effect is created by the coupling of immense amount of energy and spanning the electromagnetic waves into surroundings. The location (submarine, surface, airburst or exo-atmospheric) determines how the detonation energy is divided between the blast and the radiation. In general, denser medium around the detonation absorbs more energy and creates more powerful shockwaves limiting the area of its effect.

In the first one or two seconds after the nuclear weapon detonation, the released energy forms a huge fireball — a hot and highly luminous spherical mass of air and vaporized materials. The heat radiated from the fireball will ignite combustibles generating widespread fires or firestorms.

The fireball is also a source of extremely bright visible light which can be many times more brilliant than the sun, even at a great distance from ground zero. Observers who are not protected can be blinded, usually temporarily but also permanently if burned. Heat and light effects will be the greatest from an air burst attack [3]. The energy released by a nuclear weapon detonated in the troposphere could be divided into four main categories [4]:

a) shockwaves — 40÷50% of the total energy,
b) thermal radiation — 30÷50% of the total energy,
c) ionizing radiation — 5% of the total energy,
d) residual radiation — 5÷10% of the total energy.

The dominant effects of the nuclear weapon are the same as for conventional explosives, but the energy produced is millions of times higher and the temperatures reach tens of millions of Celsius degree. The most of electromagnetic radiation in the visible, infrared (IR), and ultraviolet (UV) spectrum regions is emitted from the fireball surface within the first minute after detonation [5, 6]. There are also special conventional charges emitting extraordinary ammount of light, due to a content of flash powders, used preferably in antiterrorist actions.

2.2. Laser — non lethal weapon

It is well-known that lasers emit monochromatic, coherent and very directional light [7-22], not only visible but also IR [10-12] or UV [13-15] (see Fig. 1).

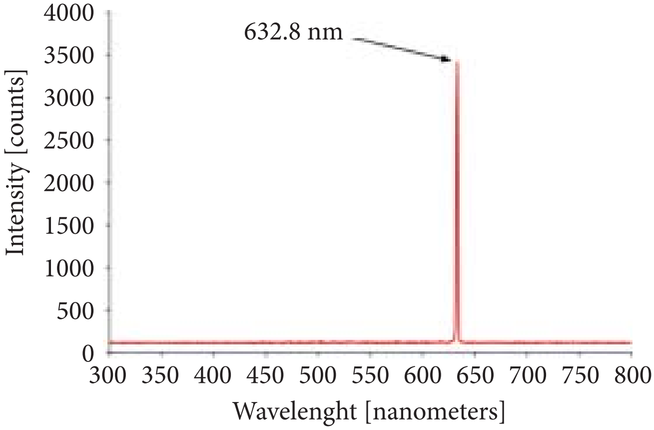

Fig. 1. Helium neon laser taken using an Ocean Optics HR2000 spectrometer by bouncing the laser off of a white benchtop and guiding the diffuse reflected light directly into the spectrometer. The emission spectrum of the HeNe laser is even more monochromatic than seen here (it is typically around a mere 2 picometers in bandwidth) and the broadening of the peak in this spectrum is actually a result of the imperfect optics and scattering of light inside the spectrometer which results in some light being detected on the parts of the (linear CCD) sensor which surround the central peak. A very high resolution spectrum of a en:Brillouin scattered HeNe laser

Lasers are used for many applications [16-19] including military ones: range-finding, target designation or illumination and can be used as directed-energy weapons. There also are many civilian laser applications including powerful ones [20-22].

So, many different uses need lasers with different output power. Lasers producing a continuous or pulse beam can be compared on the basis of their average power. Pulse lasers can also be characterized by the peak power of each pulse which is many orders of magnitude greater than its average power.

The directional energy emission can cause important eye injuries despite relatively small laser power; minor corneal burns cause a gritty feeling, like sand in the eye [13].

Permanent or temporary eye injury may cause lack of vision which is especially important for pilots, drivers, and weapon operators in the battlefield.

There are some subjects, which aviation safety experts agree pose no real hazard, including passenger (soldier) exposure to laser light, pilot distraction during cruising or other non-critical phases of flight and laser damage to the aircraft. But the main danger focuses on laser bright light effects on pilots, especially when they are in a critical phase of flight: takeoff, approach, landing, fight, and emergency maneuvers. There are four primary areas of concern called "visual effects" that temporarily distract or block pilots' vision:

1. Distraction and startle. An unexpected laser light could distract the pilot during night landing, takeoff or maneuvers. Pilots are distracted and worried that a brighter light or other threat would be coming.
2. Glare and disruption. As the light brightness increases, it starts to interfere with vision. Veiling glare would make it difficult to see out the windscreen. Night vision starts to deteriorate.
3. Temporary flash blindness. This works exactly like a bright camera flash: there is no injury, but night vision is temporarily knocked out. There may be afterimages — again, exactly like a bright camera flash leaving temporary spots.

These three visual effects are of primary concern for aviation experts. This is because they could happen with low-power lasers that are commonly available. The fourth concern, eye damage, is much less likely. It needs specialized equipment not readily available to the general public including terrorists (till now).

High power visible or invisible (IR or UV) laser light could cause permanent eye injury. The injury could be relatively minor, such as spots detectable only by medical examination or on the periphery of vision.

At higher power levels, the spots may be in the central vision area — the same one where the original light was viewed. The most unlike is an injury causing a complete and permanent loss of vision. It requires very specialized equipment. The terrorist could find far less expensive and much easier ways to attain his goals.

2.3. Night vision problem for human beings

Night-vision devices (NVDs) was invented during WW II, e.g. IR sniperscopes using near-IR cathodes coupled with suitable phosphors, but they had several disadvantages as very large active IR searchlight, which could be detected by an enemy, the cumbersome batteries and limited range of observation. However, military leaders immediately saw many uses for this technology at the enemy under cover of darkness. An army equipped with night vision goggles, helmets and weapon's sights is able to operate 24 hours a day [23, 24].

Nowadays, NVDs are used by ground troops and major weapon systems: tanks, infantry fighting vehicles, helicopters, aircrafts and missile systems. Targeting systems are particularly important for the major weapon systems due to their ability to "see" through dense smoke, dust, fog, and haze at great distances. The Iraq operations showed the necessity of NVDs improvement.

NVDs rely on an image-intensifier tube to collect and amplify IR and visible light (see Fig. 2):

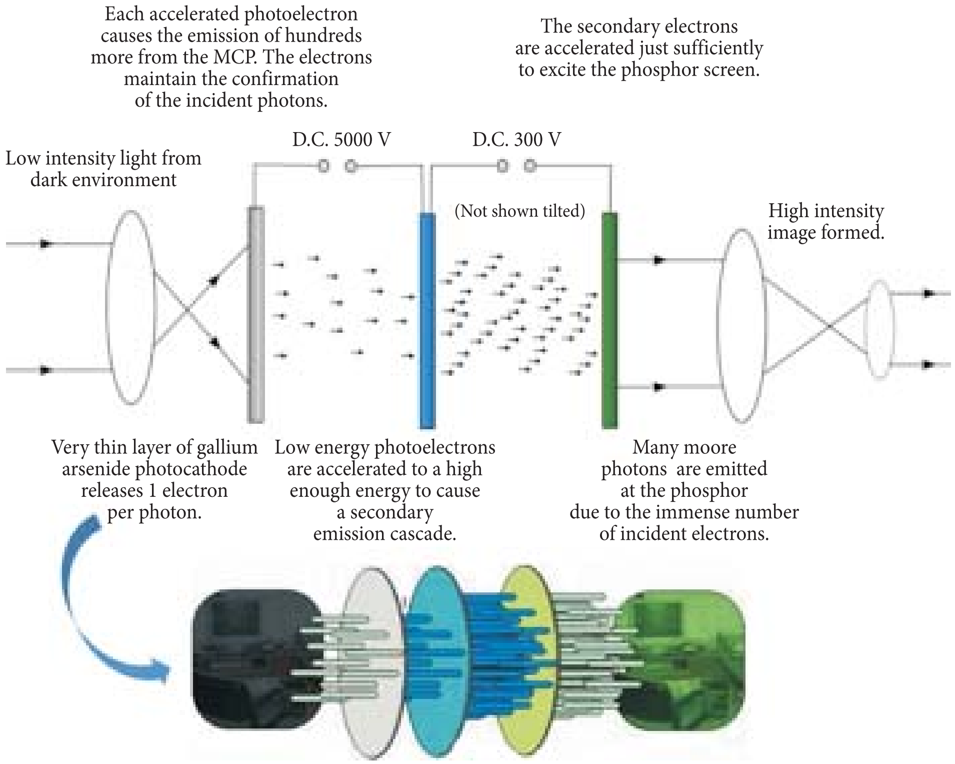

Fig. 2. The scheme of night vision device (NVD)

1. A conventional objective lens, capturing ambient visible and some near-IR light.
2. The gathered light is sent to the image-intensifier tube. In most NVDs, the power supplies are two N-Cell or two „AA" batteries with the output voltage, about 5.000 volts.
3. The photocathode of image-intensifier tube converts energy of light photons into electrons.
4. Those electrons, passing through the tube, create secondary electrons (chain reaction), i.e., act as multiplier. Each channel is about 45 times longer than it is wide, and it works as an electron multiplier.
5. At the end of the image-intensifier tube, the electrons hit a screen coated with phosphors. The energy of the electrons excites phosphors and subsequently, released photons create green image on the screen.
6. The image is viewed through ocular lens to magnify and focus the image. The NVD's may be also connected to an electronic display.

The crucially dangerous threat for soldiers using such equipment is high light intensity inciding the oculars. So, one has to cut off the bright light to secure the safe level for eye.

3. Real protection need

The exposure to the visible laser beam can be detected by a bright color flash and an after-image has got complementary color (e.g., green 532-nm laser light would produce a green flash followed by a red afterimage). When the retina is affected, there may be difficult to detect blue or green colors. The exposure to the IR laser beams as Q-switched Nd:YAG laser (1064 nm) is especially hazardous and may be initially undetected because the beam is invisible and the retina has no pain sensory nerves. Photoacoustic retinal damage may be associated with an audible pop at the time of exposure. Visual disorientation caused by retinal damage may not be apparent until considerable thermal damage has occurred. Table 1 summarizes hazards caused by various light wavelengths [13].

Laser devices can be considered as a point source of great brightness. This is of considerable consequence from the hazard point of view, since the eye will focus the waves (400-1400 nm) from a point source to a small spot on the retina while the rays from an extended source will be imaged over the much larger area. When somebody is relatively far away from a diffuse reflection (the eye can no longer resolve the image), the diffuse reflection can be treated as the "point source". Diffuse reflections are only of importance with the use of extremely high-power sources.

Different geometries of an ocular exposure are demonstrated in Fig. 3. Intrabeam viewing of the direct laser beam (Fig. 3a) is the most hazardous. Intrabeam viewing of the beam reflected from a flat surface is illustrated in Fig. 3b. It is the most hazardous when the reflecting surface is flat or concave (Fig. 3c). Finally, Fig. 3d illustrates extended source of the diffuse reflection which is usually not hazardous except of very high power lasers.

The threat from laser beams presents potentially dangerous implications and hazards for the human eye, moreover the optical sensors.

Many devices have been suggested and used to protect sight against lasers. Physical barriers such as protective nontransparent curtains, absorption or reflective shields and filters have been implemented.

Eyewear such as protective spectacles, goggles, lenses, and binoculars have incorporated similar laser protective measures. However, none of these devices or methods is suitable for pilots and/or weapon operators. These methods can be cumbersome, intrusive, or prohibit acceptable vision for flight control and navigation as well as weapon use. Many of these methods and devices have very low transmittance even in off-state, inhibit or reduce the ability of the soldier to

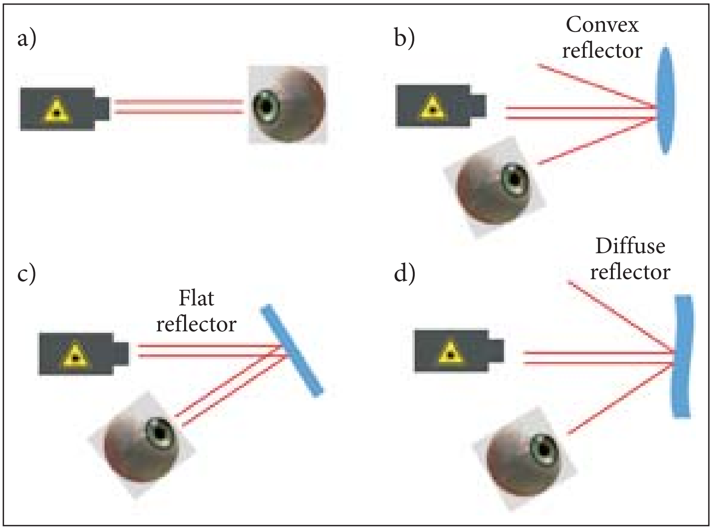

Fig. 3. Different geometries of an eye exposure for the laser beam

perform other visual tasks, or increase the overall workload. Therefore a need exists to improve solutions to protect soldiers against sight threats.

The idea is to employ optoelectronic systems for sight protection comprising a shutter assembly and an electronic control circuit, automatically adjustable between a clear and a dark state. The control circuit should store memory presets including at least one setting, corresponding to the operation of the shutter assembly.

The next idea is the light protection system including protective films. At first, single-use courtains activated by an explosive after a detection of high intensity light have been invented. Such system, however, can be adopted only in tanks or armoured carriers and needs long time to remove, i.e., to return fight ability of a crew.

The laser protective film may be a dyed absorbing film or a thin-film interference coating. Both films require transparent substrates for stress durability. The combination of the dyed substrate and coating may permit the film to be transparent within a portion of the visible spectrum and impermeable for laser radiation of given wavelengths.

The dyed substrate may be a plastic such as acrylic, polycarbonate, etc, while thin-film coating is obtained from dielectric layers. The cross member provides a structure on which the film may be mounted and by which the film may be latched or attached in an extended position to cover a window.

The eye protection is often considered uncomfortable because of the vision reduction and physical discomfort. Especially, for goggles protecting against visible-light wavelengths, color vision is impaired. Moreover, many types of goggles transmit less than 30 percent of visible light, which means that standard work environment lighting levels may be inadequate, leading to increased risks for accidents. Finally, the weight, fit, and ventilation may cause physical discomfort.

The light exposure may create dangerous conditions such as flash blindness, in addition some 18 to 35% of the population possess the autosomal dominant genetic trait, *Photic Sneeze*, that causes the individual to experience an involuntary sneezing fit when exposed to a sudden flash of light. In a critical moment of the battle, the soldier, his unit or subunit may be endangered. Eyewear of course must be selected for the appropriate wavelength, to block or attenuate it — the eyewear absorbing 532 nm typically has an orange appearance, transmitting wavelengths larger than 550 nm. It would be useless to protect against IR wavelengths. The eyewear is rated for *Optical Density* (*OD*), which is the base-10 logarithm of the attenuation factor by which the optical filter reduces light in the specified wavelength range power. For example, eyewear with OD 3 reduces the beam power by a factor of 1000. In addition to the optical density, sufficient to reduce beam power below the maximum permissible exposure, the laser eyewear can be used to withstand a direct hit from the laser beam without breaking. There is some important backdraw in the use of optic filter — a change in their properties under the influence of one or more environmental factors such as heat, light or chemicals. On the other hand, such degradation can be useful for recycling/reusing its waste to prevent or reduce environmental pollution.

In the mentioned situations, the eye safety is the avoidance of accidents, especially those, involving eye exposure to the direct light. A person exposed to the laser radiation (especially invisible one) may be unaware that damage is occurring. Some lasers are so powerful that even the diffuse reflection from a surface can be hazardous to the eye. Laser radiation predominantly causes eye injury via thermal effects on the retina. A transient temperature increase by ca. 10°C can destroy retinal photoreceptor. If the laser is sufficiently powerful, permanent damage can occur within a fraction of a second, faster than the blink of an eye.

Sufficiently powerful visible/near IR laser radiation (400-1400 nm) will penetrate the eyeball and may cause heating of the retina, whereas the exposure to laser radiation with wavelengths less than 400 nm and greater than 1400 nm are largely absorbed by the cornea and lens, leading to the development of cataracts or burn injuries. IR lasers are particularly hazardous, since the body's protective *blink reflex* response is triggered only by visible light. A pop or click noise emanating from the eyeball may be the only indication that retinal damage occurred, i.e., the retina was heated to over 100°C resulting in localized explosive boiling accompanied by the immediate creation of a permanent blind spot.

In the civilian lasers' usage, there are many measures to avoid accidents. Lasers have been classified by wavelength and maximum output power into four main classes. The classifications categorize lasers according to their ability to produce damage in exposed people, from class 1 (no hazard during normal use) to class 4 (severe hazard for eyes and skin). This classification system is a part of the revised IEC 60825 standard. From 2007, the revised system is also incorporated into the US ANSI Laser Safety Standard (ANSI Z136.1). The system uses Arabic numerals (1-4) in all jurisdictions. The laser classification is based on the concept of defined accessible emission limits (AEL). This is usually a maximum power (W) or energy (J) that can be emitted in a specified wavelength range and exposure time. For IR wavelengths above 4 μm, it is specified as a maximum power density (W/m^2).

In the European Community, eye protection requirements are specified in European norm EN 207, requirements for protective goggles are specified in EN 208. These transmit a portion of the laser light, permitting the operator to see where the beam is and do not provide complete protection against a direct laser beam hit. Finally, European norm EN 60825 specifies optical densities in extreme situations. In the European Community, manufacturers are required by European norm EN 207 to specify the maximum power rating rather than the optical density.

The most important parameter for laser characterization is the *maximum permissible exposure* (MPE) — the highest power or energy density (in W/cm^2 or J/cm^2) of a light source that is considered safe, i.e., has a negligible probability for creating eye damage. It is usually about 10% of the dose that has a 50%-chance of creating damage under worst-case conditions. The MPE increases with the beam collimation. The dependence of MPE on different parameters is given in Figs. 4, 5, and 6.

The MPE is measured at the cornea of the human eye or at the skin, for a given wavelength and exposure time. MPE calculation for ocular exposure takes into

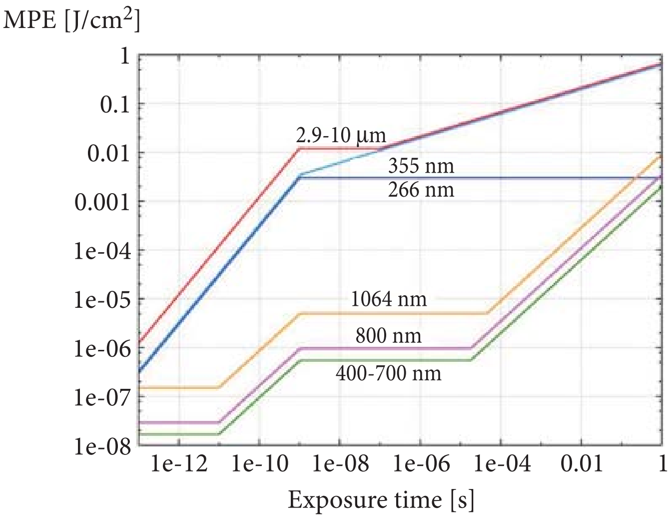

Fig. 4. Maximum permissible exposure (MPE) at the cornea for a collimated laser beam according to IEC 60825, as energy density versus exposure time for various wavelengths

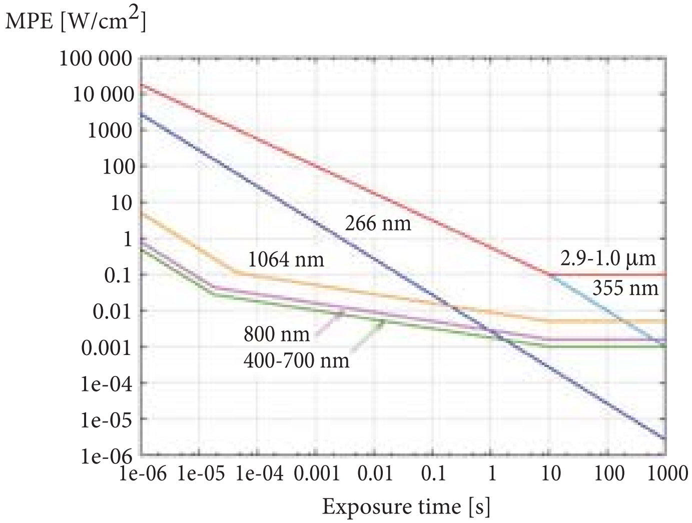

Fig. 5. MPE as power density versus exposure time for various wavelengths

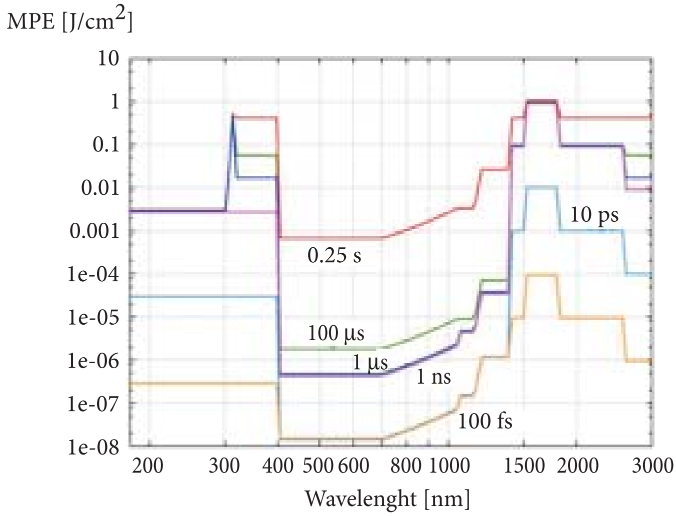

Fig. 6. MPE as energy density versus wavelength for various exposure times (pulse durations)

account the way in which light can act upon the eye. For example, deep-UV light causes accumulating damage, even at very low powers. IR light of a wavelength longer than ca. 1400 nm is absorbed by the transparent parts of the eye before it reaches the retina, which means that the MPE for these wavelengths is higher than for visible light. The MPE takes also into account the spatial distribution of the light.

Collimated laser beams of visible and near-IR light are dangerous even at relatively low powers because the lens focuses the light onto a tiny spot on the retina. In the MPE calculation, the worst-case scenario is assumed, in which the eye lens focuses the light into the smallest possible spot size on the retina for the particular wavelength and the pupil is fully open. The MPE is based on the power or energy that can pass through a fully open pupil (0.39 cm^2) for visible and near-IR wavelengths. This is relevant for laser beams that have a cross-section smaller than 0.39 cm^2. The IEC-60825-1 and ANSI Z136.1 standards include methods of calculating MPEs [25-28].

4. Protection means

Being able to prepare, maneuver and attack before the enemy can detect the threat and respond is a decisive advantage in the modern battlefield. Modern technology can expand the element of a surprise increasing a tactical advantage, especially when the enemy is not so equipped. Therefore even short period of visibility loose is highly dangerous for the Armed Forces personnel, especially for the pilots and weapon system operators.

Protective eyewear in the form of goggles with appropriately filtering optics can protect the eyes from the direct, reflected or scattered light (laser beam, nuclear blast, special conventional blast or other dangerous light, e.g. sun) of a hazardous power. An optical filter usually uses a material of wavelength-dependent transmission or reflectivity, although there are also filters using light polarization or spatial distribution. Nowadays, there are many different types of optical filters, based on different physical principles. Some examples of optical filters are:

- absorbing (dye) glass or polymer filters based on wavelength-dependent absorption; as the absorbed light is converted into heat, such filters are usually not suitable for high-power optical radiation,
- various kinds of optical filters based on interference effects combined with wavelength-dependent phase shifts during propagation; such filters exhibit wavelength-dependent reflection and transmission, and the light which is filtered out can be sent to some beam dump, which tolerates high optical powers; an important class of interference-based filters contains well-known dielectric coatings including dichroic ones,
- Fabry-Pérot interferometers and arrayed waveguide gratings are also based on interference effects, but typically exploiting larger differences of the path length; therefore, they can have sharper spectral features,
- Lyot filters involve wavelength-dependent polarization changes,
- other filters are based on wavelength-dependent refraction in prisms.

Concerning the shape of the transmission curve, there are:

a) bandpass filters, transmitting only a certain wavelength range;
b) notch filters, eliminating light of a certain wavelength range;

c) edge filters, transmitting only wavelengths above or below a certain value (high-pass and low-pass filters).

It was mentioned above that dielectric interference coatings consist of a stack of thin sub-micron layers, sometimes even more than 100 [29, 30] of transparent dielectric materials deposited on a substrate. They modify the reflective properties of the surface by the interference of reflections from multiple optical interfaces. They are widely used in optical systems so, their technology is well developed.

Dielectric coatings should be deposited onto glass or crystalline substrates securing mechanical durabilty of the device. A further area of increasing importance is the fabrication of dielectric coatings on polymers cheaper and easier to prepare. Such substrates can be used to fabricate elastic optical elements or elements with complex geometrical shape [31]. The fabrication of dielectric mirrors is usually based on: electron beam deposition, ion-assisted deposition or ion beam sputtering.

Important aspects for the selection of a fabrication technique are as follows [32, 33]:

1. The suitability for given coating materials.
2. The precision of the layer thickness values (which may be increased with automatic control involving in-situ growth monitoring).
3. The optical quality of the deposited layers.
4. The ability of the coatings to withstand high optical intensities.
5. The uniformity of layer thickness values over a larger area.
6. The reproducibility and stability of refractive indices.
7. The required substrate temperature.
8. The time required for the growth.

The simplest solution is to employ goggles, especially interference ones, but they work properly only for 90 degrees light incidence angle [34-36]. To achieve wanted degree of protection, one should adopt convex glasses of complex geometry.

The filters use the interference effect to transmit or reflect desired wavelength ranges and have extremely good contrast in comparison with absorptive colored glass filters with very narrow or sharply defined transmission bands, moreover quite small durability and short period of storage.

Although the most of interference filters have transmission side bands on both sides of the center wavelength, these bands can be blocked by combination with a multi-layer blocking or glass filter. For these filters, especially important is an effect of the incidence angle. When the filter is tilted, with respect to the incident light, its transmission band shifts towards the shorter wavelength. At angles of incidence up to about 20°, the shape of the spectral characteristic remains approximately the same, but at larger angles, the transmission band splits into two separate peaks, because the p-component (parallel to the plane of incidence) and the s-component are shifted by different degree. Since the the transmittance of p-component is virtually independent on the inclination, a single interference filter equipped with polarizer can be tilted at various angles to obtain a variety of wavelengths of monochromatic light. In normal usage, the incidence angles greater than 20° are not recommended.

Laser protective eyewear comes in two types: the full attenuation and the alignment ones. The full attenuation means the eyewear will completely block the transmission of a direct exposure laser beam. Alignment or partial attenuation allows an individual, while wearing laser eyewear, to have some visibility, which means that certain part of the beam's energy should pass through the laser protective eyewear. To talk about laser protective eyewear, one really needs to understand two terms: optical density (OD — a filtration factor) is a parameter specifying the attenuation afforded by a transmitting medium. The OD is described in logarithm units; so, goggles with a transmission of 0.000001% can be described as having an OD of 8.0 [37, 38]

$$OD = \log_{10}\left({}^{M_i}\!\!\diagup\!_{M_t} \right), \tag{1}$$

where M_i and M_t are the power of the incident transmitted beam, respectively for MPE. The higher the exposure over the MPE is, the greater the damage will be until a threshold is reached, where the damage itself moderates the energy and damage.

The simplest solution is to use special goggles similar to sunglasses that darken when exposed to the intensive light, e.g., via specific chemical reaction. The molecules of a photochromic compound do not absorb light for the normal intensity. But when exposed to high light intensity, as in direct sunlight, they undergo a photoisomerization. The new molecular structure absorbs portions of the visible light darkening the lenses. The absence of the light causes the molecules to return to their original shape resulting in the loss of their light absorbtion. The process is very rapid but gives poor protection.

5. Solution baptism fire — Liquid Crystals

Another way to protect soldiers' sight is to use an auto-darkening goggles or special kind of helmet containing an electronic shutter module.

Since the late seventies, the application of liquid crystals (LC) spread to a wide range of products, such as measuring instruments, domestic, office and audio equipment, game machines and vehicle instruments. From the early 80s, the technology of active matrix displays with thin-film transistors has been developed [39]. LC has unique electro-optical properties. When subjected to small electric fields, reorientation and alignment of the LC molecules take place, which produce striking optical effects because light propagates in different conditions.

LC light shutter is normally transparent and darkens when a voltage reorienting LC molecules is applied [40-42]. The shutter module contains a photosensor and the electronic control module. This module detects the bright light and closes the LC shutter as fast as at least in 1 ms. When ambient light returns to the normal level, the system returns to the initial state by several dozens of milliseconds. The schematic view of the LC light shutter is given in Fig. 7. Modern auto-darkening eye protection has adjustments for sensitivity, shade and time delay after light removal.

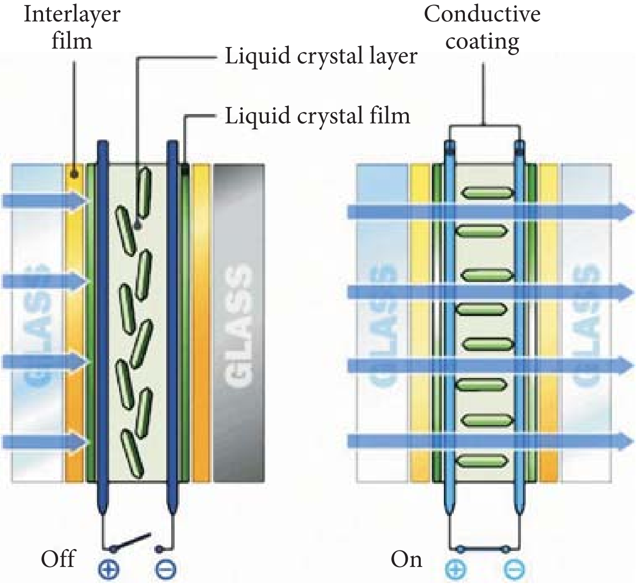

Fig. 7. Idea of protective Liquid Crystal layer in the modern goggles

Over one hundred thousand LC materials (individuals or mixtures [43]) are known. Depending on the temperature and substance nature, LC can exist at least in one of several distinct phases. Nematic LCs are commonly used [44] to perform several electrooptic effects as twisted nematic, supertwisted nematic or electrically driven birefringence. By applying an electric field (voltage) to the cell containing LC, one can control LC orientation and so light transmission [34-40, 45-46] what is widely used in information displays and beam processing devices [47, 48].

At the end of the twentieth century, the ferroelectric liquid crystals (FLCs) and antiferroelectric LC (AFLC's) having a chiral smectic C phase were discovered. Their alignment show periodic layered structures contrary to nematics having only directional order. FLCs and AFLCs exhibit fast switching (less than 10 μs) and wide viewing angle. Moreover, AFLC materials show a symmetrical response to positive and negative electric signals and no hysteresis as well as no stress vulanereability.

However, smectic liquid crystals show a large variety of defects due to their highly ordered structures. Moreover, FLC structures are often irreversibly destroyed by applyied stress. Those phenomena give a major problem for military applications.

We do not present here the details of LC technology and physics because they are extensively described in literature [49-51] nevertheless in general nematic and smectic liquid crystals can be used in eyesight protection via different electrooptical effects exploiting a switch between transparent and dark states. It should be underlined that for the effective protection against light of high intensity two LC cells in tandem are often required. It means that in so-called transparent state, only about of 15-20 per cent of ambient light can reach the observer's eye. In other words, the optical observation system is very dark.

Another solution using LC materials is electrically induced light transmission observed in polymer-dispersed LC composites (PDLC) composites [52]. Those materials contain LC droplets embedded into the polymer binder [53]. The system is scattering or transmitting without applied voltage and becomes transparent or scattering after voltage application, respectively [53-55]. In our case, the second mode (transparent → scattering) can be adopted. After detection of light danger, the electronic system automatically closes the PDLC light valve and scatters backward ambient light. Single cell is much more transparent than other LC light valves and even in tandem enables good view for the observer.

It is also possible to adopt electrically driven light deflectors using cholesteric liquid crystals pushing out the dangerous light from the optical path of the observing/ /aiming system due to selective reflection effect [56], however, those devices should be designed for light given wavelengths (at least one).

The materials mentioned above are probably the best choice for designers who will try to build up new kind of eye protection goggles.

In our opinion, the systems of effective sight protection should comprise the following elements:

1. Passive broad-band dielectric filter for the sight protection during first millisecond.
2. Active electrooptical system switched on just after the dangerous light detection. We suggest that PDLC light valve should be adopted because this device enables good visibility in off-state.
3. In case of larger viewing and aiming systems, also nematic or smectic LC based electrooptical effects can be used, but those devices has got rather poor visibility in off-state.

6. Summary and conclusions

Laser safety goggles or similar elements of optical systems are frequently used for eye protection against light of high intensity. However, their role in this context is often poorly reflected. Maintaining the human beings visual abilities in some environment is a goal which is so important that a high level of reliability is essential. That is achieved only by employing multiple means of protection, providing some level of redundancy which guarantees safety even if one layer fails for some reason — this is the most basic reason why safety goggles can only represent one of several required safety measures.

The limited reliability of safety goggles alone is quite obvious. A strong laser beam, or detonation blast can easily destroy safety glasses. The same holds for intense pulses from a Q-switched lasers; a single shot may make a protection glass crack, and at least the next shot then hits the eye without protection. Furthermore, a laser beam may come from the rear and be partially reflected at the safety glasses, so that some light gets into the eye. There may also be a laser beam at a wavelength against which the glasses provide no protection; where the involved wavelengths are changing quite often.

Of course, the chances that sight safety devices are used can be improved. The probably best way to achieve this is to provide really suitable goggles. This requires several compromises which need to be adapted to the concrete circumstances. For example, the technically safest glasses tend to be heavy and uncomfortable, while very lightweight ones may not provide sufficient safety.

Perfect safety, especially for the military personnel on the modern battlefield is impossible to obtain, but at least we can find a reasonable safety level by employing a well thought — through system of safety measures and by occasionally reflecting the essential aspects. The general conclusions are as follows:

1. Effective sight protection device should, at first, enable good visibility when the danger is absent.
2. On the other hand, in case of illumination, it should pass only small light intensity tolerated by human eye.
3. The reaction should be automatic (originated from the physical effect or electronic sensing system) and so fast that human sight will be properly protected.
4. The device should have low angular sensitivity, long period of storage, low weight, high resistance against high intensity of light, including IR and UV, high durability against environmetal and using factors, and a possibility of multiple action.
5. Liquid crystal devices of different kind, especially intelligent ones, seem to be a good solution because of
   - very good effectiveness,

- relatively good visibility in off-state,
- tolerable angular dependence of protection,
- long period of storage,
- low sensitivity for light damage due to small thickness and weight (low energy absorption),
- relatively small mass and dimensions.

The authors appreciate the financial support of the Polish Ministry of Sciences and Higher Education, Key Project POIG.01.03.01-14-016/08 "New Photonic Materials and their Advanced Applications".

Received November 2 2009, revised January 2010.

REFERENCES

[1] B. Wördenweber, J. Wallaschek, P. Boyce, D. D. Hoffman, *Automotive Lighting and Human Vision*, Springer, 2007.

[2] A. Csillag, *Atlas of the Sensory Organs: Functional and Clinical Anatomy*, Humana Press, 2005.

[3] *NATO Handbook on the Medical Aspects of NBC Defensive Operations* (Part I. *Nuclear*), Departments of the Army, Navy, and Air Force: Washington, D.C., 1996.

[4] S. Glasstone, P. J. Dolan, *The Effects of Nuclear Weapons* (third edition), Washington, D.C.: U.S. Government Printing Office, 1977.

[5] *The Effects of Nuclear War*, The Office of Technology Assessment, Washington, D.C., May 1979.

[6] *Nuclear Attack Planning Base 1990*, Final Project Report, Executive Summary, Federal Emergency Management Agency, Washington, D.C., April 1987.

[7] D. M. Finlayson, B Sinclair (ed.), *Advances in Lasers and Applications*, Scottish Universities Summer School in Physics, J. W. Arrowsmith Ltd, Bristol, 1999.

[8] M. Endo, *Gas Lasers*, CRC Press, Taylor & Francis Group, New York, 2007.

[9] R. S. Quimby, *Photonics and Lasers: An Introduction*, John Wiley & Sons, Inc., New Jersey, 2006.

[10] I. T. Sorokina, K. L. Vodopyanov (ed.), *Solid-State Mid-Infrared Laser Sources*, Springer-Verlag, New York, 2003.

[11] J. Miller, E. Friedman, *Photonics Rules of Thumb: Optics, Electro-Optics, Fiber Optics and Lasers*, 2nd ed., McGraw-Hill Professional, New York, 2004.

[12] J.-Y. Zhang, J. Y. Huang, Y. R. Shen, *Optical Parametric Generation and Amplification*, (in:) *Laser Science and Technology*, vol. 19, Harwood Academic Publishers GmbH, 1995.

[13] J. O. Hirschfelder (ed.), Lasers, Molecules, and Methods, Advances in Chemical Physics, 68, John Wiley & Sons, New York, Chichester, Brisbane, Toronto, Singapore, 1989.

[14] W. W. Duley, *UV Lasers: Effects and Applications in Materials Science*, Cambridge University Press, 2005.

[15] M. S. Shur, A. Zukauskas (ed.), *UV Solid-State Light Emitters and Detectors*, (in:) *NATO Science*, Series II: *Mathematics, Physics and Chemistry*, Kluwer Academic Publishers, Springer, 2004.

[16] O. Svelto, *Principles of Lasers*, Springer Science–Business Media Inc., New York, 1998.

[17] J. F. Ready, *Industrial Applications of Lasers*, 2nd ed., Academic Press Ltd, San Diego, 1978.

[18] M. L. Wolbarsht (ed.), *Laser Applications in Medicine and Biology*, Plenum Publishing Corporation, New York, 1991.

[19] F. Duarte, *Tunable Laser Applications*, 2nd ed., CRC Press, Taylor & Francis Group, New York, 2009.

[20] A. E. Siegman, *Lasers*, University Science Books, Sausalito CA, 1986.

[21] A. Sennaroglu, *Solid-State Lasers and Applications*, CRC Press, Taylor & Francis Group, New York, 2006.

[22] B. E. A. Saleh, M. C. Teich, *Fundamentals of Photonics*, 2nd ed., John Wiley & Sons, New York, 2007.

[23] Maj. J. L. Plaster, USAR (ret.), *Ultimate Sniper 2006: An Advanced Training Manual for Military and Police Snipers*, Paladin Press, 2006.

[24] *101 Spy Gadgets for the Evil Genius*, McGraw — Hill/TAB Electronics, 2006.

[25] *International Electrotechnical Commission (IEC), origin of international laser safety standards: IEC 60825-1* (*Safety of laser products*, Part 1: *Equipment classification, requirements and user's guide*) and IEC-60825-2 (*Safety of laser products*, Part 2: *Safety of optical fibre communication systems (OFCS)*, IEC, Geneva, 2001.

[26] *American National Standards Institute (ANSI)*, http://www.ansi.org/, Origin of the American Z-136 safety standard series, in particular the important Z-136.1.

[27] *Laser Institute of America on laser safety*, http://www.laserinstitute.org/subscriptions/safety_bulletin/laser_safety_info/

[28] *Occupational Safety* & *Health Administration*, U.S. Department of Labor, Technical Manual on Laser Hazards, http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_6.html

[29] J. R. McNeil, A. C. Barron, S. R. Wilson, W. C. Herrmann, Jr., *Ion-assisted deposition of optical thin films: low energy vs. high energy bombardment*, Appl. Optics, 23(4), 552, 1984.

[30] H. Sankur, R. L. Hall, *Thin-film deposition by laser-assisted evaporation*, Appl. Opt., 24(20), 3343, 1985.

[31] P. J. Martin, *Ion-based methods for optical thin film deposition*, J. Mater. Sci., 21(1), 1, 1986.

[32] N. Kaiser (ed.), *Optical Interference Coatings*, Springer, Berlin, 2003.

[33] A. Thelen, *Design of Optical Interference Coatings*, McGraw-Hill, 1989.

[34] M. G. Robinson, J. Chen, G. D. Sharp, *Polarization Engineering for LCD Projection*, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, 2005.

[35] I. R. Kenyon, *The Light Fantastic. A Modern Introduction to Classical and Quantum Optics*, Oxford University Press, 2008.

[36] J. Noda et al., *Polarization-maintaining fibers and their applications*, J. Lightwave Technol., 4(8), 1071, 1986.

[37] P. W. Zitzewitz, *Glencoe physics*, Glencoe/McGraw-Hill, New York, 1999.

[38] M. J. Weber, *Handbook of optical materials*, CRC Press LLC, 2003.

[39] K. Takatoh, M. Hasegawa, M. Koden, N. Itoh, R. Hasegawa, M. Sakamoto, *Alignment Technologies and Applications of Liquid Crystal Devices*, by Taylor & Francis Inc., 2005.

[40] S. Chandrasekhar F.R.S., *Liquid Crystals*, 2nd ed., Cambridge University Press, Cambridge, 1992.

[41] D.-Ke Yang, S.-Tson Wu, *Fundamentals of Liquid Crystal Devices*, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, 2006.

[42] P. J. Collings, M. Hird, *Introduction to Liquid Crystals: Chemistry and Physics*, Taylor and Francis e-Library, Philadelphia, 2009.

[43] J. A. Castellano, *Liquid GOLD. The Story of Liquid Crystal Displays and the Creation of an Industry*, World Scientific Publishing Co. Re. Ltd, 2005.

[44] H. Singh Nalwa (ed.), *Handbook of Advanced Electronic and Photonic Materials and Devices*, Academic Press, 2001.

[45] L. Vicari, *Optical Applications of Liquid Crystals, Institute of Physics Publishing*, DiracHouse, Temple Back, Bristol, 2003.

[46] A. K. Bhowmik, Z. Li, P. J. Bos, *Mobile Displays. Technology and Applications*, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, 2008.

[47] S. Kobayashi, S. Mikoshiba, S. Lim, *LCD Backlights*, John Wiley & Sons, Ltd, 2009.

[48] Jiun-Haw Lee, David N. Liu, Shin-Tson Wu, *Introduction to Flat Panel Displays*, JohnWiley & Sons Ltd, 2008.

[49] Z. Mierczyk, M. Kwaśny, B. Kuzaka, *Safety of Lasers Application*, Polski Merkuriusz Lekarski, 6(3-4), 1999, 211-217 (in Polish).

[50] Z. Mierczyk, M. Kwaśny, J. Mierczyk, J. Kubicki, *Spectral and Resistance Characteristics of Antilaser Protective Filters*, Biul. WAT, 56(1), 2007, 189-205 (in Polish).

[51] P. Konieczny, A. Wolska, J. Świderski, A. Zając, *Simulation of Threats Caused by Reflected and Scattered Laser Radiation and Selected Aspects of Design of Anti-radiation Curtains*, Biul. WAT, 56(1), 2007, 223-244 (in Polish).

[52] E. Büyüktanir, M. Mitrokhin, B. Holter, A. Glushchenko, J. L. West, *Flexible bistable smectic-A polymer dispersed liquid crystal displays*, Jpn. J. App. Physics, 45, 5A, 2006, 4146-4151.

[53] S. J. Woltman, G. P. Crawford, G. D. Jay, *Liquid Crystals*, Frontiers in Biomedical Applications, World Scientific Publishing Co. Pte. Ltd, 2007.

[54] T. Scharf, *Polarized light in liquid crystals and polymers*, John Wiley & Sons, Inc., 2007.

[55] L. Vicari, *Optical Applications of Liquid Crystals*, Institute of Physics Publishing Bristol and Philadelphia, 2003.

[56] X.-Jiu Wang, Q.-Feng Zhou, *Liquid Crystalline Polymers*, World Scientific Publishing Co. Pte. Ltd, 2004.

M. KLOSKE, S. J. KŁOSOWICZ

Współczesne pole walki i nowe materiały do ochrony wzroku

Strzeszczenie. W artykule przedstawiono przegląd głównych zagrożeń dla wzroku żołnierza na współczesnym polu walki. Ten problem ma zasadnicze znaczenie dla właściwego działania pilotów, kierowców–mechaników i operatorów uzbrojenia. Nawet chwilowa utrata wzroku może być niebezpieczna podczas działań bojowych. Spośród różnych możliwych zagrożeń dwa są szczególnie niebezpieczne: lasery i wybuchy jądrowe, a także wybuchy ładunków konwencjonalnych specjalnego rodzaju. Omówiono możliwe środki ochrony wzroku szczególną uwagę poświęcając perspektywicznym materiałom. Za najlepsze rozwiązanie dla współczesnych platform powietrznych i lądowych, jak również pojedynczego żołnierza uznano inteligentne zawory optyczne wykorzystujące ciekłe kryształy.

Słowa kluczowe: ochrona wzroku, lasery, współczesne pole walki

Symbole UKD: 681.73