RESEARCH ARTICLE

Suitability of polycarbonate safety glasses for UV laser eye protection☆

Commonly used impact resistant polycarbonate (PC) safety glasses were evaluated for suitability of use in a high power, ultra-violet (UV) laser lab in place of laser eyewear. Product bulletins for the glasses tested all specified 99.9% or greater UV absorbance for their PC materials. Safety glasses from various manufacturers were exposed to 1,501 pulses of UV light (248 nm) from a 0.6 J krypton fluoride (KrF) excimer laser over a 30 s period. Radiant energy incident on the eye wear was reduced to a nominal 200 mJ through attenuating filters. Surface damage to lens coatings was rapid. Calculations for this laser system indicated that the safety glasses tested had a minimum optical density (OD) of 2.6 (2.58–3.40). At this wavelength the safety glasses would protect from an intra-beam (direct) exposure up to pulse energies of 800 μJ at the lowest OD rating. They would not be protective for an intra-beam exposure to the system as employed for these tests (minimum OD of 5 required).

The damage threshold for surface coating destruction was 100 mJ/cm^2. Damage only occurred at radiant energies above which the lenses could provide sufficient UV attenuation. That is to say ocular damage could result before damage to the coating became evident. As damage was allowed to continue the PC material began to blister, char and distort. At this point the damage resulted in small increases in optical densities. In general, PC safety glasses would not be suitable for high energy laser applications (all Class 4 lasers and many 3B lasers) whenever intra-beam viewing was possible. Safety glasses may be suitable for diffuse viewing (indirect) situations when it can be determined that the OD provided is sufficient to attenuate the scattered energy.

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INTRODUCTION

Excimer lasers were first discovered in 1970. They are used widely today in research and development, as well as medical and industrial applications. Their success comes from the exemplary UV performance and high power levels, not achieved by any other laser sources.[1]

Safety lens materials for laser systems have evolved from optical glass to plastic. The most widely used material in the production of laser safety eyewear is polycarbonate (PC) due to its high impact resistance, UV protection, and low cost.[2] However, there are different types of PC with various features used for a variety of applications. Absorption changes in wavelength depend on polymer type and polymer blending.[3] Commonly used PC safety glasses are clear and provide protection against particles, and other hazards present in the lab environment. These widely used safety glasses may be different than the laser eye wear specified for laser applications where the primary requirements are for optical density and damage thresholds specific to the wavelength and energy of the laser. Early development of PC laser safety glasses included impact and burn through tests with positive results.[4] Today, most PC product manufacturers specify PC attenuation in the UV spectrum as greater than 99.9%; Figure 1 and the Uvex lens technology catalog are two examples.[5] Non-laser eyewear testing has typically involved visible and near IR wavelengths in which PC blocked all UV from reaching the eye.[6] Others have measured UV transmittance through sunglasses, contact lenses, and face shields with findings of similar protection factors for non-point source exposures.[7]

This experiment was derived because of the ubiquitous use of polycarbonate safety glasses in laboratory environments and manufacturer claims of UV attenuation. A variety of commonly used safety glasses were tested in a high power UV excimer laser beam in order to determine their OD and damage threshold. Although the ANSI laser standard specifically calls for the use of "eye protection devices which are specifically designed for radiation protection" (ANSI Z-136.1 – 2014 Sec. 4.4.4.2.1), the information obtained combined with a laser hazard analysis may be used by the laser safety officer (LSO) to either permit or prohibit the use of safety glasses as protective laser eyewear for UV excimer lasers.[6]

METHODS AND MATERIALS

In order to conduct this experiment, an appropriate laser was identified, test apparatus assembled, safety glasses meeting ANSI Z87 requirements procured, and then exposed to the laser beam to measure OD and estimate the damage threshold.

A Lambda Physik LPX KrF excimer laser operated at 20 kV was used to produce the 248 nm ultraviolet light for testing. This is an ANSI Class 4 laser. Laser parameters were input into LAZAN 5 Premium software and average power (9.50 W), output energy (190.00 mJ), total pulses in exposure (1,501) and target radiant exposure (182.07 mJ/cm^2/pulse) were calculated.

The incident radiant energy (Q_i) for OD testing was reduced from approximately 600 mJ to about 190 mJ radiant energy on the lens surface through the use of attenuating filters. Incident radiant energy for damage testing was varied incrementally from 480 mJ to 75 mJ. Both the incident radiant energy and extant radiant energy (Q_e) (back side of the lens surface) was measured with a Maestro power meter and Gentec pyroelectric sensor: QE25LP-S-MB.[9] The Maestro allows USB key access, and applies statistical functions on a LCD touch screen as data are being measured.

A test stand was constructed to provide a fixed position for the laser-to-lens configuration (Figure 2) at about 10 cm from the laser aperture. The lens-to-sensor was positioned as close to the lens as shape of the sensor and lens curvature permitted. Therefore there was slight variation on this distance between the eyewear tested.

ANSI Z87.1 contains tests and requirements for safety spectacles, goggles, and face shields.[10] All of the glasses tested complied with this standard as indicated by the manufacturer. There are additional tests for UV lenses, as well as others such as welding and IR. These tests are not mandatory, but if glasses meet transmittance requirements, they may be marked with a "U" and the scale number. None of the safety glasses tested in this study carried the "U" designation.

Each pair of glasses ($n = 12$) tested for OD was first measured for thickness at the exposure location with a digital read-out micrometer. Next, each lens was then exposed to the laser beam (1 cm^2 in cross sectional area) for three 10 s pulse trains with a 10 s delay between each set. The pulse repetition rate was 50 Hz producing a total exposure of 1,501 pulses. Each pulse was 1 ns in duration. Radiant energy extant from each lens tested with the Maestro power meter (calibrated by manufacturer) and Gentec pyroelectric sensor was downloaded and optical densities were calculated as:

$$\mathrm{OD} = \log_{10}\left(\frac{Q_i}{Q_e}\right) \quad (1)$$

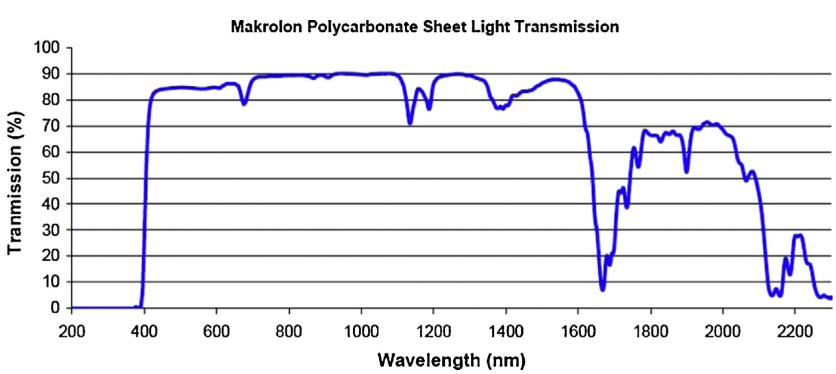

Figure 1. Makrolon polycarbonate light transmission.[8]