Design and development of laser eye protection filter

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Abstract. Laser based devices, have been operational for measurement of distances horizontally and vertically in avionics and surveillance industries. These equipments are functional on pulsed Nd:YAG laser at 1064nm, this wavelength elevate the risk of eye exposure to personnel at unexpected levels. In this paper the eye protection filters, for the wavelength 1064nm were developed with soft (ZnS) and hard (TiO2) coating materials by using thin film vacuum coating technique. The damage threshold of the filter is 0.2 J/cm². Transmission characteristics are measured and discussed. Optical damage threshold (for eye 5 x 10⁻⁶ J/cm²) at various distances is also simulated.

1. Introduction
Laser applications have been drastically thrived in the 21st century from enclosed to al fresco environment like remote sensing, surveillance, aviation and forestry. Laser range finder, laser altitude meter and laser target designator which are operational on pulsed Nd:YAG laser wavelength 1064nm raise the threat of eye exposure to unexpected levels. The need of eye protection devices is obligatory for the personnel working above mentioned fields.

The laser light in the visible and near infrared region 400 to 1400 nm can cause of retinal damage and it is known as “retinal hazard region”. Unfortunately, the wavelength of Nd:YAG Laser:1064nm lies in this region. The pulsed Nd:YAG laser has been considered one of the most harmful laser because its peak power and functioning wavelength is near infra red and invisible (Sliney 1985). Infrared lasers are particularly perilous for human eye, since the body protective blink reflexes is triggered only by visible light that means the eye does not feel pain or noticeable immediate damage during exposing of laser radiation. The coherence & low divergence of laser radiation and focusing mechanism of the eye create condition that laser light can be concentrated into a small spot on the retina and burns the surface. A transient increase of only 10 °C can destroy retinal photoreceptor and if the retina heated up to 100 °C, it creates a permanent blind spot. So that in the light of these facts, eye is extremely sensitive to the Nd:YAG laser radiation and can be permanently or partially injured from direct or reflected beam.

Now days, range finding and altitude measuring laser base devices are frequently employed in the aviation and military industries. These devices deliver the high precision collimated laser beam toward the target (Bryan and Sliney 1998), at a shorter distance from these devices, if eye exposes with laser beam the high optical density (OD) of radiation could damage the eye instantly, as

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these radiation approaches at far distance from the source, the diameter of laser beam increases due to this optical density per unit area decreases, eventually this decreases the eye damage probability too. In the above mentioned situation, the solution for bare eye and eye behind the sighting device, it is necessary that an eye protection filter must be placed in front of eye, to protect the eye by the laser radiation.

In this article, eye protection filters were developed with different materials by using physical vapour deposition method and their behaviour and optical response is discussed.

2. Experimental
By using thin film coating techniques, number of thin film coating schemes were employed with soft and hard coating materials. These coating were designed on software OPTALIX.

In first experiment, thin film coating was developed and the coating materials MgF$_2$ & ZnS were used. The Coating scheme is as follows:

At reference wavelength $\lambda_0$: 1064nm
LHLHLHLHLHLHLH 0.5L

The polished substrate of K9 (Chinese) optical glass (Diameter: 25mm and thickness 25mm) was used and thin film coating was carried out on Coating machine. Coating was performed at substrate temperature at 50°C and pressure of chamber was maintained in the range of 10$^{-6}$ mbar. MgF$_2$ and ZnS were evaporated through thermal evaporation and electron beam evaporation techniques respectively. It is a soft and fragile coating therefore coating was cemented in between of other K9 substrate for the protection of environmental effects. These coated samples have gone through the environmental test figure 1.

![Image of Transmission spectrum response of soft thin film coating (optical glass K9)](image_url)

**Figure 1.** Transmission spectrum response of soft thin film coating (optical glass K9).
In second experiment, thin film coating was designed and developed and the coating materials \( \text{MgF}_2 \) & \( \text{TiO}_2 \) were used. The coating scheme is as follows:

At reference wavelength \( \lambda_0: 1064 \text{nm} \)
\[
0.92LH0.92LH0.92LH0.92LH0.92LH0.92LH0.5L
\]

The polished substrate of K9 optical glass was used and thin film coating carried out on Coating machine. Coating was performed at substrate temperature at 280\(^\circ\)C and chamber pressure was maintained in the range of 5x10\(^{-6}\) mbar. \( \text{MgF}_2 \) and \( \text{TiO}_2 \) were evaporated through thermal evaporation and electron beam evaporation respectively.

\( \text{TiO}_2 \) is a reactive coating material therefore during the coating process a partial pressure of oxygen was maintained from 6.0x10\(^{-5}\) to 8.0x10\(^{-5}\) mbar range inside the chamber (Chen et al. 1997). It is a hard coating and components were processed from environmental test and qualified. The transmission test was carried out for both soft and hard coating samples on Spectrophotometer shown in figures 1 & 2.

![Figure 2](image_url). Transmission spectrum response of hard thin film coating (optical glass K9).

### 3. Results and discussion

The eye protection filters were developed with two types of thin film coating materials soft and hard coating, it is generally known as hot mirror coating.

The colour of coating on polished optical components was greenish blue and spectral response of theoretical simulation and experimental response is shown in figure 1. The theoretical simulation and experimental spectrum is quite similar only in the visible region experimental response is slightly less 5% as compare to theoretical simulation it is due to coating thicknesses and variation in experimental conditions during the coating process. However, in the IR region the theoretical...
simulation and experimental response is slightly less as compared to experimental curve, it is due to substrate thickness and transmission is nearly 4 percent in the NIR region which is acceptable for eye protection filter for Nd:YAG laser system.

The colour of coating on polished optical components was reddish green and spectral response of theoretical simulation and experimental response is shown in figure 2. The theoretical simulation and experimental spectrum was approximately similar. But experimental spectrum shifted towards shorter wavelength side it was due to the effect of temperature and pressure inside the chamber during thin film coating process (Selhofer et al.). The transmission profile is similar in the visible and NIR region. The cut off started from 950nm in calculated curve while in experimental it started from 875nm. Average transmission in calculated and experimental is approximately is 85% in visible region, however in NIR region the transmission is approximately 4% which is similar to transmission observed with the soft coating eye protection filter.

Laser damage threshold of these filters is 0.2 J/cm² and performance and fitting wise hard coated filter is suitable for binocular. These filters transmit the 1064nm radiation approximately 4%, this yield that these filter capable of reducing optical density 1.5x10⁻² J/cm² to safe MPE (Maximum Permissible exposure for Eye) value of 5x10⁻⁶ J/cm² (Yeo 1990). These filters are able to protect the eyes of surveillance personnel, viewing the sight by using binocular 8x30 at a distance mention in following Table 1.

Table 1. Performance of Eye Protection Filter to safe the eye with and without filter.

| Typical Equipment | Laser Equipment | Energy, divergence & pulse width | Safe Viewing distance | Without filter | With filter |
|------------------|----------------|----------------------------------|-----------------------|----------------|------------|
| Laser Range Finder | 10mJ, 10nsec | 1mRad. & 0.3mRad. & | 500m & 07 Km | 25m | 600m |
| Laser Target Designator | 100mJ, 20nsec | | | |

4. Conclusions
In the light of above observation, reflection at 1064nm should increases up to 1% which enhance the eye protection capability. It is suggested that those personnel responsible of surveillance, their sighting equipment must contain laser eye protection filter or even safe side they should wear laser protection goggle for their eyes. Finally it is suggested that the laser safety training programs are needed to be conducted in work places for surveillance personnel to avoid the laser hazard accident.

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