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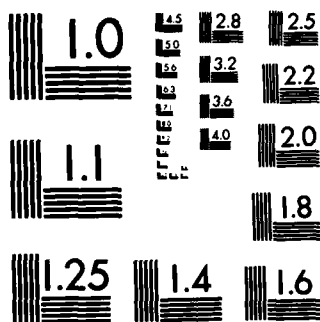
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incidence. Tests of visual function included the Snellen Acuity Chart, Arden Contrast Sensitivity Test, and Farnsworth Munsell 100 Hue Test. Pursuit tracking was evaluated using the BLASER tracking simulator which utilizes a terrain board model with moving targets and a viscous-damped tracking device.

The optical characterization test results showed that at the 530 nm rejection band the holographic filter at the 50% transmission point had a band width of 30 nm and a 3.7 OD was achieved over much of the filter. The visual functions test indicated that the subjects had difficulty in color discrimination involving blue and green. No systematic differences were found on the contrast sensitivity test or Snellen Acuity Test. Error scores on the pursuit tracking task found essentially no difference between baseline and the holographic filter during the bright ambient light tracking trials. However, during the low ambient light tracking trials the standard deviation error tracking rates were above those of the baseline trials. Taken together with the results from a previous study, the results of these tests indicate that the reflecting holographic filter may provide an acceptable means of ocular protection from lasers while minimizing possible adverse effects on task performance.

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**OPTICAL CHARACTERIZATION, VISUAL FUNCTION,
AND PURSUIT TRACKING PERFORMANCE
USING A 532 nm REFLECTING HOLOGRAPHIC FILTER**

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**LETTERMAN ARMY INSTITUTE OF RESEARCH
PRESIDIO OF SAN FRANCISCO, CALIFORNIA 94129**

Optical Characterization, Visual Function, and Pursuit Tracking
Performance using a 532 nm Reflecting Holographic Filter--Stamper et al.

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Human Subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 50-25 on the use of volunteers in research.

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Paul Macmillan 28 Oct 1982
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OPTICAL CHARACTERIZATION, VISUAL FUNCTION, and PURSUIT PERFORMANCE
using a 532 nm REFLECTING HOLOGRAPHIC FILTER -- Stamper et al

It is currently anticipated that lasers will be actively used on the modern battlefield. Present systems include ruby rangefinders for ranging and neodymium designators for guiding projectiles. These military laser systems will significantly increase the probability of ocular injury (1). Additionally, soldiers who use daylight sites in the performance of their duties run even a greater risk of ocular injury because of the focusing and magnifying properties of the optics.

Until recently, when the question of ocular protection from lasers in a military environment was raised, the response of many individuals was that BG-18 would be used. However, when prospective users are asked about placing additional materials such as BG-18 in their visual pathway, a skeptical response is not uncommon. Current and proposed laser protective materials must not significantly degrade visual performance. The ability of BG-18 to meet these requirements has been seriously questioned.

The wavelengths of military interest include 1064 nm (neodymium), 532 nm (frequency doubled neodymium), and 694.3 nm (ruby). Protection across such a wide portion of the spectrum has prompted some developers of protective materials to seek relatively narrow band protection at each wavelength. This point is crucial when dealing with the visible portion of the energy spectrum. Using a band rejection approach requires operators of magnifying optics to insert specific filters selectively for specific wavelengths or the filters must be "stacked" to provide multiple wavelength protection. However, when a series of filters are stacked, the luminous transmittance is reduced. This reduction of light is due not only to a reduction of light at each visible wavelength which is blocked, but also to the inherent surface reflection and absorption of the glass. Therefore, to insure user acceptability such filters must have the highest possible photopic luminous transmittance. A promising new approach in the development of protective material which meets these criteria (i.e., for the filter to pass most of the useful visible light) is the reflecting holographic filter.

The holographic filter is a diffraction grating formed by producing a periodically varying index of refraction in a layer of dichromated gelatin. The reflection characteristics of the grating are controlled by the spacing of the refracting index variation and

the angle between the incident beam and the plane of the index variations. Proper selection of these two factors can produce a grating which will efficiently reflect a narrow band of wavelengths which is incident at normal angle $\pm$ a small angle of deviation to the filter. The efficiency of reflection falls off as the incident beam deviates from normal incidence. The rejection band of a holographic filter can be made very narrow; however, since the range of incidence angles over which the filter is effective is proportional to the incident angle rejection bandwidth, the rejection bandwidth must be broad enough to give adequate angular coverage. An advantage of the holographic filter is the absence of any significant attenuation of bands outside the designed rejection band; this maximizes luminous transmission.

In a combat environment, vision plays a critical role in the performance of a soldier's duties. Visual tasks such as target detection acquisition, recognition, and identification are critical to the soldiers survivability and mission effectiveness. Since the filters for the frequency doubled neodymium laser (532 nm) and the ruby laser (694 nm) are in or near the visible portion of the energy spectrum, the ability to discriminate targets under low ambient light conditions or low contrast levels may be reduced. Information concerning the possible effects of prospective protective materials on these visual tasks is essential to insure that a significant performance decrement does not reduce the soldier's effectiveness while attempting to provide ocular protection. While these filters must ultimately be tested during the performance of military type tasks, preliminary information from visual function type tests may provide insights into possible problem areas.

In our laboratory we have constructed a tracking simulator (BLASER) that includes a sandbag bunker with a viscous-damped, laboratory constructed tracking device, a scale model terrain area with model tanks, and a control room with a microprocessor which monitors tracking performance and analyzes the data. Earlier research dealing with the effects of low ambient light conditions (2) was conducted using neutral density filters in the optical pathway. With the same arrangement, it was possible to evaluate the effects of various filters on pursuit tracking performance under bright and dim ambient light conditions.

This report presents data describing the optical characterization results obtained with a 532 nm reflecting holographic filter (the wavelength of the frequency doubled neodymium laser). Results obtained for three visual function tests and a pursuit tracking task with the filter are discussed.

METHODS

Subjects Five male subjects, age 23 to 40 years old, served as volunteers in the tracking study. Three of the five volunteers, who were determined to be visually normal as part of another on-going study, also participated in the visual functions tests in this present study. All of the volunteers had received extensive training and practice in the use of the BLASER tracking simulator.

Materials The test materials included (a) a 532 nm reflecting holographic filter inserted in clear optical quality glass and, (b) for control purposes, a sample of the clear glass substrate for the holographic grating less the grating. When these materials were first received from the manufacturer (Farrand Optical Co Inc, Valhalla, New York) the clear glass appeared to be lightly scratched. After the first set of visual function tests and pursuit tracking trials was run, a gonioscopic solution (ethylene glycol) was placed between two layers of the clear glass with the scratched sides placed inward. This procedure, subjectively, had the effect of removing the appearance of the scratches. Throughout the remainder of the report when reference is made to this material it will be called "corrected clear glass."

Optical Characterization Measurements and evaluation were made with a single holographic filter from an early fabrication run. The optical characteristics of the filter were determined in an attempt to establish possible relationships between the optical characteristics of the holographic filter and the visual functions tests and/or tracking performance. The characteristics which were determined were the broad band radiant transmission through the filter, the photopic luminous transmission, the optical density (OD) at 532 nm, the variation of OD as a function of location on the filter, and the relationship between the optical density and the angle of incidence.

The broadband radiant transmission was measured by using a Beckman DK2A ratio recording spectrophotometer. The transmission was measured throughout the spectral range from 350 nm to 1100 nm. The photopic luminous transmission was computed from the radiant transmission by application of the relationship:

$$LT = \frac{\int_{380}^{780} T_{\lambda} F_{\lambda} V_{\lambda} d\lambda}{\int_{380}^{780} F_{\lambda} V_{\lambda} d\lambda}$$

where T_{λ} is the transmission through the filter at wavelength λ , F_{λ} is the Commission Internationale de L'Eclairage (CIE) standard source C function and V_{λ} is the CIE standard photopic observer function.

The optical density was determined by using a 532 nm acousto-optic Q-switched laser as a radiation source. The laser was a continuously pulsed neodymium YAG device with an intracavity frequency doubler. The output consisted of a continuous train of 180 ns duration pulses at a pulse repetition frequency of 1 kHz. The output power of the laser was stable over the time required to make the measurements on the holographic filter. The emitted power of the laser was detected by a EGG 580 radiometer having an S-20 response. The design of the EGG 580 radiometer allowed accurate measurement of power throughout an intensity range of 5 orders of magnitude. First, emitted power of the laser was measured and then the power transmitted through the filter was measured. The transmission was derived as the transmitted power divided by the laser output power. The transmission was determined for incident angles at 1 degree increments from 0 degrees to 25 degrees. The optical density was computed from the transmission by the relationship:

$$OD = \text{Log}_{10} (1/T)$$

The variation of OD as a function of position was determined with the filter positioned so that the laser beam was incident at 0 degrees. The transmission was measured at 1 mm increments along two 28 mm paths at separate locations near the center of the filter. The incident beam was 2.5 mm in diameter.

Visual Functions Tests For the visual functions test, the holographic grating and the blank glass were mounted in welders' goggles frames. The visual function tests included the Farnsworth-Munsell 100-Hue test (FM 100-Hue) the Arden Contrast Sensitivity Plates, and the Snellen Acuity Chart. The FM 100-Hue test required the participants to arrange 85 colored caps into a specified color series. Caps placed out of order were scored as errors. The contrast sensitivity plates determined the thresholds at which each participant could discriminate gray spatial frequencies on a white background which ranged from 0.2 cycles/degree to 6.4 cycles/degree. The score for each person was the sum of each threshold. High contrast acuity was determined in the standard manner where the participant identified letters on a wall chart from a distance of 20 ft (6.1m). The rating for each person was made with respect to any deviation from their respective baselines (e.g., 20/20).

Simulator for Pursuit Tracking In the BLASER simulator model tanks move in a fixed arc at a simulated distance of 1 km and a constant angular velocity of 5 mrad/sec. Reduced ambient lighting conditions are simulated by inserting a 3.9 OD neutral density filter ahead of the operator's eye piece. The average terrain luminance without the filter in place was 84 cd/m² and with the filter 0.01 cd/m². Horizontal and Vertical Standard Deviation (SD) error scores, which indicate the subjects' variability around a central aiming point, were computed for each filter condition. The score for each

participant for each filter condition represented the mean ($\bar{x}$) of five trials for each filter. For a more complete description of the simulator and procedures see Stamper et al (2) and O'Mara et al (3).

Also presented in the pursuit tracking results section are data for two additional protective materials which were evaluated in a separate study (4). These materials were included to provide a basis for comparing the effectiveness of the holographic grating. The two protective materials were: Schott BG-18 glass which absorbs light at 694.3 nm and 1064 nm and KG-3 glass which absorbs light at 1064 nm. While BG-18 will provide protection at both the neodymium and ruby wavelengths, uncoated KG-3 primarily glass protects at the neodymium laser wavelength. A multilayer dielectric coating designed to reject the ruby wavelength (694.3 nm) was applied to the 3mm thick KG-3 glass. The tracking performance using each filter was compared to a baseline, non-filter set of tracking trials.

RESULTS

Optical Characterization Results The broadband radiant transmission through the holographic filter is shown in Figure 1. The width of the 530 nm rejection band at the 50% transmission point was 30 nm. No other attenuation band appeared between 400 and 1100 nm. The variation of optical density as a function of position along two lines near the center of the filter is given in Figure 2. Although an OD of 3.7 was achieved over much of the filter, many small areas of significantly reduced OD were present. Because the measured optical densities presented in Figure 2 were averaged over the 2.5 mm diameter of the laser beam, it is possible that the depressed ODs represent small holes in the base gelatin with essentially no attenuation. In a less controlled scan over other parts of the filter, an area was found where the OD dropped to 1.5. A visible defect in the filter could be seen at this location. The relationship of OD to angle of incidence is shown in Figure 3. Care was taken to insure that the incident beam remained at the same location on the filter throughout the measurements. The data in Figure 3 were obtained with the incident beam polarized perpendicular to the plane of incidence. The results were essentially the same when the laser beam was polarized parallel to the plane of incidence.

Visual Functions The results of the Farnsworth-Munsell tests are presented in Table 1A. The scores for subjects 1 and 2 indicated that the greatest number of errors in arranging the color chips were made while wearing the frames containing the clear glass. The holographic filter produced the next largest number of errors for these two subjects, followed by the corrected clear glass and baseline conditions. The errors were, in general, made in the blue end of the visual spectrum. For subject 3 the largest number of errors were made while wearing the holographic filter and the errors were made while discriminating the green hues.

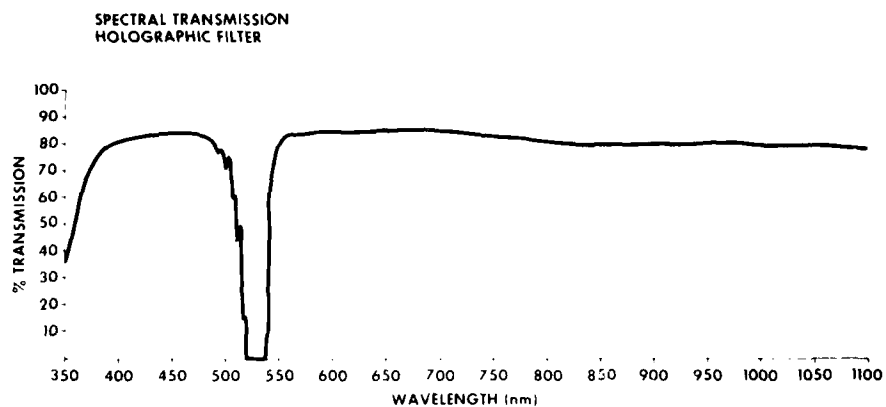


Figure 1. Spectral transmission obtained for the 532 nm reflecting holographic filter.

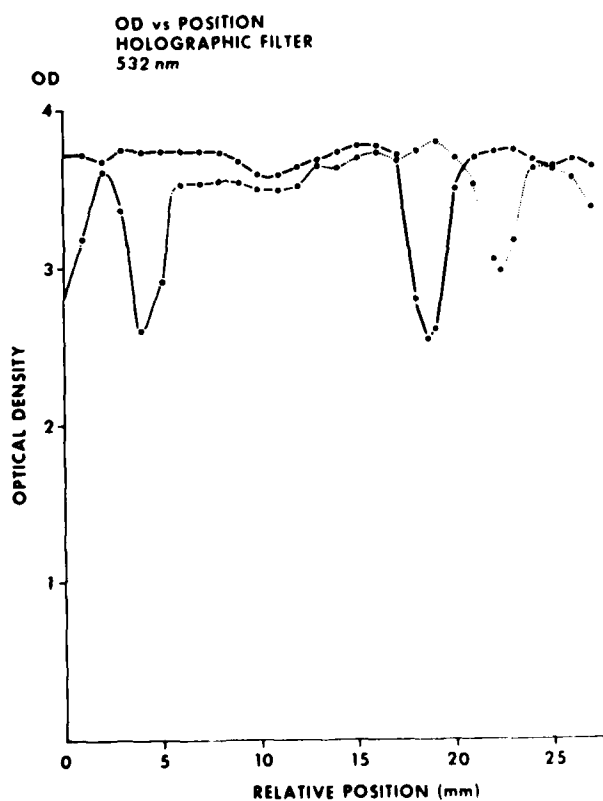


Figure 2. Optical density results obtained for two separate lines across the 532 nm reflecting holographic filter.

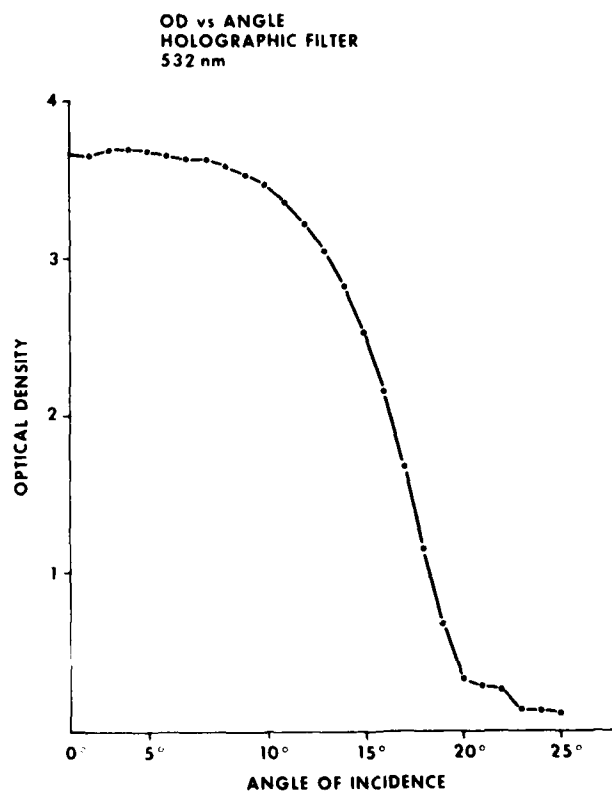


Figure 3. Optical density changes as a function of angle of incidence.

TABLE 1A

VISUAL FUNCTIONS DATA: FARNSWORTH-MUNSELL 100-HUE TEST

FILTERS	SUBJECT 1			SUBJECT 2			SUBJECT 3		
	TOTAL ERROR SCORE	COLOR DEFICIENCY		TOTAL ERROR SCORE	COLOR DEFICIENCY		TOTAL ERROR SCORE	COLOR DEFICIENCY	
CLEAR GLASS	71	Blue		72	Blue		8	None	
HOLOGRAPHIC	56	Blue		60	Blue		20	Green	
CORRECTED CLEAR GLASS	48	Blue		28	None		8	None	
BASELINE (NO FILTER)	48	Blue		39	None		4	None	

TABLE 1B

VISUAL FUNCTIONS DATA: ARDEN CONTRAST SENSITIVITY TEST

FILTERS	SUBJECT 1							SUBJECT 2							SUBJECT 3						
	PLATES			SUM OF THRESHOLDS				PLATES			SUM OF THRESHOLDS				PLATES			SUM OF THRESHOLDS			
	2	3	4	5	6	7		2	3	4	5	6	7		2	3	4	5	6	7	
CLEAR GLASS	7	6	6	5	6	6	36	7	6	7	6	4	4	34	10	8	11	8	6	5	48
HOLOGRAPHIC	7	7	6	6	8	6	40	7	6	11	7	8	5	44	10	6	7	3	4	5	35
CORRECTED CLEAR GLASS	7	7	8	7	7	6	42	8	6	7	8	7	5	41	9	6	11	5	4	5	40
BASELINE (NO FILTER)	8	7	8	6	7	6	43	13	9	12	12	9	9	64	11	9	12	8	7	7	54

The results for the Arden Contrast Sensitivity Test are presented in Table 1B. The results showed, in general, lower threshold sums (i.e., improved scores) for the holographic grating, clear glass and corrected clear glass, when compared to the no-filter baseline scores. The only exception was found for subject number 1 where the threshold sums for the baseline and corrected clear glass were equal. No systematic differences were found on the Snellen Acuity Test among any of the filter conditions for the 3 subjects.

Simulator Pursuit Tracking Figure 4 presents the horizontal SD error scores under the bright and dim ambient light conditions. During the bright light conditions few differences can be seen between the baseline trials and the holographic grating or the clear glass. Comparison of these same filter conditions during the dim light tracking trials showed that the $\bar{x}$ SD error scores for clear glass and the holographic grating were approximately 1.20-1.50 mrad higher than the baseline error rate for the dim ambient light condition. However, when the scratches were corrected in the clear glass, the horizontal SD error scores (represented by the area on the bar graph for the clear glass under dim light conditions) returned to near baseline levels.

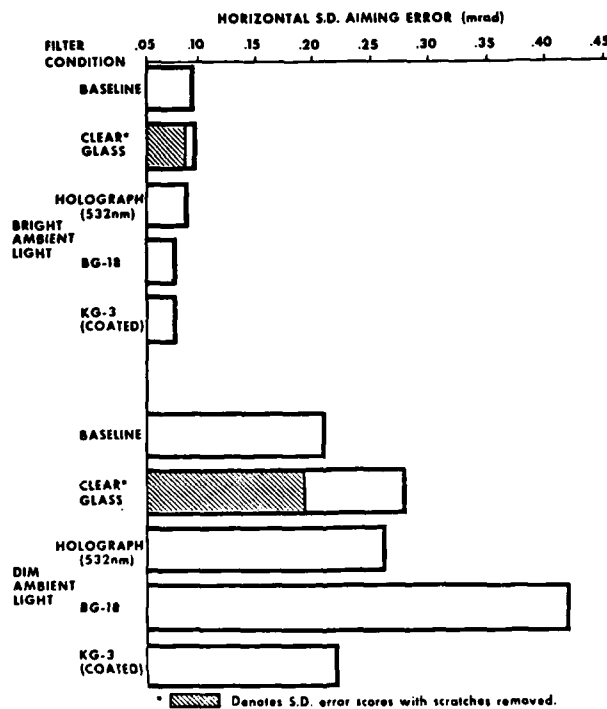


Figure 4. Horizontal S.D. pursuit tracking aiming error for the 532 holographic filter, BG-18, and KG-3 coated glass.

For comparison purposes the SD error scores for BG-18 and KG-3 trials obtained for these same individuals as part of another study (4) are also presented in Figure 4. During the bright ambient light trials little difference can be seen among the five filter conditions. However, during the dim ambient light conditions, the SD error scores for BG-18 are higher than the other four filter conditions.

COMMENT

The data evaluated in this report were based on a small number of participants. The holographic grating was obtained from an early fabrication run. After the scratches were removed from the clear glass, the tracking performance with the clear glass and the holographic filter was similar to the KG-3 coated filter.

The similarity in the level of tracking performance of the holographic grating with the other filters is encouraging in that the holographic grating has its largest attenuation near the middle of the visible band width. However, additional work should be done under environmental conditions where target and background conditions include hues of green and blue.

These findings combined with the data shown in Figure 4 (4) suggest that multiwavelength eye protection may be achieved with combinations of bulk glass absorbers, thin film, and holographic grating materials.

CONCLUSION

None

RECOMMENDATION

Additional testing of newer holographic gratings will be required.

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