Multispectral antireflection coating simultaneously effective in visible, diode laser, Nd-YAG and eye safe laser wavelength

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Abstract. Multi-spectral antireflection coating effective in visible region for sighting system, Nd-YAG laser wavelength for designator/seeker system, both diode laser and eye safe laser wavelength for ranging purpose can use common objective/receiver optics highly useful for state of art laser instrumentation. In this paper, design and fabrication of antireflection coating simultaneously effective in visible region (500 to 650nm), diode laser at 904+25nm and Nd-YAG laser at 1064±25nm, and erbium-glass laser wavelength at 1540±25nm has been reported. Inhomogeneous refractive index profile as suggested by Southwell was used to design this coating. The inhomogeneous profile was then approximated with eleven steps from substrate to air medium in order to obtain desirable antireflection property in the visible and laser wavelengths. These steps were then converted into the available coating materials (titanium-di-oxide and magnesium fluoride) of twenty-two layer stack. The multilayer stack was fabricated by using electron beam gun evaporation system in Balzers BAK-600 vacuum coating unit. The result achieved were less than 2% average reflection (98% average transmission) from 500 to 650nm, 1.5% reflection (98.5% average transmission) at 904nm, 1064nm and 1540nm. The coated samples successfully passed the specifications of MIL-C-14806 tests.

Introduction

The importance of inhomogeneous Thin films and their popularity grew considerably following the development of rugate filter theory [1] and quintic refractive index acting as broadband antireflection coating [2-4]. The quintic refractive index profile developed by W. H. Southwell serves as useful tool to design antireflection coating effective in multi-spectral wavelength regions.

Lasers operating at a wavelength below 1.4µm such as the highly popular 1.06µm Neodymium-glass and Neodymium-YAG laser pose serious eye hazard problem. These include a variety of infrared military laser systems such as range finders, target designator/seeker and imaging systems based on high performance Nd:Glass and Nd:YAG lasers that operate with pulse powers up to several megawatts and repetition rate up to 20 Hz. These lasers constitute potential eye hazard during their operation and maintenance resulting from specular or even diffuse reflectance from nearby targets. It is therefore extremely important to have an eye safe laser for ranging purpose that poses minimum risk to the user. For ranging purpose diode laser system is also an useful option and it is advantageous because of compactness of this device [5]. So for an integrated laser instrumentation system comprising of day sighting system, laser designator seeker and laser range finder system development of multi-spectral antireflection coating in the concerned wavelengths has a great potential. With this end in view, in this paper multi-spectral antireflection coating is reported having
high transmission in the visible region for sighting system (500 to 650nm), Nd-YAG laser system (1064±50nm) for designation and seeker purpose, both laser diode system (904±50nm) and erbium-glass eye safe laser system (1540±50nm) for ranging purpose.

**Design consideration**

An inhomogeneous refractive index variation from substrate to air medium that usually follows a specific quintic profile was used in this design [2]. The refractive indices/optical thicknesses are related with a fifth order polynomial given by \( n = n_1 + (n_2 - n_1)(10u^3 - 15u^4 + 6u^5) \). Here, \( u \) is the normalized optical thickness, \( u = \frac{o_t}{o_{t\text{max}}} \), \( o_{t\text{max}} \) being optical thickness and \( n_1 \) and \( n_2 \) are the refractive index values at the ends of the layer. It is not possible to construct a quintic gradient index profile from air to glass index (1.51) because index difference is small and the refractive index of best available low index material is 1.37 (magnesium fluoride). To overcome this problem, with the help of repeated experiments an index 2.28 was considered inside the multilayer stack and modified quintic profile was

![Figure-1: Quintic index profile with respect to optical distance from medium on BK-7 glass substrate for four-band AR coating](image)

![Figure-2: Eleven-layer approximate index profile that matches with quintic profile with respect to optical distance from medium](image)
constructed on either side of the high index 2.28. The refractive indices are plotted with respect to optical distance from medium in figure-1 which shows quintic profile on either side of higher index 2.28. The usefulness of this quintic profile is that Fresnel reflection at the interface is reduced over a broad wavelength band. The quintic profile was considered on either side of high indexed layer 2.28 from the substrate index 1.51 to 2.28 and from 2.28 to air medium. Since continuous variation is difficult to achieve experimentally the profile was approximated with several discrete layers (step index model) from substrate to air medium. In step index model for lower step numbers the approximation may not lead to desirable result and for large step numbers experimental realization may be very difficult to achieve.

![Reflection curve of eleven layers with respect to wavelength](image1)

Figure– 3: Reflection curve of eleven layers with respect to wavelength

![Index profile with respect to optical distance from medium of twenty-two-layer stack](image2)

Figure– 4: Index profile with respect to optical distance from medium of twenty-two-layer stack
With a trade off between step number and performance of the coating eleven steps index profile was chosen. This index profile is shown in figure 2. Reflection characteristic of approximated profile of eleven steps with respect to wavelength is shown in figure 3. Each of these eleven steps was obtained in practice with three layers equivalent stack developed by Melvin C. Ohmer[6] of magnesium fluoride/ titanium-di-oxide / magnesium fluoride combination except for top layer which is a magnesium fluoride layer. The coating materials chosen were titanium-di-oxide and magnesium fluoride with due consideration given to durability and compatibility and the eleven layer steps were converted into twenty-two-layer stack. The index profile of the twenty-two-layer stack with respect to optical distance from medium is shown in figure 4 and the corresponding reflection characteristic with respect to wavelength is shown in figure 5.

**Experimental highlights**

The substrates were cleaned using ultrasonic cleaning process in presence of soap solution followed by alcohol. Then the substrates were cleaned in vapor degreaser for half an hour. The multilayer stack designed for the antireflection coating has been fabricated using electron beam evaporation system in Balzers BAK-600 vacuum coating unit. The evaporation took place at the working vacuum range 2x10^{-5} mbar to 6x10^{-5} mbar for magnesium fluoride and 4x10^{-4} mbar to 8x10^{-4} mbar(in oxygen atmosphere) for titanium-di-oxide. The rate of evaporation in case of titanium-di-oxide and magnesium fluoride was 0.4nm/sec and 1.0nm/sec respectively [10]. The job was rotated with respect to the central point of coating chamber in order to obtain coating uniformity throughout the job holder area. Considering the aspect of stability and stochiometry the substrate was heated to 300°C (with tolerance ±15°C) for three hours inside the vacuum chamber. The substrate temperature during deposition was maintained at 300°C within a tolerance of ±5°C. After deposition process the test sample was post heated to 300°C ±15°C for one hour in presence of oxygen.
Result and discussion
The coated BK7 glass samples were measured in Beckman spectrometer of model no. λ-950 fitted with universal reflectance accessory. The experimental result is shown in figure 6. The achieved result was less than 2% average reflection from 500 to 650nm, 1.5% reflection in 904nm, 1064nm and 1540nm (both side coated sample). The experimental curve is in close agreement with theoretical design curve except in some regions that may be due to packing density variation, dispersion of materials and absorption losses. The samples were tested for environmental durability as per MIL-C-14806 shown in table1. The advantage of this coating is to develop compact laser instrumentation with common objective/receiver for sighting system, range finder and target designator/seeker system.

Figure-6: Experimental reflection curve with respect to wavelength

Table 1. Sample test record for four- band antireflection coating

| Run No | Average Reflection (%) |
|--------|------------------------|
|        | 1          | 2          | 3          | 4          | 5          | 6          |
| 500 to 650 nm | 1.8  | 1.6  | 1.6  | 1.6  | 1.6  | 1.6  |
| 904 nm ± 25 nm | 1.2  | 1.6  | 1.2  | 1.0  | 1.3  | 1.4  |
| 1064 ± 25 nm | 1.2  | 1.6  | 1.5  | 1.0  | 1.0  | 1.0  |
| 1540 ± 25 nm | 1.0  | 1.2  | 1.6  | 1.0  | 1.0  | 1.2  |

Durability and Environmental test as per Test Specification MIL-C-14806

| Adhesion          | 1 pull by scotch tape | OK | OK                        |
|-------------------|-----------------------|----|--------------------------|
| Abrasion          | 50 rubs by cheese cloth | OK | OK                        |
| Humidity          | 24 hrs; 95% to 100% (RH); 49 ± 1°C | OK | OK                        |
| Thermal cycle     | At 54 and 71°C (48 hours at each temperature) | OK | OK                        |
Acknowledgement

The author is thankful to Mr. S. S. Sundaram, Director, IRDE, Dehra Dun for his encouragement. The author is also thankful to Mr. G. K. Sharma, Associate Director, IRDE, Dehra Dun for his kind suggestion and help in the preparation of this paper.

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