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Final Report
July 1989 to July 1991

Image Quality, Space-Qualified UV Interference Filters

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1.0 INTRODUCTION

Section 2 of this report describes work done during the April to July 1991 period. Section 3 summarizes the project results, and Section 4 describes Phase III activities.

2.0 SUMMARY OF PROGRESS – APRIL TO JULY 1991

2.1 Radiation Effects

Radiation effects subcontract work was completed in the seventh quarter, however a master's thesis was published in May 1991 and an article based on the University of Lowell results was submitted for publication and presented at the MRS Boston Meeting, November 1991.

2.2 IAD Work

We produced a large number of depositions using reactive IAD of tantalum oxide, hafnium oxide, oxide and silicon oxide. Most of these depositions were multilayer filter coatings of Ta_2O_5/SiO_2 and or HfO_2/SiO_2 as the high/low refractive index layer pairs. The deposition runs were made to refine the process for use in production. We were looking for reproducibility of refractive index, minimal absorption, and high packing density (high spectral stability). We were also concerned with maximizing the coated area exhibiting the desired characteristics.

2.3 Sputter Deposition

A few sputter depositions were made during this period, extending the work of the seventh quarter.

3.0 PROJECT SUMMARY

3.1 Radiation Effects

During the project we established a close working relationship with the University of Lowell (Massachusetts) Physics Department and Radiation Laboratory. The Department Chair, Prof. A. S. Karakashian, served as the Principal Investigator for the work at Lowell performed under subcontract. We made use of the radiation laboratory's Gamma Cave for irradiation our samples. The Gamma Cave uses a Cobalt 60 gamma source that can deposit a megarad total dose in about a two hour period under our experimental conditions. The subcontract also partially supported two of Dr. Karakashian's graduate students. The experimental results provided data used by another department member in developing a computer model for determining the optical constants of radiation damaged optical materials. The gamma testing can be scheduled fairly readily and at relatively low cost, especially since a large number of samples can be simultaneously irradiated.

Another benefit of this relationship is the interest in the work expressed by one of our engineers who is now pursuing an advanced degree with Dr. Karakashian, studying radiation effects in optical materials. Because of this, Barr will now have even better access to the expertise and facilities of the Lowell Radiation Laboratory. We are planning a testing program for proton and electron radiation testing, and another program for cryogenic gamma testing.

Results of the present work show that most bulk materials (color filter glasses) lose considerable UV transmission with the one megarad gamma dose. Fused silica is an exception. Thin film materials do not seem to be affected.

Annealing of the damage usually occurs at room temperature and can be accelerated at elevated temperatures. Full recovery to pre-irradiation transmission is usually not achieved (at annealing temperatures up to about 200°C), but significant recovery does occur. Recent evidence that cryogenic thin film samples are damaged at low doses is an important discovery (at NOSC San Diego) that needs to be studied further. Their findings indicate that filters held at cryogenic temperatures may not recover transmission until returned to room temperature. This could have severe consequences for filters intended to operate at low temperatures.

3.2 IAD Results

A large number of fluorides and oxides were deposited with ion-assisted deposition techniques. The fluorides were evaporated from fluoride starting material and bombarded with argon ions. Ion current, energy and angle of incidence were variables, as were the evaporation rate and substrate temperature.

Oxides were deposited from metal or oxide starting material using electron gun evaporation. Ion current, energy, species, and angle of incidence were variables. Deposition rate, background gas and pressure, and substrate temperatures were other process variables. Oxides were usually bombarded with a mixture of oxygen and argon ions with a chamber background of oxygen.

Fluorides tended to be very sensitive to the ion parameters. Many appeared to deposit as fluoride-deficient film although no surface analysis was done. These films tended to be milky, soft and often absorbing; thorium fluoride was an exception.

The oxides seemed to be much more tolerant of a wide range of ion beam parameters. Oxides of tantalum, zirconium, hafnium and aluminum all could be produced in thin films with superior properties.

Metals were also deposited with Ar ion assist. Aluminum and silver were improved, but silver is still very weak environmentally unless protected.

3.3 Sputter Deposition

Our initial intent was to try only a few experiments using sputter deposition. The early results were so encouraging, however, that considerable effort was devoted to sputtering.

Most of our sputter depositions were oxides, with a few fluoride and metal depositions. Sputtering is similar to IAD in that it is an energetic process and some of the same benefits (high packing density, high durability) are obtained. Oxides of silicon, tantalum, hafnium, and aluminum were produced from semiconductor and metal targets using a reactive process. Argon was used as the sputtering gas and a chamber backfill of oxygen provided the reactive gas. Process variables included a target-substrate geometry, sputter power, Ar and O_2 flow, and substrate temperature. The oxides produced tended to be very smooth and defect-free. Process reproducibility was very high. Ordinarily we assume that a good optical monitor is required to produce a bandpass filter coating. Our sputter system optical monitor had a limited UV wavelength capability, so depositions were made with a quartz crystal monitor. Once calibrated, the crystal monitor could easily control the process well enough to produce excellent bandpass filters for the UV. The sputter process is, however, somewhat slower than IAD but in the UV where layers are thin, this drawback is less important.

At the end of the project we were able to produce high-performance UV bandpass and edge filters down to the transmission limit of the oxides we used—about 250 nm. Substrate temperature was usually not controlled, but is estimated to stay below 80°C during the run. This will allow us to deposit filters on temperature-sensitive substrates including, perhaps, detector devices.

4.0 PHASE III ACTIVITIES

One of the principal goals of the SBIR program is to assist in the introduction of new, innovative products or processes that can be commercially exploited. The present project has succeeded well in this regard. The results of the process development funded by this contract have been successfully applied to NASA and other national and international programs, and to new-generation commercial instrumentation. The result of the radiation effects work has aided us in better serving NASA-sponsored programs, as well as European (ESA) and Japanese (NASDA) space projects. A discussion of some of these activities follows.

A. *NASA, space and other national programs*

Barr has produced a number of filters for NASA applications based on the process developed under this contract. A number of NASA scientists are using Barr-developed narrow bandpass UV filters in LIDAR systems used in atmospheric studies. Among them are the following NASA/GSFC systems: Raman Water Vapor Lidar System used recently in the FIRE II/SPECTRE (Spectral Radiation Experiment) field campaign[1]; the NASA/GSFC Stratospheric Ozone Lidar used for UARS verification[2]; Temperature and aerosol lidar, also used for UARS verification[2]; Methane

Raman Lidar for solar atmospheric missions[3]. A related program at Sandia National Laboratory also uses this type of filter[4]. The important characteristics of these filters were their narrow passband, high rejection and very high transmission.

The Navy (NRL) LACE (Low-power Atmospheric Compensation Experiment) spacecraft was launched in 1990. The spacecraft carried an instrument called UVPI (Ultraviolet Plume Instrument) that contained the following Barr-produced coated optics: five bandpass filters, a fold mirror, beryllium gimbal mirror, secondary and primary mirrors, a fluid-filled cube beamsplitter, and two Ar-coated field lenses. This was the first application of the new technology and was specifically used in the production of the reflectance-enhancing mirror overcoats, lens Ar coating and the beamsplitter. The spectral region was from 220 to 350 nm. The bandpass filters were of conventional construction. This system was highly successful—meeting and usually exceeding performance expectations.

In Europe, we have supplied flight hardware using the new technology to Officine Galileo for the UVCS instrument to be flown on SOHO and engineering model hardware to Rutherford Appleton Laboratory for the ATSR instrument to be flown on ERS-2.

Barr recently received a contract from Hughes Aircraft Company to fabricate all VIS/NIR/SWIR/MWIR filters for the MODIS engineering and flight articles. This instrument is a major filter-based spectroradiometer to be flown on the EOS/AM platform. These miniature, high-performance, high-stability focal plane filters would not be feasible without the new process technology.

Barr has also provided breadboard filter support to the MISR (EOD/AM) 4-color striped filter program for which we are recommending the new technology.

A NSF program called GONG (Global Oscillation Network Group) is also using Barr bandpass filters specifically required to be produced by IAD. These filters will be used in remote ground-based sites to record solar oscillations. The overriding requirement is for ultra-stable spectral characteristics over several years under varying environmental conditions. At the same time, high spectral performance is required.

B. *Commercial programs*

Due to confidentially agreements, we cannot give details of most commercial instruments. However, we can say that the new process technology has been an enabling technology for several applications discussed below.

Two relevant trends are evident in new optical sensor-based instrumentation. Size is being reduced and field service almost eliminated. These facts mean that filters must be made smaller—in some cases almost microscopic—and that they must be extremely stable and reliable. Traditional interference filters often had high spectral performance but required careful sealing to protect the films from degradation due to moisture and abrasion. These environmental conditions do not affect IAD films. In addition, IAD filters are extremely spectrally stable. Because of the environmental robustness, sheets of filter material can be precision diced into devices as small as 500 microns on a side. Filters of various wavelengths can be assembled into multi-color arrays and/or mated directly to detector arrays. We are presently supplying 8-color (UV/VIS) arrays (individual filters 3 mm square) for a portable blood analyzer; 1.5 x 3 mm x 16-color arrays for the visible for use in a color analyzer; and miniature discrete ultra high-performance filters and beamsplitters for a fiber optic, fluorescence based patient monitoring system.

We have quoted and provided prototypes for a number of other commercial applications which would be difficult or unfeasible for the traditional filter technology.

4.2 Radiation Effects

Our knowledge of radiation effects gained during this contract have allowed us to better serve our NASA, ESA and NASDA customers. Specific examples are filters for LOI/SOHO designed and built for ESTEC(ESA–Holland), UVCS/SOHO filters made for Officine Galileo (Italy), engineering analysis done for Fujitsu (Japan) for the NASDA/ADEOS program.

Another real benefit is the interest developed by one of our engineers in the science of radiation effects. He is now pursuing an advanced degree part-time in this field. When this training is added to this Optics B.Sc. and filter experience at Barr, he will become an even more valuable asset to Barr and the space engineering community.

6.0 APPENDIX

Points Of Contact For Nasa, Space And Other National Programs

[1] Raman Watervapor Lidar System, Dave Whiteman: (301) 286-3115.

[2] NASA GSFC Stratispheric Ozone Lidar, Tom Magee: (301) 286-5645.

[3] Temperature and Aerosol Lidar, Tom Magee: (301) 286-5645.

[4] Methane Raman Lidar, John Goldsmith: (510) 294-2432

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15. Supplementary Notes

16. Abstract

This final report describes the progress during the contract period of Contract No. NAS7-1067. The project involved fabrication of image quality, space-qualified bandpass filters in the 200-350 nm spectral region. Ion-assisted deposition (IAD) was applied to produce stable, reasonably durable filter coatings on space compatible UV substrates. UV transmitting substrate and thin film materials were tested for resistance to simulated space effects.

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