ISSN 1671-7694

Chinese Optics Letters

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中国光学快报

Volume 8 Supplement April 30, 2010

Sponsored by the Chinese Optical Society, and
Shanghai Institute of Optics and Fine Mechanics,
Chinese Academy of Sciences

Distributed by the Optical Society of America

CHINESE LASER PRESS

Deposition

Measurement

Plasma ion-assisted deposition in UV filters

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Received December 4, 2009

Plasma ion-assisted deposition (PIAD) process for ultraviolet (UV)-induced transmission and full dielectric thin-film filters in the 200–400 nm spectral region is described. The design and manufacturing method of the UV filters are introduced. The UV filters exhibit deep blocking (> optical density (OD)5–OD6), high transmittance, and stable environment durability. These UV filters pass 10 cycles in an aggravated temperature-humidity test, according to ISO9022-2 and MIL-STD-810F standards.

OCIS codes: 310.0310, 310.1620.

doi: *10.3788/COL201008S1.0059.*

The growing requirements for applications in the 200–400 nm spectral region, such as deep blocking for military last smoking inspections, high transmittance, and power resistance for photoengraving in semiconductors, have increased the demands for ultraviolet (UV) filters with high performance and environmental durability.

Single or combined induced transmission and dielectric thin films are commonly applied in designing UV filters. In the past, evaporation process was applied in the manufacture of UV filters. For both hard and soft coating, there were inevitable defects, such as poor environmental durability, short lifetime, and so on. The key in solving such problems is the high energy ion deposition technology. Recently, Wang *et al.* applied the plasma ion-assisted deposition (PIAD) process to coat UV dielectric filters[1−4]. They also analyzed a wide range of issues that occurred in the application of such technology. Ockenfuss *et al.* adopted the reactive magnetron sputtering technology to coat UV dielectric filters[5]. They showed a potential application for an advanced coating machine.

UV-induced transmission filter (UV-ITF) can obtain a deep and wide blocking range while coated with fewer layers. However, there are multiple aluminum layers in these filters. In order to achieve advanced optical characteristics, aluminum cannot be coated under high temperature. Thus, this calls for a specialized coating process. In this letter, PIAD is applied, in the spectral range of 200–400 nm to coat UV-ITF and dielectric thin film filters. These filters show ideal environmental durability.

Metal layers in UV-ITF are made of high purity aluminum. Materials, such as Ta_2O_5, HfO_2, ZrO_2, SiO_2, Al_2O_3, MgF_2, and so on, are coated on dielectric thin films in order to give advanced environmental stability.

Aluminum is used in induced transmission filters. A wide wavelength range and deep blocking can be achieved by using multi-layers of aluminum[6,7]. The typical coating design is

$$(\mathrm{HL})^n \mathrm{H\,L'} \quad (\mathrm{ML''})^k \quad \mathrm{M\,L'H}\,(\mathrm{LH})^n,$$

where H is the high refractive index of a material layer with $\lambda/4$ optical thickness, L is the low refractive index of a material layer with $\lambda/4$ optical thickness, $(\mathrm{HL})^n$ is the n times for (HL), L′ and L″ are the optimized low refractive index material layers, $(\mathrm{M\,L''})^k$ is the k times for aluminum layer (M) and low refractive index material layer. An optimized combined multi-cavity narrow band-pass filter and a blocking filter were used in the dielectric thin-film UV filters. As such, different kinds of UV dielectric filters were produced.

It is hard to obtain a good spectrum for UV-ITF coating under high substrate temperatures due to the fact that aluminum reflectivity will be lowered and the characteristics of the materials will be changed under such conditions. Hence, UV-ITF can only be coated under low substrate temperatures. However, the dielectric film has a low density under low substrate temperatures. So PIAD was used to coat dielectric layers under low substrate temperatures. Deposition was cut off to protect the metal from oxidation while it was coated with aluminum layers. There was no metal layer in the dielectric UV filters. A stable film was obtained at high temperature with the PIAD process.

Using this process, UV filters for the 200–400 nm range were manufactured. A Leybold Syrus C coating machine with an APSpro plasma source was used. Suitable parameters were selected to achieve thin films with low absorption and full density.

Different requirements existed for different applications. Dielectric filters were applied when higher transmittances were required. An ITF or an ITF combined with dielectric filters and a color glass were applied to satisfy the need for deeper blocking. The test spectra for the band-pass filters of 214, 254, 266, 280, 340, and 365-nm wavelengths are shown in Figs. 1–8. For instance, the spectral result of ITF 254 nm had a transmittance higher than 20% with more than OD5 blocking. The spectral result of ITF 266 nm had a transmittance higher than 15% with more than OD6 blocking. Furthermore, for a 254-nm band-pass dielectric filter, the bandwidth was 10 nm and the transmittance was higher than 80%. PerkinElmer Lambda900 and Varian cary300 were used to obtain the spectrum.

To inspect the environmental durability of the UV filters, aggravated temperature-humidity tests were car-

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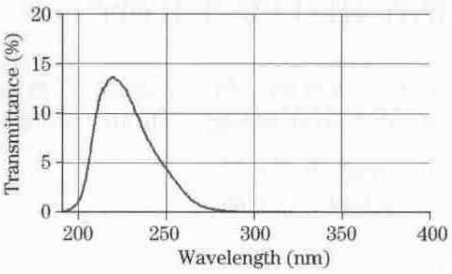

Fig. 1. Induced transmission filter spectrum of 214 nm.

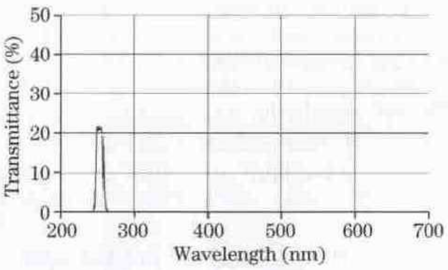

Fig. 2. Induced transmission and dielectric filter spectrum of 254 nm.

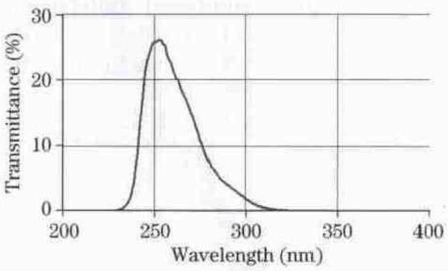

Fig. 3. Induced transmission filter spectrum of 254 nm.

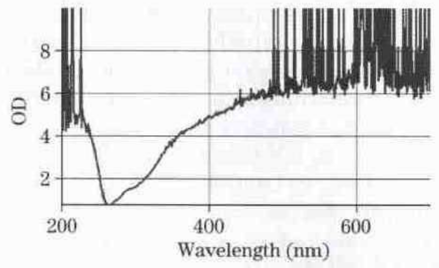

Fig. 4. Induced transmission filter blocking spectrum of 266 nm.

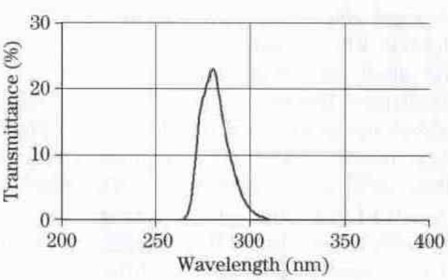

Fig. 5. Induced transmission filter spectrum of 280 nm.

ried out according to ISO9022-2 and MIL-STD-810F, inculding a controlled room environment, a general outside environment, and a worst outside condition. In this

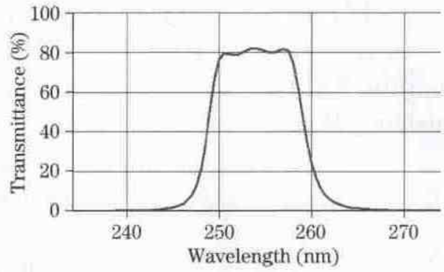

Fig. 6. Dielectric 254 nm with a bandwidth of 10 nm.

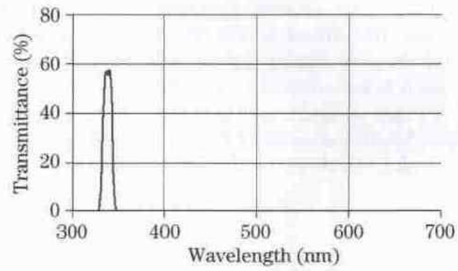

Fig. 7. Dielectric filters with color glass spectrum of 340 nm.

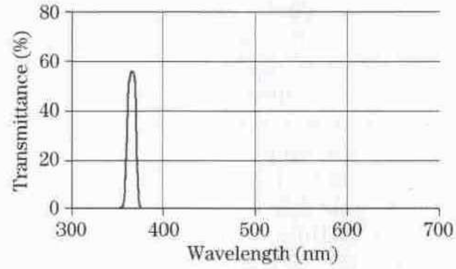

Fig. 8. Dielectric filters with color glass spectrum of 365 nm.

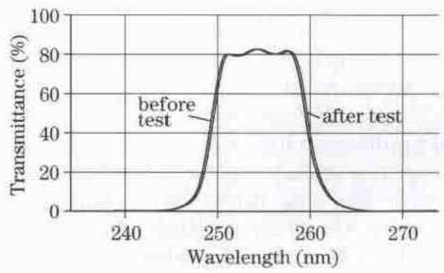

Fig. 9. Spectra for dielectric thin-film filter of 254 nm before and after 10 cycles of aggravated temperature-humidity test.

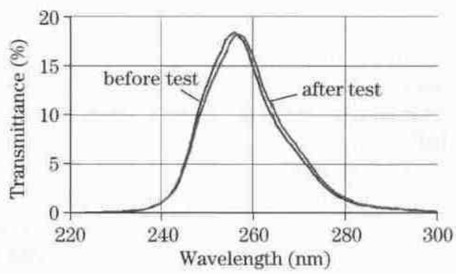

Fig. 10. Spectra for PIAD ITF of 254 nm before and after 10 cycles of aggravated temperature-humidity test.

letter, UV filters were tested under the worst outside condition simulation, wherein the temperature was changed from 30 to 60 °C and the relative humidity was changed above 85% − 95%. One cycle ran for 24 h, and a total of ten cycles were carried out.

The non-significant spectra of dielectric filters change before and after the aggravated temperature-humidity test (Fig. 9). The wavelength moved a little longer for ITF, for example, the wavelength moved 1 nm longer for the spectra of PIAD ITF of 254 nm (Fig. 10), but the spectra shape do not change. No increase imperfections in the surface quality is shown through the test.

Therefore, UV filters manufactured by the PIAD process had excellent performance after being tested under the worst outside condition simulation.

In conclusion, adopting the PIAD process to manufacture 200–400-nm UV filters can provide advanced spectrum performance and environmental durability for UV-induced transmission and dielectric filters. To obtain UV filters with better transmittance or blocking, these two processes can be selected according to the requirements of application. UV filters manufactured by PIAD have excellent environmental durability and performance, and the sample pass 10 cycles in the aggravated humidity test according to ISO9022-2 and MIL-STD-810F standards.

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