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(72) Inventors ROBERT JAMES FAY and
JOHN ROBERT CICOTTA



(54) NEUTRAL DENSITY OPTICAL FILTER ELEMENT

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to neutral density optical filter elements and in particular to an anti-reflection coating and coating method for use in producing such a filter element.

Increases in the effective range of photographic cameras by broadening the range of apertures available for picture taking have been accompanied by an increase in undesirable diffraction effects, particularly when the aperture is narrow and elongated. One method for reducing such undesirable diffraction effects is to insert a neutral density filter element into the optical axis of the camera. Filter elements formed by the deposition of a metal or metal alloy layer onto a substrate are particularly useful in this regard in that light attenuation is achieved by absorption and reflection rather than by absorption and scattering. Thus, the filter element does not destroy the image forming characteristics of the camera's optical system. However, filter elements consisting of a metal or metal alloy layer on a substrate are characterized by high reflectivity, which may result in unwanted ghost images at the film plane of the camera. The use of faster speed films to achieve available light photography under a broader range of light conditions has accentuated this problem since these films utilize narrower aperture for given light conditions and are, in

addition, more sensitive to unwanted ghost images.

In accordance with the present invention there is provided a neutral density optical filter element comprising a transparent substrate and at least five layers deposited thereon, said layers being formed alternately of spectrally neutral metal and a dielectric material, the layer immediately adjacent to the said substrate and the final layer being of metal, and the said dielectric material having a lower index of refraction than the metal, the total thickness of the layers of metal determining the optical density of the filter element and the thickness of each of the layers of dielectric material reducing the reflectance of the preceding layers to a minimum.

In a preferred embodiment of the invention, the filter element is made by the vacuum deposition of alternate layers of a metal alloy marketed under the Registered Trade Mark Inconel and containing approximately 79.5% nickel, 13% chromium and 6.5% iron and of a dielectric material such as silicon monoxide.

Also in accordance with the invention there is provided a method of producing a neutral density optical filter element having a predetermined optical density comprising the steps of:

- 1) monitoring the light passing through and reflected from an element consisting initially of a transparent substrate;
- 2) depositing a first layer of a metal alloy onto the said element until the element has a predetermined optical density less than said predetermined optical density;
- 3) depositing a first layer of a dielectric material onto the first metal alloy layer until the light reflected from the said element has been reduced to a minimum;
- 4) depositing a second layer of the said

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metal alloy onto the first dielectric layer until the said element has an optical density substantially equal to the said predetermined filter optical density;

5 5) depositing a second layer of the dielectric material onto the second metal alloy layer until light reflected from the said element has been reduced to a minimum; and

10 6) depositing a third layer of the metal alloy onto the second dielectric layer until the said element has an optical density equal to the said predetermined filter optical density.

15 The invention and its objects and advantages will become more apparent from the detailed description of the preferred embodiment presented below by way of example with reference to the accompanying drawing in which:

20 Fig. 1 shows a schematic view of apparatus used in carrying out the coating method of this invention;

25 Fig. 2 is a cross-sectional view of a filter element incorporating the anti-reflection coating of this invention.

Referring first to Fig. 1, a bell jar 10 is placed on and makes an airtight seal with a base plate 12. A vacuum may be obtained in bell jar 10 by means of a vacuum pump (not shown) having its exhaust port connected through a vacuum line 14 in base plate 12. A substrate 16 which is to be coated in accordance with this invention may be supported within bell jar 10 by a pair of support arms 18. Substrate 16 is positioned so that a thin layer may be coated upon substrate 16 from either one of a pair of crucibles 20 and 21. In one crucible 20 is placed a spectrally neutral metal or metal alloy with a relatively high index of refraction, such as Inconel (Registered Trade Mark). In the other crucible 21 is placed a dielectric material which has a lower index of refraction than the metal or metal alloy, such as silicon monoxide.

30 The amount of material deposited from each of crucibles 20 and 21 is controlled by means of a density monitoring device such as is well known in the art. A light source 22 is positioned so as to direct a light beam towards substrate 16. As a coating is formed on substrate 16, a portion of the light beam will be reflected back towards base plate 12 as may be seen in Fig. 1 while the attenuated light beam will pass through the substrate 16. A first optical detector 24, consisting of a light responsive device 26 and an indicator 28, is positioned above substrate 16 so as to monitor the attenuated beam of light passing through substrate 16. A second optical detector 30, consisting of a light responsive device 32 and an indicator 34, is positioned adjacent to base plate 12 so as to monitor the reflected light beam. An opaque shield 36 is positioned between light source 22 and

optical detector 30 so as to minimize the sensitivity of detector 30 to light passing directly to detector 30 from the light source 22.

To form the anti-reflection coating of this invention, a substrate 16, such as a portion of polyester film base, is placed upon holders 18 within bell jar 10. A vacuum is then established within bell jar 10 by means of vacuum line 14, which is preferably at a pressure less than 1×10^{-4} torr. Crucible 20 is then activated so that the metal alloy contained therein begins to evaporate. As the metal alloy evaporates, a thin layer of metal alloy will be formed upon substrate 16. Evaporation is continued until an optical density of approximately 0.25 is achieved, as indicated by optical detector 24, at which time evaporation from crucible 20 is halted. Crucible 21 is then actuated so that evaporation of the silicon monoxide contained therein begins. As a thin layer of silicon monoxide is deposited upon the metal alloy layer already on substrate 16, the reflected light is monitored by detector 30 until reflection by the coating is reduced to a minimum, whereupon the evaporation of silicon monoxide is terminated. Crucible 20 is then reactivated and an additional layer of metal alloy is deposited upon the silicon monoxide layer on substrate 16 until the optical density of the element reaches the desired level, for example 0.90, as monitored by detector 24. Evaporation of metal alloy is then terminated. Crucible 21 is then reactivated so that evaporation of silicon monoxide is begun once more and continued until the reflected light as indicated by detector 30 is again reduced to a minimum. The final step is to reactivate crucible 20, thereby depositing a third layer of metal alloy on substrate 16, which is continued until the desired optical density of 0.90 is again obtained as indicated by detector 24.

The neutral density optical filter element produced by this method is illustrated in Fig. 2. As may be seen, successive layers of metal alloy and silicon monoxide are formed on substrate 16, with a metal alloy layer being adjacent to substrate 16 and also being the final layer placed upon the coating. While the use of metal alloy of the kind comprising 79.5% nickel, 13% chromium and 6.5% iron, and of silicon monoxide is the preferred embodiment of this invention, other materials may be used for the attenuating and anti-reflection layers. In particular, any spectrally neutral metal or metal alloy may be used to produce the light attenuating layers in this coating. Moreover, any dielectric material which has a lower index of refraction than the metal or metal alloy used in the light attenuating layers may be used to produce the anti-reflection layers.

WHAT WE CLAIM IS:—

1. A neutral density optical filter element comprising a transparent substrate and at least five layers deposited thereon, said layers being formed alternately of spectrally neutral metal and a dielectric material, the layer immediately adjacent to the said substrate and the final layer being of metal, and the said dielectric material having a lower index of refraction than the metal, the total thickness of the layers of metal determining the optical density of the filter element and the thickness of each of the layers of dielectric material reducing the reflectance of the preceding layers to a minimum.
2. A neutral density optical filter element as claimed in Claim 1, wherein the metal is an alloy of the type comprising 79.5% nickel, 13% chromium and 6.5% iron.
3. A neutral density optical filter element as in Claim 1 or Claim 2, wherein the said dielectric material is silicon monoxide.
4. A method of producing a neutral density optical filter element having a predetermined optical density comprising the steps of:
- 1) monitoring the light passing through and reflected from an element consisting initially of a transparent substrate;
 - 2) depositing a first layer of a metal alloy onto the said element until the element has a predetermined optical density less than said predetermined optical density;
 - 3) depositing a first layer of a dielectric material onto the first metal alloy layer until the light reflected from the said element has been reduced to a minimum;
 - 4) depositing a second layer of the said metal alloy onto the first dielectric layer until the said element has an optical density substantially equal to the said predetermined filter optical density;
 - 5) depositing a second layer of the dielectric material onto the second metal alloy layer until light reflected from the said element has been reduced to a minimum; and
 - 6) depositing a third layer of the metal alloy onto the second dielectric layer until the said element has an optical density equal to the said predetermined optical density.
5. A method as claimed in Claim 4, wherein steps 2, 4 and 6 each consists of depositing a thin layer of a metal alloy of the type comprising 79.5% nickel, 13% chromium and 6.5% iron on the said element.
6. A method as claimed in Claim 5, wherein steps 3 and 5 each consists of depositing a thin layer of silicon monoxide on the said element.
7. A neutral density optical filter element produced by the method of any of Claims 4 to 6.
8. A photographic camera having in, or arranged for insertion in, the optical path to the film plane a neutral density optical filter element as claimed in any of Claims 1, 2, 3, or 7.
9. A neutral density optical filter substantially as hereinbefore described with reference to Figure 2 of the accompanying drawings.
10. A method of producing a neutral density optical filter element substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

L. A. TRANGMAR B.Sc. C.P.A.,
Agent for the Applicants.

