Deposition and assessment of thin dielectric films on photocathode substrate made of Kodial glass

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Abstract. The development of Cs_3Sb transmissive interference cathode technology needs processing of such photocathodes on thin dielectric films coated on glass substrates. Here the use of such films as light resonators is made for reducing the light losses due to reflection at the cathode surface. Consequently the sensitivity of the photocathode is enhanced. TiO_2 and SiO films are chosen for their good optical properties with Cs_3Sb photocathodes in interference photoemission. Deposition methods and instrumentation in assessing their properties are discussed.

Keywords. Interference photoemission; dielectric films; refractive index.

1. Introduction

Recent developments in electro-optical instrumentation with advanced technology in light sources, optical components and electronics have set the situation wherein the photocathode quantum efficiency places a limit on the total performance. Thus increasing the efficiency of the photocathode by optical interference phenomenon (Kossel *et al* 1969) is one of the methods. Thin films in conjunction with photocathode act as light resonators, due to the formation of standing wave within the films, facilitating large amount of light for photoemission. In the developmental techniques of transmissive interference photocathode (TIC) of S-9(Cs_3Sb) type, TiO_2 and SiO thin films were selected for their matching optical properties such as high refractive index value, transmission and chemical compatibility with the photocathode (Katti 1979; Katti *et al* 1981). This paper describes the deposition methods of the above films, instrumentation techniques of measuring their optical properties and the application to interference photoemission.

2. Experimental techniques

The interference photoemission needs processing of photocathode in conjunction with non-absorbing thin dielectric films of known thickness, required refractive index (RI) value and transmittance in useful spectral region.

2.1 Method of deposition

Among various methods, reactive evaporation (Pulker *et al* 1976) of TiO (supplied by Balzers Ltd, W. Germany) in the ambient of oxygen is followed to assess its suitability to the special photodiodes employing Kodial glass to Kovar glass-to metal seals.

Electron beam evaporation method is used. The O_2 pressure, rate of evaporation and substrate temperature are controlled so as to get fully oxidized and non-absorbing films of high n_1 value. Thin SiO films are deposited by vacuum evaporation of SiO powder (supplied by Merk, W. Germany) in a high vacuum of $< 1 \times 10^{-5}$ torr (Holland 1961). The evaporation source temperature in the range of 1250°C to 1350°C is maintained to prevent decomposition of SiO at elevated temperatures.

2.2 Thickness measurement

Thickness is the single most film parameter on which the end application of thin films for any device is greatly dependent. The phase condition for TIC is $n_1 t_1 + n_2 t_2 = (\lambda/2) \rightarrow 1$ where n_1 and n_2 are refractive indices and t_1, t_2 the thicknesses of the film and photocathode respectively. λ is the wavelength of exciting radiation. The values of n_2 and t_2 for the Cs_3Sb photocathode are 3.2 and 300 Å approximately. The quartz crystal thickness monitor was employed for simultaneously monitoring the film thickness during growth as well as the evaporation rate. A sensitive AT cut quartz crystal with a natural frequency of 5 MHz which was temperature-resistant and water-cooled was used. The change in oscillation frequency Δf is related to the thickness t of the growing film by the equation $\Delta f = 0.6 \times t \times d \rightarrow 2$, d being the bulk density of the film material ($d = 4.3$ g/cc for TiO_2 and 2.1 g/cc for SiO).

The thickness by the quartz crystal was monitored for different films by measuring the exact geometrical thickness using Tolansky's interferometric method. The experimental set-up is shown in figure 1. An interference filter transmitting the

Figure 1. Schematic diagram for multiple beam Fizeau fringe interferometry.

wavelength ($\lambda = 5460 \text{ \AA}$) in front of a Hg-discharge lamp gives monochromatic light. The film thickness is given by the equation

$$t = (\lambda/2)(\Delta/d) \rightarrow 3$$

where Δ is the fringe shift and d the fringe width. Since surface planacity of the glass plate is important, silver or aluminium step-coatings are given for high contrast in the array of the fringes. The calibration curves relating both methods of thickness measurement for TiO_2 and SiO films are shown in figure 2.

2.3 Refractive index and transmission measurements

In interference photoemission, a knowledge of RI of dielectric films is necessary for selecting suitable films for the photocathode to satisfy the amplitude condition. Measurement of Brewster's angle by Able's method is used here. The reflection at coated and uncoated substrate is measured using a plane-polarized, monochromatic light at different angles of incidence. The RI of the film is given by the equation $n = \tan \theta \rightarrow 4$ for equal reflection from coated and uncoated region, θ being the angle of incidence (Brewster's angle). The photomultiplier tube and M4Q III spectrophotometer are used. θ is determined graphically (figure 3). The spectral transmittance of the film is measured by using a quartz prism monochromator (M4Q III-Carl Zeiss) and is shown in figure 4. These data are essential for the TIC technology and interpretation of the results.

Figure 2. Relation between quartz crystal monitor and actual thickness for dielectric thin films.

Figure 3. RI measurement for TiO_2 films made by reactive evaporation method at different substrate temperatures.

Figure 4. Spectral transmittance of TiO_2 film (scanned by M4QIII monochromator).

The photodiode tube assembly is shown in figure 5. Films of required thickness are deposited on Kodial glass plate sealed to metallic Kovar eyelets by glass-to-metal seals. These components are used as photocathode substrates in image converter and image intensifier tubes.

3. Results and Discussion

Film properties such as RI and transmittance depend on the conditions of deposition. In order to process TiO_2 films by reactive evaporation of TiO material, oxygen pressure is

(a)

(b)

A = Tuning at 560 nm, B = Tuning at 600 nm
 C = Tuning at 620 nm, D = Uncoated region

Figure 5. (a) Experimental photodiode tube and (b) substrate configurations.

kept at 1.5×10^{-4} torr so that the films are fully oxidized and non-absorbing (Ritter 1968). The rate of evaporation is 7 Å/sec for films processed at two different substrate temperatures of 250°C and 300°C; the R_1 values for TiO_2 are 2.42 and 2.30 respectively at 300°C and 250°C (figure 3). This variation in R_1 is due to crystal imperfection as established by Bright Field (BF) and Selected Area Diffraction (SAD) electron micrographs. The films are polycrystalline, tending towards anatase. However, direct oxidation of Ti films in air at 450°C yields TiO_2 of R_1 value 2.6, which is required for TIC. We could not pursue this method further because of its unsuitability to Kodial glass substrates with glass to metal seals. Thin films of SiO are deposited in a vacuum of less than 1×10^{-5} torr, the substrate temperature being 250°C. The evaporation source

Figure 6. (a) Spectral gain and (b) reflectance characteristics for TiO_2 -TiC samples: A. TiO_2 -TiC at 560 nm; B. TiO_2 -TiC at 600 nm; D. S-9 Photocathode; E. Computed (R) for S-9; F. Computed (R) for TiO_2 -TiC at 560 nm.

temperature was kept within 1350°C because the films above this temperature are likely to contain Si and SiO_2 . SiO films of RI value 1.82 can be obtained with the above conditions in addition to the rate of evaporation of 12 Å/sec.

The quartz crystal thickness monitor and Tolansky's interferometric instrument for the assessment of thickness of the films are complementary to each other. RI measurement for these optical films by Able's method is quite simple; however the use of photomultiplier tube spectrometer with fine angular graduations and the optical arrangement of lenses, slits and monochromator increase the accuracy of measuring techniques. The accuracy obtained in RI value is ± 0.05 , fairly sufficient for the TiC development work.

The enhancement in photocathode sensitivity by interference mode is achieved to the tune of 1.45 for TiO_2 -TiC (Rangarajan and Katti 1978) in the tuned spectral region as shown in figure 6. The agreement obtained between experimental results and theoretical computations shows the right optimization of the deposition parameters of these films as well as the reliability of the instrumentation in assessing their properties.

A gain of 1.25 in photocathode sensitivity in tuned spectral region is recorded for SiO-TiC.

4. Conclusions

TiO₂ films deposited at 300°C substrate temperature by reactive evaporation of TiO in O₂ pressure of 1.5×10^{-4} torr are polycrystalline, tending towards anatase, of n_1 value 2.42 and nonabsorbing, in the useful spectral region. SiO films of $n_1 = 1.8$ are obtained by evaporation of SiO in a vacuum $< 1.0 \times 10^{-5}$ torr. The enhancement in photocathode sensitivity is 1.45 times over the normal mode for TiO₂-TiC in the tuned spectral region.

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