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Thin film thickness step gauge

S K GUPTA, A K KAPIL, C M SINGAL and V K SRIVASTAVA
Department of Physics, University of Roorkee, Roorkee 247667

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Abstract. The Blodgett-Langmuir technique is used to deposit multilayer films of barium stearate on EDF glass. The thickness of the film varies in steps of 10 monolayers, and the thickness of each monolayer is about 25 Å. When viewed in white light at near normal incidence vivid interference colours are seen in reflection, with good contrast between adjacent steps. The reliability of the step gauge is tested for dielectric films of MgF_2.

Keywords. Multilayer films; barium stearate; dielectric film; thickness step gauge; interference colours.

1. Introduction

In this paper, we have successfully applied the Blodgett-Langmuir technique (Blodgett 1935, Blodgett and Langmuir 1937 and Srivastava 1973) to deposit dielectric monolayers of uniform and accurately reproducible thickness. The thickness of a barium stearate monolayer was earlier determined as 25·75 Å using multiple beam interferometry (Srivastava and Verma 1962, 1966). The property of constancy of thickness and their value has already been utilized (Srivastava 1973) to study the dielectric breakdown, dielectric constant, optical reflection and transmission as a function of thickness of the Langmuir films. We have also used the above property to make a step gauge which will be useful to measure the thickness of transparent dielectric films by visual colour comparison.

2. Theory

Consider white light incident from a medium of refractive index n_0 at normal incidence on a dielectric film of refractive index n_1 coated on a glass of refractive index n_2 with $n_0 < n_1 < n_2$. The incident light undergoes multiple reflections and comes out by transmission on both sides of the film. In the present case we have considered light as reflected from the film system. The reflectivity at normal incidence is obtained by summing up multiple reflected beams (Chopra 1969). The maximum and minimum reflectance derived from this equation is as follows:

$$R_{\max} = \left(\frac{n_2 - n_0}{n_2 + n_0}\right)^2 \text{ at } \lambda_{\max} = \frac{2n_1 t}{m} \tag{1 a}$$

and

$$R_{\min} = \left(\frac{n_1^2 - n_2 n_0}{n_1^2 + n_2 n_0}\right)^2 \text{ at } \lambda_{\min} = \frac{4n_1 t}{2m + 1} \tag{1 b}$$

At a particular thickness t, therefore, the colours with wavelengths near λ_{min} will be suppressed in intensity in the reflected beam and the reflected beam will have a colour complementary to that of the suppressed colours. Further, the reflectivity at λ_{min} will be zero provided $n_0 n_2 = n_1^2$. For this reason the refractive index of the glass substrate used for thin film coating should be close to the square of the refractive index of the film divided by n_0 so as to obtain sharp colours. As the thickness is varied the value of λ_{min} changes and different colours are observed in the reflected light at different thicknesses. Thus at different steps on the gauge different colours are observed.

3. Experimental

The Blodgett-Langmuir technique of depositing Langmuir films requires a long narrow trough of an inert material like teflon, perspex, etc., the interior portion being heavily waxed. The size of the perspex trough used is 16×6 × 1 in. The details of the apparatus and the deposition technique are given by Srivastava (1973).

The barium stearate monolayer is now transferred in a clean EDF glass slide (refractive index 1·65) in ten steps of 10–100 monolayers. The thickness of each monolayer is 25·75 Å and therefore this step gauge gives a thickness range of 257–2575 Å. Distinct colours are seen in reflection when viewed at near normal incidence in white fluorescent light. A thin protective layer of magnesium fluoride (MgF_2) is deposited on the gauge in a high vacuum coating unit by thermal evaporation. For this purpose, a compressed pellet of MgF_2 was prepared and evaporated in vacuum using a tungsten filament. We have chosen MgF_2 since it forms a good transparent and protective layer. No effect is seen on the barium stearate layer when pumped in the vacuum chamber (Holt 1967) and there is satisfactory reproducibility.

4. Results

The colours on the step gauge, when viewed at near normal incidence in reflection at various thicknesses of the step, are given in table 1.

Table 1. Step-gauge colours observed at near normal incidence in reflection

Thickness (T)	Colour
10 d (d = 25 Å)	Light brown
20 d	dark brown
30 d	Violet
40 d	dark blue
50 d	light blue
60 d	light green
70 d	light yellow
80 d	dark yellow
90 d	Orange
100 d	Pink

The description of the colours given in the table is somewhat approximate because it is difficult to identify the various shades of any colour. These colours qualitatively agree with those expected at the corresponding thicknesses using eqs (1 *a*) and (1 *b*). As an example, consider the step with thickness equal to 100 d. From eqs (1 *a*) and (1 *b*) and using $n_1 = 1\cdot 43$ and various values of *m*, we obtain

$$\lambda_{min} = 5100\,\text{Å},\ 3060\,\text{Å}$$

and

$$\lambda_{max} = 7150\,\text{Å and } 3575\,\text{Å}$$

The minimum at 5100 Å eliminates green light from the reflected beam and the maxima at 7150 Å and 3575 Å allow large portion of red and orange spectrum and blue and indigo part of the spectrum to come in the reflected beam. Thus, the reflected light by the combined effect of the two end portions of the spectrum gives pink colour. Similarly the other colours can be verified.

To estimate the thickness of any dielectric film it should be simultaneously deposited on a dummy slide of EDF glass (refractive index 1·65) and the colour observed in the reflected light from this film should be matched with the colour of one of the steps by simultaneous viewing of the step gauge and the test slide in white light. The step number should be seen in column two with the corresponding thickness (T) in column one. The unknown thickness (τ) is determined by

$$\tau = 1\cdot 43\ T/n \qquad (2)$$

where n is the refractive index of the material of unknown thickness.

The reliability of this step gauge on dielectric films of MgF_2 was tested and for this purpose films of varying thicknesses were deposited in EDF slide. Their colours were matched with the steps of gauge in white fluorescent light and the corresponding thicknesses were estimated using eq. (2). The thicknesses of the same films of MgF_2 were measured by means of Talystep (U.K.). The thicknesses estimated by step gauge and those directly measured by Talystep were quite close to one another (*see* table 2) thus confirming the reliability of the step gauge for thickness estimation. The above device is useful to estimate the thicknesses upto 2500 Å.

This step gauge appears to be a simple and low-cost device for quick estimation of thicknesses of dielectric films and can be used for films of SiO_2, Al_2O_3, MgF_2, TiO_2, ZnS which are commonly used in thin film technology.

Table 2. Calculated and observed thicknesses of MgF_2 films

Colour of MgF_2 Films	Step number on gauge	Calculated thickness 'τ' by eq. (2)	Measured thickness of MgF_2 film by Talystep
1. Violet	Three	794 Å	600±50 Å
2. Light yellow	Seven	1853 Å	1400±100 Å
3. Pink	Ten	2648 Å	3000±200 Å

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