Dielectric mirrors for high power laser applications

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Abstract. Development of low loss dielectric high reflecting mirrors for high power laser applications presents some problems in selecting suitable thin film materials and in understanding their optical constants. Some of these problems have been solved by a systematic study of the dependence of optical constants on different evaporation parameters for a number of thin film materials. Using the data thus obtained high reflecting dielectric mirrors for different laser applications in the UV, visible and near-infrared regions were successfully developed indigenously by the method of vacuum evaporation.

Keywords. Mirrors; lasers; thin films; optics; multilayers; coatings.

1. Introduction

With correct choice of thin film constants, film thicknesses and number of films, it is possible to design different dielectric mirrors and other thin film devices (Dobrowolski 1965, 1981; Apparao 1977). But practical realization of low loss, stress free and hard thin film devices which can withstand high power lasers presents some problems (Pawlewicz *et al* 1980; Carniglia 1981; Kuster and Ebert 1980). Selection of appropriate thin film materials having the required optical and mechanical properties, knowledge of optical losses and constants and their dependence on the process parameters are some of the involved problems. In order to meet the specific needs of research activities using lasers some of these problems have been solved and different thin film devices including dielectric mirrors for high power laser applications were developed indigenously. Some of the important results derived during the development work are presented in this paper.

2. Thin film devices development

It is well known that a multilayer dielectric thin film device is made up of at least two materials and depending on the application the films of each material should have the desired refractive index, transmission, scattering, thickness, stress, hardness, defects, optical losses, resistance to laser radiation etc. Unfortunately despite all the advances in materials science and sophisticated instrumentation during the last few years, it is difficult to achieve all the desired film properties in any process because the film growth during the process of evaporation, as is well known, is complex and depends upon different process parameters like evaporation method, rate of evaporation, substrate temperature, ambient pressure, vapour angle, vapour chopping, glow discharge, starting material, substrate material etc. For example, for laser applications, optical loss of the coatings is one of the important factors to be controlled during the evaporation

process. These losses, which include losses due to absorption, adsorption, scattering and fluorescence, depend upon the bulk absorption, stoichiometry, voids in the structure, surface roughness, rough internal boundaries, density changes, pin holes, cracks, microdust etc in the films which are all process-dependent except the bulk absorption. So exact and reproducible process and chamber parameters which give the desired film properties with the specified tolerance limits are very essential to develop high quality thin film devices for laser applications. The present situation is such that although basic optical properties of different thin film materials are available (Jenkins 1958; Hass and Ritter 1967; Macleod 1969; Ritter 1975; Pulker 1979), full details of optical constants and mechanical properties of the films and their dependence on process parameters are not available in the voluminous literature published in the field, particularly for the films in the uv region from 240 nm to 400 nm. This is because most of the parameters are considered as trade secrets and patents and are not published. The few results published are not exactly reproducible and are different for different experimental set-ups. In addition human element in the form of experience, skill and judgement plays a role in achieving the required film properties in the given process.

In our programme to develop thin film devices indigenously, studies have been undertaken to evaluate all necessary film data for different thin film materials like TiO_2 , CeO_2 , Al_2O_3 , MgF_2 , SiO_2 , MgO , Ta_2O_5 , Na_3AlF_6 , ZrO_2 etc. using the method of vacuum evaporation. Using the data thus obtained low loss, stress force and hard high reflecting mirrors of conventional design having reflection as high as 99.5% with losses as low as 0.5% were developed for different wavelengths ranging from 300 to 1060 nm. The coatings developed are in constant use in our laboratories and are found to withstand the available lasers operating upto 1 MW maximum power with 10 nsec pulse widths. High reflecting mirrors developed so far include the coatings working at XeCl , N_2 , HeCd , visible dye, II YAG, Ar^+ , Cu vapour, HeNe and YAG glass laser wavelengths.

3. Development work

Space does not permit a discussion of the entire development work and so some details of the investigations carried out for developing the dielectric mirrors for the uv region from 240 nm to 400 nm are presented in this paper. The uv coatings were developed, using ZrO_2 as high index and SiO_2 as low index materials, by the method of reactive evaporation. The results concerning the optical losses of ZrO_2 films prepared under different evaporation parameters are given. The dependence of the optical losses and constants on the rate of evaporation, ambient oxygen pressure, substrate temperature, film thickness and chopping the vapour before reaching the substrate have been studied and the results of the most significant evaporation parameters are briefly discussed and the results presented.

3.1 Experimental

ZrO_2 films were deposited on a 25 mm diameter fused silica substrates by evaporating optical grade ZrO_2 using the electron beam gun in a conventional 500 mm vacuum coating unit. The chamber was evacuated to better than 2×10^{-6} mbar before evaporating the material. For reactive evaporation IOLAR grade pure oxygen from a high pressure cylinder was admitted into the chamber and maintained at the required

value ranging from 3×10^{-4} mbar to 5×10^{-6} mbar by controlling the needle valve and pressure regulating valves. The substrate was heated to the assigned temperatures ranging from 50°C to 400°C and the evaporation rate ranging from $1 \text{ \AA}/\text{sec}$ to $100 \text{ \AA}/\text{sec}$ was measured and controlled with the quartz crystal monitor. Chopped films were prepared by introducing suitable rotating mask between the substrate and the source. A total of 35 samples were prepared for the present studies, each with different evaporation conditions. For all the samples prepared uniformity of film thickness over the whole surface was found to be within $\pm 2\%$ of the average thickness. The transmittance spectrum of each substrate was recorded before and after depositing the film using double beam spectrophotometer (Hitachi model 330). The optical losses L were taken as the difference of transmission peak maxima and the substrate transmission at the respective peak wavelengths. Refractive index n , physical thickness t and the effective extinction coefficient k of each sample film were deduced by the method of Swanepoel (1983).

Figure 1. Dependence of optical losses of ZrO_2 films on rate of evaporation. (a) $20 \text{ \AA}/\text{sec}$, $t = 250 \text{ nm}$, (b) $10 \text{ \AA}/\text{sec}$, $t = 275 \text{ nm}$ and (c) $5 \text{ \AA}/\text{sec}$, $t = 320 \text{ nm}$

3.2 Results and discussion

The measured percentage losses L were plotted against the wavelength λ for each set of films prepared under identical conditions with one parameter variable. Figure 1 shows one such plot where the variation of optical losses is shown for films prepared at different evaporation rates. All the films shown in figure 1 were prepared at the same ambient oxygen pressure (2×10^{-4} mbar) and substrate temperature (260°C). As can be seen from figure 1 the optical losses are minimum for ZrO_2 films evaporated at $5 \text{ \AA}/\text{sec}$. The present investigation also indicated that the losses are further reduced as expected at higher substrate temperatures and low oxygen ambient pressures. It was also found that the losses in the visible region (where the absorption is negligible) remained almost constant with increasing film thickness indicating that the losses were greater due to surface scattering than bulk scattering. Such changes can be attributed to changes in the film structure, grain size, density fluctuations, stoichiometry and the extent of reoxidation of the film (Pulker 1976; Baumeister and Arnon 1977). For the best 275 nm thick ZrO_2 films prepared the optical constants L , n and k' respectively at different uv laser wavelengths are found to be 8% , 2.35 , 7.0×10^{-3} at 248 nm , 0.6% , 2.16 , 4.7×10^{-4} at 308 nm , 0.24% , 2.12 , 1.2×10^{-4} at 337 nm and 0.14% , 2.11 , 8.8×10^{-5} at 351 nm . The data from the present investigations were used successfully to develop uv coatings for laser applications. Full details of the present investigations and those connected with other materials for developing dielectric mirrors for visible and near infrared region will be published elsewhere.

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