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Thickness Dependence of the Optical Properties of Vacuum Evaporated YF_3 Thin Films

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Abstract

Rare earth oxides and fluorides are well known for their refractory nature and chemical stability and so they find considerable application in electronic and optical devices. The present investigation deals with the optical properties of vacuum evaporated Yttrium fluoride thin films. The thicknesses of the films deposited on cleaned glass substrates were measured by a multiple beam interferometer. XRD technique has been used for structural analysis and dependence of film thickness on structure has also been discussed. Transmittance measurements were made over the wavelength range 400-800 nm. It has been observed that the transmittance decreases with the increase of film thickness. From the transmittance data the absorption index k_f and refractive index n_f were evaluated for the films of different thicknesses (78 to 136 nm). For a film of thickness 103 nm k_f and n_f were calculated as 0.007 and 1.23 respectively at a wavelength of 500 nm. From α^2 versus $h\nu$ plot the optical band gap energy has been estimated as 2.0 eV and the type of transition was found to be allowed and direct.

Key words: Thin films, optical materials

Introduction

Rare earth oxides and fluorides are well known for their refractory nature and chemical stability and so they find wide spread applications in electronic and optical devices (Kierz & Pecold 1969; Goswami & Goswami 1974; Maddocks & Thun 1962). Considerable amount of work has been done on the optical properties of various rare earth fluoride thin films (Hass, Ramsey & Thun 1959; Panasenko, Nesmelov & Tagirov 1980; Paramasivam, Radhakrishnan, & Balasubramanian 1983; Bezuidenhout & Pretorius 1987). However not much work has been carried out on the optical properties of Yttrium fluoride (YF_3) thin films. This paper reports our work on the thickness dependence of optical properties of vacuum evaporated YF_3 thin films.

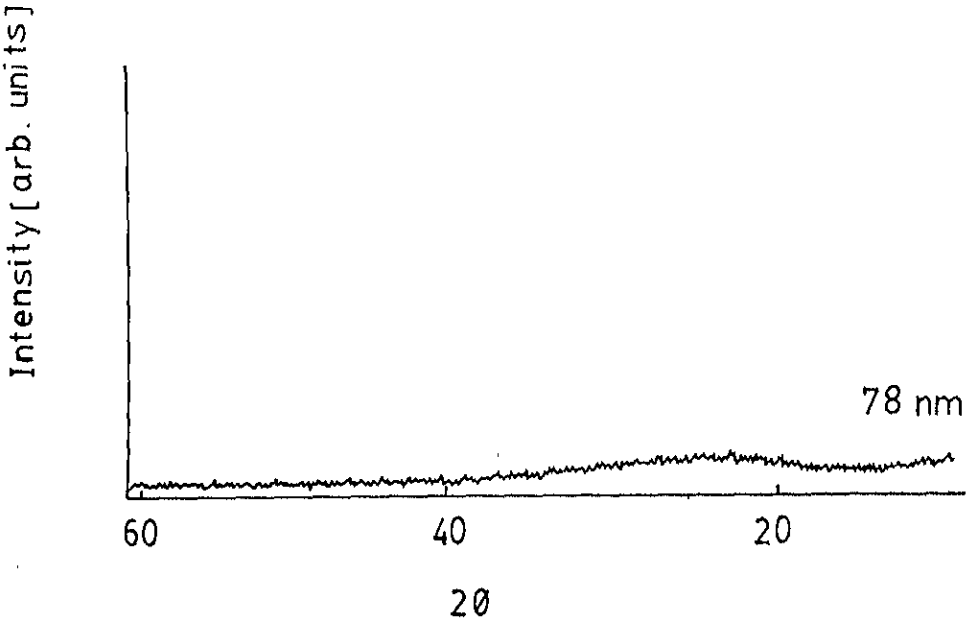

Figure 1. X-ray diffractogram of Yttrium Fluoride thin film of thickness 78 nm.

Experiment

The films were prepared by making use of a 0.3m conventional vacuum coating unit at a pressure of 2.66×10^{-3} pa. The Yttrium fluoride powder of purity 99.99% (Indian Rare Earths Limited, India) made in the form of pellets was evaporated from a resistively heated tungsten conical basket onto cleaned glass substrates to form the YF_3 layer. A constant rate of evaporation was maintained during the film formation. The thicknesses of the films were measured by making use of Tolansky technique (Fizeau fringes). Transmission measurements were made over the wavelength range 400-800 nm using a double beam spectrophotometer (Philips, pye unicom 8825, England). The structural studies have been carried out with the help of an X-ray generator and diffractometer PW1729 (Philips Holland) with filtered CuK_α radiation (0.15418 nm).

Results

The Figs.1 and 2 show the X-ray diffractogram of an YF_3 thin films of thickness 78 nm and 152 nm respectively coated at room temperature. The absence of peak observed from the Fig.1 for a film of thickness 78 nm reveals that the deposited film possesses amorphous structure. From the Fig.2, it can be inferred that the observed small peaks may be due to the small crystallites for the deposited film having higher thickness.

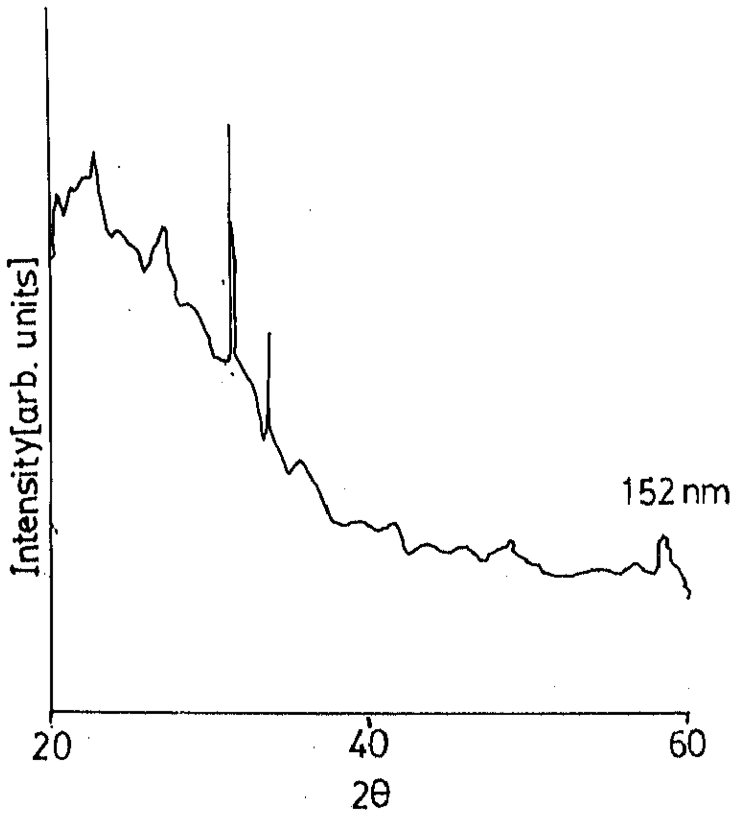

Figure 2. X-ray diffractogram of Yttrium Fluoride thin film of thickness 152 nm.

Fig.3 reprsents the variations of transmittance with wavelength for YF_3 film of different thicknesses. It is observed that the transmittance in the visible region is fairly high and increases slowly with wavelength. At higher wavelength (800 nm) region, it tends to become constant thereby suggesting that the films are non-absorbing in that region. The non-absorbing nature of rare earth fluoride films has already been well established with spectrophotometric measurements by Hass et al. (1959). Similar effect has also been observed by Goswami et al. (1974) for Dy_2O_3 thin films.

The absorption index (k_f) and refractive index (n_f) for the films have been calculated using the relation (Goswami & Goswami 1975)

$$\frac{4n_b}{T_0} = (n_{b+1})^2 cos^2 \frac{2\pi d}{\lambda} n_f + (n_b/n_f + n_f)^2 sin^2 \frac{2\pi d}{\lambda} n_f$$

where n_b is refractive index of glass substrate, n_f is refractive index of film and d is thickness of the film.

The absorption coefficient α can be calculated as

$\alpha = 4\pi k_f/\lambda$, and the absorption index

$$k_f = 2.303 \times (d/4\pi\lambda) \times log(1/T_0)$$

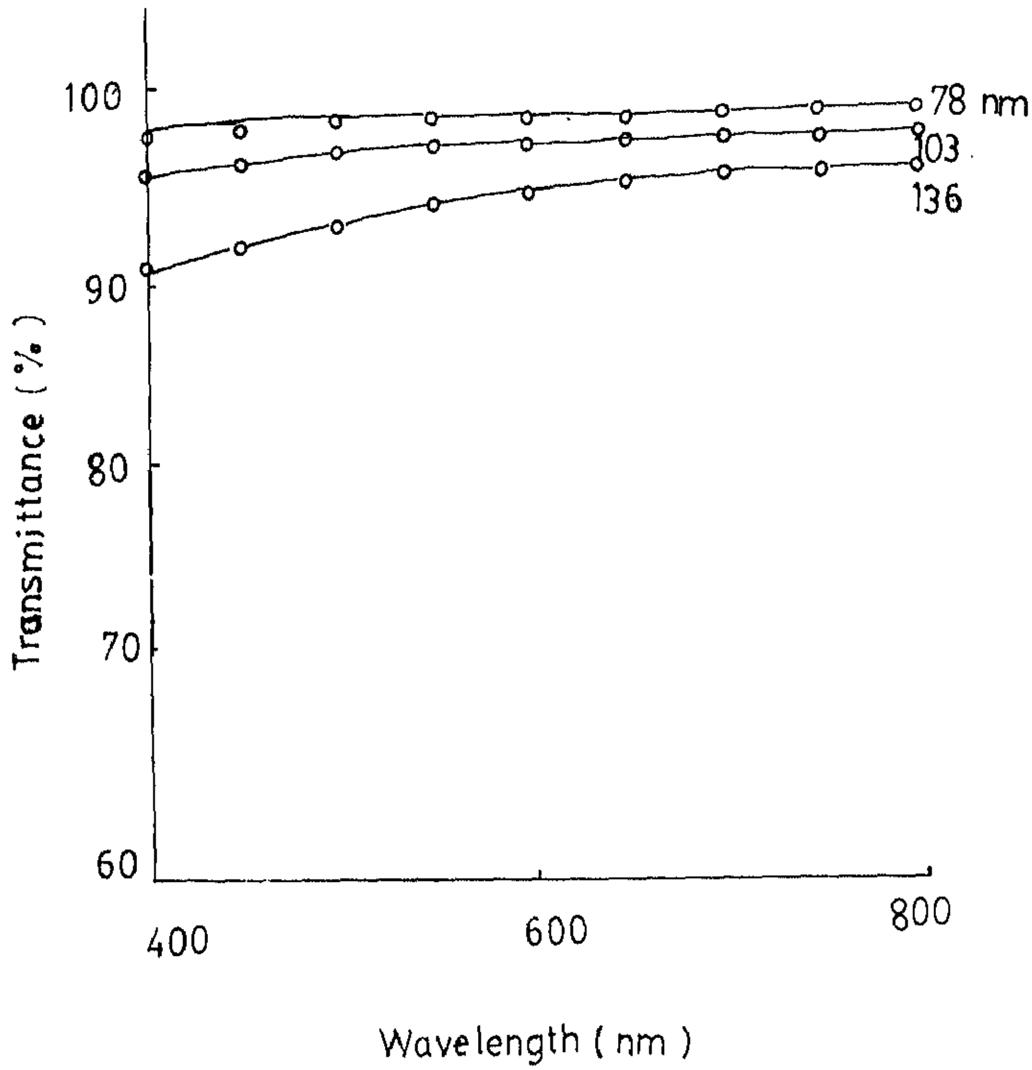

Figure 3. Plot of transmittance (%) versus wavelength.

Fig.4 represents the variation of n_f with wavelength (λ) for different thicknesses. It is seen that n_f is almost constant in the wavlength region of 400 - 800 nm (Paramasivam, Radhakrishnan & Balasubramanian 1983). The refractive index is found to be slightly decreasing with increase of film thickness which may be due to the incorporation of the residual air molecules during he film formation (Maissel & Galang 1975). Also, the band gap energy increases with the increase of film thickness. This may be due to the budding of crystallite at higher thicknesses of the film (Chopra 1976) which is in conformity with our earlier observation on the structural studies. And the type of transition has been found to be allowed and direct.

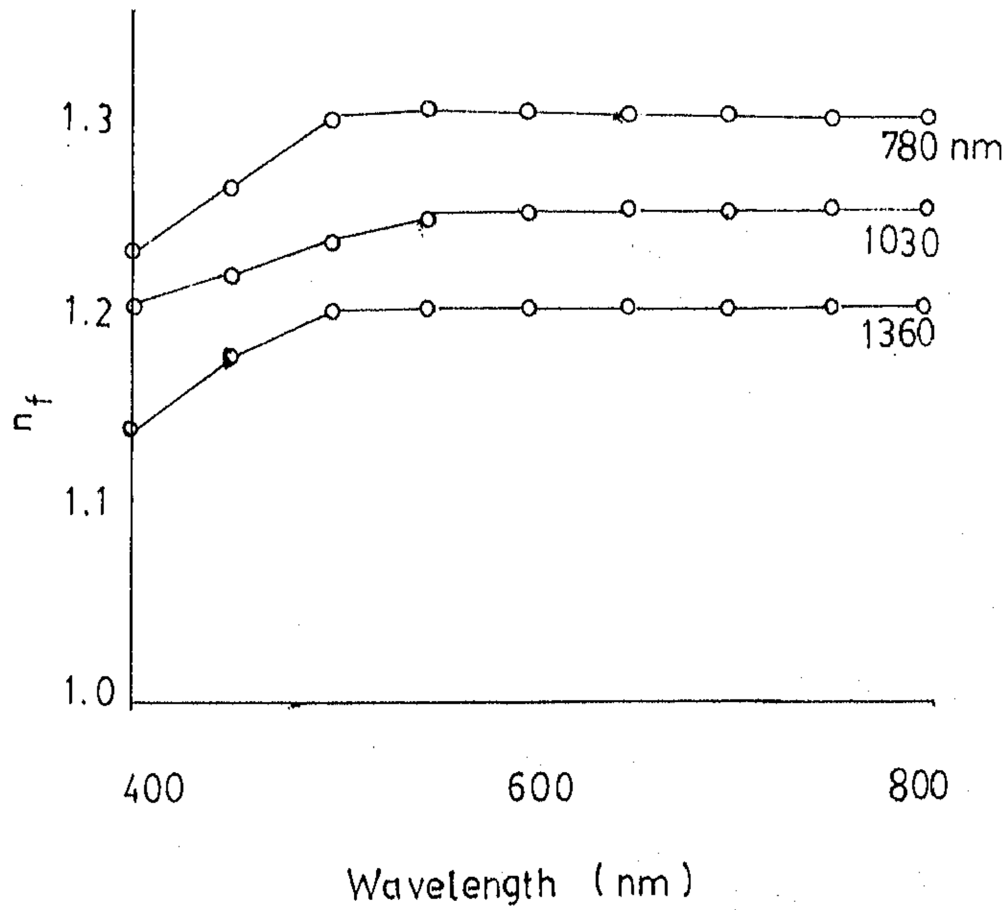

Figure 4. Variation of refractive index with wavelength for different film thicknesses.

From Fig.5, α^2 (absorption coefficient) versus $h\nu$ (photon energy) plot, the optical band gap energy has been estimated for different thicknesses of the films and the results are given in the Table 1.

Table - 1

Film thickness (nm)	n_f	Band gap energy (eV)
78	1.31	1.7
103	1.23	2.0
136	1.20	2.15

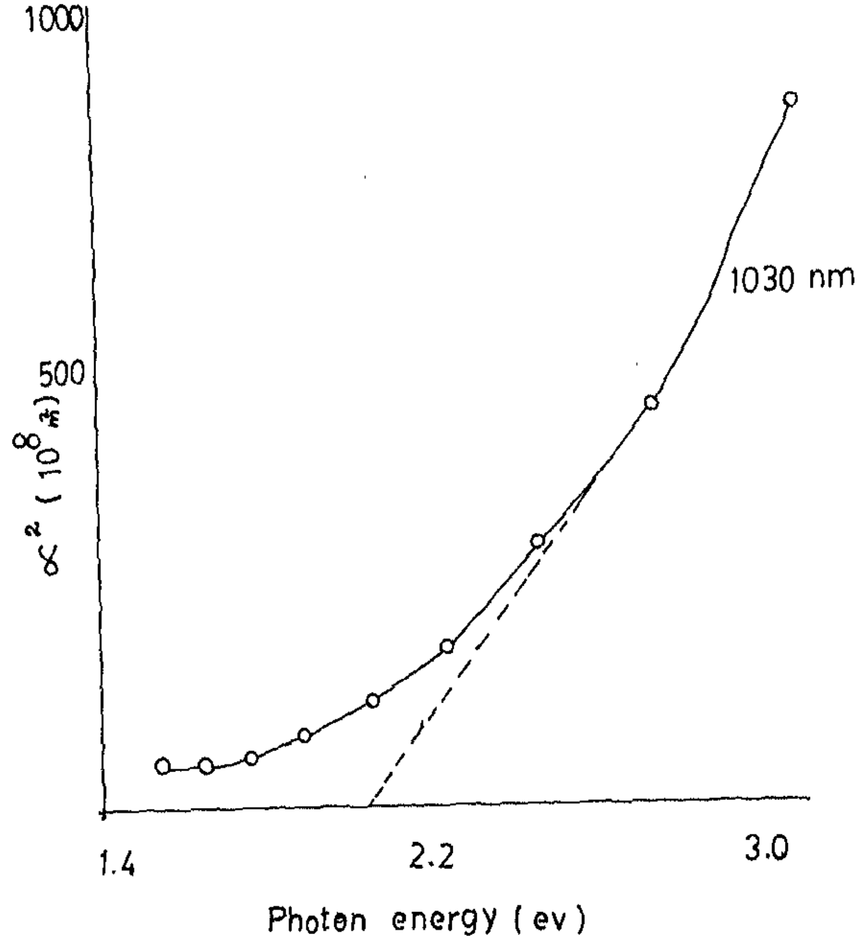

Figure 5. Variation of absorption coefficient versus photon energy.

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