DETERMINATION OF THE OPTICAL PROPERTIES OF ROHDAMINE 6G THIN – FILMS

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Abstract:

In this work, thin films were produced from Rhodamine 6G deposited on glass substrate that has a thickness of 1mm and refractive index equal 1.3 in a vacuum chamber.

The thickness of the thin film was measured by interference phenomena using He-Ne laser with a power of 1 mW during the deposition process.

Incident and transmitted intensity of different laser wavelengths, extended from mid visible (532nm) to near infrared region (1064nm), from the prepared films were measured. These intensities were used to calculate the transmission percentage and the reflectance of the thin film as a function of wavelengths. Furthermore, index and the absorption coefficient for each thin film were deduced. All these measured and calculated values were obtained at normal incidence of laser on the thin film.

The results gave a good indication that this material can be used as filters at some wavelengths. Some variation in the results were noticed where this may be attributed to the inhomogeneous deposition of some of the fabricated films.

1. Introduction:

The study of the optical components requires knowledge of two disciplines, the physics of light and the physics of matter (mostly solid-state). Not to underestimate them, other disciplines such as metallurgy, chemistry, and crystallography are equally critical, but for the purpose of this paper, they are of secondary importance. Here we focus on that part of the physics of light and matter that helps one to understand the optical properties of the thin films used as optical components [1].

Usually, thin films are modeled as parallel – sided homogeneous slabs of some material, which are characterized by the optical constants n (refractive index, real part) and an intolerances physical thickness d [1].

1 - 1 General theory of filter:

There are many different ways of describing the performance of optical coating and filters. For example, transmission and reflection filter intended for visual application are adequately described by a color name alone, or by reference to one of the several existing color system. However, the most complete information on the performance of the filter is provided by spectral transmittance, reflectance, absorptance, and optical density curves [2, 3].

Referring to fig (1), at wavelength (λ), the normal incidence spectral transmittance T(λ) of a filter placed between two semi-infinite media is equal to the ratio of the light intensity of that wavelength transmitted $I_T(\lambda)$ by the filter to that incident $I_0(\lambda)$ upon it [4].(see eqn. 1)

$$T(\lambda)=\frac{I_T(\lambda)}{I_0(\lambda)} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

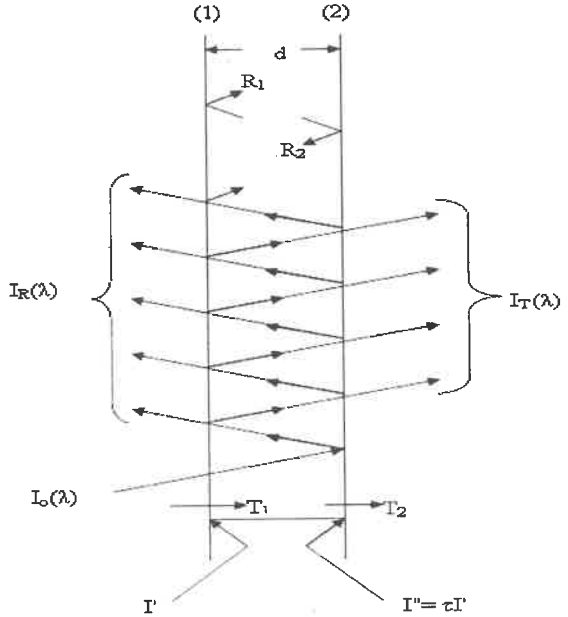

Fig (1): Specular transmission and reflection of light by a plane-parallel plate

At non-normal incidence, the component of the intensity perpendicular to the interface must be used in the preceding equation. The spectral reflectance R (λ) of the filter is defined in a similar way,

$$R(\lambda)=\frac{I_R(\lambda)}{I_0(\lambda)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The relationship between the transmittance T (λ) and the density of filter, sometimes also called the absorbance, is given by

$$D(\lambda)=\log\frac{1}{T(\lambda)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

1 - 2 Thin – film manufacturing methods:

There are many different methods for the manufacturing of thin films; some of the more common processes are reviewed below:

I. Evaporation:

Conventional (non-reactive) or reactive evaporation from resistance, induction, or electron beam gun sources is a low-energy process (~0.1eV) and the resulting films frequently have a porous structure. The porosity may vary with the material, the substrate temperature, the residual pressure in the deposition chamber, the deposition rate, and angle of incidence of the vapor on the substrate. On exposure to the atmosphere, some of the voids in the film may absorb water vapor. This increases the effective refractive index of the films and results in a shift of the spectral features of the multilayer towards longer wavelengths ("ageing"). This shift is partially reversible – by placing the filter in an inert atmosphere or in a vacuum, or on heating. Some of the adsorbed water vapor can be removed. Unless it has been allowed for at the design stage, such ageing can render some filters useless [4, 5].

II. Sputtering:

Sputtering is a vacuum process used to deposit very thin films on substrates for a wide variety of commercial and scientific purposes. It is performed by applying a high voltage across a low-pressure gas (usually argon at about 5 millitorr) to create a "plasma," which consists of electrons and gas ions in a high-energy state (this is sometimes called a "glow discharge" process because the plasma emits a colorful halo of light.) as well as neutral particles in collective behaviour .

During sputtering, energized plasma ions strike a "target", composed of the desired coating material, and cause atoms from that target to be ejected with enough energy to travel to, and bond with the substrate [4, 6].

Reactive or non-reactive dc or RF magnetron sputtering is also used to deposit optical multilayer coating. Many variations of this process exist. Most are significantly slower than evaporation and the targets can be quite expensive. Filters produced by dc or RF sputtering may therefore also be more expensive. However, the process is stable, provides excellent control over the thicknesses of the layers, and can be readily scaled tō provide uniform coating over large areas. Both metal oxide layers can be produced. Sputtering is an energetic process whicn results in dense, bulklike layers which exhibit virtually no ageing [4, 7]

III. Deposition from solutions:

In this procedure, the substrate is either dipped in an organo-metallic solution or withdrawn at a very steady rate from it, or the solution is applied from a pipette onto a spinning substrate. The substrate is then placed in an oven to drive off the solvent. The thickness of the film depends on the concentration of the solvent and on the rate of withdrawal or spinning. Other factors which influence the process are temperature and humidity, as well as the freshness of the solution. Although it yields quite porous films, this method is of interest because many of the layers produced in this way have a high laser damage threshold. The process has also been adapted for the coating of quite large area substrates with multilayer antireflection coatings for picture frame glass and for display windows [4].

2. Experimental part:

A. Setup:

Figure (2) shows the arrangement of the setup used to produce the thin film and measuring its thickness.

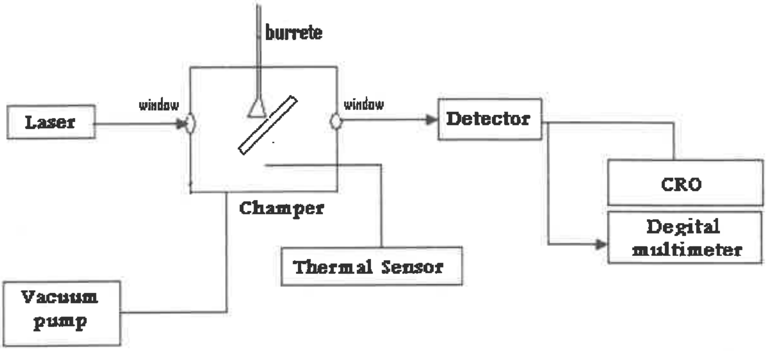

Fig.(2) : The arrangement of the setup used to produce the thin films and measuring the thickness.

Different laser sources were used to measure the thickness and the optical properties of the deposited thin film:

He - Ne Laser with wavelength of 632.8nm and power of 1mW was used to measure the thickness. Nd: YAG with 1064nm wavelength and maximum peak power of 150W with its second harmonic (532 nm), Omega laser (a type of diode laser) with two probes, the first with wavelength of 675 nm and output power of 30 mW, and the second probe with wavelength (820) nm and output power of 200 mW, Ora – Laser jet of wavelength of 810nm and power of 20 W, and Dornier Medilas D SkinPulse laser (a type of diode laser) with a peak power of 120 watt and 940 nm wavelength, were used in this work to measure the optical properties of the deposited thin films.

B. Samples material:

Rhodamine is a family of related chemical compounds, fluorine dyes. Examples are Rhodamine 6G and Rhodamine B. They have been used as a dye and as a dye laser gain medium. It is often used as a tracer within water to determine the rate and direction of flow and transport. Rhodamine dyes fluoresce and can thus be measured easily and inexpensively with instruments called fluorometers. Rhodamine dyes are soluble in water, methanol, and ethanol. Figure (3) shows the structure of Rhodamine 6G molecule [8].

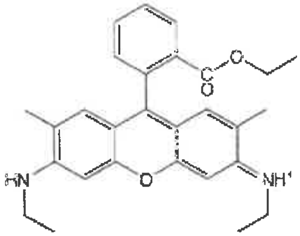

Fig (3): Rhodamine 6G structure

Rhodamine 6G is often used in a laser dye pumped by the 2nd harmonic (532 nm) from a Nd: YAG laser since it has a remarkably high photostability, high quantum yield, low cost, and close proximity to the absorption maximum (approximately 530 nm). The lasing range is 555 to 585 nm with a maximum at 566 nm.

Rhodamine 6G is also called Rhodamine 590, R6G, Basic Rhodamine Yellow, or C.I. 45160. Molecular Formula: $C_{28}H_{31}N_2O_3Cl$, Molecular Weight: 479.02 g/mol [8, 9].

C. Experimental procedure:

The experimental procedure was done as follows:

- The experimental setup was arranged as shown in fig (1).
- The sample holder was inserted in the vacuum chamber.
- The vacuum pump was turned ON to evacuate the chamber.
- Helium – neon laser was turned ON and the transmitted intensity, (***I_0***), was detected and measured by CRO.
- The sample was deposited slowly from the burrete on the glass substrate, in the same time the transmitted intensity was detected by CRO during the deposition, and the interference fringes were recorded as shown in fig (4), indicated that the thin film is formed, then the transmission intensity (***I***) was measured.
- The thickness of the thin-film can be deduced via the interference fringes, here it was equal to half-wavelength of the He-Ne laser (316.4 nm).
- The optical properties of the thin film were obtained using different laser sources.
- The absorption coefficient and the refractive index for all the thin films were calculated using the measured reflectivity ***R*** and the glass refractive index ***n_s*** according to [10, 11]:

$$n = \left\{\frac{n_s\left(1+\sqrt{R}\right)}{1-\sqrt{R}}\right\}^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (4)$$

$$n_s = \frac{1}{T_S}\left(\frac{1}{T_S^2}-1\right)^{\frac{1}{2}}$$

where ***T_s*** represents the transmission of glass substrate.

- The absorption coefficient was deduced from the measured value of reflectivity ***R***, transmittance ***T***, refractive index n_s, and thickness d according to:

$$\alpha = \frac{1}{d}n\frac{\left(1-R\right)^2}{T} \quad \ldots\ldots\ldots\ldots (5)$$

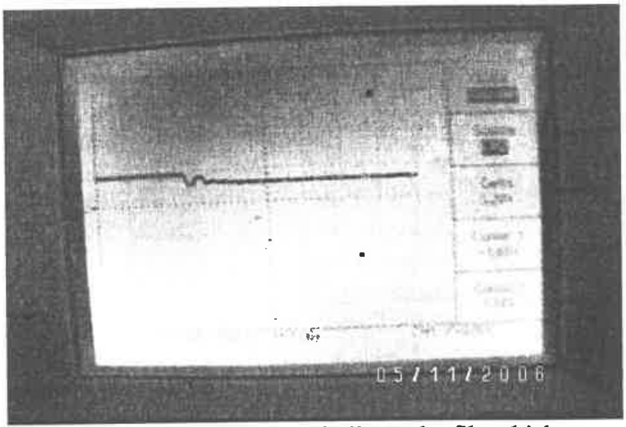

Fig (4): interference fringes indicate the film thickness.

3. Results and discussion:

This work was limited to the case of a single layer deposited on a substrate. Practically, this kind of thin films can be used in the ultraviolet, visible, or infrared regions of the spectrum. As a filter, some wavelengths were transmitted, and others are reflected, according to the characteristics of the layer that constitute this optical filter.

In a general way, each layer is characterized by its refractive index (n), its absorption coefficient (α), and its thickness (d).

Two samples were prepared at the same condition of concentration and thickness, and also the substrate. Howevere, the difference between the two samples come from the difference in the room temperature.

Sample S_1 at (27):

The transmission spectrum of this sample, in the region between 532 and 1064 nm, is shown in figure (5) below.

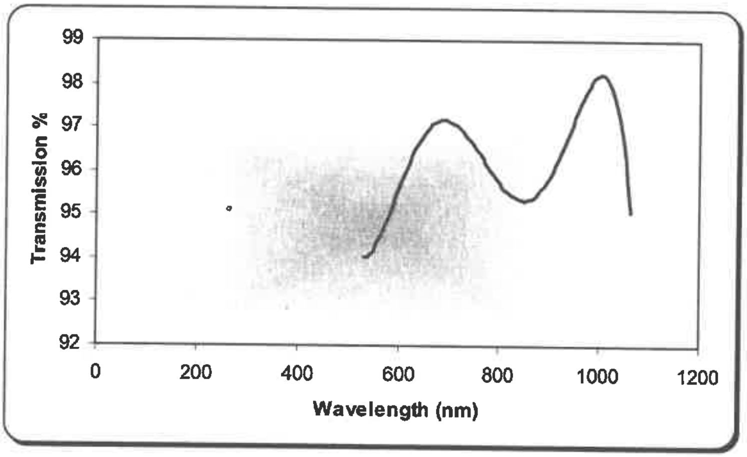

Fig (5): Transmission spectrum of sample S_1

From this figure one can see that the transmission at (1040) nm is very high compared with other wavelengths, and then one can use this property to make a transmission filter from this material. Also one can do the same thing at the wavelength (700) nm. The transmission at (532) nm is very low compared with other wavelengths and this property give ability to make an optical filter, specially if we used this material with a thickness greater than this thickness, (or we deposited it in multilayer), or by mixing this material with other materials (by different concentrations or different thicknesses), also one can make the same assumption for this sample at (850, and 1064) nm.

Also this figure gives a good permeation to use this material as an absorption filter at the wavelengths (532, 850, and 1064) nm, or to use it, with multilayer each with the same thickness, like cold mirror in the range from (650) to (750), and (940) to (1050) nm, due to the high transmission of this material at this range.

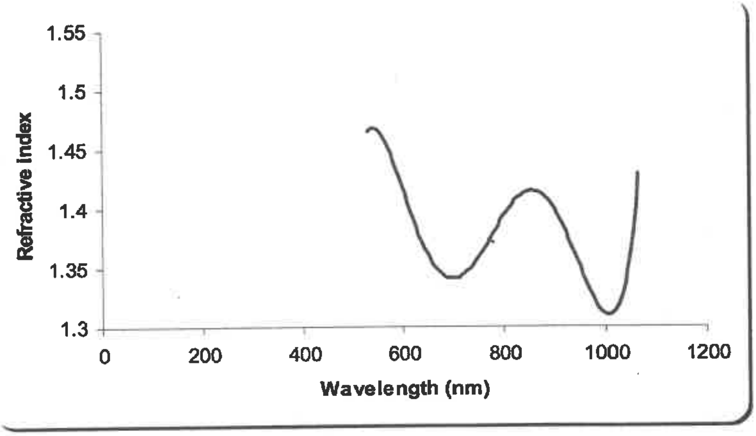

Fig (6): Refractive index of sample S_1 as a function of wavelength

Figure (6) illustrates the relationship between the refractive index of sample (S_1) and laser wavelengths.

Also one can see from this figure that this material can be used with a thickness equal to a quarter – wavelength like (anti-reflection single layer coating) at wavelength (1000) nm and that depends on the following relationship [10]

$$n_1 = \sqrt{n_0 n_s}$$

where (n_0) is the refractive index of air, and (n_s) is the refractive index of the glass surface, while (n_1) is the refractive index of the material. One can do the same thing at the wavelength (700) nm.

From figures (5 and 6) one can see that the refractive index become high when the transmission percentage become low and vise versus.

The absorption coefficient (α) for these samples was deduced from the measured values of the incident intensity (I_0) and transmitted intensity (I) in addition to the thickness (x) according to Beer's Lambert law. Its variation as a function of the wavelengths is shown in fig (7) below.

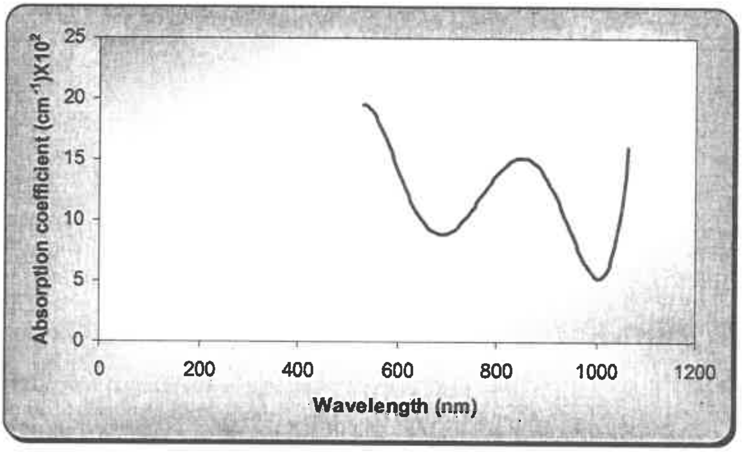

Fig (7): The Absorption coefficient of sample S_1 as a function of wavelength

Also, this figure supported the usage of this material as a cold mirror at the range (650) to (750), and (940) to (1050) nm, because it shows low absorption coefficient at that specific range. One can see also that when the refractive index is high, the absorption coefficient is high and vise versus.

Sample S_2 at (25^{0}C):

The transmission spectrum of sample (S_2) in the range between 520 and 1064 nm is Shown in Figure (8).

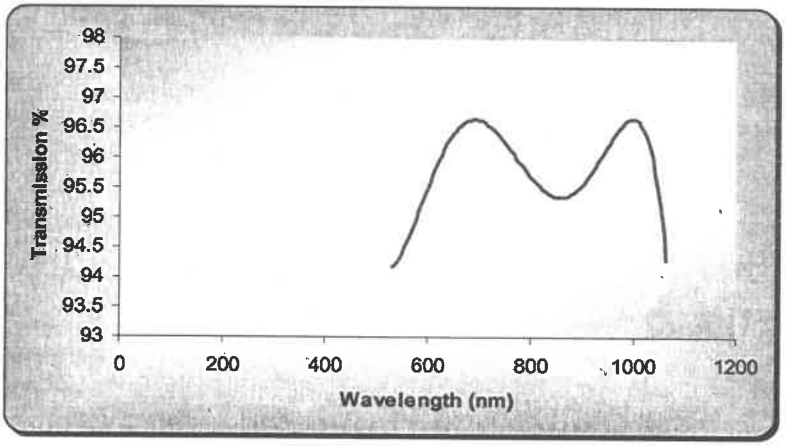

Fig (8): Transmission spectrum of sample S_2

The comparison between figure (5) and figure (8) shows a slight increase in the transmission of sample (S_1) than sample (S_2) in the region between 550 and 750 nm. The same thing can be noticed between 900 and 1064 nm, so sample (S_2) can be used to get good filter (band pass filter) in these two regions. The same thickness of sample (S_1) was gained for sample (S_2).

Since the two samples have equal thickness, then the difference in the values of transmission comes from the difference in the room temperatures.

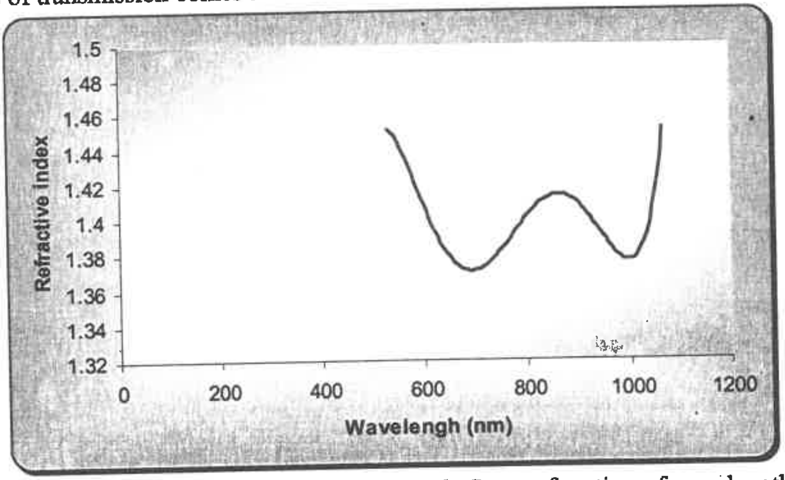

Fig (9): Refractive index of sample S_2 as a function of wavelength

The refractive indexes (n) of the two films were calculated using the calculated reflectivity (R) and the glass refractive index (n_s) according to equation (4).

Fig (6) and fig (9) show the variation of the refractive index (n) with the laser wavelengths for samples (S_1) and (S_2) that were prepared in different room temperatures. These figures show that the refractive index of sample (S_1) increase slightly more than the refractive index of sample (S_2).

The variations in the data between the two samples are depending on the difference in the temperature which contribute, with the deposition itself, to how much the film is homogeneous or not.

Fig (7) and fig (10) show the absorption coefficient as a function of wavelength for samples (S_1) and (S_2), respectively. They are similar in the regions from 532 to 620 nm and from 800 to 900 nm, but there is a slight increase for absorption coefficient of sample (S_2) than sample (S_1) between these two ranges and that which isdne to the difference in temperature during the deposition process.

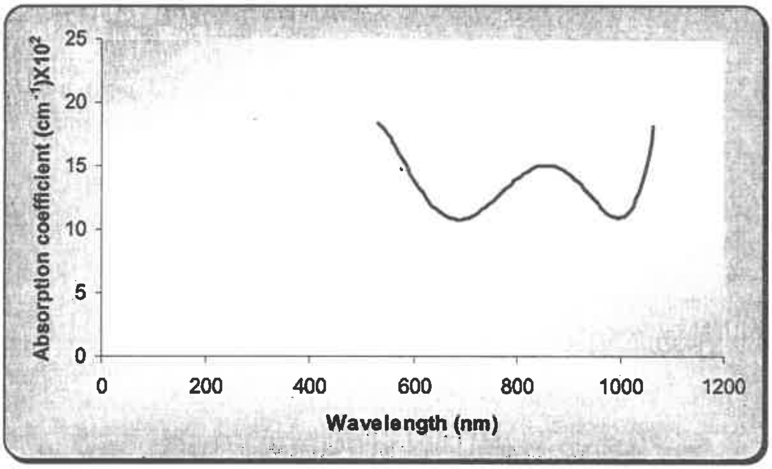

Fig (10): Absorption coefficient of sample S_2

4. Conclusions:

Form the obtained optical properties of Rohdamine 6G thin films at room temperature in the spectral range (520 - 1064) nm, one concludes that:

- The thickness of the deposited liquid samples can be controlled and measured via interference fringes of the transmitted laser light.
- The results showed that the increase in the room temperature affected the transmission of the films where the refractive index, absorption coefficient are depending mainly on it.

This material can be used to produce optical components in the range from (532) to (1064) nm.

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