Original article

# Determination of the optical properties of chloroform thin-films

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**Abstract**
In this work, thin films were produced from chloroform deposited on a glass substrate in a vacuum chamber, at room temperature and different temperatures. The thickness of the thin film was monitored during the deposition process. Incident and transmitted intensity were measured for the prepared films at different laser wavelengths extended (532–1064 nm). Also, the refractive index and the absorption coefficient for each sample were derived. The results obtained give a good indication of the use of these films as optical components such as filters, reflectors, attenuators and mirrors. Moreover, the optical properties of the thin films don't depend on the thickness, but mainly on the temperature of the substrate.

**Key words:** Thin-films, chloroform, optical properties, thickness.

## Introduction

Chloroform, also known as tri-chloromethane and methyl tri-chloride, is a chemical compound with the formula $CHCl_3$ [1]. It is not compatible with combustion in air, although it will burn when mixed with more flammable substances, the major use of chloroform today is in the production of the Freon refrigerant R-22 [2].

The absorption coefficient and the refractive index are important physical parameters, which are widely used in physics and chemistry, there are used to identify, purity, and concentration of liquid. If we consider the interaction of light with media then typical phenomena that can be observed are light refraction, reflection and scattering, in all these three phenomena's the refractive index of the medium is an important factor affecting of light due to interaction [3]. The refractive index is dependent on the wavelength of light because the speed of light waves depends on their wavelength [3], also it depends on the density of the measured sample, which is affected by its high pressure and high temperature [4].

However, in the present work the optical properties of chloroform thin film specimens were investigated utilizing different laser sources with different wavelengths and power output. In addition, the results obtained give a good indicator to be used these film specimens as optical components. As well as, the optical properties of the thin films are independent on the thickness, which mainly depend on the temperature of the substrate.

## Materials and methods

The experimental setup was arranged as shown in Fig. 1. The sample holder was created in the vacuum chamber, which was

closed after that carefully. The vacuum pump was turned (ON) to evacuate the chamber and the pressure was measured inside the chamber after 10 minuts by a vacuum gauge. Helium-neon laser was turned (ON) and then the incident intensity ($I_0$) was measured by a digital multi-meter. The signal was detected by CRO. The sample specimen was deposited slowly from the burette on the glass substrate, which has a refractive index equal to 1.3 and a thickness of 1mm. The signal was detected by CRO during the deposition, and the interference fringes were recorded as shown in Fig. 2, indicating that the thin-film is formed, and the transmission intensity ($I$) was measured. The thickness of the thin-film is well-knew from the interference fringes, which is equal to the half-wavelength of the He-Ne laser 632.8nm. The optical properties of the thin-film were controlled in various 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:

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

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

Where, $T_s$ represents the transmission of glass substrate [5, 6].

The absorption coefficient was deduced from the measured value of reflectivity $R$, transmittance $T$, refractive index $n_s$, and thickness d according to [5,6] :

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

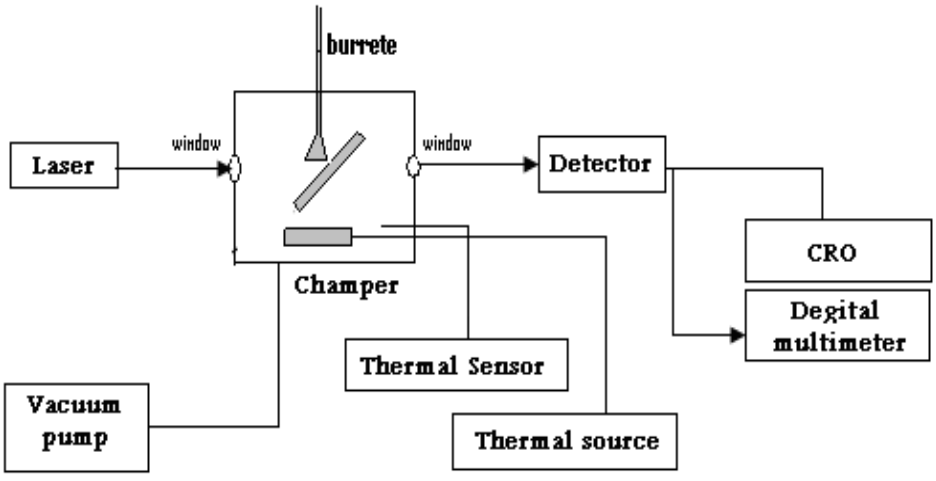



**Figure 1.** Setup experiment diagram

Thermal source was inserting inside the chamber to heat the substrate to separate temperature and then new thin films were formed. All optical properties were calculated using equations above. After determining the optical properties of the samples in a graph between wavelengths and the ratio between (I and $I_o$) has been drawing

as Fig. 3 showed. Also, the affect of the temperature on the optical properties drawn as showed in Fig. 4.

## Results and discussion

Some of these results were measured and the others were calculated to determine the parameters that optically characterize a thin film. This work was confined to the case of a single layer deposited on a substrate [7]. Practically, this kind of thin films can be employed in the ultraviolet, visible, or infrared regions of the spectrum [8,9]. As a filter, some wavelengths were transmitted, and others are reflected, according to the characteristics of the layer that constitutes this optical filter. In a general way, each layer is characterized by its refractive index [7], its absorption coefficient [8], and its thickness [9].

Different samples were prepared from chloroform as a series of thin films under different temperatures, as listed in Table 1.

**Table 1.** Series of thin films under different temperature degrees

| Name | Material | Temperature $^0$C |
|---|---|---|
| $S_1$ | chloroform | 25 |
| $S_2$ | chloroform | 28 |
| $S_3$ | chloroform | 38 |
| $S_4$ | chloroform | 45 |
| $S_5$ | chloroform | 49 |

First of all the results obtained from the study of chloroform that was deposited without heating (at room temperature = 25 $^{\circ}$C, i.e. S1) will be presented with full details. All the data for this sample will be listed in tables and figures, while for other samples the results will be presented in figures only in order not to repeat the presentation of all the numbers gained during the experiments.

**Sample ($S_1$):**

The measured values of incident and transmitted intensity of different laser wave lengths are listed in Table 2.

**Table 2.** The incident and transmitted intensity of laser wavelengths for sample ($S_1$)

| λ (nm) | $I_0$ (Volt) | I (Volt) |
|---|---|---|
| 532 | 0.285 | 0.264 |
| 632.8 | 0.450 | 0.436 |
| 675 | 0.471 | 0.448 |
| 810 | 0.563 | 0.546 |
| 820 | 0.543 | 0.538 |
| 940 | 0.472 | 0.461 |
| 1064 | 0.467 | 0.439 |

According to the transmittance relationship ($T = I/I_0$) [10], the transmission percentage of this sample was calculated and listed in Table 3.

**Table 3.** The transmission percentage of sample ($S_1$)

| λ (nm) | T |
|---|---|
| 532 | 0.926 |
| 632.8 | 0.969 |
| 675 | 0.951 |
| 810 | 0.970 |
| 820 | 0.991 |
| 940 | 0.977 |
| 1064 | 0.940 |

From the results in Table 3, and depending on the relationship $T + R = 1$, the reflectance was calculated and listed in Table 4.

**Table 4.** The transmittance and reflectance of ($S_1$)

| λ (nm) | T | R |
|---|---|---|
| 532 | 0.926 | 0.074 |
| 632.8 | 0.969 | 0.031 |
| 675 | 0.951 | 0.049 |
| 810 | 0.970 | 0.030 |
| 820 | 0.991 | 0.009 |
| 940 | 0.977 | 0.023 |
| 1064 | 0.940 | 0.060 |

One of the important points of this work is the measurement of the film thickness, where it was measured using the interference phenomena. By assumption, there is a transparent surface acknowledges their thickness and refractive index, and there is a monochromatic light pass through it, some of it will be reflected and the other transmitted. When a thin layer coated over this surface some of the light will be reflected at the boundary between the two surfaces and the other transmitted. The reflected light will be reflected again at the boundary between the thin layer and air and then transmitted through the transparent surface and interfere with the first one because it comes after it by full wavelength [11-14].

Then, the thickness of the thin layer that deposited on the transparent surface will be equal to half–wavelength for the light that was used [11-14]. Figure 2 shows a photograph of the signal of interference fringes that the thin film, $S_1$, thickness can be calculated from it.

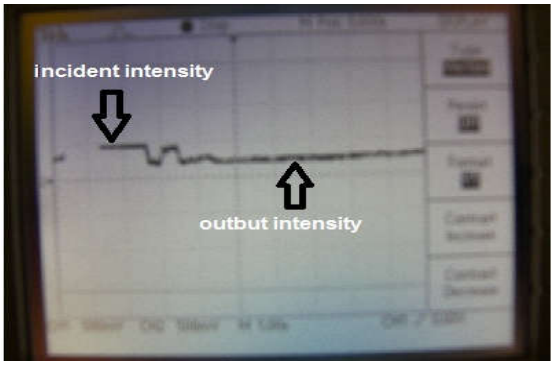



**Figure 2.** The signal of interference fringes that the thickness of sample (S1) can be calculated from.

By using Beer Lambert law and knowledge of the film thickness and with the results in Table 2, the absorption coefficient for this sample was calculated at different wavelengths, and the results are listed in Table 5.

**Table 5.** The absorption coefficient of ($S_1$)

| λ (nm) | α ($cm^{-1}$) X$10^2$ |
|---|---|
| 532 | 24.19 |
| 632.8 | 9.99 |
| 675 | 15.82 |
| 810 | 9.69 |
| 820 | 2.92 |
| 940 | 7.45 |
| 1064 | 19.54 |

By using the following relationship [5,6]

$$n = \left\{ \frac{n_s\left(1+\sqrt{R}\right)}{1-\sqrt{R}} \right\}^2 \quad \ldots\ldots (3)$$

Where (n) is the refractive index of the film, ($n_s$) is the refractive index of the glass substrate, and (R) is the reflectance of film, and the results in Table 4, the refractive index of this sample was calculated and the results of it are tabulated in Table 6.

**Table 6.** The refractive index of (S1)

| λ (nm) | n |
|---|---|
| 532 | 1.507 |
| 632.8 | 1.362 |
| 675 | 1.428 |
| 810 | 1.358 |
| 820 | 1.254 |
| 940 | 1.329 |
| 1064 | 1.464 |

These parameters (thickness, absorption coefficient, and refractive index) represent the optical properties of the sample ($S_1$) which are the most important parameters for any thin film [15,16]. The transmission spectrum for this sample, in the region between 532 and 1064 nm, is shown in Fig. 3.

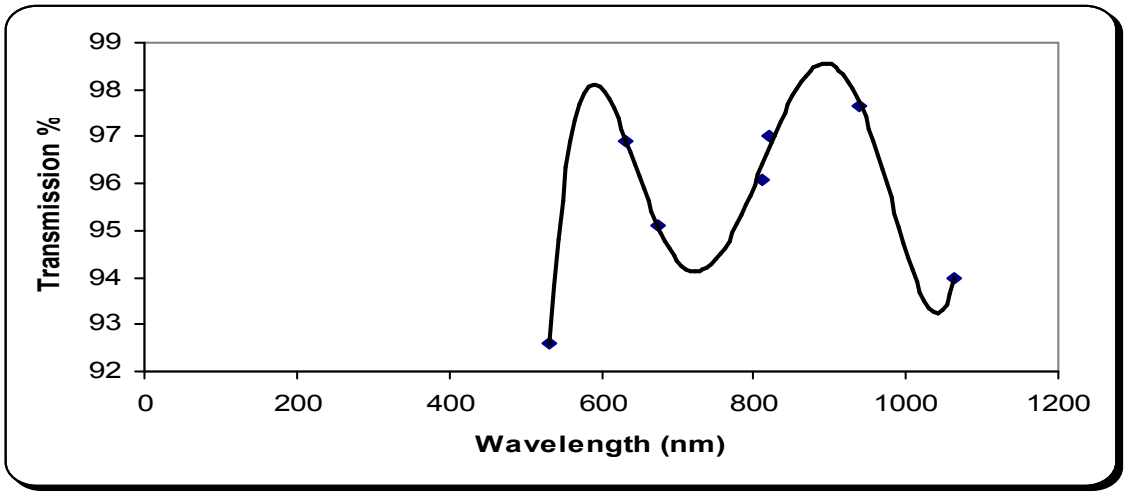



**Figure 3.** Transmission spectrum of sample (S1)

From this figure, one can see that the transmission (%) for a sample ($S_1$) is very high at 600 nm compared with other wavelengths. It is a good indicator to use this property to produce an optical filter at this wavelength, especially if we used this material with a thickness greater than this thickness, (or we deposited it in multilayers), or by mixing this material with other materials (by different concentrations or different thicknesses). However, one can do the same assumption for this sample at the wavelength of 900 nm.

If we look at the wavelengths 532, 720 and 1064 nm, one can see that the transmission percentages of it are lower than other wavelengths. Then, one can take advantage of this sample to produce a reflector at these wavelengths.

Figure 4 illustrates the relationship between the absorption coefficients for sample ($S_1$) and laser wavelengths.

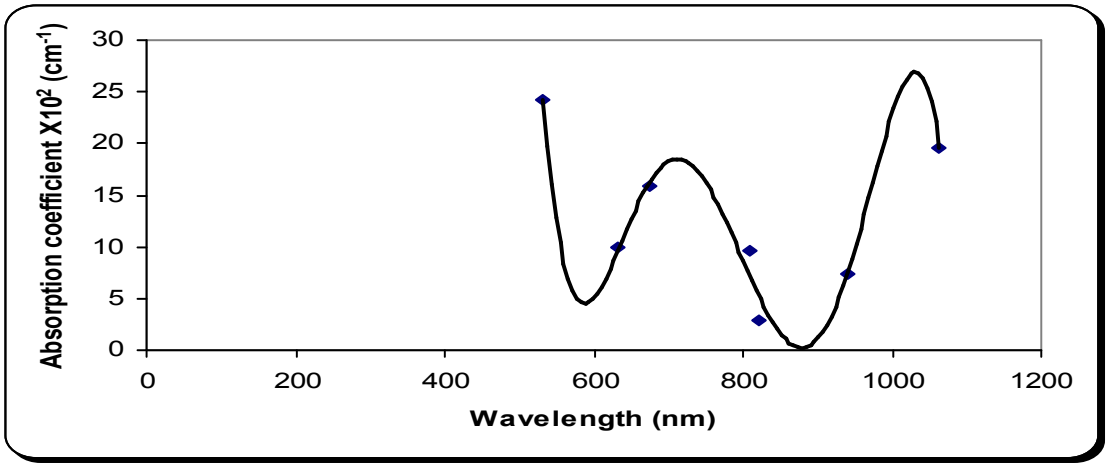



**Figure 4.** The absorption coefficient of sample (S1) versus wavelengths

This figure supported the idea to use this sample as an absorption filter or as a reflector in the wavelengths 532, 720, and 1064 nm because the absorption coefficient of it at these wavelengths is very large compared with other wavelengths. By noting the absorption coefficients at 590 and 890 nm, one may use sample ($S_1$) as a transmission filter, because the absorption coefficient of it at these wavelengths is very low.

Figure 5 represents the relationship between the refractive index of the 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 820 nm that depend on the following relationship [6].

$$n_1 = \sqrt{n_0 n_s} \quad \ldots\ldots (4)$$

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.

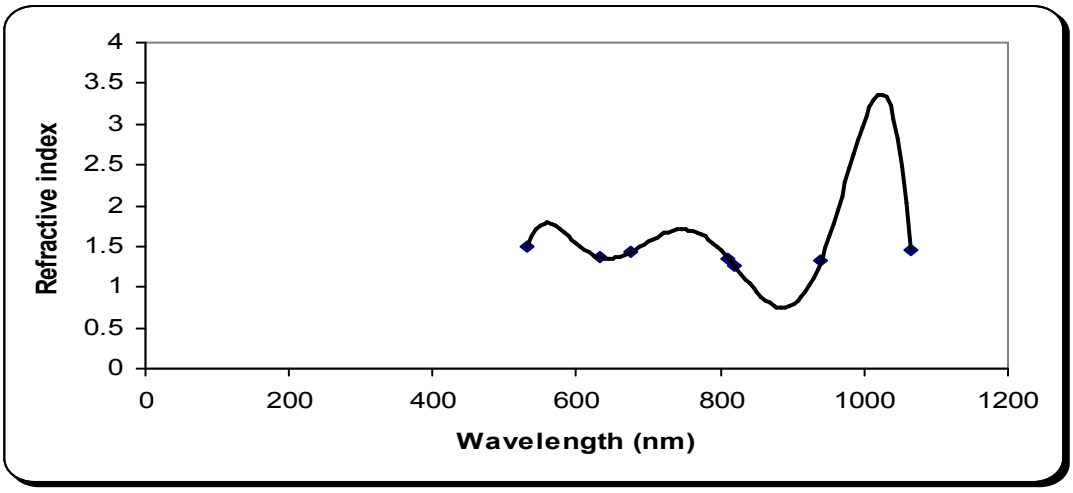



**Figure 5.** The refractive index of sample ($S_1$) versus wavelength

One can see also, from Figs. 4 and 5, that when the absorption coefficient is high, the refractive index is also high at the same wavelengths.

**Sample ($S_2$):**

Figure 6 shows the transmission spectrum of sample ($S_2$) in the range between 520 and 1064 nm.

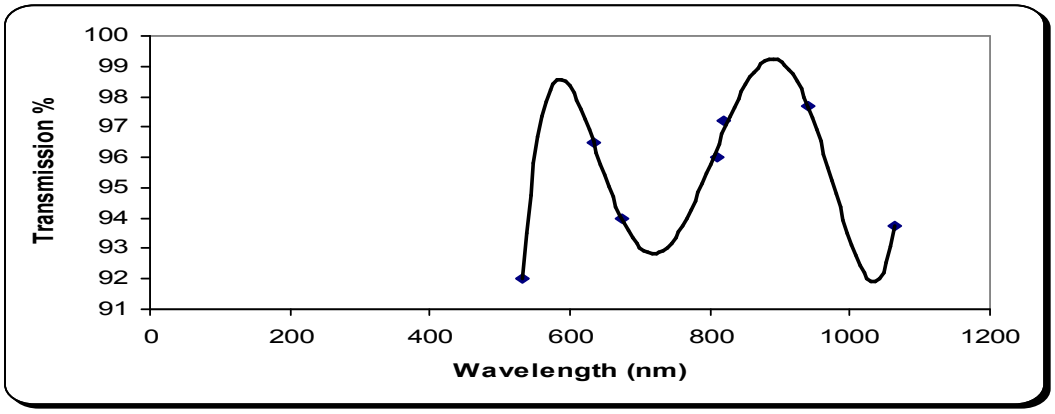



**Figure 6.** Transmission spectrum of sample ($S_2$)

The comparison between Figs. 3 and 6 show a slight increase in transmission of the sample ($S_1$) than the sample ($S_2$) in the region between 532 and 810 nm. The same thing can be noticed between 940 and 1064 nm, so sample ($S_2$) can be used to get a good filter (band pass filter) in these two regions. The thickness of sample ($S_2$) was controlled during the deposition via the interference fringes. The same thickness of sample ($S_1$) was gained for sample ($S_2$) as showed in Fig. 7. Since the two samples have equal thickness, then the difference in the values of transmission comes from the difference in the room temperatures.

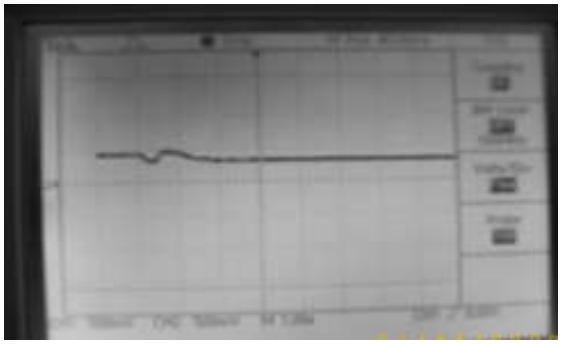


**Figure 7.** The signal of interference fringes that represent the thickness of sample ($S_2$)

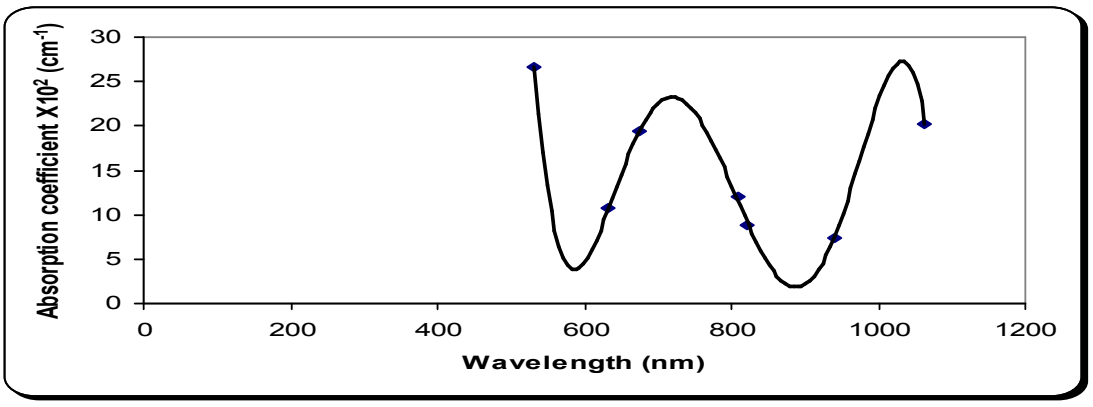



**Figure 8.** The absorption coefficient of sample ($S_2$) as a function of wavelength

Figures 4 and 8 show the absorption coefficient as a function of wavelength for the samples ($S_1$) and ($S_2$), respectively. They are similar in the regions from 532 to 630 nm and from 930 to 1064 nm, but there is a slight increase for absorption coefficient of sample ($S_2$) than sample ($S_1$) between these two ranges and that is because, of the difference in temperature during the deposition process.

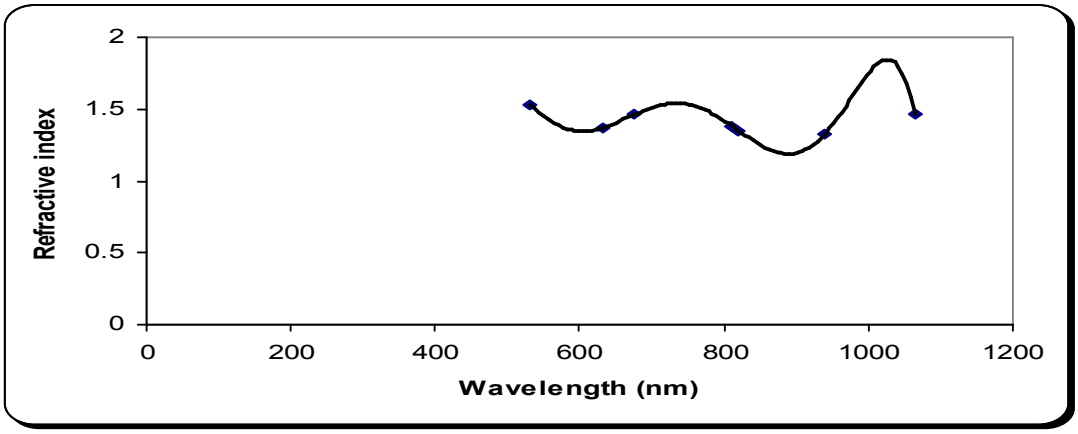



**Figure 9.** The refractive index of sample ($S_2$) versus the wavelength

The refractive index (n) of the two films was calculated using the calculated reflectivity (R) and the glass refractive index ($n_s$) according to equation (1).

Figures 5 and 9 indicate the variation of the refractive index (n) with the laser wavelengths for the samples ($S_1$) and ($S_2$) respectively, that were prepared without heating. These figures show that the refractive index of sample ($S_1$) increases slightly than the refractive index of the sample ($S_2$). The variations in the data between the two samples are depending on the difference in the temperature which contributes, with the deposition itself, to how much the film is homogeneous or not.

**Samples ($S_3$, $S_4$ and $S_5$):**

Thermal stability is a major factor in the suitability of thin film coated optical elements for certain applications. However, there are some more phenomena related to thermal treatment like the temperature dependence of the optical properties of thin films must particularly be considered in sophisticated applications such as a narrowband filter or laser mirrors [17]. Thin films tend to dilate when the temperature eases. The important conclusion that can be derived from these investigations is that the effect of the temperature is semi uniform for more types of films as shown in Fig. 10.

Figure 10 depicts the transmission spectra in the range 520-1064 nm obtained for films of chloroform deposited on substrates maintained at different temperatures. All curves show a slight increase in the transmission with increasing substrates temperature up to 49 $^0$C, where the

transmission increases drastically between 38 $^0$C to 45 $^0$C. It can be noticed that at higher temperature, all films become transparent and no light is scattered or absorbed as (R + T = 1).

As observed, there is a discernible effect of a higher temperature on the behavior of transmittance. If the temperature becomes near 50 $^0$C, the material may become full, transparent, and that is because the chloroform has a very low melting point.

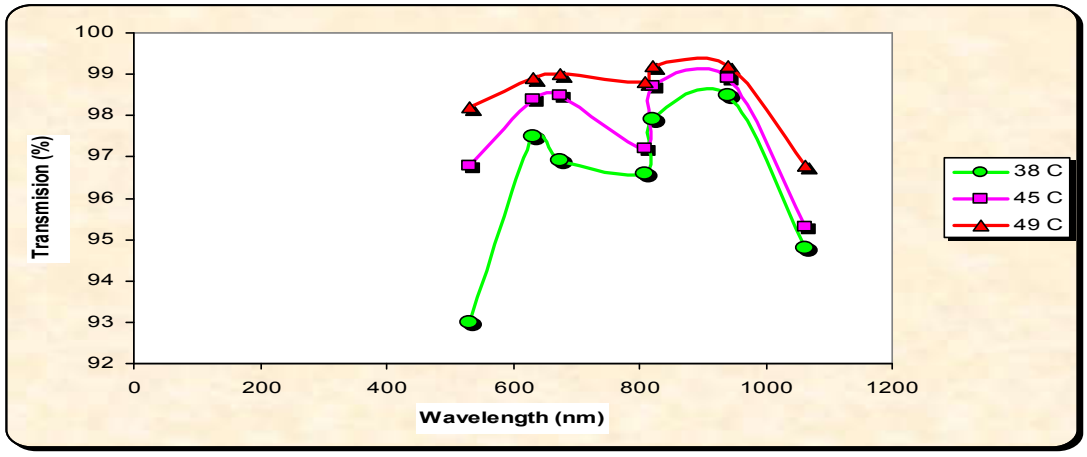



**Figure 10.** Transmission spectra of samples ($S_3$, $S_4$ and $S_5$)

The absorption coefficient was calculated, we had seen that it increase when the temperature of the substrate decreases, there was a large increase of the absorption coefficient at 520 nm for sample ($S_5$) than the others.

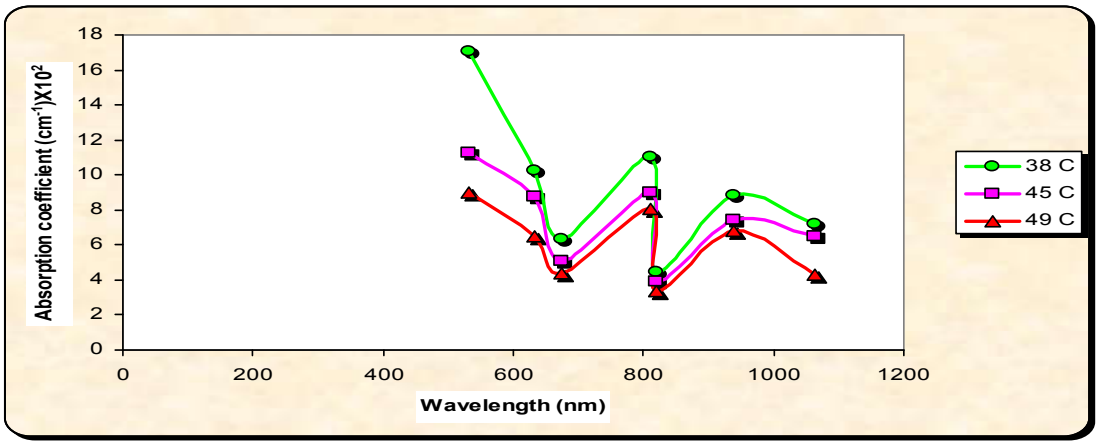



**Figure 11.** Absorption coefficient of samples ($S_3$, $S_4$ and $S_5$) as a function of laser wave lengths

The values of T (λ) and R (λ) were measured at normal incidence in the wavelength 520-1064 nm. The reflectivity was used to determine the real part of the refractive index, we can see from Fig. 12 that the refractive index increases when the temperature of the substrate decreases. In addition, the variation is slightly increases and the behavior of the curves was affected by the decrease in temperature.

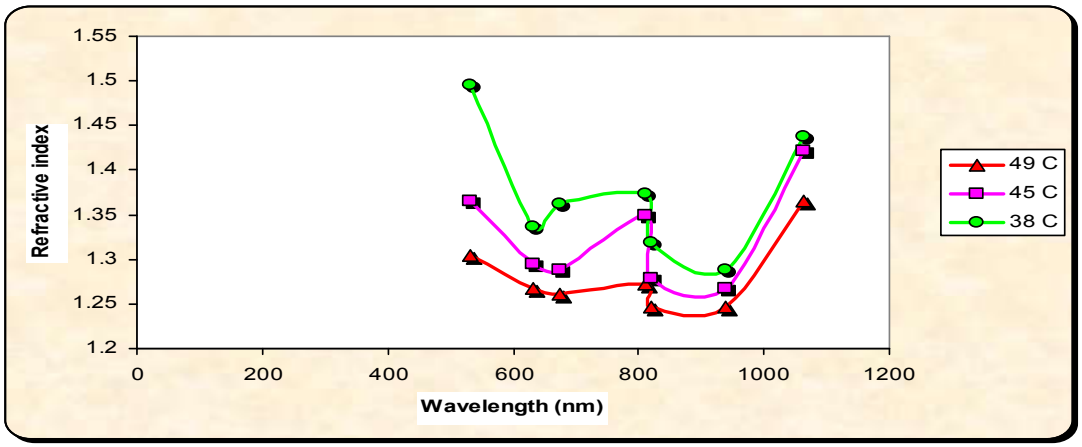



**Figure 12.** Refractive index of samples ($S_3$, $S_4$ and $S_5$) as a function of laser wavelengths.

## Conclusion

From the obtained optical properties of chloroform thin films, we conclude 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 temperature affected the transmission of the films, where the refractive index and absorption coefficient is depending mainly on it. The materials can be utilized to produce optical components in the range from 532 to 1064 nm.

## Future work

- Determination of the optical properties of these thin-films using other substrates.
- Study of mechanical properties, by utilizing non-distractive testing (NDT) like acosto-optic.
- Analysis of the quality of the prepared films by using X-ray diffraction.

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