The Novel Refractive Index for Optical Coating Applications

Rand H Ali¹, Kadhim A Aadim ², and Alaa N Abd Algaffar³
¹,³Department of Physics, College of Science for Women, University of Baghdad, Iraq.
² Department of Physics, College of Science, University of Baghdad, Iraq.
* E-mail: rand.hussein1204a@csw.uobaghdad.edu.iq

Abstract. In this work, an attempt to produce a novel refractive index using mixing dielectric material. Composed of ZnS and MgF₂ with a different concentrate ratio using a pulsed laser deposition (PLD) technique. The effect of shots and energy were studied. Resulting indicate that flexibility refractive indexes can be obtained with optimum optical performance for optical coating application.

Key words. Mixed dielectric material coating, PLD, Lorentz-Lorenz theory, dispersion phenomena, ARCs.

1. Introduction

Optical interference filters have numerous applications in, scientific designs, manufactures, biological detectors, and long-term environmental stability.

These filters require materials to satisfy the optical performance of its applications, like anti-reflection coating, beam splitter etc [1-5]. There is no flexible able available to find materials that have a refractive index that uses for the fabrication of optical devices like, single-layer anti-reflection coatings. So the advantage of mixing selected materials is to create material that has desired refractive index [6-9]. In this work, ZnS and MgF₂ were selected as mixed materials with a different concentrate ratio. Thin mixed film production by pulsed laser deposition for different combinations of ZnS and MgF₂ on the glass as a substrate [10]. ZnS as a high refractive index (n_H=2.35) and MgF₂ as low refractive index (n_L=1.38) [11].

2. Basic theoretical

The Computation Reflection of optical filter depends on the Characteristic matrix theory [12].

\[
\begin{pmatrix}
B \\
C
\end{pmatrix} = \begin{pmatrix}
\cos\delta & isin\delta/N_1 \\
inN_1sin\delta & \cos\delta
\end{pmatrix} \begin{pmatrix}
1 \\
N_c
\end{pmatrix}
\]  \hspace{1cm} (1)

\([B]_{C}=[C]=defined as the characteristic matrix of the assembly.

N_i= refractive index of material coating.
Ns = refractive index of substrate.

There for the reflectance (R) can be write as follow [12].

$$R = \left( \frac{N_0B-C}{N_0B+C} \right) \left( \frac{N_0B-C}{N_0B+C} \right)^*$$  \hspace{1cm} (2)

$N_0$ = refractive index of the air.

The Computation of refractive index of the mixed films depends on the Yadava [13]

If the volume of a mixture is equal to the sum of the volumes of the components, then, the molar refractivity of the mixture of two substances is equal to the sum of the contributions due to each substance. Thus, if two materials of molar refractivities $A_1$, and $A_2$ are mixed, and if unit volume of the first material contains $N_1$, molecules and unit volume of the second $N_2$, molecules, then the molar refractivity of the mixture will be

$$A = \frac{N_1A_1+N_2A_2}{N_1+N_2}$$  \hspace{1cm} (3)

$A_1$, and $A_2$ the molar refractivities.

$N_1$ = molecules of a unit volume of the first material

$N_2$ = molecules of a unit volume of the second material

Using the Lorentz-Lorenz formula for the mean polarizability

$$\alpha = \frac{3}{4\pi N} \frac{n^2-1}{n^2+1}$$  \hspace{1cm} (4)

the values of the molar refractivities are

$$A_1 = \frac{4}{3} \pi N_m \alpha = \frac{N_m n_1^2 - 1}{N_1 n_1^2 + 1}$$ \hspace{1cm} and \hspace{1cm} $A_2 = \frac{N_m n_2^2 - 1}{N_2 n_2^2 + 1}$  \hspace{1cm} (5)

Where $N_m$ is the Avogadro number = $6.022 \times 10^{23}$ mol$^{-1}$

$n_1$ and $n_2$ are the refractive indices of the two materials.

By solving eqns. (3) and (5) it can be shown that the refractive index of the mixture is given by [14]

$$n = \left[ \frac{\pi^2}{p_1 (C_1 - 1) + \pi^2 p_2} \right]^{1/2}$$  \hspace{1cm} (6)

Where $a_1 = \frac{1}{(n_1^2+2)}$ and $a_2 = \frac{1}{(n_2^2+2)}$

$p_1$ and $p_2$ are the densities of the two materials

$C_2$ is the concentration (in parts by weight) of component 2.

3. **Experimental part**

In this work, several mixtures of two dielectric materials, ZnS and MgF$_2$, were prepared with different proportions. These materials were mixed well to obtain a mixture. This mixture was pressed by hydraulic
pressure. The glass substrate cleaned in ultrasound baths with distilled water and alcohol. The substrate was placed on the holder inside the chamber. While the target placed on the target holder, where the preparation was done in a vacuum under pressure \((P = 2.5 \times 10^{-2})\) mbar. The mixture deposited on BK7 glass substrates at room temperature using the pulsed laser deposition (PLD) technique. With using Nd: YAG laser a wavelength (1064 nm) at different values of energies and the number of shots. As shown in table (1).

Table (1) a, b shows the change in the proportions of the dielectric material components, the deposition energies, and the number of shots.

**Table 1.a** fixed deposition energy (200mJ) and a variable number of shots.

| Mix | ZnS | MgF₂ | Energy (mJ) | No. of shots |
|-----|-----|------|-------------|--------------|
| 1   | 0.70| 0.30 | 200         | 100          |
|     |     |      |             | 200          |
|     |     |      |             | 300          |
|     |     |      |             | 400          |
| 2   | 0.90| 0.10 | 200         | 100          |
|     |     |      |             | 200          |
|     |     |      |             | 300          |
|     |     |      |             | 400          |
| 3   | 0.25| 0.75 | 200         | 100          |
|     |     |      |             | 200          |
|     |     |      |             | 300          |
|     |     |      |             | 400          |

**Table 1.b** fixed number of shots (100) with variable energy.

| Mix | ZnS | MgF₂ | Energy (mJ) | No.of shots |
|-----|-----|------|-------------|-------------|
| 1   | 0.90| 0.10 | 200         | 100         |
|     |     |      |             | 300         |
|     |     |      |             | 400         |
|     |     |      |             | 500         |
| 2   | 0.25| 0.75 | 200         | 100         |
|     |     |      |             | 300         |
|     |     |      |             | 400         |
|     |     |      |             | 500         |

4. Results and discussion

In figure1. shows UV-VIS spectroscopy of mix dielectric thin layer. This layer composed of ZnS (0.90) and MgF₂ (0.10), at deposition energy (200) mJ.
Figure 1. Refractive index behavior for composed of ZnS (0.9) and MgF$_2$ (0.1), at deposition energy (200) mJ with number of shots is (100, 200, 300, and 400). Along visible – Near IR region.

The above figure shows the stability of the refractive index for a wide region of wavelengths (400-1000 nm), but for the shots (400) we notice the stability of the refractive index for a narrow region of the wavelengths (400-700 nm). At the shots (400) we getting a highest values of the refractive index, its good for fabricate some optical filter. Figure (2) shows of mix dielectric thin layer. This layer composed of ZnS (0.70) and MgF$_2$ (0.30) with deposition energy (200) mJ.

Figure 2. Refractive index behavior for composed of ZnS (0.70) and MgF$_2$ (0.30), at deposition energy (200) mJ with number of shots is (100, 200, 300, and 400). Along visible – Near IR region.

Where this figure shows the refractive index versus the wavelength (nm). We generally notice when the number of shots is (100, 200, 300, and 400) the stability of the refractive index for a wide range of
wavelength ranges from (400-1100 nm). Also notice in these mixing ratios, as the number of shots increases, the refractive index decreases. Also notice get at the shots (400) a novel refractive index of 1.23 is obtained, this refractive index satisfy the condition for fabricate single layer anti-reflection coating. Figure (3) shows synthesis thin layer with another rate of mix. This layer composed of ZnS (0.25) and MgF₂ (0.75), at deposition energy (200) mJ.

Figure (3). Refractive index behavior for composed of ZnS (0.25) and MgF₂ (0.75), at deposition energy (200) mJ with number of shots is (100, 200, 300, and 400). Along visible–Near IR region

This figure appears the lowest values of the refractive index at the shots (100) and the highest values of the refractive index at the shots (400). Also notice in these mixing ratios, as the number of shots increases, the refractive index increases. And also we note the stability of the refractive index for a wide range of wavelengths (400-1100nm). The effect of the changed energies on the value and the behavior of refractive index on the mix dielectric thin layers appears in fig. 4 and fig. 5. Figure (4) shows thin layer with concentrate ratio of ZnS (0.90) and MgF₂ (0.10). At no. of shots (100) and deposition energy (200, 300, 400, and 500) mJ.

Figure (4). Refractive index behavior for composed of ZnS (0.9) and MgF₂ (0.1), at no. of shots (100) with deposition energy (200, 300, 400, and 500) mJ. Along visible –Near IR region
This figure appears at energy (200, 300 mJ) the stability of the refractive index for a wide range of wavelengths (400-1100 nm), while at energy (500) the refractive index was unstable, but at energy (400 mJ) the refractive index was stable for a narrow region of the wavelength (600-1100 nm). Figure (5) shows the thin layer. This layer composed of ZnS (0.25) and MgF$_2$ (0.75), at no. of shots (100). and deposition energy (200, 300, 400, and 500) mJ.

![Figure 5: Refractive index behavior for composed of ZnS (0.9) and MgF$_2$ (0.1), at no. of shots (100) with deposition energy (200, 300, 400, and 500) mJ. Along visible – Near IR region](image)

Figure 5. Refractive index behavior for composed of ZnS (0.9) and MgF$_2$ (0.1), at no. of shots (100) with deposition energy (200, 300, 400, and 500) mJ. Along visible – Near IR region

Figure 5. Appears that when the energy increases, the refractive index decreases. We also note the stability of the refractive index at all energies (200, 300, 400, 500 mJ) over a wide range of wavelengths (400-1100 nm). The value of refractive indices at all energies (200, 300, 400, 500 mJ) on thin film of this concentrate ratio mix are useful for optical coating applications.

5. Conclusion

Ideal indices of refraction can be obtained by mixing dielectric materials. The mixture consisting of ZnS (0.70) and MgF$_2$ (0.30) at energy (200 mJ) and shots (400). Achieved the state of zero reflection, and through the mixture itself, we obtained a refractive index equal to (1.23). For wide range region of visible region and near-infrared region. Used for perfect anti-reflective coating. Results refers that the concentrate ratio, energy deposition and number of shots effects on the behavior and value of refractive index.
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