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The Study of Gamma Ray Absorption Parameters of Heavy Metal Oxide Thin Films

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Abstract: **The present work deals with the study of mass attenuation coefficients of $(PbO)_{1-x}(CdO)_x$ (x = 0, 0.2, 0.4, 0.6, 0.8, 1) heavy metal oxide thin films at 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV respectively using XCOM software. The values of mass attenuation coefficient were further used to calculate other parameters such as effective atomic number and electron density. The variation of these shielding parameters with incident photon energy and chemical composition has been discussed. It has been found that the values of these shielding parameters decreases with increase in incident energy. The data will be useful for radiation safety and other shielding applications. The mass attenuation coefficients of the present thin films have been compared to the shielding concretes. The higher values of the mass attenuation coefficients of the present thein films indicates that they possess better shielding efficiency than concretes.**

Keywords* —*Mass attenuation coefficient, effective atomic number, electron density, thin films.

I. INTRODUCTION

Lead oxide (PbO) and cadmium oxide (CdO) both are transparent conducting oxides (TCOs) having low resistivity and high transmission characteristics [1]. These oxides have been widely used in semiconductor based device technology such as solar cells, photo transistors, photo diodes, optical heaters, gas sensors, IR detectors and liquid crystal displays [2]. PbO and CdO thin films both have n-type semi conductivity due to oxygen vacancies as well as high transparency in the visible region or extraordinary luminescence characteristics [3]. The resistivity of CdO is very low and exhibits direct band in the range 2.2-2.5 eV and indirect band gap of 1.98 eV [1]. TCOs have high melting point and high specific volume, therefore these oxides does not easily react with oxygen and water in air [3]. The shielding parameters of prepared thin films have been discussed such as mass attenuation coefficient (μ_m), effective atomic number (Z_{eff}) and electron density (N_e).

II. THEORY

The attenuation coefficient is a measure of the average number of interactions between incident photon and matter that occur in a given mass-per-unit area thickness of the material encountered i.e. the attenuation coefficient is interaction process dependent.

A narrow beam of monoenergetic photons having an initial intensity I_0 is attenuated to an intensity ‘I’ after passing through a layer of material with mass-per-unit-area ‘x’, according to the exponential law:

$$I = I_0 e^{-\mu_m x} \qquad (1)$$

where μ/ρ is the mass attenuation coefficient. Above can be rewritten as:

$$\mu_m = \frac{\ln\left(I_0 / I \right)}{x} \qquad (2)$$

The theoretical values of the mass attenuation coefficient have been determined by XCOM software based on mixture rule [4]

$$\mu_m = \sum_i W_i\,(\mu_m)_i \qquad (3)$$

where $(\mu_m)_i$ is the mass attenuation coefficient of each element in mixture and w_i is the fractional weight of the element in mixture.

The effective atomic number (Z_{eff}) by following formula [5]

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \qquad (4)$$

where $\sigma_{t,a}$ (barn/atom) is the total atomic crossection and $\sigma_{t,el}$ (barn/atom) is the total electronic crossection.

The value of $\sigma_{t,a}$ and $\sigma_{t,el}$ has been determined by given formula [6 - 7]

$$\sigma_{t,a} = \frac{\mu_m M}{N_A \sum_i n_i} \qquad (5)$$

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and $$\sigma_{t,el} = \frac{1}{N_A}\sum_i \frac{f_i}{Z_i} A_i (\mu_m)_i \qquad (6)$$

where $M = \sum n_i A_i$ is the molar mass, N_A is the Avogadro's constant, n_i is the number of atoms of the element i having atomic weight A_i, $f_i = \frac{n_i}{\sum n_i}$ is the number of atoms of the element relative to the total number of atoms present in the formula and Z_i is the atomic number of the element i.

The electron density (N_e) is the number of electrons per gram can be derived from [8]

$$N_e = \frac{\mu_m}{\sigma_{t,el}} = \frac{Z_{eff}}{M} N_A \sum_i n_i \qquad (7)$$

III. Results and Discussion

The theoretical values of mass attenuation coefficient μ_m (cm^2/g) for six thin films were determined by XCOM software based on mixture rule at 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV energies and have been tabulated in Table 1.

Table 1. Mass attenuation coefficient of the selected thin films

Energy (MeV)	Mass attenuation coefficient					
	S1	S2	S3	S4	S5	S6
0.122	3.140	2.840	2.490	2.060	1.520	0.821
0.356	0.274	0.255	0.232	0.205	0.170	0.124
0.511	0.151	0.144	0.134	0.123	0.109	0.090
0.662	0.108	0.104	0.099	0.093	0.085	0.076
0.84	0.083	0.081	0.078	0.075	0.071	0.065
1.17	0.062	0.061	0.059	0.058	0.056	0.054
1.275	0.058	0.057	0.056	0.055	0.053	0.051
1.33	0.056	0.055	0.054	0.053	0.052	0.050

The variation of μ_m of the selected thin films with incident photon energy displayed in Fig 1. It has been observed that the value of μ_m decreases as photon energy increases. This is due to the dominance of Compton scattering crossection. From table 1, it is clear that S1 has maximum mass attenuation coefficient value and S6 has minimum value. The values of μ_m ranges from 3.140-0.056 for S1, 2.840-0.055 for S2, 2.490-0.054 for S3, 2.060-0.053 for S4, 1.520-0.052 for S5 and 0.821-0.050 for S6.

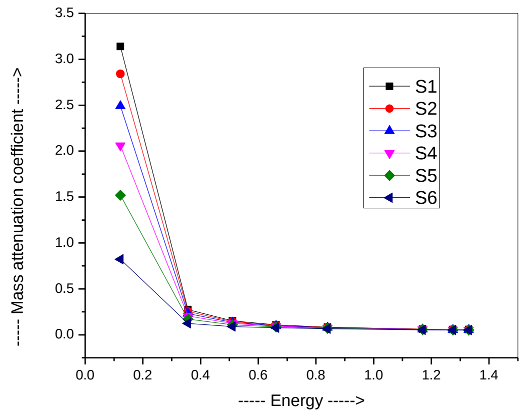

Fig 1. Variation of mass attenuation coefficient with energy

Table 2. shows the values of effective atomic number (Z_{eff}) at 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV energies respectively.

Table 2. Effective atomic number of the selected thin films

Energy (MeV)	Effective atomic number					
	S1	S2	S3	S4	S5	S6
0.122	79.55	77.19	73.88	68.88	60.45	43.23
0.356	65.99	61.95	56.99	50.78	42.74	31.94
0.511	59.45	55.18	50.28	44.61	37.97	30.07
0.662	55.58	51.37	46.72	41.55	35.79	29.33
0.84	52.83	48.73	44.33	39.58	34.46	28.89
1.17	50.19	46.28	42.17	37.86	33.33	28.55
1.275	49.78	45.90	41.84	37.60	33.17	28.52
1.33	49.64	45.77	41.73	37.52	33.12	28.51

The variation of Z_{eff} with incident photon energy of present thin films is shown in Fig 2. We conclude that the value of Z_{eff} decreases as photon energy increases for the present thin films. This is attributed to the dominance of Compton scattering process. The value of Z_{eff} ranges from 79.55-49.64 for S1, 77.19-45.77 for S2, 73.88-41.73 for S3, 68.88-37.52 for S4, 60.45-33.12 for S5 and 43.23-28.51 for S6. S1 have maximum value of Z_{eff} due to the presence of maximum percentage composition of PbO.

The variation of electron density with incident photon energy is shown in Fig 3. and values are tabulated in Table 3. Fig 3. shows that the electron density decreases as energy of incident photon increases. The number of electrons present in S1 is maximum; therefore value of N_e is maximum for S1. This is due to the higher concentration of PbO present in it which in turn increases the value of Z_{eff}.

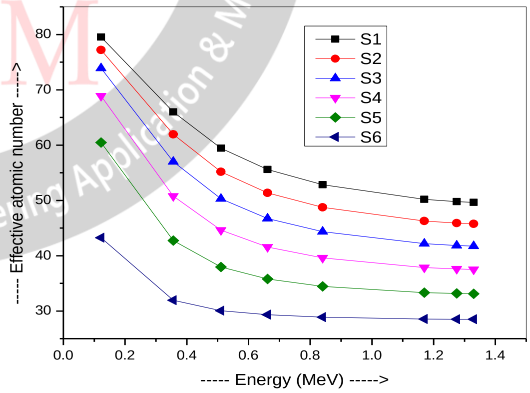

Fig 2. Variation of effective atomic number with energy

Table 3. Electron density of the selected thin films

Energy (MeV)	Electron density					
	S1	S2	S3	S4	S5	S6
0.122	4.29	4.55	4.80	4.99	4.94	4.05
0.356	3.56	3.65	3.70	3.68	3.49	2.99
0.511	3.21	3.25	3.27	3.23	3.10	2.82
0.662	2.99	3.03	3.04	3.01	2.92	2.75
0.84	2.85	2.87	2.88	2.87	2.82	2.71
1.17	2.71	2.73	2.74	2.74	2.72	2.68
1.275	2.69	2.71	2.72	2.72	2.71	2.67
1.33	2.68	2.69	2.71	2.72	2.71	2.67

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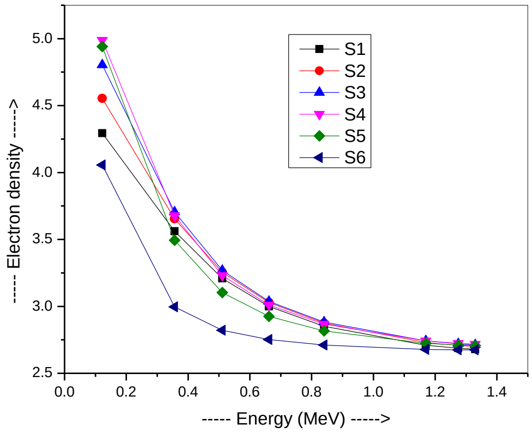

Fig 3. Variation of electron density with energy

The mass attenuation coefficients of the present thin films have been compared to the shielding concretes of the bashter [9] and is represented in Fig. 4. It is found that the mass attenuation coefficients of the present thin films are higher than the mass attenuation coefficients of the standard shielding concretes. Thus the present thin films possess better shielding efficiency than concretes.

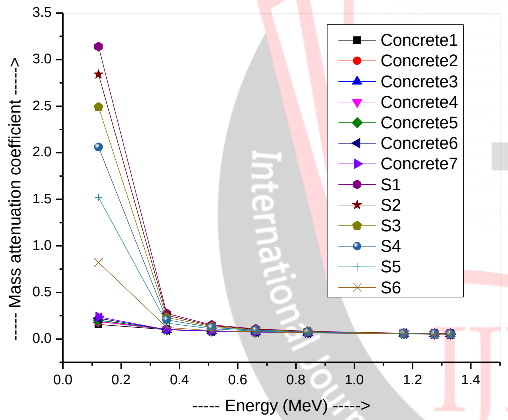

Fig. 4. Comparison of μ_m of thin films to standard shielding concretes

IV. Conclusion

In the present work, gamma ray shielding features for different thin films of composition $(PbO)_{1-x}(CdO)_x$ (x=0, 0.2, 0.4, 0.6, 0.8, 1) were investigated at 0.122, 0.356, 0.511, 0.662, 0.84, 1.17, 1.275 and 1.33 MeV energies respectively in terms of μ_m, Z_{eff} and N_e. The μ_m of all thin films were determined by WINXCOM software. The values of Z_{eff} and N_e were determined with the help of μ_m at given energies. The μ_m and Z_{eff} are maximum for S1 glass and are minimum for S6 glass whereas electron density is maximum for S4 and is minimum for S6. We conclude that all the shielding parameters decreases as photon energy increases due to the dominance of Compton scattering in the given energy region. The mass attenuation coefficients of the present thin films have been compared to the shielding concretes. The higher values of the mass attenuation coefficients of the present thein films indicates that they possess better shielding efficiency than concretes.

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