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Research Paper

Structural and Optical Properties of Black Velvet Tamarind Doped Magnesium Sulfide Thin Films Grown by Sol-Gel Technique

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Abstract— The properties of MgS thin film crystals doped with locally grounded black velvet tamarind (VT) shell and deposited using a sol-gel method were investigated in the work to determine their suitable area applications. Freshly prepared solutions of sodium silicate, tartaric acid, magnesium nitrate and thiourea were the precursors used, while solution drops of the locally prepared grounded black velvet tamarind shells served as dopant. The grown crystals were subjected to thermal annealing at temperature of 104 ^{O}C and subsequently characterized to investigate their structural, optical and compositional properties for device applications. The results of our characterizations showed that the grown films have crystalline structures and the crystallite sizes are in the range of 19.406-29.243 nm while the micro-strain is in the range $4.92x10^{-3}$-$7.531x10^{-3}$ and are influence by doping with VT. The EDS analysis showed that Mg, S as well as O were detected in the films and the atomic % of Mg has maximum value of 73.60 % for 1 drop VT/MgS, while the atomic % of sulphur in the samples increased from 4.20 % to 13.0 % as the number of drops of VT increased to 3 drops. FT-IR analysis showed that the films composed of =C-H stretch and C=C aromatic compounds but the presence of O-H as the number of VT drops increased to 3 drops. The films have low absorbance value but the film grown with 1 drop of VT doping has high value in the range of 0.5 – 1.1 in the near VIS (350 – 400 nm) region. The direct bandgap energy of the films was found to decreased from 3.42 eV to 3.20 eV as a results of doping MgS with VT drops. These properties exhibited by the grown thin films of un-doped MgS and VT/MgS make them suitable for many optoelectronics applications.

Keywords— Magnesium, Sulfide, Sol-Gel, Velvet Tamarind, Bandgap, Opto-Electronics

1. Introduction

Wide bandgap materials have demonstrated promise for many applications in the field of science and technology today. In solar energy device application, wide bandgap materials play vital role of buffer layer to the narrow gap materials (absorption layer), [1]. Electrical and electronic components that require high temperature and voltage are best made with wide bandgap materials as they can withstand such conditions to avoid breakdown. Many wide bandgap materials that belong to II-VI semiconductors such as CdS, ZnS, ZnO, MgS and their ternary counterparts have been identified to hold promise for many electronics and optoelectronic applications, [2]. The bandgap energy of most materials in this group of compound semiconductors are known to fall within the range of about 2.0 eV to 6.0 eV, [3]. The range of bandgap energy values position these sets of materials for applications in the short wavelength (high energy) range such as blue LEDs and LASERs, high energy sensors and photodetector devices etc. These energy gaps of these sets of materials can be altered by preparing the materials either in thin film or in the nano-film forms using different methods under certain conditions. Alteration of the energy bandgap of any material by preparing the material under certain condition opens room for further potential applications of the material. Magnesium sulfide (MgS) is one of the wide bandgaps materials of the II-VI which has been known to exist in three crystal phases – Rock salt (RS), Zinc blade (ZB) and wurtzite phases. The zinc blend (ZB)-phase MgS (beta-MgS) structure has larger wide band gap with interesting useful physical characteristics and can be used as barrier material with other II–VI semiconductors to produce outstanding quantum confinement effect. However, they are less stable as compared to the more stable rock salt (RS) structure, [4]. The direct bandgap energy of MgS has been reported to range between 3.0 eV to 5.5 eV at room temperature, while the indirect bandgaps have been theoretically stated to stretch between 2.08 eV to 6.48 eV, [5]. These energy gap range of MgS position it for many applications such as window layer to solar cells to replacing the more toxic ones like CdS material, high energy photodetectors and ultraviolet sensors, [6]. Reports have shown that MgS thin films have demonstrated good applications in solar collectors, microwave shielding coatings, solar absorber coating, solar control coating, electro conductive coating, flame retardant, dye-sensitized solar cells, and as sensors device fabrications, [7, 8]. Specifically, in environmental protection, fire detection, missile acquisition, chemical and biological analysis, inter satellite communication and instrumentations, the detectors/sensors for these purposes are highly sensitive devices that required high energy photons for operations. These high energy photons are photons of wavelength shorter than 280 nm and devices that can operate under the actions of these photons must has good long wavelength rejection power. The detectors or sensors of this nature are referred to as solar blind UV detectors/sensors and they are based on the wide bandgap materials such as MgS among others, [9]. Report has equally shown that Mg-S has the potential to replacing Lithium–ion batteries (LIBs) in the future. This stem from the fact that Mg metal has a relatively higher reduction potential of -2.37 V versus SHE in comparison with lithium (Li) metal (-3.04 V). Another reason been that the divalent Mg^{2+} enables two electrons transfer per Mg atom hence resulting in theoretical specific capacity of 2205 mAh g^{-1}, [10]. To widen the applications of MgS material, some research works have been carried out on doping of the material using different deposition techniques.

2. Related Work

To that effect, [11] have used Magnetron Co-Sputtering Technique to deposited thin films of $Zn_{1-x}Mg_xS$ and studied their optical and structural properties. The authors concluded that $Zn_{1-x}Mg_xS$ thin films have transmittance of more than 76 %, wider bandgap energy in the range of 4.39 to 3.25 eV and the films have cubic phase with preferred orientation along the (111) plane. Structural and optical characterization of sprayed Mg and Ni co-doped CdS thin films for photovoltaic applications have been fabricated and studied by [12]. The authors discovered that energy bandgap decreased from 2.46 to 2.40 eV with increasing Mg concentration (Mg, Ni) co-doped CdS and this property make films a potential material for window material in solar cell applications. Effect of Mg and Cu doping on structural, optical, electronic, and thermal properties of ZnS quantum dots deposited using chemical bath method have been reported by [13]. They found out that $Zn_{0.9}Mg_{0.1}S$ sample represent a single-phase ZnS zincblende cubic structure. The bandgap energy shifted from 3.3 to 3.39 eV which was attributed to the shift in Mg–s and p states as a result of higher energy compared with states of Zn and S. Nano-particles of MgS:Eu prepared by pulsed laser vapor condensation has been reported by [14]. The authors found that the material has a high ratio of Eu2 to Eu ions and spectral hole-burning performed showed enhanced broadening of the Zero Phonon Line (ZPL) in the nano-particles and number of possible spectral holes was also found to increase in the nano-particle samples. These phenomena were attributed to the size distribution effect and the large surface to volume ratio in the material. Previous study by [15] have shown that high-density spectral hole-burning can be achieved in thin films of MgS:Eu and CaS:Bu deposited by the same method. Further studies on these materials by [16, 17] indicated that the materials have great potential for ultra-dense spectral storage. They observed that oxygen impurity had great affinity to form these centers. Eu-center in MgS and these centres showed very high spectral hole burning densities in the materials. In this report, grounded black velvet tamarind shells was used as dopant to dope MgS thin film crystals using the sol-gel method to study their properties for applications. The choice of the velvet tamarind as dopant was spurred by its remarkable physical properties. [18, 19].

3. Theory/Calculation

The properties of the grown thin film crystals of velvet tamarind doped magnesium sulfide (VT/MgS) studied through calculations based on the measured properties are as follows.

Transmittance: this calculated based on the absorbance values obtained experimentally using the Beer-Lambert relation as given by [20, 21].

$$T = 10^{-A} \tag{1}$$

Where A is the absorbance.

Reflectance: this was evaluated using the relation as given by [22].

$$R = 1 - (\frac{e}{10})^{A/2} \tag{2}$$

Absorption coefficient and extinction coefficient: these properties are calculated using the equations as given by [23, 24].

$$\alpha = \frac{A}{\lambda} \tag{3}$$

$$k = \frac{\alpha\lambda}{4\pi} \tag{4}$$

Refractive index: the refractive index of thin film material is calculated using the relation as given by [25].

$$n = \frac{1+R}{1-R} + \sqrt{\frac{4R}{(1-R)^2} - k^2} \tag{5}$$

Bandgap energy: this other property is a very important property of thin film material and can be estimated from the plot of Tauc formula according to [26, 27].

$$(\alpha h v)^2 = A(hv - E_g) \tag{6}$$

Crystallite size, dislocation density and micro-strain: these properties of material can be evaluated using the Debye-Scherrer and Wilson relations as given by [28-33].

$$D = \frac{K\lambda}{\beta Cos\theta} \tag{7}$$

$$\delta = \frac{1}{D^2} \quad (8)$$

$$\varepsilon = \frac{\beta}{4Tan\theta} \quad (9)$$

Where β, are full weight at half maximum, θ is diffraction angle, λ is wavelength of cu-kα x-ray radiation and k is a constant known as shape factor (with value of 0.9).

4. Materials and Method

The following materials were used in this work; Digital weighing balance, 100 ml glass beakers, 5 ml measuring cylinder, magnetic stirrer with hot plate and magnetic bead, Electric oven and Whatman filter paper (110 mm) thick. The reagents used include; magnesium nitrate ($Mg(NO_3)_2$), thiourea, sodium silicate, tartaric acid [HOOC $(CHOH)_2$COOH] and locally prepared black velvet tamarind (VT).
Sol-gel method was used to grow the thin film crystal samples.

4.1 Experimental details

To prepare the undoped MgS sample, 25 ml of freshly prepared sodium silicate ($NaSiO_3$) solution of pH 11.0 was measured into a 100 ml beaker and stirred using magnetic stirrer to get a homogenous mixture. The solution was then titrated with some quantities of tartaric acid [HOOC$(CHOH)_2$COOH] (of concentration 1 M). The solution mixture formed gel and its pH value was 8.0. Thereafter, 20 ml of magnesium nitrate ($Mg(NO_3)_2$ solution was added to the set gel to give magnesium-tartanate as follows;

$$Mg(NO_3)_2 + H_6C_4O_6 \rightarrow MgH_4C_4O_6 + 2HNO_3$$

The magnesium-tartanate was generated in the gel as a white column ring system of gradually increasing thickness and the precipitation completed within fortnight (two weeks). At the end 20ml of a freshly prepared solution of thiourea was added to the set gel and covered to obtain MgS according to the reaction;

$$MgH_4C_4O_6 + CH_4N_2S \rightarrow MgS + H_6C_4O_6 + CH_2N_2$$

In preparing the velvet tamarind doped MgS samples, a fresh solution of smoothly grounded black velvet tamarind shell was prepared. The above procedure used for MgS preparation, was repeated and pipette drops of the freshly prepared solution of grounded local black velvet tamarind were together added with 10 ml of thiourea unto the magnesium-tartanate ($MgH_4C_4O_6$) and covered for 24 hours to obtain the velvet tamarind doped MgS (VT/MgS) crystal films. The doping process were done for one pipette drop, two pipette drops and three pipette drops of the solutions of the locally prepared black velvet tamarind (VT) as dopant to obtain 1 drop VT/MgS, 2 drops VT/MgS and 3 drops VT/MgS respectively.

The grown sample was first treated with all glass distilled water to avoid impurities and made slurry before, it was introduced into a Buckner funnel covered with filter paper, then attached to a suction flask connected to a vacuum pump through its nozzle. When the pump was put on, it created a vacuum that allowed for the absorption of H_2O from the sample. The filter in the Buckner funnel prevented the solid from being sucked. The sample was then taken to the oven at temperature of 104 ^OC for 30 minutes. After which, it was placed inside the desiccators to maintain dryness. $CaCl_2$ was used as a desiccant.

The grown films were subsequently characterized using X-ray diffractometer, UV-VIS spectrometer, Fourier Transform Infrared (FT-IR) Spectroscopy and SEM/EDS machines to investigate the optical, structural, morphological and compositional properties of the grown thin film crystals respectively for possible device applications.

5. Results and Discussion

5.1 Structural Properties

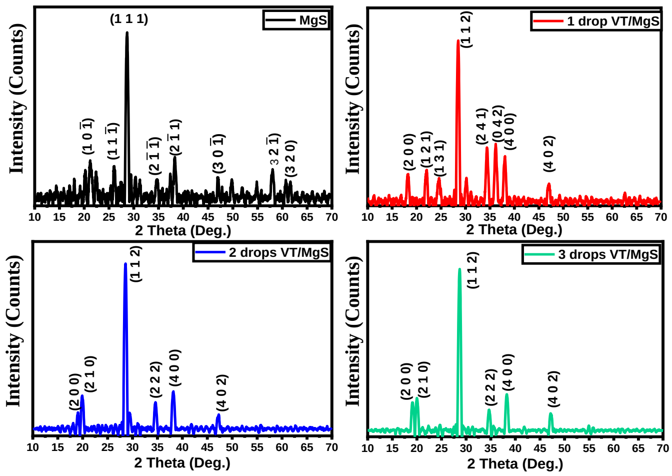

Figure 1. plots of XRD patterns for deposited MgS and VT/MgS

Table 1. XRD Structural Parameters for deposited MgS and VT/MgS thin films

Samples	Standard values		Experimental values		FWHM (rad)	h k l	Crystallite size (nm)	Dislocation density (nm^{-2}) x10^{-3}	Micro strain x10^{-3}
	2 (θ^o)	d (Å)	2 (θ^o)	d (Å)					
MgS	20.16	4.401	20.18	4.396	0.0067	(1 0 -1)	20.96	2.28	9.44
	25.33	3.513	26.09	3.413	0.0065	(1 1 -1)	21.98	2.07	6.99
	29.57	3.018	28.64	3.114	0.0070	(1 1 1)	20.43	2.40	6.86
	35.29	2.541	34.67	2.585	0.0048	(2 -1 -1)	30.56	1.07	3.81
	36.95	2.431	38.28	2.349	0.0063	(2 -1 1)	23.44	1.82	4.51
	47.42	1.916	47.01	1.931	0.0061	(3 0 -1)	24.88	1.62	3.49
	59.80	1.545	58.07	1.587	0.0065	(3 2 -1)	24.43	1.68	2.92

	60.31	1.533	60.73	1.524	0.0056	(3 2 0)	28.67	1.22	2.39
	Average						**24.417**	**1.768**	**5.051**
1 drop VT/MgS	19.03	4.660	18.22	4.865	0.0066	(2 0 0)	21.18	2.23	10.34
	20.25	4.381	22.00	4.037	0.0066	(1 2 1)	21.28	2.21	8.54
	24.58	3.619	24.64	3.610	0.0115	(1 3 1)	12.33	6.58	13.17
	28.36	3.145	28.53	3.126	0.0071	(1 1 2)	20.24	2.44	6.95
	34.09	2.628	34.45	2.601	0.0079	(2 4 1)	18.42	2.95	6.36
	36.16	2.482	36.22	2.478	0.0077	(0 4 2)	19.06	2.75	5.85
	38.61	2.330	38.09	2.360	0.0069	(4 0 0)	21.17	2.23	5.02
	47.09	1.928	47.05	1.930	0.0070	(4 0 2)	21.57	2.15	4.03
	Average						**19.406**	**2.942**	**7.531**
2 drops VT/MgS	19.03	4.660	19.04	4.658	0.0047	(2 0 0)	29.63	1.14	7.07
	20.02	4.433	19.91	4.455	0.0052	(2 1 0)	27.04	1.37	7.41
	28.36	3.145	28.59	3.120	0.0052	(1 1 2)	27.54	1.32	5.10
	31.43	2.844	31.09	2.874	0.0044	(2 4 0)	32.52	0.95	3.98
	34.74	2.580	34.62	2.589	0.0056	(2 2 2)	25.73	1.51	4.53
	38.61	2.330	38.17	2.356	0.0053	(4 0 0)	27.57	1.32	3.85
	47.09	1.928	47.13	1.927	0.0044	(4 0 2)	34.67	0.83	2.50
	Average						**29.242**	**1.204**	**4.920**
3 drops VT/MgS	19.03	4.660	19.13	4.636	0.0066	(2 0 0)	21.43	2.18	9.74
	20.02	4.433	20.03	4.430	0.0065	(2 1 0)	21.56	2.15	9.25
	28.36	3.145	28.66	3.112	0.0074	(1 1 2)	19.47	2.64	7.19
	34.74	2.580	34.68	2.584	0.0063	(2 2 2)	23.13	1.87	5.03
	38.61	2.330	38.27	2.350	0.0069	(4 0 0)	21.26	2.21	4.97
	47.09	1.928	47.20	1.924	0.0067	(4 0 2)	22.51	1.97	3.85
	Average						**21.558**	**2.171**	**6.671**

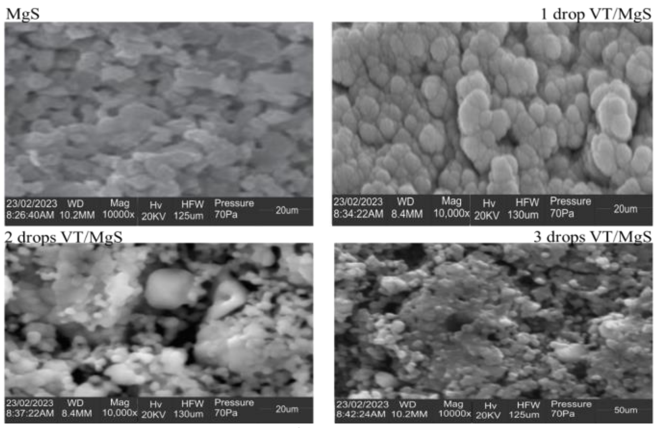

Figure 2. Micrograph images of the deposited MgS and VT/MgS thin film crystals

5.2 Compositional properties

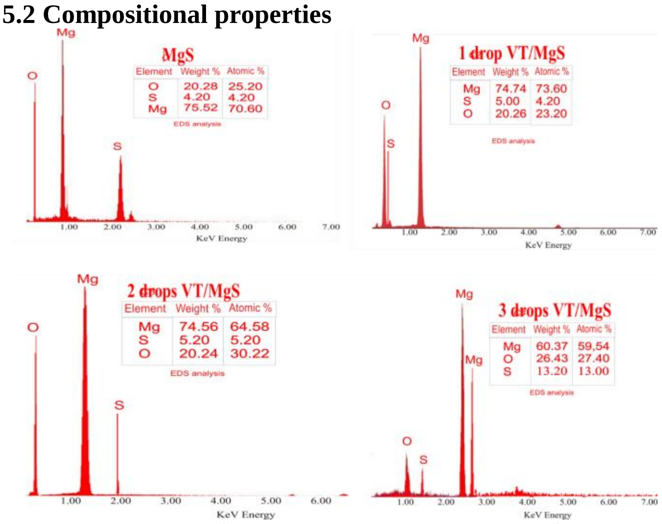

Figure 3. EDS Spectra of the deposited MgS and VT/MgS thin film crystals

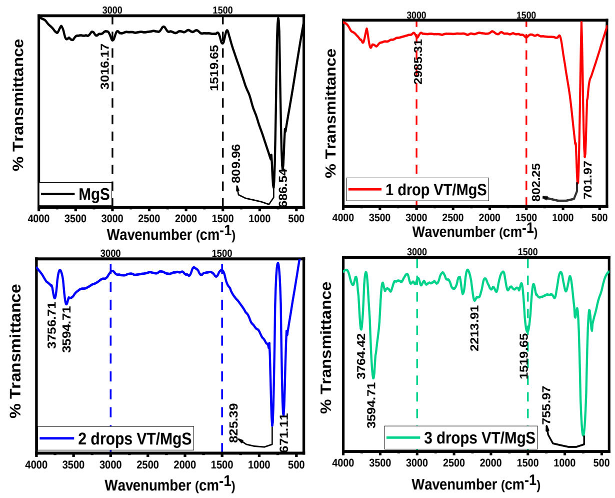

Figure 4. Plots of FT-IR spectra for deposited MgS and VT/MgS films

5.3 Optical properties

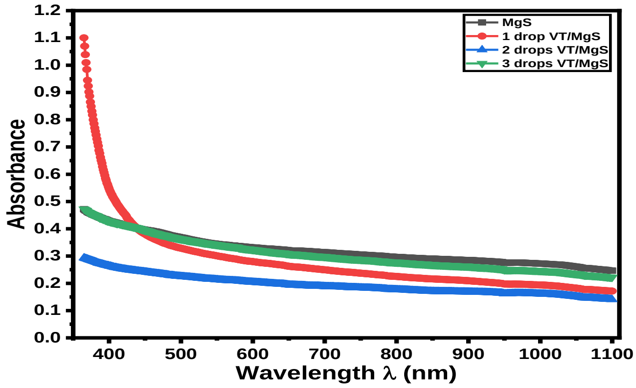

Figure 5. Graph of absorbance against wavelength for deposited MgS and VT/MgS

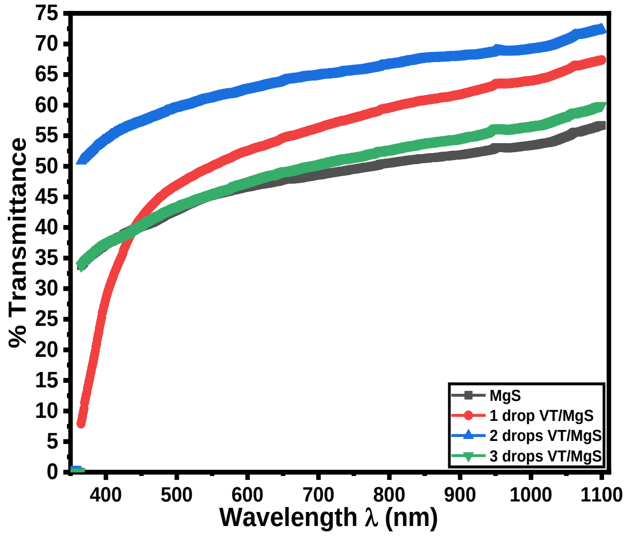

Figure 6. Graph of % transmittance against wavelength for deposited MgS and VT/MgS

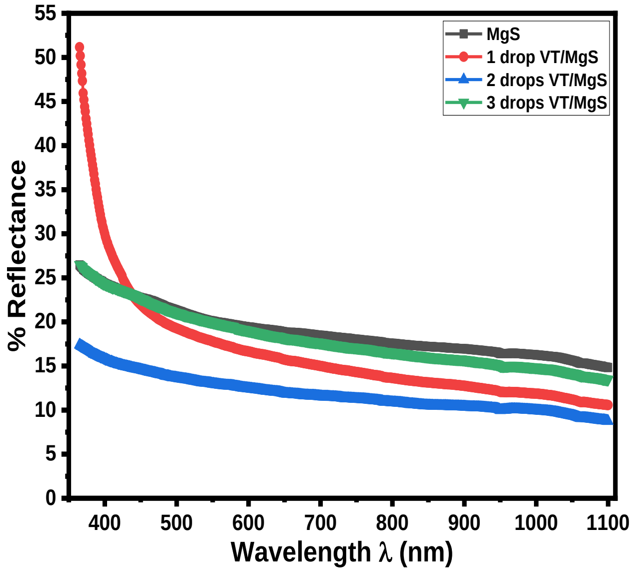

Figure 7. Graph of % reflectance against wavelength for deposited MgS and VT/MgS

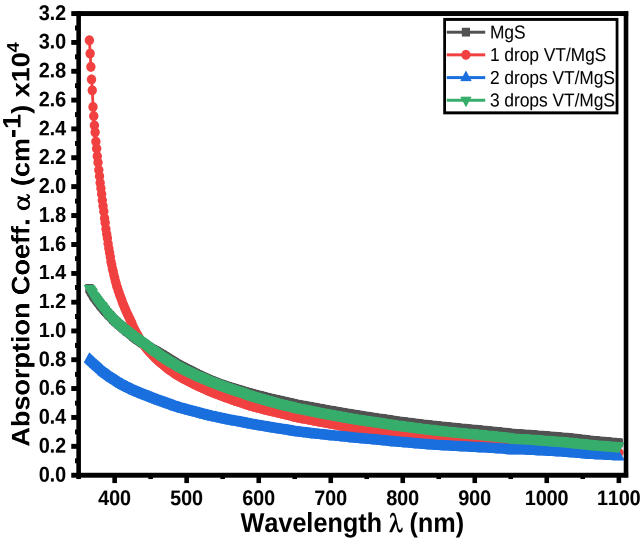

Figure 8. Graph of absorption coefficient against wavelength for deposited MgS and VT/MgS

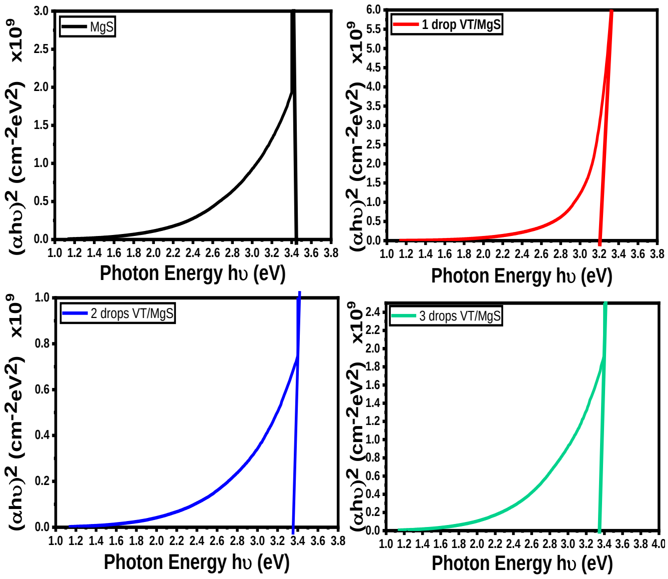

Figure 9. Plots $(\alpha h\nu)^2$ against photon energy for deposited MgS and VT/MgS

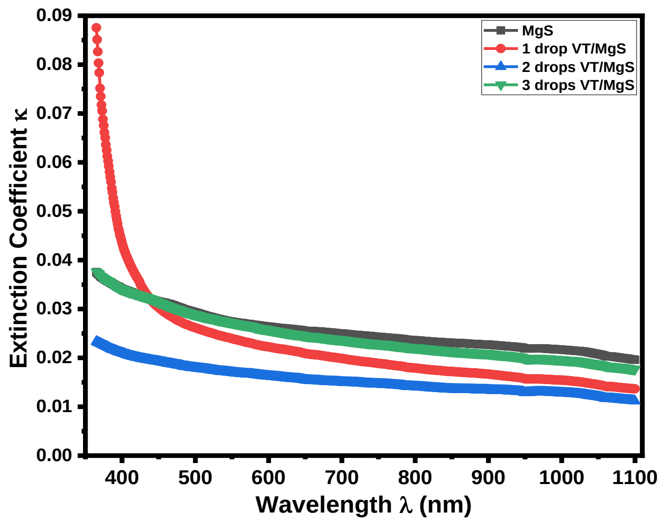

Figure 10. Graph of extinction coefficient against wavelength for deposited MgS and VT/MgS

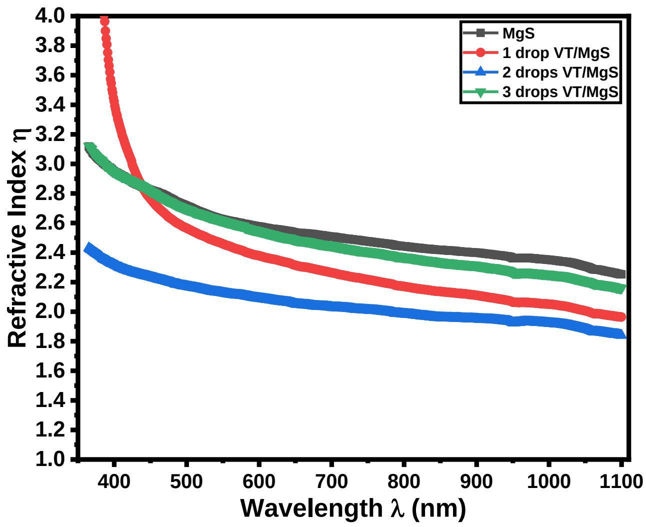

Figure 11. Plot of refractive index versus wavelength for deposited MgS and VT/MgS

Discussion

The results of the XRD analysis of the deposited thin films of MgS and VT doped MgS are displayed in figure 1. From the figure it was observed that the deposited films are crystalline as there exist sharp peaks at different two theta positions indexable to crystal planes as shown in the XRD patterns of the films. The pattern for un-doped MgS film matched well with the standard JCPDS NO: 00-110-0081 with (space group R3: R) for $MgSO_3(H_2O)_6$. The patterns for 1 drop, 2 drops and 3 drops VT doped MgS matched rather well with the standard JCPDS NO: 00-901-5178 with (space group Pnma and orthorhombic crystal structure) for MgO_9S_2. The crystallite sizes, the dislocation density and micro-strains of the deposited films calculated at their different two-theta peak positions using Debye-Scherrer relation as well as their average values are as shown in details in Table 1. From the Table 1, it was observed that the average values of the crystallite size, dislocation density and micro-strains are the range of 19.406 – 29.242 nm, $1.204x10^{-3}$ - $2.942x10^{-3}$ nm^{-2} and $4.92x10^{-3}$-$7.531x10^{-3}$ respectively.

The SEM micrograph of the deposited thin films of MgS and VT doped MgS is displayed in figure 2. From the figure, it was observed that the un-doped MgS film has cluster of irregular large particles that are closely packed upon one another and there are no pores in between them. The particle sizes of the films deposited with 1 drop VT are of more spherical in shapes and clustered on each other very compactly. The surface of the film is highly rough with limited number of gaps within the particles. The 2 drops VT/MgS composed of small particles that are more of spherical in shapes and some large particles. The surface of the film is rough and there exist hollows in between the particles. The 3 drops VT/MgS film also composed of small particles that are spherical in shapes and some other larger particles with pores and hollows in between the particles. The surface of the film is also rough as for all the other films which confirm their crystalline nature.

The results of energy dispersive spectroscopy (EDS) analysis carried out on the deposited thin films of MgS and VT doped MgS are as displayed in figure 3. The figure showed that the Magnesium (Mg), Sulfur (S) and Oxygen (O) were detected in all the samples with the weight % of Mg being highest among the elements. However, the atomic % of the element Mg for un-doped MgS is 70.60 % and increased to maximum value of 73.60 % for 1 drop VT/MgS and thereafter decreased to 64.58 % and 59.54 % for 2 drops VT/MgS and 3 drops VT/MgS samples respectively. The atomic % of the sulfur (S) in the sample however increased from 4.20 % to 13.0 % as the number of dopants drops increased to 3 drops. These results conformed well with the results of the XRD analysis.

The FT-IR spectra of the deposited thin films of MgS and VT doped MgS are displayed in figure 4. From the figure, it was observed that in the un-doped MgS film there exist very short absorption peaks at 3016.17 cm^{-1} and 1519.55 cm^{-1} in the functional group region, which correspond to =C-H stretch and C=C aromatic compounds in the film. The strong absorption peaks at 809.96 cm^{-1} and 686.54 cm^{-1} in the figure print region in the film suggest the presence of C-H bending (1,2,3-trisubstituted) and C=C bending (alkene group) respectively. In the film 1 drop VT/MgS, the short absorption peak around 2985.31 cm^{-1} signal the presence of C-H stretching (alkane) while the two sharp peaks in the figure print region at 802.25 cm^{-1} and 701.97 cm^{-1} indicated the presence of C-H bending (1,2,3-trisubstituted) and benzene derivative respectively. In the film 2 drops VT/MgS, the peaks in the functional group region occurred at 3756.71 cm^{-1} and 3594.71 cm^{-1} and both correspond to O-H stretching while the peaks in the figure print region at 825.39 cm^{-1} and 671.11 cm^{-1} are also suggestive of C-H bending (1,2,3-trisubstituted) and benzene derivative respectively in the film. For the film 3 drops VT/MgS, in addition to absorption peaks at 3764.42 cm^{-1} and 3594.71 cm^{-1} which equally signaled the presence of O-H stretching, other peaks that occurred at 2213.91 cm^{-1} and 1519.65 cm^{-1} in the film correspond to C≡C stretching (alkyne) and C=C (aromatic compound) respectively. The strong absorption peak at 755.97 cm^{-1} in the finger print side suggest the presence of C-H bending (monosubstituted) in the film.

The plot of absorbance against wavelength for the deposited thin films of MgS and VT/MgS is depicted in figure 5. The figure revealed that the absorbance of the films decreased as wavelength increased. The film grown with 1 drop of VT doping has higher value in the range of 0.5 – 1.1 in the near VIS (350 – 400 nm) region. In the remaining part of VIS and NIR (400 – 1100 nm) regions, the absorbance of MgS decreased with an increase in the number of VT drops with the film 2 drops VT having the lowest value in the range 0.17 – 0.3. The absorbance thereafter increased to the values in the range 0.25 – 0.45 with 3 drops VT doping in the VIS and NIR regions of EMS.

The percentage transmittance of the deposited thin films of MgS and VT/MgS increased with an increase in wavelength (figure 6). The percentage transmittance of the films increased to the highest value in range 50 – 72.5% as the number of VT drops increased to 2 drops and thereafter started to decreased to the range 32.5 – 57.5% at 3 drops VT doping. The increase in the percentage of the as deposited MgS and VT doped MgS towards the infrared region of EMS make them good materials for poultry house coating and for window coating in the low temperature regions of the world.
Figure 7 is the graph of percentage reflectance of the films as a function of wavelength. The figure showed that the reflectance of the films is low and decreased with wavelength. The film 1 drop VT/MgS however has high reflectance range of 27 – 51.5% in the wavelength range (350 – 400 nm). The reflectance of MgS decreased to the lowest percentage range of 10 – 17 % with 2 drops VT doping and thereafter increased to the value in the range of 15 – 26.5% in the VIS and NIR regions. The low reflectance percentage exhibited by the films position them for anti-reflection coating applications.

The graph of absorption coefficient against wavelength for the deposited thin films of MgS and VT doped MgS is shown in figure 8. The graph showed that the absorption coefficient of the films is quite low except for film grown with 1 drop VT doping whose absorption coefficient increased to the order of $x10^4$ within 350 – 400 nm wavelength range. The absorption coefficient of the films decreased with an increase in wavelength with film 2 drops VT/MgS having the lowest value in the range 2.0 $x10^3$ – 8.0 $x10^3$ cm^{-1} in the VIS and NIR regions.

The plots of $(\alpha hv)^2$ against photon energy for determination of the direct bandgap energy of the deposited MgS and VT doped MgS are presented in figure 9. From the figure, it was observed that the bandgap energies of the films obtained by extrapolating the straight-line portion of the curves at $(\alpha hv)^2 = 0$ on the photon energy axis decreased from 3.42 eV to 3.20 eV as a consequent of doping MgS with VT drops. These bandgap energy values are in closed proximity to the values reported by [34] for Cu doped MgS thin films. These bandgap energies are wide bandgap values and thus make the deposited thin films good materials for applications in high temperature energy devices, [35].

The plot of extinction coefficient against wavelength is displayed in figure 10. The figure showed that the extinction coefficient of the films is low generally and decreased with wavelength. The film 1 drop VT/MgS has the highest value of 0.04 – 0.09 in the wavelength range 350 – 400 nm while the film 2 drops VT/MgS has the lowest extinction coefficient value in the range 0.01 - 0.022 in the VIS and NIR regions of EMS. The low extinction coefficient value exhibited by films position them for photo-thermal application.

The graph of refractive index against wavelength for the deposited thin films is presented in figure 11. From the figure, it was observed that the films have high refractive index and they decreased with an increase in wavelength. The film 1 drop VT/MgS has the highest value in the range 3.2 – 4.0 in the wavelength range of 350 – 400 nm while the film 2 drops VT/MgS has the lowest in the VIS and NIR regions. The VT doping influenced the MgS film by decreasing its refractive index within the wavelength range 450 – 1100 nm. The refractive index values exhibited by the films are considered high and hence can be suitable for waveguide applications.

6. Conclusion and Future Scope

The results of the characterization of the thin film crystals of MgS and VT-doped MgS grown in this work exhibited crystalline structures based on the structural analysis carried on them. The crystallite sizes of the films are 24.417 nm, 19.406 nm, 29.242 nm and 21.558 nm for un-doped MgS, 1 drop VT/MgS, 2 drops VT/MgS and 3 drops VT/MgS respectively. The dislocation density and micro-strain are influenced by VT doping and they are in the range of $1.204x10^{-3}$ - $2.942x10^{-3}$ nm^{-2} and $4.92x10^{-3}$-$7.531x10^{-3}$ respectively. The SEM analysis indicated that the particle sizes of the films are small and are mainly spherical in shape. However, the film 2 drops VT/MgS composed of small particles and some large particles. The surface of all the films are rough thus confirming that they are crystalline. The EDS results showed that the atomic % of the element Mg for un-doped MgS is 70.60 % and increased to maximum value of 73.60 % for 1 drop VT/MgS and then decreased to 64.58 % and 59.54 % for 2 drops VT/MgS and 3 drops VT/MgS samples respectively. The atomic % of sulfur in the samples increased from 4.20 % to 13.0 % as the number of dopants drops increased to 3 drops. The results of FT-IR analysis revealed that the films composed of =C-H stretch and C=C aromatic compounds but as the number of VT drops increased to 3, absorption peaks started emerge at 3764.42 cm^{-1} and 3594.71 cm^{-1} which signaled the presence of O-H stretching. The absorbance of the films is low. However, the film grown with 1 drop of VT doping has high value in the range of 0.5 – 1.1 in the range (350 – 400 nm) region. The transmittance of the films is low in the VIS region but increased in the NIR region hence positioning the films for cold window coating in the low temperature region of the World as well as for poultry house coating. The direct bandgap energy of the films was found to decreased from 3.42 eV to 3.20 eV as a consequent of doping MgS with VT drops. The extinction coefficient is generally low and decreased with wavelength. The film 1 drop VT/MgS has the highest value of 0.04 – 0.09 in the wavelength range 350 – 400 nm while the film 2 drops VT/MgS has the lowest extinction coefficient value in the range 0.01 - 0.022 in the VIS and NIR regions of EMS. This low value positions the films for photo-thermal application. The refractive index is high and decreased with an increase in wavelength and VT doping within the wavelength range 450 – 1100 nm. The high value of refractive index makes the films suitable for waveguide applications.

Limitation

The major drawback to this research work was limited source of fund. We therefore recommend that thin film crystals of this nature should be prepared by other researchers and other properties, be investigated to determine other suitable areas of their applications.

Conflict of Interest

Authors declare that they do not have any conflict of interest.

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Authors' Contributions

The author Uchechukwu A. Kalu performed the experiment for the preparation of the samples subject to their characterisations and subsequent analysis. The authors Okpala U.V. and Okereke N. A. supervised the experimental preceding and subsequently examined the whole work to completion. The author Nwori A.N. did the data analysis, the literature review and drafted the first manuscript of the article subject to review by the authors Okpala U.V and Okereke N.A. All authors reviewed and edited the manuscript and approved the final version of the manuscript as per the journal template.

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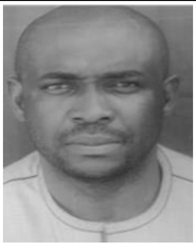

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