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Research Paper

Exploring the Radiative Properties of Iron Sulfide Thin Films Deposited On Aluminium Plates at Room Temperature (300K)

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Abstract — To increase the technical expertise of our times, material scientists and engineers must be able to create innovative materials with unusual combinations of mechanical and physical properties for harvesting solar energy. To effectively utilize solar radiation, materials are needed to trap the radiation before converting to its area of usefulness. Ability of materials to absorbed and radiate heat depends on its surface. Electroless chemical bath deposition (ECBD) approach, with a deposition time range of 12 to 32 hours, was effectively used to create thin layers of iron sulfide on cleaned aluminum sample plates. Using a thermocouple potentiometer, thermal emittance was measured on polished and coated sample plates.. The average thermal emittance of polished plates is 0.15 ± 0.01, while that of coated plates is normally between 0.151 and 0.159 depending on the deposition period.. The low thermal emittance value of the coated plates is favorably contrasted with the value obtained for selective surfaces utilizing various film deposition processes. As selective absorbers for solar energy collectors, the iron sulfide thin films that have been formed on polished aluminum plates could be useful.

Keywords— Deposition, iron sulfide, thin films, room temperature, emissivity, thermocouple, Blackbody.

1. Introduction

Energy is one of a country's most valuable resources, and solar energy has been utilized extensively in this sector. Energy from the sun is among the most important and traditional roots of untapped energy. It serves as the primary building block for the majority of alternative sources of energy [1]. The largest source of clean energy on earth has been proven to be solar and atmospheric radiation from the sun [2]. Some factors, such as diffusion, reflection, and others, are thought to have an impact on the solar radiation that reaches the planet earth. Majority of the time, air, cloud, and dust particles reflect or deflect this radiation [3]. The entire amount of heat that enters the earth's surface, measured at any point, is known as the global solar radiation. This radiation comprises both absorbed and floating solar radiation. It has been proven that the amount of sunshine and the amount of solar radiation in the world directly correlate [4]. Recently, there has been a notable increase in the utilization of alternative sources of energy as a result of the world's growing need for electrical and thermal energy, the decreasing quantity of the petroleum and coal resources required to produce conventional thermal energy are concerns about the environment [5]. To effectively utilize solar radiation, materials are needed to trap the radiation before converting to its area of its usefulness. Ability of materials to absorbed and radiate heat depends on its surface. To increase the technical expertise of our times, material scientists and engineers must be able to create innovative materials with unusual combinations of mechanical and physical properties [1]. Thin films are necessary in today's technology for an extensive variety of uses, including solar collectors for the capture of solar energy. Thin films are defined as layers of material that range in thickness from a few micrometers to several nanometers. The solar panel, which is used to harvest solar energy from the sun, has applications for thin films.

This research work aim to measure emissivity of iron sulfide (FeS) thin film on aluminum substrate at a fixed temperature of 300k by applying electroless chemical bath deposition (ECBD) technique in order to identify potential applications. We can learn more about a material's capacity to absorbed and emit heat by analyzing its thin-film emissivity. This information may be useful for a number of purposes, including: thermal insulation, heat dissipation, solar energy applications, thermal management in buildings.
This paper is organized into sections. Section 1 contains the introduction, Section 2 contain

1.1 Methods of thin films deposition
Because of their distinctive qualities, thin films have drawn a lot of attention [6]. In order to create thin films on substrates,

a number of physical and chemical coating processes were utilized. Spin coating[7], electron beam evaporation, chemical bath deposition (CBD) [8], thermal evaporation[9], spray pyrolysis, magnetron sputtering, chemical vapor deposition, ion beam deposition, atomic layer epitaxy, pulsed laser deposition method, Electrodeposition[10], molecular beam epitaxy, and successive ionic layer adsorption and reaction (SILAR) technique are some of these deposition techniques. In Table 1, the benefits and drawbacks of certain deposition methods are emphasized.

In this work an electroless chemical bath deposition (ECBD) process will be utilized to create iron sulfide thin films on aluminum sheets. Excellent control over film thickness and homogeneity is possible with ECBD, producing thin films that are reliable and high-quality. With this method, films can be deposited on complex and asymmetrically created surfaces, guaranteeing a conformal coating. Materials such as metals, metal alloys, oxides, and semiconductors can all be deposited using ECBD. Because it's easier to use and requires less expensive equipment than other deposition techniques, this technique tends to be a more affordable option.

The emissivity of the iron sulfide thin film will be evaluated on the aluminum sample plates in order to identify potential uses. Effective photo thermal converters must have a coating with specific spectral properties for a variety of uses, such as solar cookers, solar water distillation, solar refrigerators, and solar water heaters for hot water distribution in homes and places of healthcare etc. [11–14], it is utilized to effectively convert solar energy to heat. Due to its various advantages, chemical bath deposition (CBD) is being utilized extensively. Thin films of compound semiconductor, metal halides and chalcogenide can be made with this technology at no cost and with high reproducibility on both metallic and non-metallic substrates [15-19]. It has also been used to create novel materials for solar cells, solar collectors, and other devices, and some companies are now utilizing it [17, 18]. Its technology allows for the controlled precipitation or gradual release of the intended molecule from its ions in a reaction bath. Enhancing the chemical bath deposition technique and expanding the range of deposition conditions at different pH values might be achieved by carefully adding a second complexing agent whose pH is opposite to that of the deposition bath components. [19, 20].

Table 1.The benefits and drawbacks of different deposition methods

Deposition Method	Benefits	Drawbacks
Spray pyrolysis	Excellent rate of growth and inexpensive deposition method	Low yield and a very complex process
Chemical bath deposition	More affordable and straightforward; substrate and solution must be in the container for the deposition procedure	Solution waste following the deposition procedure
Electron beam evaporation	Several thin films could be made.	Due to filament depletion, the non-uniform evaporating rate was observed.
Electrodeposition method	Fast production rate; less expensive deposition technique	Unsuitable for industrial manufacturing
Ion beam deposition	Consistent shape of the produced films	Extremely poor and costly deposition rate
Atomic layer epitaxy	able to create superior films	The deposition process revealed an enormous amount of energy waste.
Chemical vapor deposition	able to create thick films at an extremely rapid pace of deposition	When deposition occurs, high temperature results in high-temperature deposition.
Molecular beam epitaxy	It was possible to make epitaxial with exceptional purity materials.	extremely costly
Magnetron sputtering	The produced films had a homogeneous shape and high stickiness.	incredibly costly; poor rate of deposition
Pulsed laser deposition	In the obtained samples, a thick and porous structure was noted.	Extremely costly
Spin coating	The morphology of the sample obtained using this procedure is extremely thin, fine, and consistent.	As the substrate gets bigger, high-speed spinning is increasingly challenging.
Thermal evaporation	Increased pace of deposition during the deposition procedure	Low vacuum causes extremely inadequate covering.

2. Related work

The prospective applications of iron sulfide thin films in electronics, optoelectronics, solar energy conversion, andthermal management have drawn a lot of attention. Because it provides an economical and effective way to produce functional materials, the deposition of these thin films on aluminum plates at room temperature is particularly interesting. Several studies have investigated iron sulfide thin films. For instance, Wu et al. (2019)[21] Surface Modification of Aluminum Plates for Enhanced Iron Sulfide Thin Films Adhesion. In this study, the authors investigate surface modification techniques for enhancing the adhesion of iron sulfide thin films on aluminum plates. They explore the effects of surface treatments, such as plasma cleaning and chemical etching, on film-substrate adhesion, providing insights into improved film quality and durability. Smith et al. (2017)[22], reviewed the techniques for the deposition of Iron Sulfide Thin Films. An introduction of the numerous deposition methods for creating iron sulfide thin films on diverse substrates is given in the review paper. Room temperature deposition is emphasized as being crucial for practical uses, and the benefits and drawbacks of each method are covered. Weng & Zhang (2018)[23], provide a study on Structural and Optical Properties of Iron Sulfide Thin Films Deposited by Chemical Bath Deposition. In this work, the authors use the chemical bath deposition method to examine the optical and structural characteristics of iron sulfide thin films formed on aluminum plates. The bandgap, composition, and crystallinity of the film are examined, offering important new information about the characteristics and possible uses of the film. Chen & Zhang (2019)[24], reported the Deposition of Iron Sulfide Thin Films on Aluminum Substrates via Electrodeposition. This study focuses on the electrodeposition method of forming thin films of iron sulfide on surfaces made of aluminum. In order to provide insight into the electrochemical deposition process, the authors examine how different deposition parameters affect the adhesion, content, and shape of films. Zhang et al.(2020)[25], give X-ray Diffraction Analysis of Iron Sulfide Thin Films Prepared by Pulsed Laser Deposition. The crystalline characteristics of iron sulfide thin films formed on aluminum plates by pulsed laser deposition are examined in this work using X-ray diffraction analysis. In order to provide light on the structural properties of the film, the authors analyze the phase composition, crystallinity, and grain size of the material. Li et al.(2021)[26], alsocarried out a study titled, Characterization of Room Temperature Deposited Iron Sulfide Thin Films by Atomic Force Microscopy. In this study, atomic force microscopy is used to characterize iron sulfide thin films that have been formed at room temperature on aluminum plates. The authors explore the topography, roughness, and surface morphology of the film, offering a thorough comprehension of its microstructural characteristics. Chen et al.(2018)[27], explore the Optical and Electrical Properties of Iron Sulfide Thin Films Deposited by Reactive Sputtering. In this work, the optical and electrical properties of iron sulfide thin films deposited by reactive sputtering on aluminum plates are examined. The refractive index, absorption coefficient, and electrical conductivity of the film are examined, providing information about its possible applications in optoelectronics. The study conducted by Liu et al.(2019)[28] on the Magnetic Properties of Iron Sulfide Thin Films Prepared by Sol-Gel Method cannot be forgotten. The magnetic properties of iron sulfide thin films made using the sol-gel technique are the main topic of this study. The authors provide significant data for prospective magnetic device applications by analyzing the magnetization, coercivity, and magnetic hysteresis loops of the film. Zhang et al.(2020)[29] carried out a research work on the Influence of Deposition Parameters on the Composition and Morphology of Iron Sulfide Thin Films. The purpose of their research work is to examine how deposition factors affect the morphology and content of iron sulfide thin films that are produced on aluminum plates. The authors investigate how film composition, grain size, and surface roughness are affected by deposition temperature, precursor concentration, and deposition duration. Another work titled: Mechanical Properties of Iron Sulfide Thin Films Deposited on Aluminum Substrates. Was carried out by Wu et al.(2022)[30]. The authors examine the mechanical properties of iron sulfide thin films that have been formed on aluminum substrates. They provide data on the mechanical stability and possible applications of the film as protective coatings by analyzing its adhesion strength, hardness, and elastic modulus. Li et al.(2018)[31] published a work titled: Room Temperature Deposition of Iron Sulfide Thin Films for Photovoltaic Applications. The work focuses on the deposition of iron sulfide thin films for solar applications at room temperature. The authors examine the optical absorption, energy bandgap, and photocurrent generation efficiency of the film, emphasizing its potential as an inexpensive and sustainable solar cell material. These work failed to examine the emissivity of iron sulfide thin film on aluminum plate, hence this study delve into studying this all important material by examining its emissivity for possible application in thermal energy.

3. Materials and Methods

The materials used for the experiment:includes: Aluminum plates, emery paper, water, detergent, alpha polishing alumina, cotton wool, methylated spirit, glass beaker, iron sulfide solution, sodium hydroxide solution, thaurea, EDTA, thermocouple potentiometer, electronic weighing machine.

Electroless chemical bath deposition (ECBD) method was employed in this experimental work. The ECBD is a methodology utilized for coating a substrate (such as aluminum plate) with a thin film of a suitable material without requiring outside supply of electricity. The process of ECBD involves the use of a chemical bath solution containing the needed components for the deposition reaction to take place. In this case of iron sulphide deposition, the bath solution consists of a reducing agent, a metal salt precursor, a complexing agent, and other additives to control the deposition parameters.

3.1 Preparation of aluminum plates surface

In this work, the deposition process begins by preparing the aluminum plate surface through thorough cleaning and activation as follows:

Plain sheets made of aluminum of the different dimensions and thickness was first cleaned with emery paper (sand paper). The aluminum plates were then washed with detergent to remove dirt and then cleaned with alpha polishing of grade AB with the aid of a cotton wool to get their mirror finishing. The plates were then washed with detergent after which is rinsed with distilled water and finally cleaned with methylated spirit and allowed to dry in air. This step of preparing the surface of the aluminum plates is to ensure that any impurity is removed and also to promote better bonding between the aluminum plates and the deposited thin film.

3.2 Preparation of chemical bath solutions

The deposition baths employed in this research are glass beakers of $400cm^3$ containing different molar solutions. The solutions include 0.8M iron (II) sulfate heptahydrate ($FeSO_4.7H_2O$) as root of iron sulfide ions (Fe^{2+} S^{2-}), 1.0M sodium hydroxide (NaOH), 0.8M thaurea as complexing agent, 0.7M Ethylenediamine tetraacetic acid (EDTA) as a binder and another complexing agent, and distilled water. Using an electronic weighing device, the appropriate masses of these reagents were determined, and the masses are evaluated as in equation (1)

$$m = \frac{M \times W \times V}{1000} \qquad (1)$$

Where

M = needed molar concentration

W = molar mass of the chemical reagent

V = volume of the solution required

Different solutions containing the various molarities were measured in six beakers, and the solutions contained in the various beakers were elevated to a particular level by adding distilled water. The resulting solutions in the beakers are then stirred with glass rod for proper mixture.
Table 2 shows the detailed of the bath constituent at different time and at the same room temperature.

Table 2: Bath constituent for deposition of iron sulpide (FeS)

Platte No	H_2O Vol (ml)	$FeSO_4.7H_2O$ (0.8M) Vol (ml)	EDTA (0.7M) Vol (ml)	NaOH (1.0M) Vol (ml)	Thaurea (0.8M) Vol (ml)
F1	20	7	25	16	12
F2	18	24	22	14	12
F3	16	23	19	12	10
F4	14	30	16	10	10
F5	12	39	13	8	8
F6	10	40	10	6	8

Chemical Reaction
The basic reactions for the deposition of iron sulphide (FeS) thin film is shown in equation (2 - 7)

$$FeSO_4.7H_2O + EDTA \rightarrow \{Fe(EDTA)\}^{2+} + 7H_2O + SO_4^{2-} \quad (2)$$
$$\{Fe(EDTA)\}^{2+} \rightarrow Fe^{2+} + EDTA \quad (3)$$
$$(NH_2)_2CS + OH \rightarrow CH_2N_2 + H_2O + HS \quad (4)$$
$$HS + OH \rightarrow H_2O + S^{2-} \quad (5)$$
$$Fe^{2+} S^{2-} \rightarrow FeS \quad (6)$$

The overall reaction

$$FeSO_4.7H_2O + EDTA + (NH_2)_2CS + 2OH \rightarrow FeS + CH_2N_2 + 9H_2O + EDTA + SO_4 \quad (7)$$

3.3 Deposition process
The thoroughly cleaned sample plates labeled F1, F2, F3, F4, F5 and F6 were immersed in the beakers containing the various prepared solutions for 12 hours, 16 hours, 20 hours, 24 hours, 28 hours, and 32 hours respectively which is 4 hours interval at room temperature of 300K for all sample plates, after which the plates were removed from each of the beakers and rinsed with distilled water. To deposit iron sulfide (FeS) thin films on the aluminum sample plates by ECBD technique, gradual release of Fe^{2+} and S^{2-} ions from cations and anions sources is needed in an aqueous intermediate. The deposition of iron sulfide thin film takes place when the ionic product (IP) of Fe^{2+} and S^{2-} ions is more than the solubility product (SP) of FeS. The ion-ion condensation occurs on the aluminum plates dipped in the solution [16, 17]. Applying the law of mass action, the solubility constant can be evaluated with equation (8)

$$K_{SP} = \frac{[\![Fe^{2+}]\!][\![S^{2-}]\!]|}{[\![FeS]\!]} \quad (8)$$

Where K_{SP} is the solubility constant of the deposited iron sulfide thin film

4. Results and Discussions

4.1 Measurement of the mass of thin film
The mass of sample plate (aluminum) was taken before and after the iron sulphide thin film was deposited using electronic weighing machine and the difference in the mass accounted for the mass of the iron sulphide thin films. Table 3 shows the mass of polished aluminum plates, coated aluminum plate and the deposited iron sulfide thin films.

The temperature of deposition was room temperature, though it was still measured by a thermometer to be 27^0C which is equivalent to 300K in Kelvin scale.

Table3: Mass Of Deposited Iron Sulphide Thin Film On Aluminum Plates

Plate number	Mass of polished Plate (g) ±0.01	Mass of coated Plate (g)±0.01	Mass of thin film (g) ±0.01	Deposition time (hrs)
F1	21.28	21.29	0.010	12
F2	21.69	21.71	0.020	16
F3	15.06	15.09	0.030	20
F4	16.47	16.51	0.040	24
F5	14.55	14.62	0.070	28
F6	13.57	13.66	0.090	32

4.2 Evaluation of thin film thickness
The thickness of the deposited iron sulphate thin Film was evaluated using equation (9)

$$t = \frac{M}{2A\rho} = \frac{M}{2A\rho \times 10^{-2}} \quad (9)$$

where,
M= mass of thin film
ρ=density of thin film = 1.898gcm^{-3}
A = Area of coated thin films on plates.
Table 4 shows the thickness of the deposited iron sulfide the films as calculated from equation 9.

Table 4: Thickness Of Deposited Iron Sulfide Thin Film

Plate Number	Length of thin film(cm)	Width of film (cm)	Area of films (cm^2)	Mass of film (g)	Film thickness (μm)	Deposition time (hrs)
F1	7.3	1.7	12.41	0.010	0.832	12
F2	6.7	2.0	13.40	0.020	1.542	16
F3	7.0	1.9	13.30	0.030	2.542	20
F4	6.5	1.9	12.35	0.040	3.330	24
F5	7.5	2.0	15.00	0.070	4.821	28
F6	6.5	1.9	12.35	0.090	7.528	32

4.3 Evaluation of emissivity of polished plates
The emissivity of the sample plates before the deposition of iron sulfide thin films was evaluated from the recorded thermocouple reading of the sample plates using equation 10. Table 5 shows the emissivity of the thoroughly prepared sample plates

Table 5: Emissivity Of Polished Aluminum plates

Plate NO	Mass of polished plates (g±0.01)	Reading of black body plate Vb±0.01(mv)	Reading of polished plate Vs ±0.01	Emissivity of polished plates Ɛs ±0.01
F!	21.28	96.00	83.00	0.156
F2	21.69	119.00	86.00	0.130
F3	15.06	107.00	90.00	0.151
F4	16.47	100.00	82.00	0.148
F5	14.55	104.00	86.00	0.149
F6	13.57	98.00	85.00	0.156

Average Emissivity of polished plate = 0.148 $\pm$ 0.01

$$\frac{\varepsilon_s}{\varepsilon_b} = \frac{V_s}{V_b} \quad (10)$$

Where:
ε_S = emissivity of sample plate
ε_b = emissivity of black body = 0.18
V_S = thermocouple reading of sample plate
V_b = thermocouple reading of black body
Heat was provided by an electric pressing iron and the thermocouple potentiometer was used in measuring the heat emitted from the coated plates and the black body was used as control for the aluminum coated plates

4.4 Evaluation of the emissivity of coated plate

After the iron sulphide thin film was deposited on the aluminum plates, emissivity of the coated plate was calculated using equation11after taking the thermocouple reading of the coated plates.

$$\frac{V_c}{V_b} = \frac{\varepsilon_c}{\varepsilon_b} \quad (11)$$

ε_c = emissivity of iron sulfide coated plates
ε_b = emissivity of black body = 0.18
V_c = thermocouple reading of iron sulfide coated plate
V_b = thermocouple reading of black body
Heat was provided by an electric pressing iron and the thermocouple potentiometer was used in measuring the heat emitted from the coated plates and the black body was used as control for the aluminum coated plates
The calculated values are shown on table 6.

Table 6 : Emissivity Of Coated Aluminium Plate

Plate NO	Mass of coated plate(g)±0.01	Reading of Black body (V_b)±0.01	Reading of coated plate (V_{cs})±**0.01**	Emissivity of coated plate (εc) ±0.01
F1	21.29	104.00	92.00	0.159
F2	21.71	102.00	88.00	0.155
F3	15.09	116.00	98.00	0.152
F4	16.51	107.00	90.00	0.151
F5	14.62	110.00	93.00	0.152
F6	13.66	112.00	98.00	0.158

Average Emissivity of coated plate = 0.155 $\pm$ 0.01
Error in emissivity of coated plates was evaluated using the standard error/deviation method as show in equation (12)

$$\delta = \frac{\sqrt{\Sigma(X-\bar{X})^2}}{n} \quad (12)$$

where $\bar{X}$ = mean of emissivity of coated plates
X = the individual coated plate emissivity
N = number of plates
Σ = summation

4.5 Emissivity of iron sulfide thin film

The emissivity of iron sulfide thin film was evaluated by finding the difference between the emissivity of coated plates and polished sample plates. Table 7 accounted for the emissivity of the iron sulfide thin film

Table 7: Emissivity of iron fulfide thin film

Plate No	Emissivity of polished plates (εs) ±0.01	Emissivity of coated plate (εc) ±0.01	Emissivity of FeS thin film
F1	0.156	0.159	0.003
F2	0.130	0.155	0.025
F3	0.151	0.152	0.001
F4	0.148	0.151	0.003
F5	0.149	0.152	0.003
F6	0.156	0.158	0.002

Average emissivity of FeS thin film = 0.006±0.01

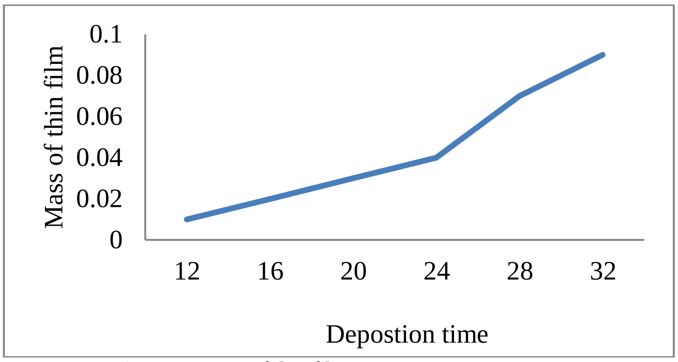

Figure 1: Mass of thin film Against Deposition time

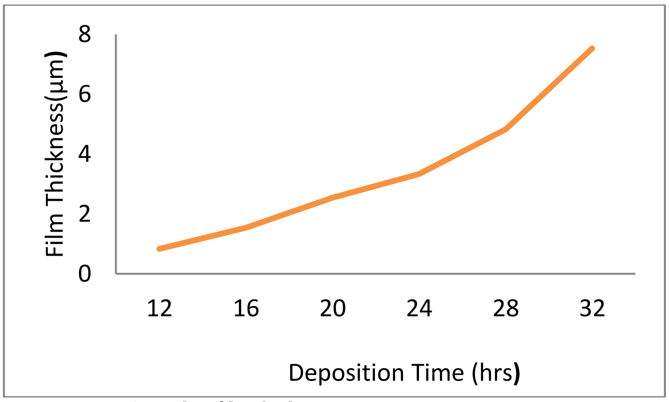

Fig 2: thin film thickness Against Deposition time

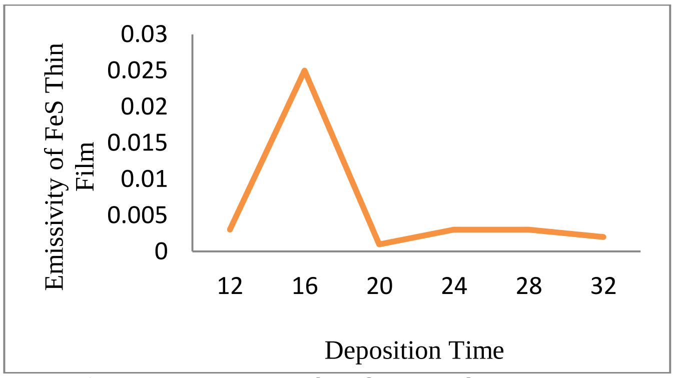

Figure 3: Emissivity FeS Thin Film against deposition Time

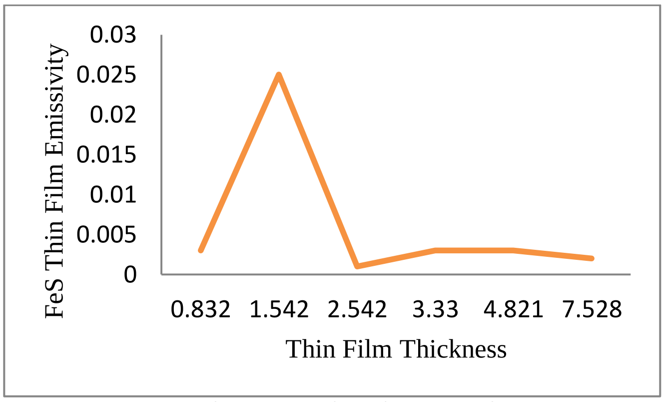

Figure 4: graph of Emissivity of thin film against film thickness

4. Discussion

Iron sulfide thin film was successfully deposited on the aluminum plates at room temperature of 300k at different deposition time. The thermal emittance of the films was measured using a thermocouple potentiometer. A black body was used as a reference for measurement whose emissivity was used as a control for the aluminum plates. An electric pressing iron was used to supply heat at an interval of 30 seconds. The emissivity of the polished plates and the coated plates were calculated from equation (10) and (11) respectively. The Value of the emissivity of coated plates ranges from 0.151 t0 0.159 with an average of 0.155 $\pm$ 0.01 as shown in table 6. These results showed good agreement with the emissivity values of 0.18±0.01 for AISI 321 chemically oxidized stainless steel and aluminum plates (Sharma and Hutchins 2006) [23] and (Arekumo ThankGod1, Marere Omamode, 2018). The thickness and mass of the FeS thin film were also calculated and respectively plotted against deposition time as shown in figure 1 and 2. It was observed that the mass and thickness of FeS thin Film increases with deposition time as depicted in table 1 and 2 respectively.

Figure 3 shows the plot of emissivity of FeS thin film against deposition time which shows instantaneous rise for the first 16 hours of deposition time and then decline with deposition time at 16 to 20 hours. It then continue to rise with deposition time at 20 to 32 hours. Figure 4 shows the plot of FeS thin film against film thickness which show similar trend with figure 3 where there is a rapid increase of emissivity with film thickness from 0.832μm to 1.542μm before declining to a thickness of 2.542μm. A steady increase of the emissivity with film thickness from 2.542μm to 7.528μm is further observed in figure 4.

5. Conclusion and Future Scope

Iron sulfide thin films of selective surfaces of thermal emittance properties have been successfully deposited on polished aluminum sample plates using the electroless chemical bath deposition (ECBD) method at a temperature of 300k and different deposition time ranging from 12 to 32 hours. The average emissivity of polished plate is 0.148 $\pm$ 0.01. These values agree well with the emissivity values of 0.13 to 0.18$\pm$ 0.01 for polished aluminum at 27^0C. The emissivity of the coated aluminum plate ranges from 0.151 to 0.159$\pm$ 0.01. The mass of the deposited FeS thin films increases from 0.010 to 0.090g in accordance with the deposition time. As deposition time increased, the thickness of the thin films deposited spanned from 0.832μm to 7.528μm.

With the right deposition time span, this method of deposition could be applied to create selective absorbers for solar thermal applications at temperatures that are high as well as low.

The study results indicate that FeS thin films can be used as selective absorber coatings in solar thermal collectors. The low emissivity obtained can helps to maximize heat loss through radiation, increasing the overall efficiency of the solar thermal collector. The results also indicate that FeS thin film can be applied to surfaces of heat exchanger. The low emissivity of the coating helps to reduce heat loss from the hot part of the heat exchanger. This low emissivity of FeS thin film also allows for efficient detection of infrared radiation, making it suitable for applications such as thermal imaging, night vision, and remote temperature sensing.

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