Enhanced power conversion efficiency of the polycrystalline solar cells using spinel $MnFe_2O_4$ nanoparticles as an ARC material

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The Spinel magnetic nanoparticles ($MnFe_2O_4$) were prepared by using the precursors Manganese Chloride ($Mncl_2$) and Ferric Chloride ($FeCl_2$) using co-precipitation method. The synthesized nanoparticles can be used as a suitable Antireflective coating (ARC) for increasing the power conversion efficiency (PCE) of silicon solar cells. The prepared nanoparticles are deposited on the silicon solar cells using spin coating method. Single to quadruple layers of $MnFe_2O_4$ were coated. The prepared nanoparticles were confirmed by using characterization such as X-ray Diffraction (XRD), Fourier-Transform Infrared Spectroscopy (FTIR), Atomic Force Microscopy (AFM), Field Emission Scanning Electron Microscope (FESEM) and Energy Dispersive Spectroscopy (EDX). The XRD analysis reveals the formation of the spinel nanostructure for the synthesized $MnFe_2O_4$ nanoparticles. EDX analysis was used to check the elemental composition of the Mn, Fe and O in the samples. The crystal structure, particle size and lattice parameters were obtained by the XRD technique. The optical and electrical characterizations were done comprehensively to find out the performance of coated and uncoated solar cells. The surface morphology and the coating thickness were measured using the AFM technique.

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1. Introduction

In emerging countries, the main focus is on addressing the existing energy security challenges, environment and climate change. Among these clean-energy resources, Photovoltaic (PV) systems gained much interest across residential, business, farming and commercial processes, due to their low cost and easy maintenance . In spite of these benefits, the power conversion efficiency of PV solar cells is limited due to various factors such as reflection and recombination loss [3].Various methods are used in practice to reduce these losses. One such technique is applying the Anti-reflection coatings (ARCs) on the solar cells to reduction the reflection loss and thus by improving the light-trapping efficiency .Various materials are used as ARCs, among them, the spinel structured nanoparticles attracted huge interest due to their excellent properties such as ferromagnetic and semiconducting properties. Manganese ferrite ($MnFe_2O_4$) has a regular spinel structure with Mn^{2+} ions on the A^- site and Fe_2O_4 on the B^- site. These ferrites are used in multiple applications such as waste water treatment , cancer treatment [16], Super capacitors [2], Microwave absorption [10], Lithium-ion batteries and dye degradation process . Some of the different methods to synthesize the magnetic nanoparticles are co-precipitation[10], hydrothermal route[21], sol-gel method[7] and microemulsion method [14]. The properties of the spinel ferrites are affected by crystal size, morphology, synthesis and fabrication techniques. In this work, $MnFe_2O_4$ were prepared by using the co-precipitation method due to its low cost, enhanced uniformity and also requires the low temperature to prepare the materials.

Various deposition methods are used to deposit the synthesized materials in the silicon substrate such as spray pyrolysis, chemical vapour deposition , spin coating [7], sputter coating

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[6], pulsed laser deposition, electrospinning [8] etc., The synthesized nanoparticles are deposited on the silicon solar cells using the spin coating technique. Single to quadruple layers of the coating was deposited. The structural, morphological and optical properties for the synthesized nanoparticles which is coated on various silicon solar cells were analysed.

2. Experimental part

2.1. Materials and chemicals

Manganese chloride ($MnCl_2$), Ferrous chloride ($FeCl_2$) and Sodium hydroxide (NaOH) with 99% purity were purchased from Merck Private Ltd (India). Ethanol with 99.9% purity was purchased from Loba chemical Private Ltd(India). PV solar cells with 52 x 38 mm dimensions were purchased from Ecoworthy (China).

2.2. Preparation of Spinel MnFe2O4 Nanoparticles

To synthesize $MnFe_2O_4$ nanoparticles $MnCl_2$ and $FeCl_2$ were used as the precursors. The precursors of 1g each were mixed with the 100ml distilled water and 75ml of NaOH solution were added to act as a co-precipitator, then the solution was stirred continuously at 750 rpm by using a magnetic stirrer at 75℃ for two hours. The product was allowed to settle down and its pH was maintained constantly at 7.5.The precipitate was kept in a hot air oven at 110℃ for 12 hours and then it is calcinated at 500℃ using a muffle furnace. The obtained bulk $MnFe_2O_4$ was grained repeatedly to obtain the $MnFe_2O_4$ nanoparticles. In order to deposit the $MnFe_2O_4$nanoparticles on the solar cells, 0.1g of $MnFe_2O_4$ are added with 10ml of ethanol. Ethanol was chosen as the suitable solvent due to its excellent results. This solution is magnetically stirred for 2 hours at room temperature before the deposition. The solar cells were initially cleaned by using Ethanol and dried. The solution is coated on the solar cells using the spin coating technique with a constant speed of 3000 rpm. Single to quadruple layers (A1 to A4) were coated on the solar cells. After each deposition, the cells are dried at 150℃before the next layer coating

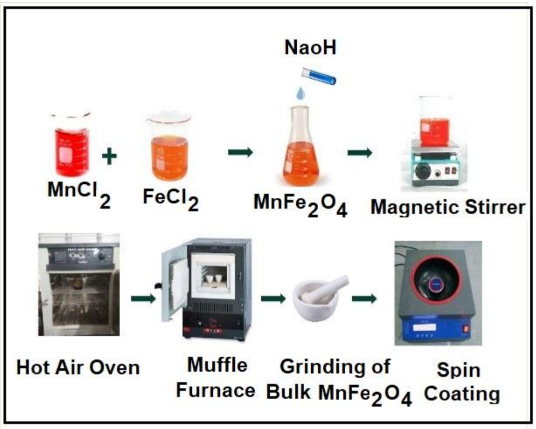

Fig.1.Process Flow Diagram.

3. Results and discussion

X-ray diffraction (XRD) was used to analyze the phase of the samples on a Rigaku D/Mmax 2500 PC diffractometer using Cu-K radiation.The crystallinity and the purity of the synthesized nanoparticles were examined by using XRD [10]. The diffraction peaks in the XRD is indexed to the $MnFe_2O_4$ lattice planes (220, 311, 400, 422) with the JCPDS NO 73 – 1964, confirmed the synthesized nanoparticles is having high crystallinity without any other impurities. Fig. 2 shows the XRD Patterns of the $MnFe_2O_4$ nanoparticles calcined at 550 ℃for two hours.

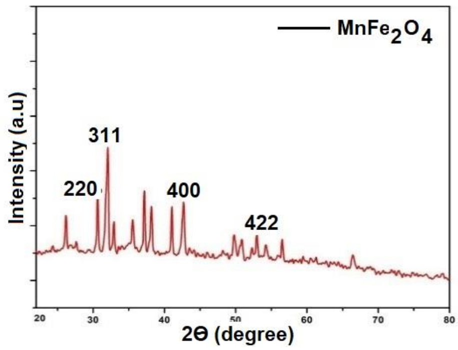

Fig. 2.XRD of Synthesized $MnFe_2O_4$.

Vibrational spectroscopy is regarded as an extremely useful method for detecting chemical and structural changes. Fig 3 displays the synthesized spinel $MnFe_2O_4$ FTIR spectrum in the wavelength from 4000 – 500 cm^{-1} which is calcinated at 550°C. FTIR analysis revealed the presence of the metal oxides vibrations in the high-frequency fingerprint region and also to exhibited the presence of functional organic bonding in the low energy zones as shown in the FTIR Spectra [5-8]. The spinel $MnFe_2O_4$nano particles shown in the characteristic peak at 3191 cm^{-1},confirms the presence of the hydroxyl groups and the peak at 673 cm^{-1} is aligned to Fe – O bond vibration.

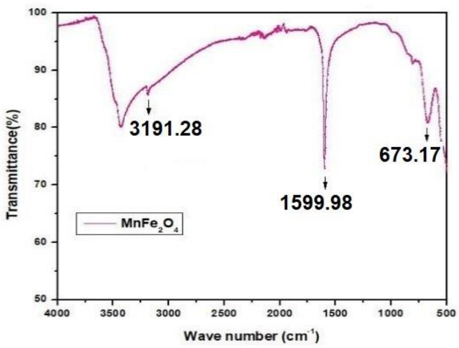

Fig 3.FTIR of $MnFe_2O_4$.

The surface morphology, topology and the coating thickness of the various layered solar cells were identified by using the AFM images for A1 to A4 layers. Fig 4 shows the 2D and 3D topographic images of the $MnFe_2O_4$ coated on the solar cells: a) single-layer coating b) double layer coating c) three-layer coating d) four-layer coating.

From the AFM images, it is found out the thickness is 100 nm, 205 nm, 270 nm and 480 nm for A1, A2, A3 and A4 layers respectively. It is evident from the AFM images that as the coating layer increases the thickness also increases due to the deposition of the Mn^+ ions in the Ferrites which increase the thickness. The AFM study intimates that the thickness of the coating increases due to the agglomeration of the particles on the surface layers [6, 2].

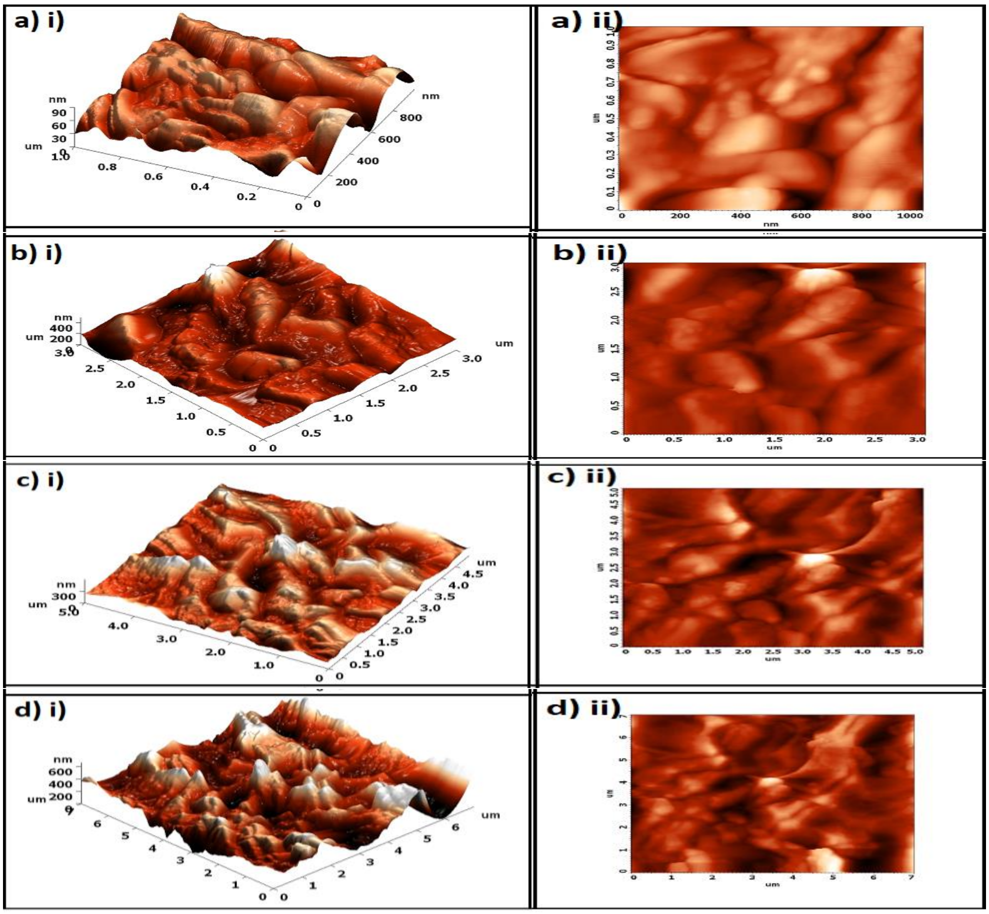

Fig. 4.AFM images oz a) single layer coating b)Double layer coating c)Three layer coating d) Four layer Coating.

The Morphology of the coated $MnFe_2O_4$ sample (A3 Layer) is shown in the Fig 5 a).From the FESEM morphology it is observed that $MnFe_2O_4$sample is dispersed .The EDX spectrum was shown in the Fig 5 b) and the obtained atomic percentage of Mn,Fe agreed with the designed composition. The FESEM and EDX confirm the presence of $MnFe_2O_4$ sample coated in the A3 Layer of Silicon solar cells.

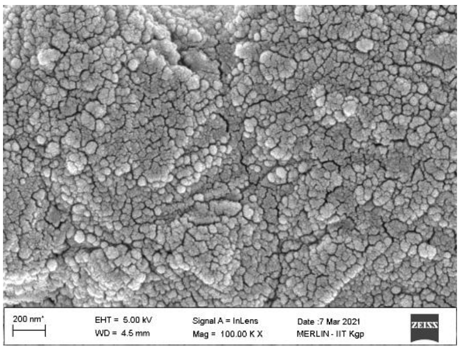

Fig. 5. a) FESEM image of $MnFe_2O_4$ Coated A3 Layer on Silicon solar cell.

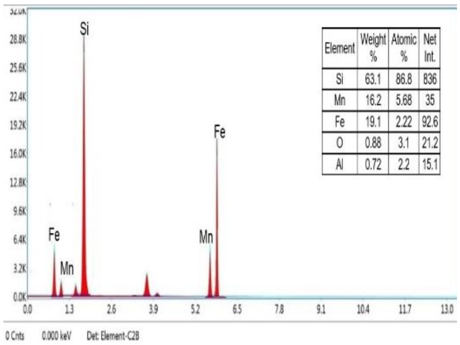

Fig. 5. b) EDX spectrum of $MnFe_2O_4$ Coated A3 Layer on Silicon solar cell.

The Fig 6.Shows the transmittance of the $MnFe_2O_4$ samples with the variable film thickness. The spinel $MnFe_2O_4$ samples (A1 to A4) shows better transmittance above 85% in the wavelength region from 350 – 800 nm. It is observed from the spectrum the transparency is greatly increased for the coated samples as the coating layer increases, while comparing to the uncoated solar cells[2].

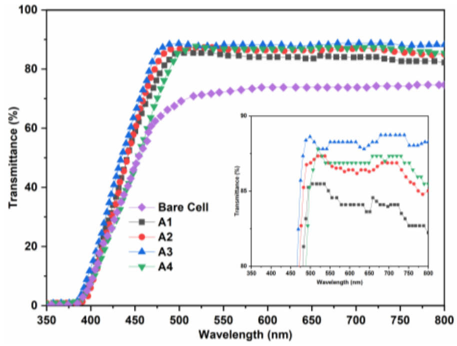

Fig. 6.Optical Transmittance of $MnFe_2O_4$solar cells.

The resistivity of the $MnFe_2O_4$ coated samples and the reference solar cells were measured by using the four probe technique and the results are depicted in the Fig 7. A3 layer shows low resistivity of 3 x 10^{-3} Ω-cm while comparing to the uncoated solar cell of resistivity 7 x 10^{-3} Ω-cm. The decrease in the resistivity is due to the presence of Mn and Fe ions on the Silicon substrate. The decrease in the resistivity is confined to the increase in the conductivity of the solar cells. Further increase in the layer thickness (A4) results in increase in the resistivity; this is due to the agglomeration of the particles due to layer thickness[4].

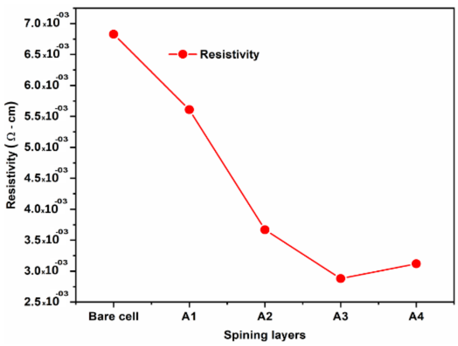

Fig. 7.Resistivity of $MnFe_2O_4$ samples.

The power conversion efficiency (PCE) of the coated and uncoated solar cells were performed under the controlled atmospheric condition and it is calculated using the formula

$$\eta = \frac{I_{sc} V_{oc} FF}{P_{in}} \quad (1)$$

Where I_{sc} is the short circuit current, $V_{oc}$is the Open circuit voltage, FF is the Fill Factor and P_{in} the Incident radiation. It is observed from the table that

Table 1.PCE of Coated Solar Cells.

Solar cell	**J_{sc} (mA/cm^2)**	**V_{oc} (V)**	**Fill factor (%)**	**Efficiency η (%)**
Ref. cell	31.10	0.625	76	15.24
A1	32.60	0.631	76.1	16.10
A2	35.71	0.631	76.4	17.50
A3	37.30	0.652	77.5	19.20
A4	38.50	0.651	77.2	18.50

Fig. 8. shows the photovoltaic performance of the spinel $MnFe_2O_4$ coated solar cell (52 mm x 32 mm) under the closed atmospheric condition with the 1.5 AM global simulated spectrum. The performance of coated and uncoated solar cells was measured and the readings are tabulated as shown in Table 1.The A3 layer shows better performance of open circuit voltage (V_{oc}) of 0.652V short circuit current (J_{sc}) of 37.30 (mA/cm^2) compared to the uncoated solar cell[7]. The PCE found to be increased from 15.24 to 19.20 %.

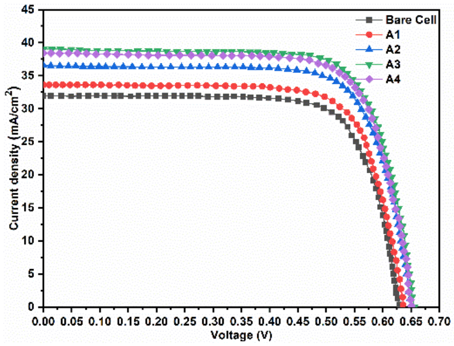

Fig. 8.Photovoltaic performance of the spinel $MnFe_2O_4$ coated solar cell compared with the bare cell under closed atmospheric conditions.

4. Conclusion

Sol-gel technique was used to synthesize the spinel $MnFe_2O_4$ nanoparticles using the precursors Manganese chloride and Ferric chloride. The XRD results proved that the miller indices are well indexed with the spinel $MnFe_2O_4$ nanoparticles. FTIR spectra reveal that the characteristic peaks contain the Hydroxyl groups and the presence of Fe-O vibrations and are well indexed with the synthesized nanoparticles. The Surface Topology of the spinel $MnFe_2O_4$ nanoparticles coated on the solar cells was calculated by using AFM and the coating thickness of the A1 to A4 layers was found to be 100 nm, 205 nm, 270 nm and 480 nm. From the FESEM and EDX of the A3 layer, it is observed that the coated $MnFe_2O_4$ were dispersed evenly throughout the surface of the solar cells and the elemental composition well coincides with the synthesized $MnFe_2O_4$ nanoparticles. The A3 coated layer rendered maximum Transmittance of 89% and resistivity of 3 x

10^{-3} Ω-cm while comparing to the uncoated and other coated layers. The performance of the Uncoated and coated solar cells was calculated by using closed atmospheric condition and the overall performance of the solar cells increased drastically to 19.20% for the A3 layer (270nm).Hence it is observed that spinel $MnFe_2O_4$ nanoparticles can act as a suitable ARC material for increasing the PCE of the silicon solar cells.

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