Enhancement Open Circuit Voltage of Calcium Titanate AR Coated Magnesium Solar Cell

K.Kathirvel, S.Selvakumar, S.Dhamotharan, G.Bharath, M.Sivaraman

Abstract: ***The present research aims to enhance the open circuit voltage of fabricated solar cell through Anti–Reflection (AR) coating on the cell substrate. Solar cell is fabricate using ITO Glass, titanium dioxide, magnesium and redox. Calcium Titanium Oxide (CaTiO3) is chosen as the AR coating material for constructing thin film layer on fabricated solar cell. Selected AR coating material have unique features such as orthorhombic, biaxial, non-radioactive and non-magnetic with electron bulk density of 3.91 g/cm3 respectively. Commonly, voltage generation of the multi crystalline solar cell is low (12% to 14%) due to much reflection of inward sun radiation. Deposition of AR coating on the substrate (fabricated solar cell) can minimize the reflection loss of sun radiation. The maximum improvement in solar cell efficiency after AR coating has been reported as 19.3%.***

Sputter coating technique is more favorable for thin film coating due to its salient features like uniform coating thickness controlled by time. This uniform coating thickness absorbs more sun radiation. Radio Frequency (RF) magnetron sputter coating technique is utilized in the current research to deposit $CaTiO_3$ ***on solar cells. Prior to coating, the AR material is pelletized using Universal Testing Machine (UTM). The substrate are coated under varying time duration of 15-minutes, 30-minutes and 45-minutes in order to analyze the variation in open circuit voltage. The deposition of coating on the substrate are confirmed using SEM and FESEM. Open circuit voltage of controlled atmosphere studies for pure and AR coated solar cells (fabricated) are examined. Controlled atmosphere tests of AR coated thin films are conducted by placing the substrate inside a solar simulator and the solar simulator consist of IR thermometer (To measure Temperature), solar power meter (To measure Radiation) and multimeter (To measure Open circuit voltage). Neodym daylight lamp is used to control the radiation in solar simulator. The improvement in cell voltage proves that thin film AR coating considerably minimizes the reflective loss.***

Keywords ***:Anti Reflection Coating, Solar cell, Voltage Generation, Solar Simulator, Open Circuit Voltage.***

Manuscript published on November 30, 2019.

* Correspondence Author

Mr. K.Kathirvel*, Mechanical Engineering, Kongu Engineering College, Erode, India.

Dr.S.Selvakumar, Mechanical Engineering, Kongu Engineering College, Erode, India.

Mr.S.Dhamotharan, Mechanical Engineering, Kongu Engineering College, Erode, India.

Mr. G.Bharath , Mechanical Engineering, Kongu Engineering College, Erode, India.

Mr. M.Sivaraman, Mechanical Engineering, Kongu Engineering College, Erode, India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

I. INTRODUCTION

Renewable energy is energy produced from sources that are not exhausted or can be supplemented during human life. The most common examples are wind, sun, geothermal energy, biomass and hydropower. Solar cells or photovoltaic cell are electrical devices that convert light energy into electricity through the direct light-emitting effect of physical and chemical phenomena. The photocell has electric characteristics like current, voltage, and resistance when exposed to light. The solar devices are not suitable for all weather conditions and also it is effective only in day time. The sun is the major resource for solar energy which energizes the solar cells and it produces electricity according to the level of solar radiation.

The solar energy is useful in home appliance, colleges, hospitals, remote areas, and more so solar is the major resource in solar cells. Anti-reflection (AR) coating reduces the sunlight reflection in solar glass panel and increases the rate of light absorption. AR coating on solar cell is similar to those used on other optical equipment such as camera lenses.

Sputter coating is a physical vapor deposition process used to apply a very fine, functional coating on a subtract. Sputter coating machine is used to deposit $CaTiO_3$ on the top surface of the solar cell, this process starts by electrically charging a sputtering cathode which in turn forms a plasma cause material to be ejected from the target surface.

II. MAERIALS & METHODS

A. ITO Glass

The Indium Tin Oxide (ITO) coated glass is a types of Transparent Conductive Oxides (TCO) glass. The ITO coated glass have high transmittance properties and good conductivity. The chemical formula of ITO is $Sn:In_2O_3$. The uniform thin layer of ITO over a glass substrate makes it low surface resistance and highly transparent of sun light. Indium Tin Oxide is coated on the glass plate by magnetron sputtering method. Sputter coating processing temperature is maintained at 300°C. One face of the glass plate is coated with ITO and other face is insulated. ITO face is Conductive and withstand the temperature of 350°C.

B. Titanium Dioxide

The pure commercially available of 99.9% titanium dioxide is chosen.

The particle size of titanium dioxide is 25µm. The material have the following properties

- High photo reactivity
- High oxygen ion vacancy tolerance
- No magnetic field is produced during charge transfer
- Stable structure even at a high pressure and temperature
- Band gab is 2.04eV
- High thermal stability
- Low toxicity
- Good chemical stability

C. Magnesium Oxide

Magnesium oxide is a naturally occurring compound found in metamorphic rocks. The chemical formula of magnesium oxide is MgO, its forming an ionic bond. Magnesium oxides white in color and odorless powder. Magnesium oxide is very basic and it has a high pH of 10.3. Magnesium oxide is soluble in water at 0.0086 g of powder per 100 mL of water.

D. Carbon

Carbon considered as inorganic material and conductive. Carbon formed in glass plate by using candle flame.

E. Redox Shuttle

Redox shuttle additives made of mixing of ethylene glycol, iodine crystal and potassium iodide in the ratio of 1:12:80.

F. Calcium Titanate

The pure commercially available of 99.9% Calcium titanate is chosen as AR coating material. $CaTiO_3$ materials have unique property such as (i) high photo reactivity, (ii) high oxygen ion vacancy tolerance, (iii) no magnetic field produced during charge transfer, (iv) stable structure even at a high pressure and temperature, (v) electron bulk density of $CaTiO_3$ is 3.78 g/cm^3 .

G. Die Construction

The AR coating materials are purchased in powder form from the market. Solid target is required for RF sputter coating system. The dimensions of solid target are 50.8mm diameter and 5mm thickness. The solid targets are prepared by pelletization process by using Mild Steel (MS) die. This die has the inner diameter of 50.8mm and bottom portion has 5mm thickness while the wall thickness of the MS die is 30mm. The die has the many parts: bottom plate, male part and female part. The bottom plate of MS die is nickel coated for easy removal of target from the die.

Fig. 1. Die

H. Pelletization Process

The $CaTiO_3$ powders (13gm) are filled in the die set and then the die is kept inside UTM. Load (15 ton) is applied on the male part of the die. Further, the compressed solid targets are removed from the die. The compacted solid target is exposed to a temperature of 110ºC for 15-minutes in the electric furnace in order to remove the moisture content from the solid target.

I. Thin Film Coating

Sputter coating machine (VR SPU – 06D) is used to deposit $CaTiO_3$ on the top surface of the solar cell. In vacuum chamber, 5cm distance is maintained between substrate and target by holders. AR material is coated on the substrate with varying time duration of 15-minutes, 30-minutes and 45-minutes. The process parameters adopted during coating are described below.

- Constant vacuum chamber pressure = 6 x 10^{-2}mbar.
- Process current: 75watts for $CaTiO_3$

When vacuum pressure attains the prescribed value, the argon gas is introduced into the vacuum chamber, which acts as a working medium to impinge the target material particle and to deposit the same on the solar cell. Further, the sputter coating is tuned to generate the plasma. After initiation of plasma generation the substrate is subjected to coating for 15-minutes, 30-minutes and 45-minutes of time interval. Mostly, the target top face is contaminated. In order to remove the contaminated particles, initially the coating is done in a movable steel plate which restricts the contaminated coating on magnesium substrate. After a few seconds, the steel plate is moved with the help of lever. Further, the coating is performed on the silicon substrate.

J. Scanning Electron Microscope (SEM)

The AR coating material is incorporated into the solar cell to enhance the power conversion efficiency. The morphological analysis of formed thin film is enhanced by SEM. The SEM results explicit compact, uniform and dense surface morphology with small grains homogeneous in size.

K. Field Emission Scanning Electron Microscope (FESEM)

Morphological analysis of formed thin film is carried out by FESEM. The FESEM results can show uniform distribution of nano particles in substrate.

L. Electron Dispersive Spectroscopy (EDS)

Electron Dispersive Spectroscopy (EDS) analyses the properties of structural stability and electrical properties of solar cell. SEM with energy dispersive X-ray spectroscopy (EDS) provides the topographical information and the elemental composition of thin film. In EDS test, 22kV is used for the process voltage.

III. RESULT & DISCUSSION

A. Control Atmospheric Test

Table- I: Percentage Of Increase In The Open-Circuit Voltage Of AR Coated (Catio3) And Pure Fabricated Solar Cells Under Controlled Atmospheric Conditions 15-Minutes

Uncoated solar cell under standard atmosphere						
S. No.	**Radiation from light (W/m^2)**	***Temperature and open-circuit voltage***				
		35°C	***40°C***	***45°C***	***50°C***	***55°C***
		mV	***mV***	***mV***	***mV***	***mV***
1	200	299	292	273	269	254
2	250	301	296	289	281	273
3	300	311	304	296	285	276
4	350	320	310	298	291	283
5	400	320	313	301	291	282
6	450	320	312	300	293	288
AR Coated (15-minutes) solar cell under standard atmosphere						
S. No.	**Radiation from light (W/m^2)**	***Temperature and open-circuit voltage***				
		35°C	***40°C***	***45°C***	***50°C***	***55°C***
		mV	***mV***	***mV***	***mV***	***mV***
1	200	305	301	283	282	269
2	250	311	307	301	296	290
3	300	322	318	311	301	296
4	350	336	328	319	312	306
5	400	337	332	322	313	308
6	450	339	334	324	320	317

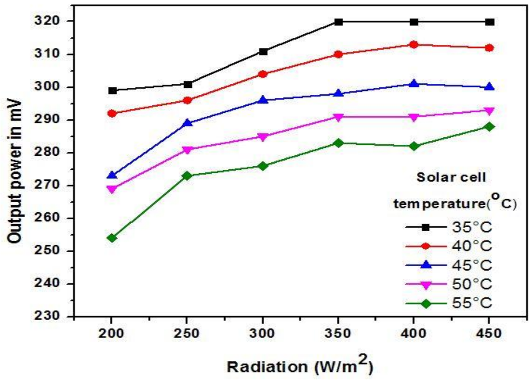

Fig. 2. Uncoated solar cell used for 15- minutes AR coating

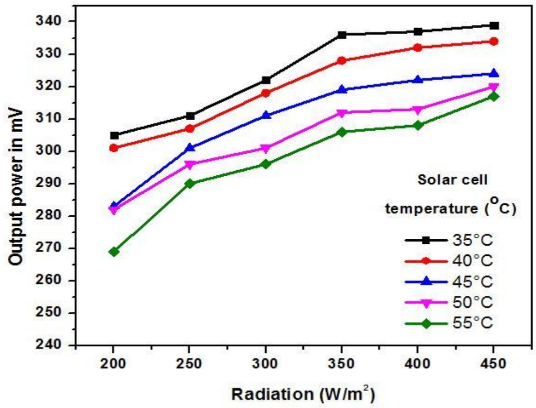

Fig. 3. Coated solar cell (15- minutes AR coating)

In solar simulator the radiation level is maintaining at 200 W/m^2 to 450 W/m^2 (50 W/m^2 Step) by using AC potentiometer. The temperature of AR coated solar cell attain 35^0C, 40^0C, 45^0C, 50^0C & 55^0C and take cell voltage by the help of multimeter. The temperature of the substrate is measured by IR thermometer. These components are equipped with solar simulator. Pure and AR coated solar cells readings are shown in above table.

If the temperature of the solar cell increases the output open circuit voltage decreases. In low temperature the solar cell give maximum efficiency. An efficiency increase of 9.1% is achieved with 15- minutes AR coated solar cell when compared with uncoated solar cell.

Table- II: Percentage Of Increase In The Open-Circuit Voltage Of AR Coated (Catio3) And Pure Fabricated Solar Cells Under Controlled Atmospheric Conditions 30- Minutes

Uncoated solar cell under standard atmosphere						
S. No.	Radiation from light (W/m²)	*Temperature and open-circuit voltage*				
		35°C	*40°C*	*45°C*	*50°C*	*55°C*
		mV	*mV*	*mV*	*mV*	*mV*
1	200	251	230	225	220	213
2	250	260	252	243	240	234
3	300	280	272	255	250	246
4	350	286	275	270	261	251
5	400	310	305	296	291	288
6	450	310	305	300	293	289
AR Coated (30-minutes) solar cell under standard atmosphere						
S. No.	Radiation from light (W/m²)	*Temperature and open-circuit voltage*				
		35°C	*40°C*	*45°C*	*50°C*	*55°C*
		mV	*mV*	*mV*	*mV*	*mV*
1	200	268	253	253	257	257
2	250	285	281	278	284	282
3	300	312	309	297	297	300
4	350	323	314	312	312	309
5	400	358	357	354	354	353
6	450	362	362	361	358	358

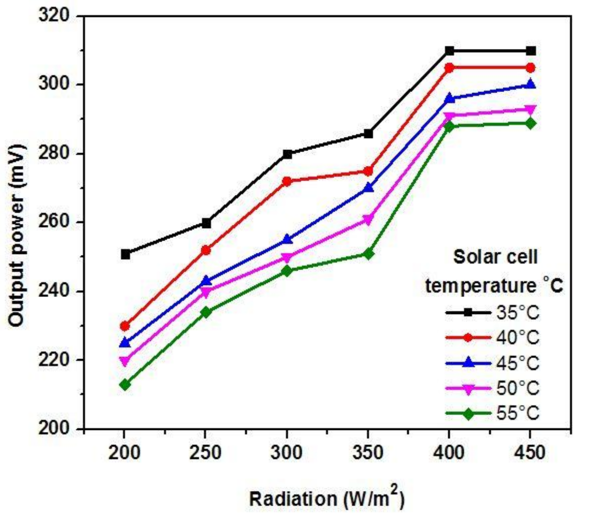

Fig. 4. Uncoated solar cell used for 30- minutes AR coating

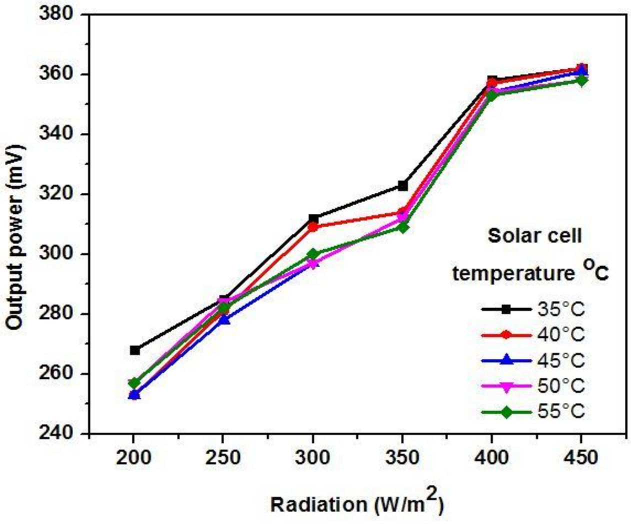

Fig. 5. Uncoated solar cell (30- minutes AR coating)

From the above table maximum voltage generation difference is 69mV at 55^0C cell temperature. At 35^0C cell temperature, the AR coated solar cell produces 52mV. This Study proves that AR coated solar cell produces the maximum efficiency in low temperature.

Retrieval Number: C6660098319/2019©BEIESP
DOI:10.35940/ijrte.C6660.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table- III: Percentage of increase in the open-circuit voltage of AR coated ($CaTiO_3$) and pure fabricated solar cells under controlled atmospheric conditions 45-minutes

Uncoated solar cell under standard atmosphere						
S. No.	Radiation from light (W/m²)	*Temperature and open-circuit voltage*				
		35°C	*40°C*	*45°C*	*50°C*	*55°C*
		mV	*mV*	*mV*	*mV*	*mV*
1	200	270	256	242	238	230
2	250	260	250	241	237	232
3	300	280	272	254	243	241
4	350	290	282	273	260	253
5	400	310	303	294	283	285
6	450	310	302	299	290	286
AR coated (45-minutes) solar cell under standard atmosphere						
S. No.	Radiation from light (W/m²)	*Temperature and open-circuit voltage*				
		35°C	*40°C*	*45°C*	*50°C*	*55°C*
		mV	*mV*	*mV*	*mV*	*mV*
1	200	276	264	252	250	243
2	250	270	262	255	252	249
3	300	292	287	271	263	265
4	350	304	299	294	285	283
5	400	326	324	321	315	323
6	450	330	329	332	330	331

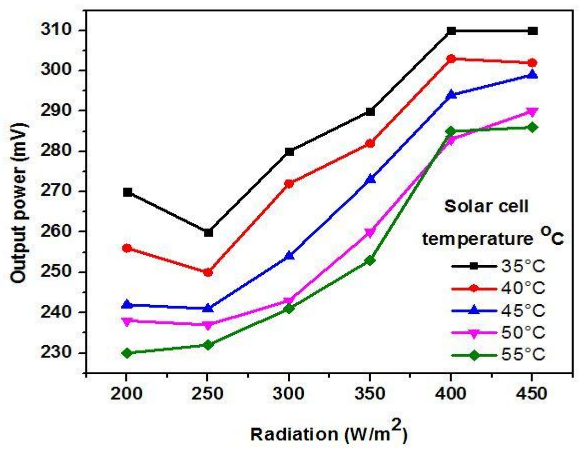

Fig.6. Uncoated solar cell used for 45- minutes AR coating

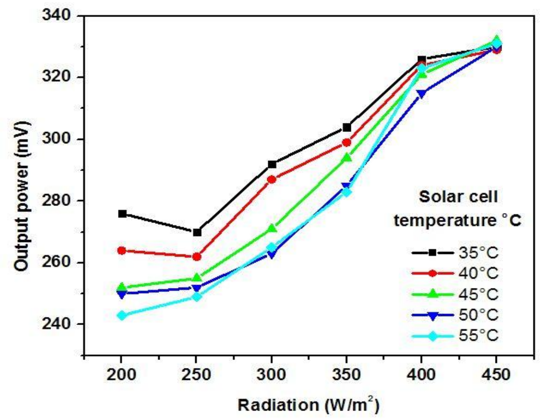

Fig.7. Uncoated solar cell used for 45- minutes AR coating

The above table shows 45-minutes AR coated solar cell at 55°C temperature of the solar cell produces maximum open circuit voltage of 331mV. Due to coating heaviness the percentage difference of open circuit voltage production is reduced when compared to 30-minutes AR coating.

Calcium Titanate material will considerably reduces the reflection of incoming radiation. coating time increases means coating thickness increases, if coating thickness increased means reduced the velocity of photon in thin film. If velocity of photon reduced means open circuit voltage production capacity will reduced. So optimized coating time is 30-minutes.

The study shows sputter coating above 30- minutes found to be in effective. All the tests are carried out in controlled atmosphere in solar simulator. In open atmosphere, weather condition may change time to time, the test not suitable for comparison.

Retrieval Number: C6660098319/2019©BEIESP
DOI:10.35940/ijrte.C6660.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

B. SEM Test

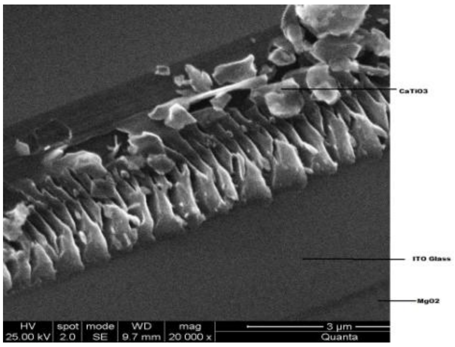

Fig. 7. SEM Image

The figure 7 shows the SEM image of AR coated solar cell. The picture clearly depicts the $CaTiO_3$ spread on the substrate

C. FESEM Test

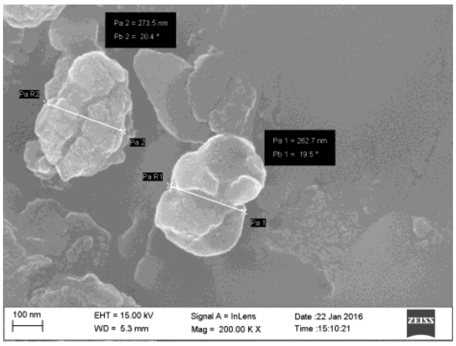

Fig. 8. FESEM Image

The figure 8 shows the FESEM image of AR coated solar cell. The picture clearly depicts the particle size of $CaTiO_3$. The average particle size of $CaTiO_3$ is found to be around 280nm.

D. EDS Measurement

EDS analysis carried out for AR coated substrates demonstrates the elemental percentage of $CaTiO_3$ layer. The table conforms the composition of $CaTiO_3$.

Table IV Elemental Composition

El	AN	Series	Atomic concentration (%)
Si	14	k-series	39.19
Ca	20	k-series	25.23
Ti	22	k-series	20.66
O	8	k-series	14.92
		Total	100.00

IV. CONCLUSION

In the present study, $CaTiO_3$ AR coated solar cell (Fabricated) is tested under controlled atmosphere. AR coating is done on the substrate using RF magnetron sputter coating technique. Further, the morphology of the coated substrates is analysed through SEM and FESEM. SEM analysis proves the deposition of AR coating on the substrate. The presence of coating elements on the substrate was analysed using FESEM analysis. Under controlled atmospheric conditions for a constant radiation level of 450W/m², $CaTiO_3$ coated silicon substrate showed 19.3% enhancement in open-circuit voltage (30-minutes AR coating) when compared with uncoated substrate. The decrease in the cell voltage was found with increase in AR coating time. The increase in PCE for the coated solar cells can be attributed to utilization of wider band gap materials which minimizes the reflection of sun radiation.

REFERENCES

1. Kathirvel, K., Rajasekar, R., Shanmuharajan, T., Pal, S. K., Sathish Kumar, P., & Saravana Kumar, J. (2017). Development of calcium titanium oxide coated silicon solar cells for enhanced voltage generation capacity. Materials Science-Poland, 35(1), 181–187. doi:10.1515/msp-2017-0036
2. Akihiro Kojima, Kenjiro Teshima, Yasuo Shirai & Tsutomu Miyasaka 2009, 'Organometal halide perovskite as visible sensitizer for photovoltic cells'. Journal of the Americal cemical society, vol. 131, pp. 6050-51.
3. Amrani, El, Menous, A, Mahiou, I, Tadjine, L, Touati, RA & Lefgoum, A 2008. 'Silicon nitride film for solar cells'. Renewable Energy, vol .33, pp. 2289–2293.
4. Awais, M, Rahman, M, MacElroy, D, Coburn, N, Dini, D, Vos, J & Dowling, DP 2010, 'Deposition and characterization of NiOx coatings by magnetron sputtering for application in dye-sensitized solar Cells'. Surface and Coatings Technology, vol. 204, pp. 2729-2739.
5. Brain, o, Regan, Michael & Gratzel 1991, 'A low cost high efficiency solar cell based on die sensitized colloidal TiO2 films'. Institute of physical chemistry, vol. 535, pp. 737-740.
6. Byung-Ho, Moona, Youl-Moon, Sunga & Chi-Hwan Han 2013, 'Titanium oxide films prepared by sputtering solgel and dip coating methods for photovoltaic applications'. Energy procedia, vol. 34, pp. 589-596.
7. Collins, RW 2013, 'Evolution of microstructure and phase in amorphous, polycrystalline and microcrystalline silicon studied by real time spectroscopic ellipsometry', Solar Energy Materials and Solar Cells, vol. 78, pp. 143-180.
8. Das, S, Alam, I, Raiguru, J, Subramanyam, BVRS & Mahanandia, P 2013, 'A facile method to synthesize CZTS quantum dots for solar cell applications'. Physica E: Low-dimensional Systems and Nanostructures, In press.
9. Dmitry Mikulik, Maria Ricci, Gozde Tutuncuoglu, Federico, Matteini & Jelena 2017, 'Conductive-probe atomic force microscopy as a characterization tool for nanowire-based solar cells'. Nano energy, In press.
10. Dobrzanski, LA & Szindler, M 2012, 'Sol gel TiO2 antireflection coatings for Silicon solar cells'. Journal of Achievements in Materials and Manufacturing Engineering, vol. 52, pp. 7-14.

Retrieval Number: C6660098319/2019©BEIESP
DOI:10.35940/ijrte.C6660.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

AUTHORS PROFILE

Mr.K.Kathirvel had completed M.E degree in Bannari Amman Institute of Technology in the year of 2012 and received gold metal. Ph.d research work in enhancement of power conversion efficiency of solar Cell. Published more than 3 papers in various journals and presented research work in more than 12 conferences. The published journals covers technical areas like solar cell, optimization and physical coating techniques. Servicing as an Assistant Professor in Kongu Engineering college for more than 86 months. Worked as an Engineering trainee in Quality Assurance and Development for one year in industry. Life member of ISTE and member of SAE

Dr.S.Selvakumar serves as Associate Professor in Mechanical Engineering Department at Kongu Engineering College, Erode, India with the teaching experience of 16 years. Holds PhD degree in the area of Fixture Design and Optimization from Anna University, Master of Engineering in Computer Aided Design from Periyar University and Bachelor degree in Mechanical Engineering from University of Madras. Member of the Indian Society of Technical Education. Research interests in the field of Computer aided design and optimization. Serving as Editorial board member in three international journals and reviewer in ten international journals and published 12 papers in international journals and 20 papers in conferences.

Mr.S.Dhamotharan had completed M.E degree in Kongu Engineering College in the year of 2013. Currently doing research work in the area of Internal Combustion engines particularly focusing on four stroke spark ignition engine. Published journals and conferences in the area of Internal Combustion Engines, Optimization and FUZZY Logic. Attended various workshops and seminars in reputed institutions in the field of emission control and dimensional tolerances. Servicing as an Assistant Professor in Kongu Engineering college for more than Six years. Worked as an assistant engineer in Quality department for five years in ARROW Tech PVT. LTD, Indore. Life member of ISTE and member of SAE.

Mr. G.Bharath had completed B.E (Automobile Engineering) in Anna University in the year 2018. Currently doing Maters in Engineering Design at Kongu Engineering College, Erode. Carried out projects in the area of alternate fuel for Internal Combustion engines during under graduation. Post Graduate research work in Solar cell area specifically development of high efficient inorganic solar cells. Presented the research work in more than 4 international conferences in the area like Internal combustion engine, alternative fuel and solar cell. PG phase one project done in solar cell area. Undergone industrial training for more than one month in field of Automobile.

Mr. M.Sivaraman had completed Diploma (Mechanical Engineering) in Shree Venkateshwara Hi-Tech polytechnic college, B.E (Mechanical Engineering) in Anna university. Currently doing Maters in Engineering Design at Kongu Engineering College, Erode. Worked at Pricol PVT. LTD, Coimbatore as a Quality Inspector. Post Graduate research work in Internal Combustion engines area particularly focusing on four stroke spark ignition engine. Attended more than two conferences. Presented the research work in more than 3 international conferences in the area like Manufacturing , Abrasive water jet machining and Internal Combustion engine. PG phase one project done in IC engine area. Undergone industrial training for more than one month in field of Automobile.