A Report on Metal-Oxides for ARC Application

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Abstract- Antireflection is the phenomenon of reducing the reflection from the surface and broadly employed to eliminate the undesirable surface reflection. ARC have wide range of applications in the optical and optoelectronics. With the advent of nanotechnology the research on ARC materials has been increased extensively. This paper, reviewed on the various factors effecting reflection and the major aspects need consideration. The studies based on different types of ARC have been presented. This paper mainly focused on the materials used for single, double and multi-layer ARCs which exhibited high transmittance ~99.9%. Besides this, a brief discussion has been carried out on the synthesis methods like sol-gel, physical vapour deposition, co-precipitation, CVD, sputtering etc. and characterization methods like XRD, FESEM for the material morphology and UV-Visible, Raman spectrometry for optical properties. Apart from this a short glance on the change in electrical properties like energy band gap, the output efficiency of the electronic devices like solar cells, leds, display devices etc. has been made when coated with ARC.

Key words: antireflection coatings, reflection, transmittance, efficiency, optoelectronic devices

I. INTRODUCTION

In general, the reflection occurs on the surfaces between two medium with different refractive index, however the reflection can be reduced when the refractive indices of the media are similar. The concept of anti-reflective coatings was first coined by Lord Rayleigh in the 19th century. He observed that there is an increase in the transmittance of glass when it is tarnished, which led to the strategy of achieving anti-reflectivity by varying refractive index. In 1817, Fraunhofer produced actual antireflective coatings by etching the surfaces in sulphur and nitric acid vaporous atmosphere [7]. Later in 1892, H. Dennis Taylor observed that the coated camera lens permitted photography with less exposure, and developed a mechanism for obtaining anti-glare coating properties by the variation of refractive index [12].

In the recent years, the potential applications for the decrease of reflectivity has been increased which includes optoelectronics devices like super- compact cameras, LED displays, LCDs, touch screens. Besides, it has wide application in the field of military, medical equipment, space, aeronautics, photo-voltaic solar cells. Hence,a lot of research is been carried out to reduce the reflection of light. The reflection depends on the surface topography, synthesis of material, refractive index, thickness etc. A comprehensive study has been made by scientists on the materials properties, new synthesis methods were investigated to suite the antireflection properties. A brief discussion on the basic concept and the structures of ARCs were given by [1-4, 7-8, 12, and 21].

II. THEORY

Reflection is the optical phenomenon which occurs when the light travels between two media due to the change of refractive index. The mathematical model for reflection and refraction was given by Fresnel equation [7].

The following assumptions are made to deduce the conditions for ARCs:

- The reflected waves have same intensity and one reflected wave per interface.
- Optical interactions like scattering, absorption are negligible.

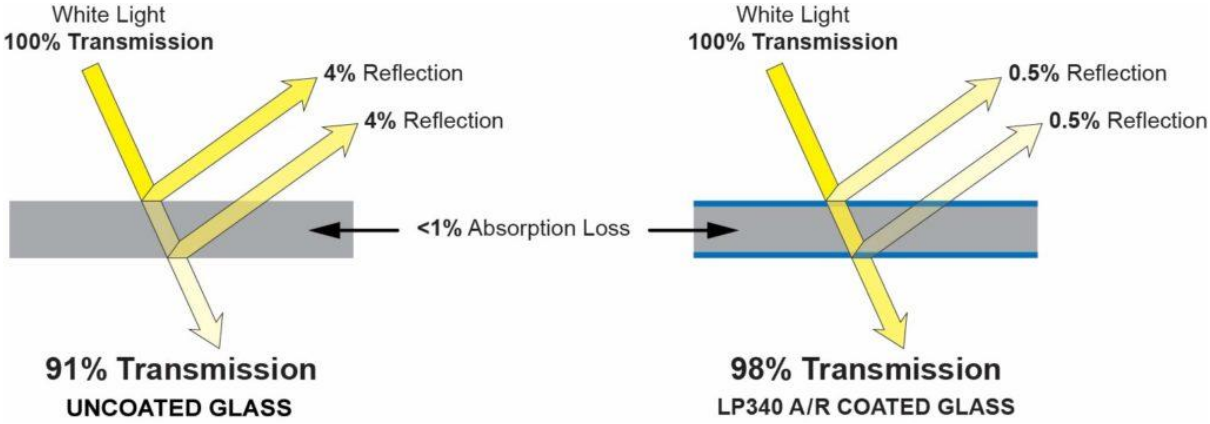


Fig: 1 Difference between uncoated and coated glass

The essential criteria for anti-reflection:

- ❖ The reflected waves should have a phase difference of nп/2 and the waves are out of phase by п radians.
- ❖ The film thickness should be an odd multiple of wavelength (λ/4).

Single layerARC

The homogeneous and non-absorbing surface to have a zero reflectance should accomplish the following conditions.

$$n_{arc}= (n_s.n_{env})^{1/2}$$

$d_{arc}=\lambda/4.n_{arc}$

The above equations are satisfied only for homogeneous and non-absorbing surfaces and become more complicated for absorbing surfaces due to losses. The reduced reflectivity is limited for single layer ARC [12].

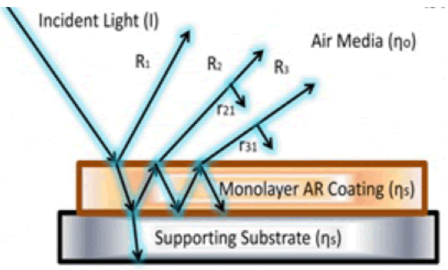
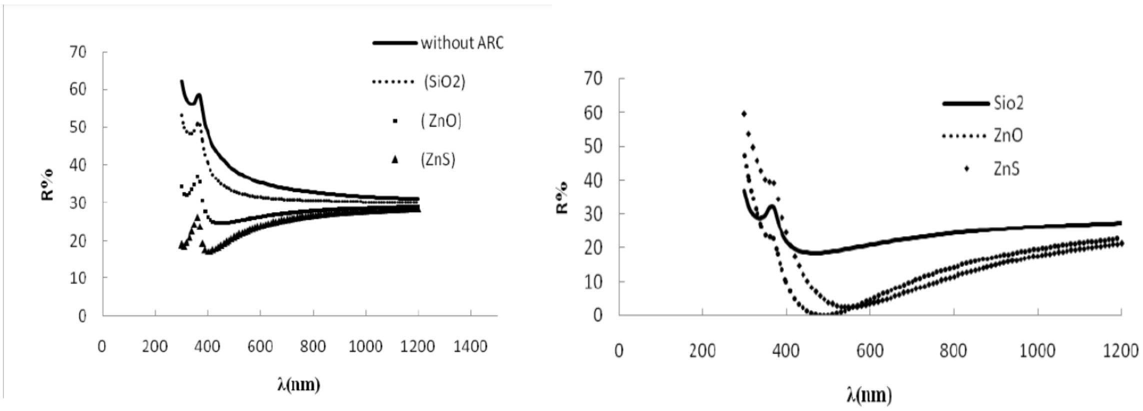


Fig: 2 Schematic representation of single-layer ARC Copyright: © 2017 Bashir Khan S, et al. [2]

The anti-reflective coatings were generally deposited on the surface of the substrate, for a single-layer ARC the layer with λ/4 thickness is usually deposited for better outcomes; some studies show that the thickness can also be λ/2. For single-layer ARCs, the mostly used materials were metal oxides like ZnO, SiO_2,SiON,SnO_2, TiO_2, Al_2O_3, HfO_2, CeO_2, zinc sulphide (ZnS), Zinc Selenide, magnesium fluoride (MgF_2) and composites (TiO2:SnO2-ZnO, SnO_2 :In, TiO_2: MgF_2, SnO_2:Al) etc. The single-layer ARCs are widely used in the low power applications. The efficiency of the solar cell increased with the deposition of ZnO, SiO_2, ZnS as the ARC layer and transmittance increased to 99.6% [11, 24]. The LEDs with SiON ARCs enhanced the efficiency by 11.38% [31]. The optical power of the Laser diodes was enhanced by the deposition of Al_2O_3, SiO_2, and MgF_2 as ARC layers [30, 97]. The composite TiO_2: MgF_2showed an increase in the power conversion efficiency by 5.56% for DS solar cell than TiO_2 alone [58].



(a) (b)

Fig:3 Reflectance of single-layer ARC on silicon with (a) thickness 30nm (b) 60nmCopyright: © 2016 Nabeel M. Naser et al. [11]

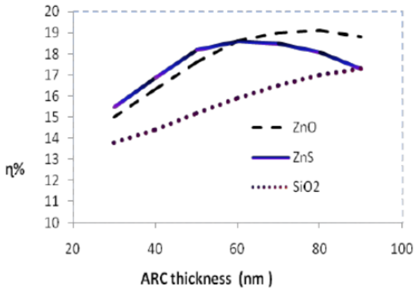


Fig: 4 Thickness vs efficiency of device Copyright: © 2016 Nabeel M. Naser et al. [11]

Fig 3 shows the reflectance curves of single-layer ARC for SiO_2, ZnS, and ZnO. Nabeel M. Naser et al [11] carried out a simulation of ARC coating using PC1D simulation for solar cell application. The simulations were recorded for the change in reflectance with respect to the wavelength and found that the reflectance is approximately <1% and hence an increase in efficiency of the device is increased by 18 to 19% which is shown in fig 4 for the thickness range 30-60nm.

III. DOUBLE LAYER ARC

Industries commonly use double layer ARCs. Usually in double layer ARCs the upper film facing air has lowest refractive index and other layers were deposited in ascending order. The interference condition must be fulfilled with single layer thickness usually quarter and half ($\lambda/4$ and $\lambda/2$) [12]. The geometry obeys.

$$n_1.d_1=n_2.d_2$$

The sufficient condition to reduce reflectance

$$n_1.n_2=n_0.n_s$$

The increase in the efficiency of the of the optoelectronic devices for double-layer is high compared to the single-layer ARCs. To have a double layer ARC the second layer is deposited on the top of the first layer, i.e.; deposited one above the other as a stack. The two layers can be of same material (both the layers are one material likeSiO_2 on SiO_2) and the layers can be of different material (like MgF_2/SiO_2). There is an improvement in the conversion efficiency of solar cell by 16.01 and 16.94% for multi crystalline and single crystalline silicon substrate respectively [56]. TiO_2/ZnO can be used as UV protector [36]. The SiO & TiO_2 ARC layer showed an enhancement of 12% in short circuit current of solar cell [74], textured silicon/ ZnO coating increased the conversion efficiency of solar cell [35]. The solar cell coated with MgF_2/SiO_2 AR double layer exhibited an increase in sort circuit current by 11.8%, power conversion efficiency increases by 12.5% [110].

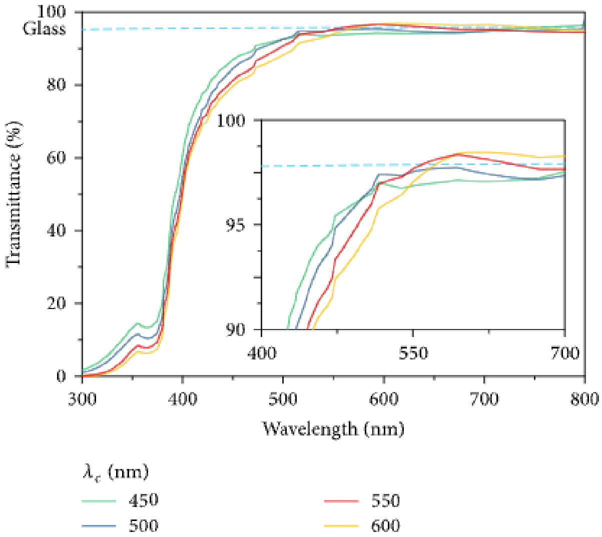


Fig: 5 Transmittance spectra of UV absorbing film as a function of wavelength with different center wavelengths (i.e., λc, 500, 550, and 600 nm) Copyright: ©Han Sung Song et al (2017) [36]

Center wavelength (nm)	450	500	550	600
T (%)				
UVB (310 nm)	2.78	1.76	0.35	0.20
UVA (360 nm)	13.80	10.84	8.05	6.48
Visible (avg 400–700 nm)	90.84	90.43	89.95	89.23

Table: 1 Transmittance of UV absorbing films different center frequenciesCopyright: ©Han Sung Song et al (2017) [36]

Han Sung Song et al [36] developed a double layer ARC coating with ZnO/TiO_2 for UV protection. The studies revealed that the design transmits the visible light and absorbs the UV light which is shown in table 1at different center frequencies.

IV. MULTI-LAYER ARC

According to Fresnel equation the reflectance in M layers

$$R_i= (\rho_i+ R_{I+1}{}^{e-2jk_il_i}i)/ (1+ \rho_i R_{i+1}{}^{e-2jk_il_i}i), i=M, M-1\ldots 1$$

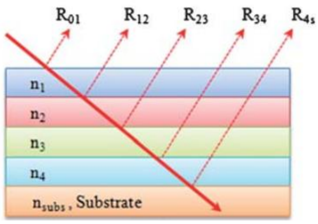
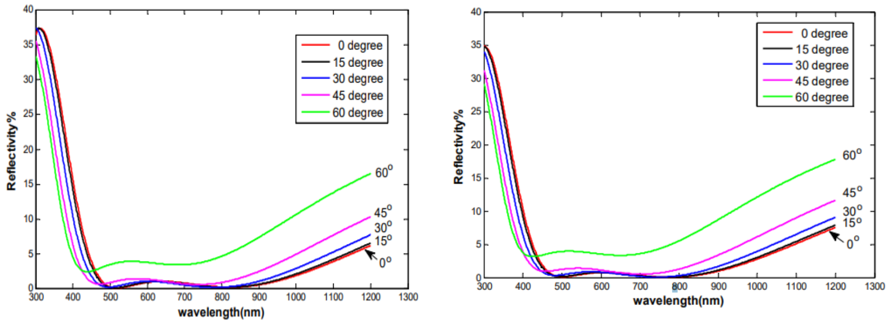


Fig:6 Schematic of multi- layer ARC Copyright: © [7]Hemanth Kumar Raut et al 2011

The multi-layer ARCs may of three, four, five layer stacks; the stack can contain any number of layers (10 to 100 & 1000) depending on the application. The thickness of the layers can be (λ/4,λ/2,and λ/4) or (λ/4, λ/4,λ/4). The multi-layer AR coatings provide higher efficiencies. The reflectance measurements for both layers $LaF_3/HfO_2/SiO_2$&$LaF_3/HfO_2/MgF_2$determined to be 0.85% and 0.75% [104]. Ta_2O_5, ZnS, Al_2O_3 single layer, MgF_2/ZnS double layer and MgF2/ Al_2O_3/ZnS triple layer exhibited an increase in efficiency of 29.4% and short circuit current by 31% for optoelectronics devices [95,101]. MgF_2, TiO2, La_2O_3, SiO2, CeF_3 AR multi-layer coating for Laser produced minimum reflection [60].



(a) (b)

Fig: 7 The variation in reflectivity of optimal passivation and antireflection coatings (a) $MgF_2/ZnS/Al_2O_3$ (b) $MgF_2/ZnS/SiO_2$ Copyright: © Wang Lisheng, Chen Fengxiang (2012) [59]

F(%)	0^0	15^0	30^0	45^0	60^0
$MgF_2/ZnS/Al_2O_3$	1.08	1.04	1.04	1.61	4.86
$MgF_2/ZnS/SiO_2$	1.15	1.10	1.10	1.69	5.03

Table: 2 The comparison of weighted average reflectivity Copyright: © Wang Lisheng, Chen Fengxiang (2012) [59]

Wang Lisheng, Chen Fengxiang [59] developed the multi-layer anti reflection for improving the conversion efficiency of solar cell. The multi-layer ARC was composed of $MgF_2/ZnS/Al_2O_3$and MgF2/ZnS/SiO_2. The weighted average reflectivity shown in fig 7 was calculated for both the combinations considering the parameters like influence of optimal angle, the angles range of incident sunlight, the spectra of silicon and the distribution of solar spectrum. The results or both the combinations was compared and identified that the Al_2O_3 combination reduces the reflectance than SiO_2.

V. BIO-MIMETIC ARC

The unique structures of Moth eye have the ability to reduce the reflectance. Environmental pressures have caused the evolution of regular repeating prominent 3D patterns on the eye structure which reduces reflection effectively [1]. S. Chattopadhaya et al talked about the biomimetic (natural design for controlling light) structures such as AR moth eye or cicada wings for anti-reflection coatings in the sub wavelength scale to reduce reflection [4]. Gang Shi et al studied the 3D biomimetic moth eye coating with ternary materials (polypyrrole nanoparticles, TiO_2 nanorods, Si micro pyramids) which reduced the reflectivity <4% and exhibited remarkable super hydrophobicity [6]. Mikhail Kryuchov et al discussed the biological antireflective surfaces formed by the silk-moth ancestors. They mainly focused on the structure of the silk-moth and what makes the structure to reduce from its surface which is more suitable for the application of ARC. The structures were studied under AFM and discussed the materials suitable for designing the ARC layer [27].

VI. SYNTHESIS AND CHARACTERIZATION

In general, the nano materials were synthesised by top-down and bottom-up approach. To achieve the desired optical properties the materials were synthesised by sol-gel, physical vapour deposition (PVD), atomic layer deposition (ALD), thermal evaporation, APCVD, Aerosol, aerosol assisted CVD, spray pyrolysis, magnetron sputtering etc., [46,67,70,103, 105,108,132].

The characterization of the material is very important as it carries out the studies on the topography, structure, size, crystal structure, etc. The SEM analysis gives the crystal structure, size. The surface roughness, porosity can be studied through AFM. XRD plots show the formation of crystal phase. The confirmation of the elements present in the compound can be achieved by EDX/EDAX analysis. The optical properties can be analysed from UV-VISIBLE spectroscopy, FTIR, Raman spectroscopy.

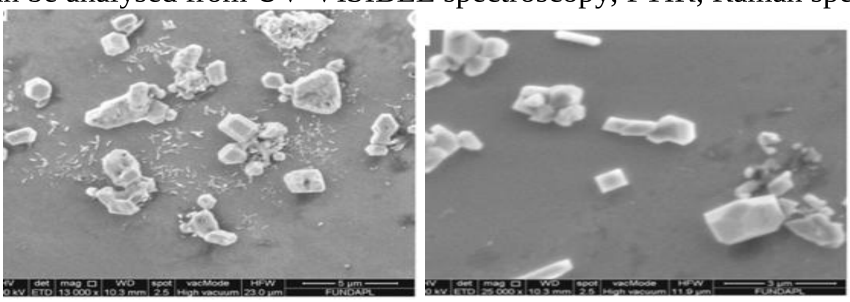


Fig: 8SEM images of TiO_2:SnO_2 Copyright: © F. Medjaldi et al (2020) [49]

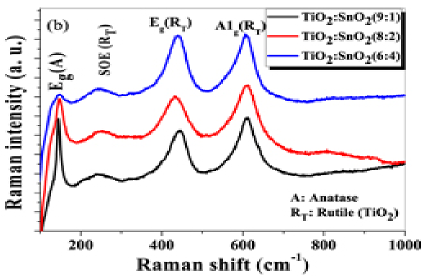


Fig: 9 Raman spectra Copyright: © F. Medjaldi et al (2020) [49]

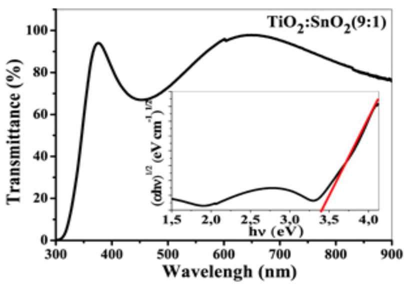


Fig: 10 UV –visible spectra Copyright: © F. Medjaldi et al

F. Medjaldi et al [49] synthesised the TiO_2, SnO_2 and TiO_2:SnO_2 nanocomposite (using different ratios) by sol-gel method and the thin films were coated by dip coating method which are characterised by SEM for morphology studies and Raman and UV spectra for the study of optical properties.

VI. CONCLUSION

ARCs have a variety of applications like solar cells, LEDs, display devices, ophthalmology, submarines, sensors etc. It is also used in interferometers by using lenses coated with ARC material. A wide range of research has been carried out in the area of ARCs in order to reduce the reflection from the surface and to increase the efficiency of the device. A variety of materials, synthesis processes and deposition methods has been identified to reduce surface reflection. The selection of material and deposition method depends on the application. The discussions show that there is an improvement in the efficiency and working of devices coated with ARC layers.

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