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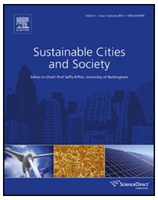

Theoretical and measured optical properties of Ni-Al_2O_3 over Al substrate selective absorber

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ABSTRACT

Theoretical calculations were done using (EMTs) and character matrix method. *Bruggeman theory* gives better fit than Maxwell-Garnett theory. The behaviour of the reflection measurements (*R*) as a function of wavelength was found to be the same for both theories. The absorption increased greatly over the solar range and slightly over the infra-red range.

There are small deviations between theoretical and experimental results which were discussed in details. The reflection was reduced up to about (20 ± 1)% over the solar range and up to about (3 ± 1)% in the infra-red range (2.0–6.0 mm) by the presence of porous alumina (of wide and narrow pores). The presence of small traces of metals in the aluminium substrate (aluminium alloy) reduces the reflectance more than the highly pure aluminium substrate. The predicted reduction of reflectance will reach about (30 ± 1)% on using the aluminium alloy as a substrate.

1. Introduction

Harvesting solar energy can be done by using the collectors where its main part is the absorber. The absorber can be selective and non-selective. Selective coating is characterized by its high absorption in the visible region and high reflection beyond the visible region of the sun spectra. Selective absorbers are of different types like: black nickel (NiS–ZnS), black chrome (CrO), black copper (CuO), undoped and doped tin oxide (SnO_2), and nickel pigmented aluminium oxide. Some of them are nanocrystalline material. Nanocrystaline materials are of very great importance for technological applications. They have properties superior to those of conventional coarse grained polycrystalline materials and amorphous alloys of the same composition (Kadirgan, 2006). There are various techniques which can be used for the preparation of selective coating like: vacuum evaporation, ion exchange, vacuum sputtering, chemical vapor deposition, chemical oxidation method, dipping in appropriate chemical baths, electroplating, spraying method, and painting and other methods (Bayón, San Vicente, Maffiotte, & Angel Morales, 2008; Zemanova, Chovancova, Gáliková, & Krivosik, 2008; Zhao, 2007). Electroplating was used to prepare our selective absorbers. Various electrolytic baths are used for the preparation of nickel pigmented aluminium oxide selective absorber. Electroplating time, solution temperature, solution concentration, solution pH, types of current (ac, rpc), current time, and current density are optimized to get desired optical and thermal properties. The initial cleaning of the substrates plays an important role in the final surface and optical quality of the coating. The coatings of the metal blocks can be prepared by electrolytic technique, while that of tin oxide by spray technique. A number of metal substrate like, copper, aluminium, galvanized iron, nickel plated copper have been used for metal blocks, while coatings of tin oxide were prepared on glass substrates. The selective coating is basically a two layered deposition of thin coating of bright and black metal successively. Generally, aluminium is chosen as a metal substrate, because it is of low cost, light weight, low emissivity and high thermal conductivity (Rai, 1984).

Optical modelling of the selective coating is essential, since designing the coating theoretically prior to experiment saves time, effort and money. The optical properties of any system of the selective coatings can be calculated from known optical constants data of the layers. For a single layer, the optical properties can be calculated easily. However for multilayer structures, the number of layers, their order and thicknesses are required to calculate the optical properties.

Therefore, the optimum number of layers, their arrangement and thicknesses are determined prior to deposition. The layer may be made of one component or more than one component

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(composite or cermet layer). The optical constants data for one component layer are found easily in the hand books of optics. However, the optical constants for composite layers are calculated using the effective medium theories (EMTs). These theories are used for two-component composite layers.

The effective medium theories are used to modelize the selective coating. These are: 1. Maxwell-Garnett theory, 2. Bruggeman theory, 3. Ping Sheng theory, and 4. Bruggeman–Hanai theory.

In this paper we will use two effective medium theories (Maxwell-Garnett and Bruggeman) to calculate the optical constants of the composite layer. The character matrix method is used to calculate the optical properties of the nickel pigmented aluminium oxide selective absorber on aluminium alloy substrate. These calculated optical properties are compared with experimental ones that were studied in our last paper (Wazwaz, Salmi, & Bes, 2010).

2. Experimental

2.1. Substrates preparation

A 1050a aluminium alloy (99.95%) of rectangular shape sheet of 20 mm × 40 mm is used as the substrate. Samples are initially decreased in a bath made up of sodium hydroxide, sodium carbonate and sodium gluconate for 1 min. After that, a sodium hydroxide solution (25 g/l) is used for one minute (etching process). In order to neutralize the surface, the substrate is immersed in a nitric acid bath (20%, v/v) for 2 min. All these stages, carried out at ambient temperature to enable us obtaining a satisfactory surface quality before anodic oxidation.

2.2. Anodization of alumina

Anodic oxidation is carried out in a phosphoric acid solution. There are many experimental variables involved in the anodic oxidation of the Alumina such as: acid concentration, anodization voltage and time, etc. In order to obtain optimization of the anodization process we have made an exhaustive investigation of the effects of all these different parameters. The different oxidation parameters are reserved in the following ranges:

Acid concentration: $0.5\,\text{mol/L} < X < 3\,\text{mol/L}$
Anodization voltage: $5\,\text{V} < U < 25\,\text{V}$
Anodization time: $10\,\text{min} < t < 25\,\text{min}$
The anodization temperature was kept at 20 °C and the electrodes distance of 4 cm.

2.3. Nickel impregnation

Nickel impregnation is carried out at ambient temperature, under AC (Alternate Current) (50 Hz) in nickel bath consisting of $NiSO_4$ (30 g/l), H_3BO_3 (20 g/l), $(NH_4)_2SO_4$ (20 g/l) and $MgSO_4$ (20 g/l). Reverse periodic current impregnation is performed in the same nickel solution under the following reverse periodic parameters: J_c = cathodic current density 1.0 A/dm^2, duration 10 ms, J_a = anodic current density 0.50 A/dm^2, duration 5 ms with different relaxation time t_r between the pulses.

3. Optical properties measurements

3.1. Diffused reflectance

UV/vis/near IR spectra are used for diffuse reflectance measurements. Diffuse reflection spectroscopy measurements in the UV/vis/near IR reign are carried out on a Jasco VERY-570 spectrophotometer equipped with an integrating sphere. Spectra are recorded at room temperature from 200 to 2000 nm with scanning speed of 100 nm/min using $MgCO_3$ as a reference. Hemispherical absorptivity, α, and emissivity, ε, are measured using absorptiometer and emissiometer (EL 510-520 ELAN INFORMATIQUE).

Diffused reflectance is measured using a double beam spectrophotometer as a function of wavelength in the range 0.2000–2.000 μm (where this range is the limit of the spectrophotometer used and which represents the solar range) against $MgCO_3$ standard reflector. Due to the presence of both specular and diffuse components, it is important to measure the integrated total reflectance of the selective coatings using an integrating sphere reflectance accessory. Integrating reflectometers of different designs have been developed to measure the solar reflectance and transmittance directly without the need of computation. These reflectometers use white light source for illumination of the sample and either the sample of known absorptance, MgO or $MgCO_3$ standard reflector for calculation of the absorptance of the sample by comparison method. The sample is either fixed at the surface of the sphere for evaluation of the absorptance or at the centre of the sphere for the angular hemispherical reflectance measurements. Silicon photocell and PbS detector with silicon window have been used to cover the whole solar spectrum range.

The Kubelka–Munk remission function (K/M) is calculated from the recorded diffused reflection measurements.

3.2. Total hemispherical absorptivity and emissivity

The hemispherical absorptivity (αs) and emissivity (ε) are measured using an absorptiometer (El 510 Elan Informatique) and an emissiometer (El 520 Elan Informatique) at 70 °C, respectively (Maissel & Glang, 1970; Salmi, Bonino, & Bes, 2000).

The absorptiometer is used to measure the total hemispherical absorption factor; however, the emissiometer is used to measure the total hemispherical emission factor.

4. Method of calculations

Simple matrix multiplication (character matrix method) is used to calculate the optical properties of single- and multilayer coatings (Born & Wolf, 1980; Liddell, 1981; Macleod, 1969; McDonald, 1971).

Reflectance (R) and Transmittance (T) are calculated using this method. However, the Absorptance (A) is calculated using Kirchhoff's law:

$$A = 1.00 - (R + T) \tag{1}$$

These optical properties are calculated by writing software using Turbo C++ language.

The optical constants of all layers should be known in order to calculate the optical properties of any system of coatings. Optical constants of materials are taken from Handbooks of optics and other literature data. However, the optical constants of the composite layers are calculated using the effective medium theories.

4.1. The effective medium theories (EMTs)

The scattering coefficient of the coated sphere (CS) has a series approximation developed by expanding the Bessel functions in power of their arguments. The dielectric constants (ε_A and ε_B) and the particle dimensions are assumed sufficiently small so that these series can be terminated after one or two terms.