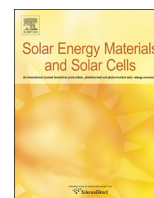




ELSEVIER

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Electrophoretically deposited carbon nanotube spectrally selective solar absorbers

Zhonghua Chen^{a,b,*}, Tobias Boström^b^a Norut Northern Research Institute Narvik AS, Narvik, Norway^b UiT, The Arctic University of Norway, Department of Physics and Technology, Tromsø, Norway

ARTICLE INFO

Article history:

Received 20 May 2015

Received in revised form

10 September 2015

Accepted 15 October 2015

Available online 11 November 2015

Keywords:

Carbon nanotube

Electrophoretic deposition

Spectrally selective solar absorbers

Solar absorptance

Thermal emittance

ABSTRACT

Three types of carbon nanotubes (CNT) have been investigated regarding their suitability as spectrally selective solar thermal absorbers. The CNT coatings were electrophoretically deposited on aluminum substrates using kinetically stable CNT aqueous suspensions, of which two CNT aqueous suspensions (N-CNT and P-CNT suspensions) were prepared as part of this study and the third one (T-CNT suspension) was purchased. The CNT suspension systems are simple and consist of only CNTs, DI water and a cathodic surfactant. Heat treated CNT coatings are visibly uniform. The CNT coating thickness, surface morphology and reflectance of CNT absorbers were characterized by White Light Interferometry, Scanning Electron Microscopy and Spectrophotometry, respectively. T-CNT absorber achieved a solar absorptance α of 0.79 and a thermal emittance ε of 0.14. N- and P-CNT absorbers achieved better spectral selectivity, with $\alpha=0.90$ and $\varepsilon=0.14$ for N-CNT absorber, $\alpha=0.90$ and $\varepsilon=0.13$ for P-CNT absorber. The effect of CNT coating thickness, deposition parameters and peak heat treatment temperature on the spectral selectivity were studied. For these CNT suspension systems, the thickness and the heat treatment peak temperature are the key factors to achieving a good spectral selectivity.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Solar thermal absorbers are used to absorb and convert solar radiation into heat in solar thermal collectors. The solar absorber needs to be spectrally selective in order to be optically and thermally efficient, which translates to a high solar absorption in the UV–vis–NIR solar spectrum and a low thermal emittance in the IR wavelength region. They are usually constructed with a selectively solar absorbing thin film coated on a highly infrared reflective metal substrate. The top absorbing layer is designed to absorb the solar radiation while the metal substrate should reflect infrared light, i.e. heat. Solar absorbers having this structure are called tandem absorbers [1].

Highly reflective metals such as aluminum [2–4], copper [5] and stainless steel [6] are commonly used as substrates. For the absorbing layer, black chrome [7,8], black nickel [9,10], and cermets [11–13] are among the most used materials. Techniques like anodization, electroplating, sputtering, spin-coating, chemical and physical vapor deposition are or have been utilized to fabricate absorbing coatings. Most manufacturing methods require costly high technology equipment, high energy consumption or toxic chemicals, and are therefore not environment-friendly. In this study, direct current electrophoretic deposition (EPD) has been employed to prepare absorbing coatings on

aluminum substrates. EPD can be applied with simple devices and uses simple systems like aqueous suspensions. The chemical consumption is very low and the deposition process takes a few seconds at ambient conditions. Electrophoretically deposited coatings exhibit good microstructure homogeneity and the thickness of coating can be easily controlled by tuning the EPD parameters, such as voltage, inter-electrode spacing, and deposition time [14].

Carbon nanotube (CNT) was discovered by Iijima in 1991 [15]. Since then, it has been extensively studied due to their unique thermal, electronic and mechanical properties. Aligned CNTs array also has good light absorptance at wavelengths from far ultraviolet to near infrared [16]. A tandem structure prepared by synthesizing aligned CNTs on Au films did not exhibit spectral selectivity over the solar spectrum though a high absorptance of 95% was attained [17]. However, our previous work simulating solar absorber using single-walled carbon nanotube coating as absorbing layer indicated that CNT absorber exhibited good spectral selectivity [18]. The objective of this work has been to experimentally investigate the suitability of electrophoretically deposited CNT coatings on aluminum substrates for use as spectrally selective solar absorbers.

2. Methods

Three types of CNTs were investigated: T-CNT, N-CNT and P-CNT. T-CNT aqueous suspension was provided by the company n-Tec AS and

* Corresponding author at: Norut Northern Research Institute Narvik AS, Narvik, Norway. Tel.: +47 769 653 50.

E-mail address: zhonghua.chen@norut.no (Z. Chen).

consisted of functionalized multi-walled CNTs, water and a cathodic surfactant. The suspension was sonicated in a bath for 2 h before EPD. P-CNT and N-CNT are also functionalized multi-walled CNTs and were obtained from the companies Plasmachem and Nanocyl, respectively. These two types of as-purchased CNTs were used to prepare CNT aqueous suspensions without any pre-treatments. To prepare N-CNT suspension, a cathodic surfactant was first dissolved in DI water with assistance of stir before adding N-CNTs. Then the mixture was subjected to a sonication bath for dispersion until a stable CNT suspension was formed. The P-CNT suspension was prepared using the same procedure. All the three suspensions had a solid content of 0.1 wt%. The kinetically stable suspensions can be stored for months with insignificant sedimentation.

EPD is a facile process for fabrication of films and coatings from aqueous or organic suspensions on substrates and bulk bodies with even complicated surfaces. Under an applied electric field, charged particles in the suspension move toward and deposit on the substrate with the opposite charge. In CNT suspensions, CNTs stabilized by the existed cathodic surfactant are negative charged. Therefore, the CNT coating is deposited on the anode. Fig. 1 is a schematic diagram of electrophoretic deposition of carbon nanotubes. Highly specularly reflecting aluminum were used as electrodes i.e. substrates. The deposited area is 30 mm × 27 mm. The EPD process takes only a few seconds. As-deposited CNT coating is wet and has a bad adhesion to the Al substrate. Following drying and heat treatment are necessary to solidify the CNT coating. In this work all samples were dried for 20 h at ambient conditions before heat treatment, though the samples can be heat treated directly after EPD. Then they were heat treated in a tube furnace under an atmosphere environment. The rate of temperature increase was set to 50 °C per minute. The peak/final temperature T_p was tuned for different purposes. The dwell time at T_p was fixed to 5 min based on the results of previous experiments. Then the CNT absorber samples were left in the tube furnace until the temperature decreased to 300 °C before they were removed and stored at room temperature for fast cooling. The heat treated CNT coatings have a fairly well adhesion to the aluminum substrates and are resistant to taping.

There are a few EPD factors such as CNT concentration, electric field, inter-electrode spacing, deposition time affecting the quality and performance of the CNT coatings. The deposition mass i.e. the coating thickness for planar geometries is proportional to the solid concentration, the electrophoretic mobility, the electric field and the deposition time [19]. For an aqueous CNT suspension system, the electrophoretic mobility of CNTs is related to the CNT concentration. To simplify the experiments in this study, the effect of

CNT coating thickness was investigated by tuning only the deposition time while the CNT concentration for the respective CNT type was kept constant throughout all experiments. In addition, the effect of the applied voltage while keeping a constant electric field and the effect of peak temperature of the heat treatment were also investigated.

3. Characterization

3.1. Characterization tools

During EPD, aluminum substrate was taped partly, which created a step where the thickness can be measured. A Veeco NT9080 Profilometer which uses high precision white light interferometry was employed for thickness measurement after heat treatment. Surface morphology of the samples was investigated by a ZEISS Merlin VP Scanning Electron Microscope. Reflectance in the wavelength interval 0.3–2.5 μm was measured with a Perkin-Elmer Lambda 900 spectrophotometer equipped with an integrating sphere of 150 mm diameter, circular beam entrance and sample port of 25 mm. A Bruker Tensor27 FT-IR spectrophotometer was employed to measure the reflectance in the infrared wavelength range 2.5–20 μm. The obtained reflectance data were used to calculate solar absorptance and thermal emittance of solar absorbers as introduced in Section 3.2.

3.2. Optical characterization

Solar thermal absorbers are usually evaluated by two parameters – the solar absorptance and the thermal emittance under normal incidence of radiation. Normal solar absorptance, α , is defined as a weighted fraction of the absorbed radiation to the incoming solar radiation on a surface (Eq. (1)).

$$\alpha = \frac{\int_{0.3}^{2.5} I_{\text{sol}}(\lambda)(1-R(\lambda))d\lambda}{\int_{0.3}^{2.5} I_{\text{sol}}(\lambda)d\lambda} \quad (1)$$

The spectral solar irradiance, I_{sol} , is defined according to ISO standard 9845-1 (1992) for air mass of 1.5. λ is the wavelength of incident radiation in units of μm and $R(\lambda)$ is the reflectance at a certain wavelength.

Normal thermal emittance, ε , is the ratio of emitted radiation of a surface to that of Planck's blackbody, I_p , at 100 °C and can be calculated following:

$$\varepsilon = \frac{\int_{2.0}^{50} I_p(\lambda)(1-R(\lambda))d\lambda}{\int_{2.0}^{50} I_p(\lambda)d\lambda} \quad (2)$$

Because the reflectance data only could be measured up to 20 μm, an extrapolation method was introduced to estimate the reflectance from 20 to 50 μm so that the calculation by Eq. (2) can be completed. The standard deviation of α and ε , which has been calculated from repeated reflectance measurements of the same sample over an extended time period, is respectively 0.002 and 0.01 for the solar absorber samples in this study.

There are several ways to evaluate the spectral selectivity. One of the most frequently used methods is to calculate the ratio of solar absorptance to thermal emittance (α/ε). However, we judge this method to be inappropriate to assess photothermal conversion efficiency. For example, a solar absorber with a solar absorptance of 0.60 and a thermal emittance of 0.03 achieves a ratio of 20 but does not have higher photothermal conversion efficiency than an absorber with a solar absorptance of 0.90 and a thermal emittance of 0.1 which achieves α/ε of only 9. The opposite is actually true since the solar absorptance is twice as important as the thermal emittance. In order to rate the spectral selectivity and hence the performance of a solar absorber we use the expression $\alpha - 0.5\varepsilon$ in this study to reflect

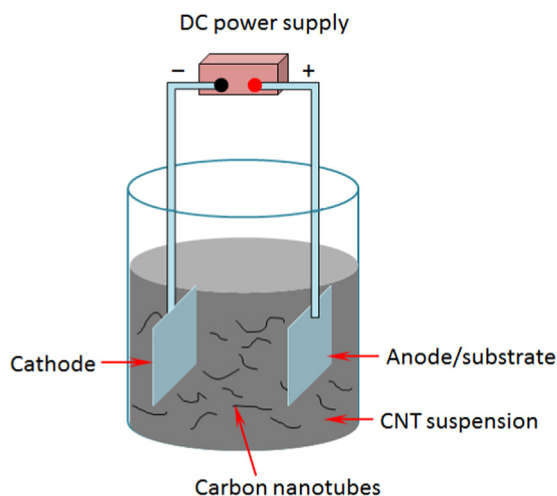


Fig. 1. Schematic diagram of electrophoretic deposition of carbon nanotubes.

Download English Version:

<https://daneshyari.com/en/article/6534980>

Download Persian Version:

<https://daneshyari.com/article/6534980>

[Daneshyari.com](https://daneshyari.com)