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Fabrication and Characterisation of Selective Solar Absorber Surfaces Prepared By Sol-gel Technique

G KATUMBA[1], L OLUMEKOR[1], A FORBES[2] & E WÄCKELGÅRD[3]

[1]Department of Physics, University of Zimbabwe, Harare, Zimbabwe

[2]CSIR National Laser Centre, PO Box 395, Pretoria 0001, South Africa

[3]Department of Materials Science, Uppsala University, Uppsala, Sweden

E-mail: katumba@science.uz.ac.zw

INTRODUCTION

The investigation and development of carbon-silica composites has been going on for some time. Different applications such as adsorbents, biosensors, templates and solar absorbers have emanated from these studies.

The concept of using solar absorbing nanoparticles embedded in a dielectric matrix has been investigated both theoretically and experimentally by a number of authors. It appears that there is no comprehensive study of thin coatings of carbon-in-silica, especially for selective solar absorber applications.

EXPERIMENTAL

All details of the substrate and sample preparation can be found in the literature[1].

Optical characterization: The near normal spectral hemispherical reflectance, R, of the prepared samples was measured in the wavelength interval 0.3 to 20.0 µm[1] using a Lambda 900 spectrophotometer and a Bomem-Michelson 110 FTIR spectrometer. Solar absorptance, α_{sol}, and thermal emittance, ε_{therm}, were calculated for near-normal incidence according to Katumba *et al.*[1]

SEM and X-HRTEM: The surface morphology of the samples in the tetraethyl orthosilicate (TEOS)-only, methyltriethoxysilane (MTES) and acetic acid anhydride (Ac_2O) categories were investigated with a Philips XL30 scanning electron microscope (SEM). The structure of the above samples was studied by cross-sectional high-resolution transmission electron microscopy (X-HRTEM) using a Technai F30 ST transmission electron microscope (TEM).

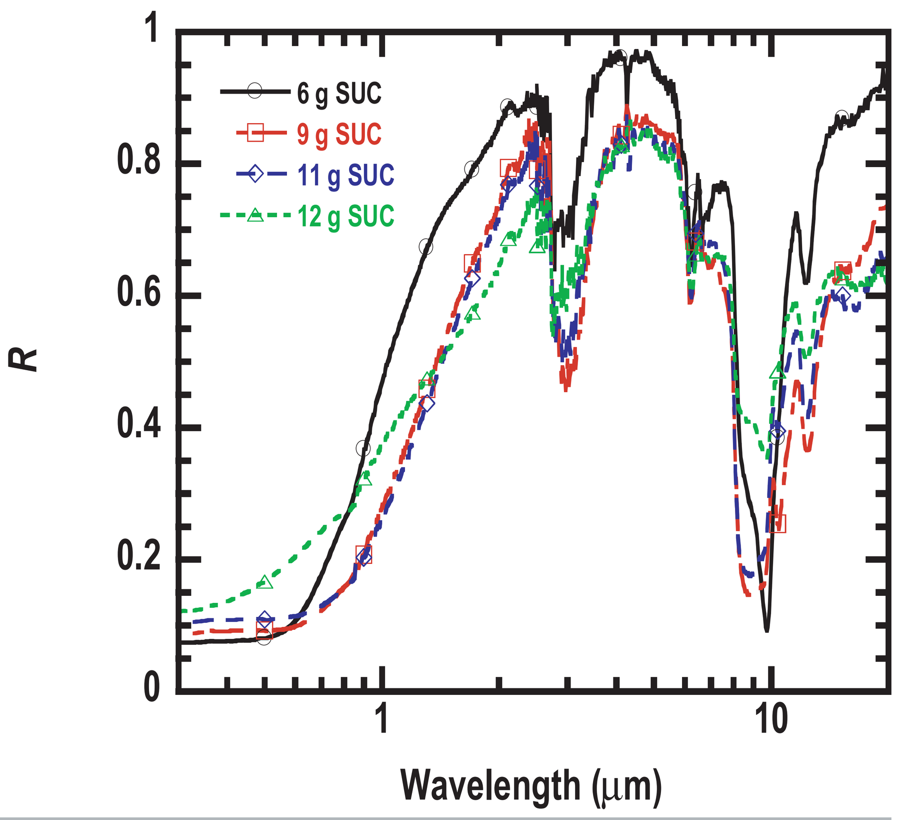

Figure 1: Effect of the amount of SUC in samples spin-coated at 4000 rpm

RESULTS AND DISCUSSION

Effect of amount of carbon precursor: Figure 1 shows the variation of total reflectance with the amount of SUC in the sols. The low to high reflectance transition appears to move towards an apparent limit of 2 µm with increasing amount of SUC.

An optimum for samples with high-absorptance and low-emittance was determined to be 11 g SUC.

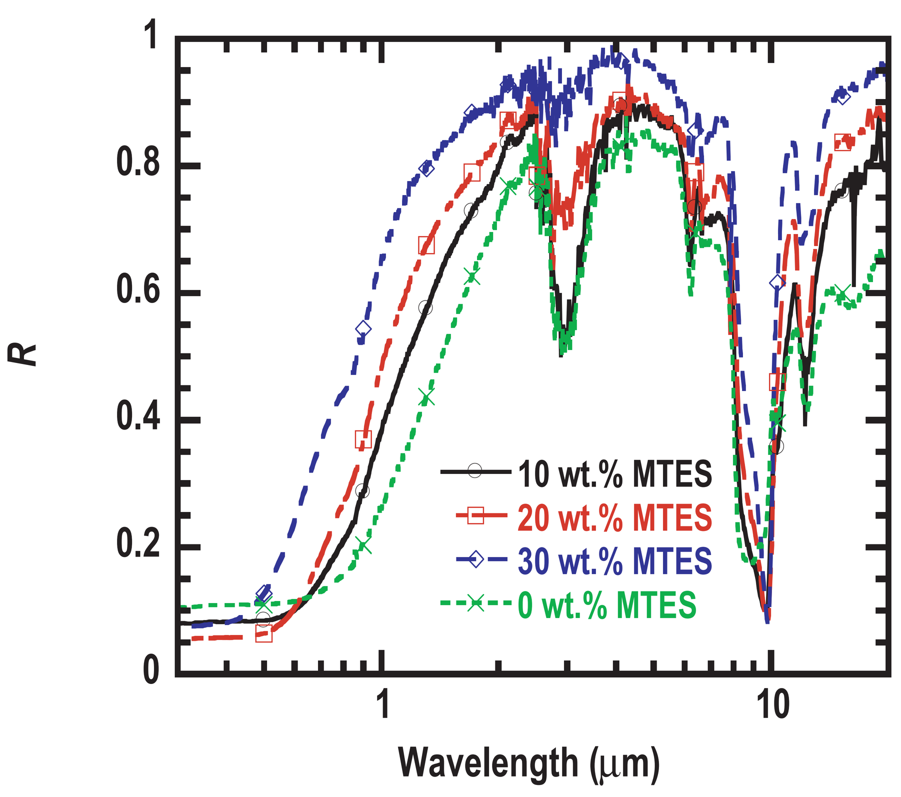

Figure 2: Effect of MTES on samples with H_2O:SUC ratio 9:11. The transition step moved towards shorter wavelengths with increase in MTES content. Samples with 20% MTES had the optimum behaviour

Minimization of cracks in samples: Samples made from acid-catalysed TEOS:H_2O:SUC sols showed severe cracking after heat treatment at 550°C for 1 hour. Two ways were used to minimize the cracks:

Use of organic-inorganic hybrid silica: When the organic groups are integrated into the silica matrix, they fill in the pores between the inorganic oxide chains. This results in low shrinkage of the matrix during heat-treatment. In this experiment MTES was chosen for this purpose and also for the fact that it has an affinity for water.

Reflectance spectra of samples of 10, 20 and 30 wt.% MTES are shown in Figure 2. The transition from low to high reflectance moved towards the Vis wavelength interval with increase in the amount of MTES. As expected, the cracks and OH absorption gradually disappeared with increase in the amount of MTES.

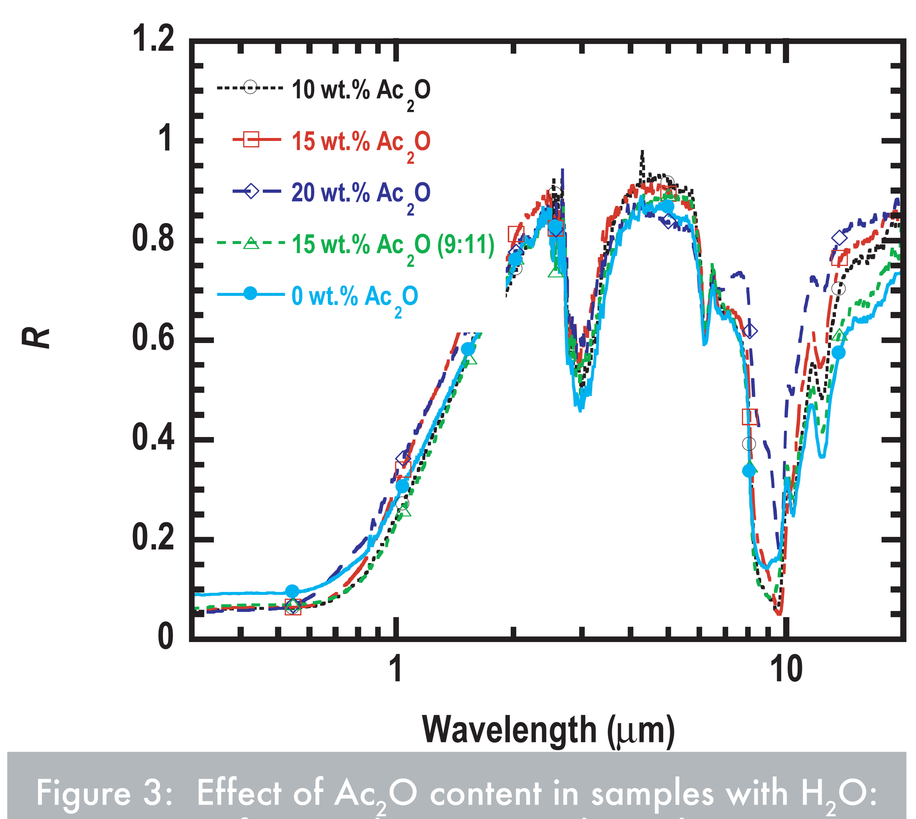

Figure 3: Effect of Ac_2O content in samples with H_2O:SUC ratios of 9:9 and 9:11. Samples with 15% Ac_2O are optimal

Use of acetic acid anhydride: Ac_2O of 10, 15 and 20 wt.% were added to the pure silica reagents. The spectra of the Ac_2O samples are shown in Figure 3. Samples with 15% Ac_2O showed the least amount of cracking while there was minimal change in optical parameters.

Limits of absorptance and emittance: The absorptance and emittance data showed that the limit for absorptance was about 0.95 and that for emittance was about 0.1. The optimum figures achieved in a single sample are 0.88 for absorptance and 0.41 for thermal emittance calculated at 373 K.

SEM RESULTS: Figure 4 shows SEM images made at a magnification of 500 that allowed for the relative comparison of the severity of cracks in the TEOS-only, MTES and Ac_2O samples.

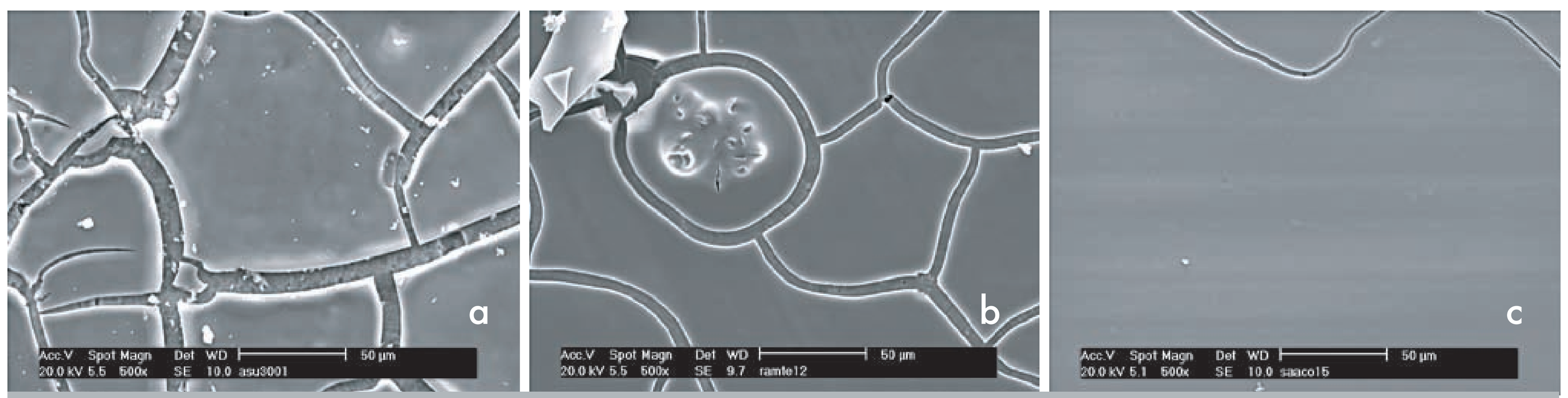

Figure 4: A typical size and distribution of cracks in (a) a TEOS only sample, (b) an MTES sample and (c) an Ac_2O sample. All images were taken at 500X

Figure 4(a) shows that the TEOS-only sample has numerous wide cracks of widths ranging from 9 to 12 µm. Figures 4(b) and 4(c) show that the MTES and Ac_2O samples have fewer cracks and narrower fissures of about 2 to 6 µm.

X-HRTEM RESULTS: Figure 5 shows that films with MTES and Ac_2O have an excellent adherence to the substrate with smooth surface and uniform thickness. The thicknesses of the films are between 0.8 to 1.4 µm. Scale bars in Figure 5 are 3 µm. It seems that the MTES film (Figure 5 (2)) has a slightly rougher interface than that of Ac_2O (Figure 5 (3)).

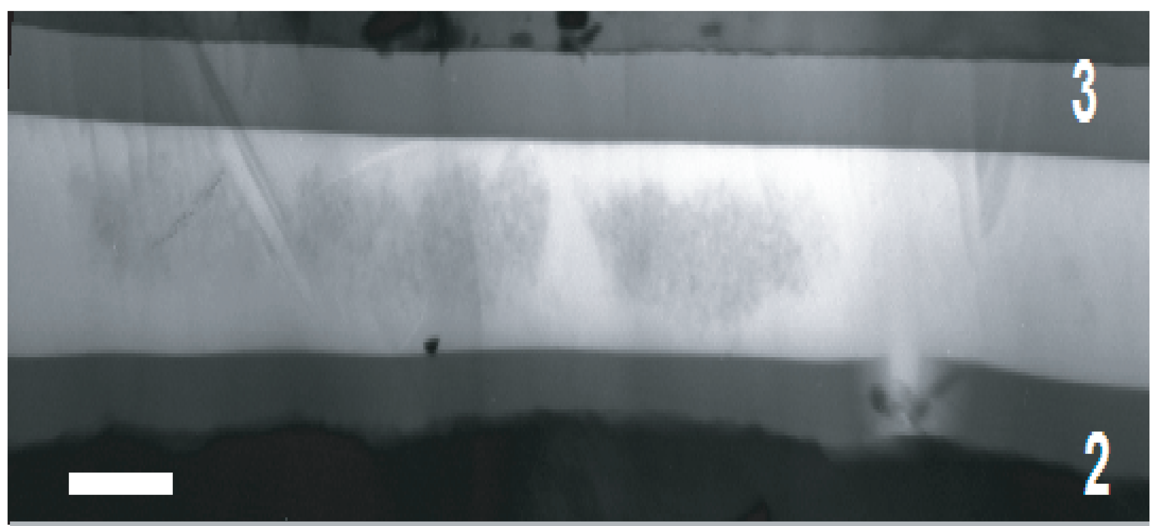

Figure 5: The bright field image of an MTES film (2) and an Ac_2O film (3). The images show that films have flat surface and uniform thickness

Figure 6(a) demonstrates that the TEOS-only film has a uniform composition distribution while Figure 6(b) for the Ac_2O film exhibits a segregation of composition in nano-scale.

EELS mapping with a carbon K peak was used to determine the carbon distribution. The bright region in Figure 7 corresponds to carbon or carbon-rich region. The segregation in composition is confirmed

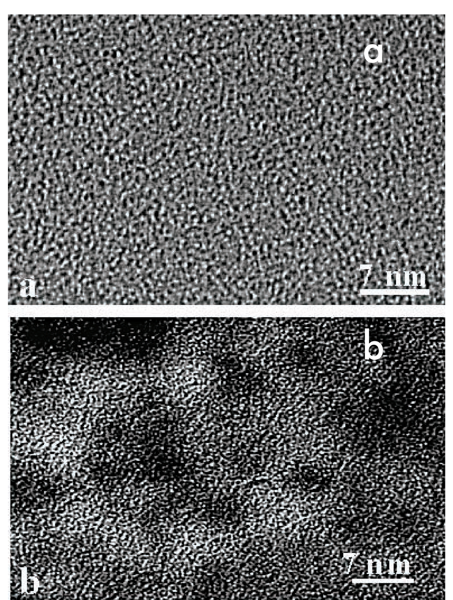

Figure 6: X-HRTEM images of (a) TEOS-only sample with uniform composition and (b) Ac_2O sample with segregated composition

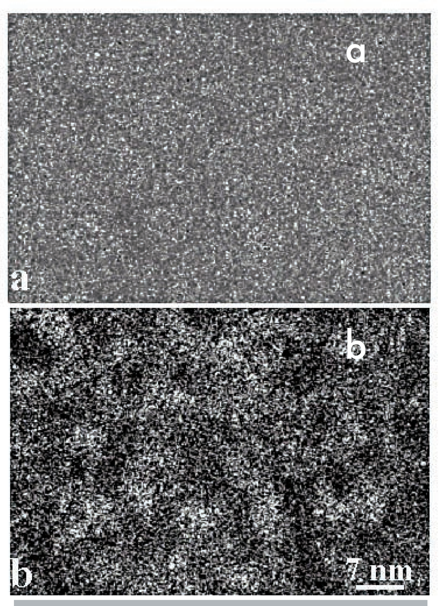

Figure 7: EELS carbon mapping from (a) TEOS-only sample showing uniform carbon distribution (b) Ac_2O sample showing segregated carbon distribution

COMMENTS AND CONCLUSIONS

The optimum performance achieved in a single sample is 0.88 for absorptance and 0.41 for thermal emittance.

A short chain-like structure of both carbon absorber particles and the silica matrix is quite evident.

ACKNOWLEDGEMENT

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1. G. Katumba, J Lu, L Olumekor, G Westin and E Wackelgard, Low cost selective solar absorber coatings: characteristics of carbon-in-silica synthesized by sol-gel technique, J. Sol-Gel Science and Technology, 36, 33-43 (2005).