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Space environmental testing of flexible coverglass alternatives based on siloxanes

N.J. Smeenk [a, *], C. Mooney [b], J. Feenstra [a], P. Mulder [a], T. Rohr [b], C.O.A. Semprimoschnig [b], E. Vlieg [a], J.J. Schermer [a]

[a] Radboud University Nijmegen, Institute for Molecules and Materials, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands
[b] European Space Agency, ESTEC, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands

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ABSTRACT

With the development of thin-film, high-efficient III–V solar cells using the epitaxial lift-off technique, flexible solar panels for space applications can be designed. Besides new deployment options, this also reduces the mass and thus launch costs of a satellite. One requirement for such a flexible panel configuration is the replacement of the brittle coverglass, which shields the solar cells from the harsh space environment, by a flexible alternative. In this work we have tested several compositions of a polysiloxane candidate material for a flexible shielding layer by exposing them to high energy UV and electron radiation at elevated temperatures. It was found that irradiation by electrons with a fluence corresponding to 15 years in space produces little degradation. UV radiation, on the other hand, has a more pronounced impact on the material properties, causing a discolouration of the transparent material and for some compositions even cracking of the samples.

1. Introduction

Over the last decade the epitaxial lift-off (ELO) technique has been developed as a method to reduce the costs of III–V solar cells [1,2]. It encompasses the separation of the solar cell from its growth template (GaAs or Ge wafer) by selective etching of an intermediate release layer [3,4]. Cost reduction can be achieved by reusing the wafers for the production of subsequent solar cells [5]. It has been demonstrated that the use of the ELO technique results in flexible, thin-film solar cells, with efficiencies equal to that of cells on a wafer [6]. Recent developments even yield single-junction thin-film cell structures with efficiencies that surpass the best performance of wafer-based cells [7].

Most of the wafer-based III–V solar cells produced nowadays are used for powering satellites. The ELO technique produces thin-film, flexible solar cells, that for space applications were demonstrated to have a similar or better radiation hardness as their wafer-based counterparts [8]. The fact that these thin-film ELO cells are flexible means that besides the direct weight reduction obtained by removal of the substrates also the weight of the support structure for the space solar panel can be significantly reduced because it does not necessarily need to be rigid anymore. Besides giving new deployment options, this is an opportunity to significantly reduce the weight of the panels in order to minimise the launch costs of the satellites [10,11]. Current space solar panels are equipped with rigid and brittle coverglasses (e.g. CMX glass, a cerium doped borosilicate glass) to shield the solar cell from the harsh space environment. The development of a flexible panel thus also requires the replacement of the coverglass by a flexible alternative. Requirements for this layer include sufficient flexibility to handle the stresses during production and launch, and maintain sufficient transparency in the 350–1250 nm wavelength range during operation in space while retaining its flexibility.

In the current study we examine the effects of UV radiation, elevated temperatures, and electron irradiation on the optical properties of one type of such a flexible coverglass alternative that consists of methyltrimethoxysilane (MTMS) based siloxanes (MBS). MBS was chosen because it showed decent flexibility and good transmission and outgassing properties and could be synthesized reproducibly in various compositions. Several of these MBS compositions were exposed to high energy and intensity UV radiation, since the prolonged exposure to elevated temperatures and UV radiation can have a detrimental effect on transparent materials. Also samples of space qualified adhesives have been exposed. These adhesives, used to bond the coverglasses to the solar cells in current state-of-the-art space solar panels, might in principle also be used

* Corresponding author. Tel.: +31 243652586.
E-mail address: n.smeenk@science.ru.nl (N.J. Smeenk).

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as flexible shielding layers. However, they are known to degrade if they are not shielded by a cerium doped coverglass [12,13], therefore in this study they will primarily be used to provide a reference to which the performance of the MBS films can be compared.

Charged particle radiation is the major reason why shielding of solar cells in space is required, since these particles create defects (i.e. recombination centres) in the solar cell thereby decreasing its efficiency [14]. Therefore, MBS samples were also exposed to irradiation by high energy electrons to see the impact of charged particles on our proposed shielding material.

2. Experimental

The MBS samples were synthesized by a sol–gel reaction of MTMS, to which other precursors like tetramethylorthosilicate (TMOS), dimethyldimethoxysilane (DMDMS) and phenyltrimethoxysilane (PhTMS) were added to alter the composition (Fig. 1). Also, in order to minimise the effects of UV radiation cerium was incorporated into some of the MBS samples, either $Ce(NO_3)_3 \cdot 6H_2O$ or $Ce(NH_4)_2(NO_3)_6$ was used as cerium precursor. The methoxy groups of the precursors can be hydrolyzed via an acid-catalyzed reaction to form hydroxyl groups. These hydroxyl groups then underwent a polycondensation reaction forming the Si–O–Si bonds of the polysiloxane. The synthesis resulted in free-standing MBS films of approximately 250–300 μm thickness. Subsequently, all samples were cured for 8 h at 150 °C at reduced pressure (10^{-1} mbar) to evaporate the water and methanol formed during synthesis of the films.

For the UV exposure test, samples of 2 × 2 cm^2 were cut out of these films. These samples were placed in between two UV grade (i.e. transmittance ≥85% at 200 nm) quartz plates of 1 mm thickness. Kapton tape was used on the corners to mechanically fixate these quartz-sample sandwiches, see Fig. 4 for a photograph of such a sandwich. The samples of the reference adhesives consisted of approximately 20 μm of adhesive in between quartz plates (no Kapton tape was required for fixation for these samples). The adhesive are all Pt addition cured systems, i.e. a Pt catalyst is used to polymerize the vinyl groups during curing. In Table 1 an overview of the samples that were exposed to high energy UV radiation is given. For each of the 12 MBS compositions three samples were tested; two samples of these were exposed to the full UV spectrum, while on top of each third sample a 100 μm CMX coverglass filter was placed to eliminate wavelengths shorter than 350 nm. For the adhesives two samples were exposed to the unfiltered spectrum.

The UV exposure was performed at the solar UV (SUV) facility [15] of the European Space Research and Technology Centre (ESTEC). The SUV facility, schematically depicted in Fig. 2, consists of a high vacuum chamber ($<10^{-6}$ mbar) with an internal cold shroud and a temperature controlled sample tray on which plates holding the samples are mounted. The cold shroud is a copper plate cooled by liquid nitrogen and is used to mimic the background space thermal environment and was kept at a temperature of −170 ± 5 °C during the tests. The UV source consists of an array of halogen discharge lamps controlled by a stabilised power supply. UV radiation is directed through a UV-grade quartz window onto the sample tray in the chamber at normal incidence. The temperature of the sample tray as induced by the UV exposure is measured using Pt100 temperature sensors, which are fixed onto the front and side of the sample tray. There was no direct thermal contact of the sensors with the samples (since these are in between the quartz plates), so the sample temperature during exposure is not exactly known. Only the sample area in the centre of the sample tray was used for the UV exposure of the samples, since the intensity of the UV radiation was most uniform there.

The intensity of the UV lamps was measured at six locations on the sample tray with UV detectors before mounting of the samples for exposure and after demounting. The measurements were performed using a set of three detectors, UV-A for the 315–400 nm wavelength range, UV-B for 280–315 nm and UV-C for 200–280 nm. Based on the intensity measurements of these sensors the average acceleration factor is determined. This acceleration factor is the ratio of the UV intensity of the SUV facility over that of the air mass zero (AM0) solar spectrum (in the 200–400 nm wavelength range), an acceleration factor larger than 1 thus indicates a higher UV intensity than encountered outside of the earth's atmosphere. In Fig. 3 the normalized spectra of the lamps in the SUV facility as well as the AM0 spectrum are shown for the 200–400 nm wavelength range.

Three exposure runs were performed in the SUV facility, all with approximately 1000 equivalent sun hours (ESH), as calculated by multiplying the exposure duration with the acceleration factor. An exposure duration of 1000 ESH was chosen as a compromise between the limited availability of the SUV facility and the fact that it

Table 1
Overview of the samples that were exposed to the high energy UV radiation. The samples were synthesized at 100 °C unless mentioned otherwise.

General name	Compositions
MBS	MTMS
	MTMS (synthesis temperature 80 °C)
	MTMS (synthesis temperature 120 °C)
	MTMS:TMOS 10:1
	MTMS:TMOS 5:1
	MTMS:DMDMS 10:1
	MTMS:DMDMS 5:1
MBS + PhTMS	MTMS:PhTMS 99:1
	MTMS:PhTMS 4:1 (20%)
Ce–MBS	MTMS:TMOS 10:1 + 0.5% Ce
	MTMS:TMOS 10:1 + 1% Ce
	MTMS:TMOS 10:1 + 2% Ce
Reference adhesives	Dow Corning DC93-500
	Wacker Elastosil S690
	Wacker Elastosil S695
	Nusil CV16-2500

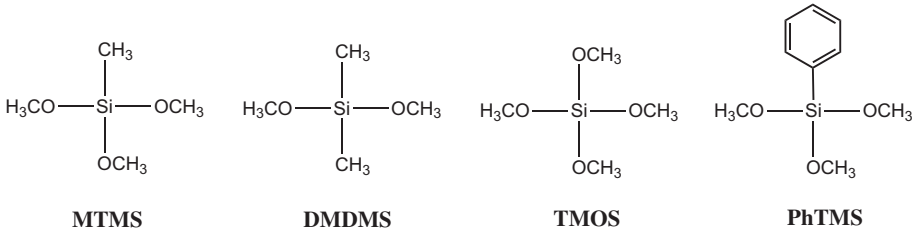

Fig. 1. Structural formulae of the precursors used for the synthesis of the MBS samples.