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Optical degradation of silicone in ZnO/silicone white paint irradiated by <200 keV protons

Haiying Xiao *, Chundong Li, Dezhuang Yang, Shiyu He

Space Materials and Environment Engineering Laboratory, Harbin Institute of Technology, Harbin 150001, China

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Abstract

By compared with ZnO powders and silicone resin, the optical degradation of the ZnO/silicone white paint caused by <200 keV protons was investigated, and the damage mechanism was revealed by X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectrum analysis (FTIR). Experimental results show that the optical degradation mainly occurs in the visible region and the absorption band shifts towards longer wavelengths with increasing proton fluence. Under the proton irradiation, the resistance to optical degradation of the ZnO/silicone white paint is less than the ZnO powders and better than the silicone resin. Such a change can be related to the damage of the silicone. The damage of the silicone binder enhances the degradation of ZnO/silicone white paint, whereas the existence of ZnO pigment relieves the degradation of the silicone binder. The major damage product changes from the cyclotrisiloxane in the silicone resin to the net Si–C=O structure in the silicone binder of the ZnO/silicone white paint.

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Keywords: Thermal control coatings; ZnO/silicone white paint; Proton irradiation; Optical degradation

1. Introduction

Thermal control coatings are important components of the passive thermal control system on spacecraft, which can adjust the surface balance temperature of spacecraft through their own thermo-physical properties such as solar absorptance a_s and semispherical emissivity ε. Under the exposure of space energetic particles, the optical properties of thermal control coatings are degraded, influencing the lifetime and reliability of spacecraft. A large amount of <200 keV protons exists in the Earth radiation belts, which is an important factor to cause radiation damage for the thermal control coatings used on spacecraft in orbit [1]. The ZnO/silicone white paint is a typical thermal control coating used on spacecraft extensively [2–4]. ZnO is a semiconductor of compounds with a wide forbidden band (3.37 eV at room temperature) and better processing performances, being suitable as a pigment in thermal control coatings. The organic silicone is often used as a binder in the ZnO/silicone white paint, for it has a unique structure in which the main Si–O chains are spiral-shaped and the good performances such as the electric isolation and the resistance to heat, weather and aging.

The investigation on optical degradation of ZnO/silicone white paint caused by the protons are often emphasized on the damage of ZnO pigment [5–8]. It is believed that under proton exposure, the degradation in optical properties in the visible region of solar spectrum is related to the radiation-induced vacancies of oxygen for the ZnO/silicone white paint. Our previous work [7,8] demonstrates that the optical degradation of ZnO/silicone white paint induced by <200 keV protons can be attributed to three major events: the ionization to form electrons and holes, the formation of free oxygen and oxygen vacancies, and

* Corresponding author. Tel.: +86 451 86414445; fax: +86 451 86415168.

E-mail addresses: xhyhit@gmail.com (H. Xiao), lichundong1972@yahoo.com.cn (C. Li), dzyang@hit.edu.cn (D. Yang), syuhe@163.com (S. He).

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the damage of organic silicone binder. The formation of free oxygen and oxygen vacancies in the ZnO lattice plays an important role in degrading the ZnO/silicone white paint under proton exposure. The oxygen vacancies can trap and bound electrons to form colour centers in the ZnO pigment, and the free oxygen promotes the formation of peroxy radicals to damage the silicone structure. Both the two events could result in optical degradation of the ZnO/silicone white paint.

In order to further reveal the mechanism of optical degradation in the silicone binder of the ZnO/silicone white paint, the changes in optical properties and chemical structure caused by <200 keV protons are compared for the ZnO/silicone white paint, the ZnO pigment and the silicone resin in this study. The changes in chemical structure of the silicone resin and the silicone in the ZnO/silicone white paint are examined by X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectrum analysis (FTIR). The silicone is usually characterized in terms of the binding performance and thermal resistance [9,10]. A little work was conducted on optical degradation of the silicone irradiated by protons. It is of significance to clarify the optical degradation mechanism for the silicone irradiated by <200 keV protons. The result will be beneficial to an improvement upon ZnO/silicone white paint for its application on spacecraft.

2. Experimental

The test samples of ZnO/silicone white paint were 20 mm in diameter and 150 μm in thickness, and the ZnO particle size was in the range of 0.4–0.9 μm. Polydimethylsiloxane was chosen as the silicone binder, in which a small amount of additives were added. The paint samples were coated on an Al alloy substrate. The samples of the polydimethylsiloxane resin were 20 mm in diameter and 150 μm in thickness, which were cured at room temperature and dead-ender with hydroxy groups. The silicone resin is white in colour after film-forming. The ZnO samples with 20 mm in diameter and 2 mm in thickness were formed by pressing, in which the ZnO particles ranged from 0.4 to 0.9 μm.

The ground-based simulation equipment used in this study can simulate the radiations of solar electromagnetic rays, protons and electrons in orbit, independently and simultaneously. The proton energy was chosen as 150 keV. The proton flux was 5×10^{11} cm^{-2} s^{-1}, and the fluence in the range of 5×10^{14}–1×10^{16} cm^{-2}. The samples were placed in a vacuum chamber of 10^{-5} Pa. During the proton exposure, the temperature of samples was maintained at 298 ± 5 K.

The spectral reflectance over the wavelength interval of 200–2500 nm was immediately measured in air after proton

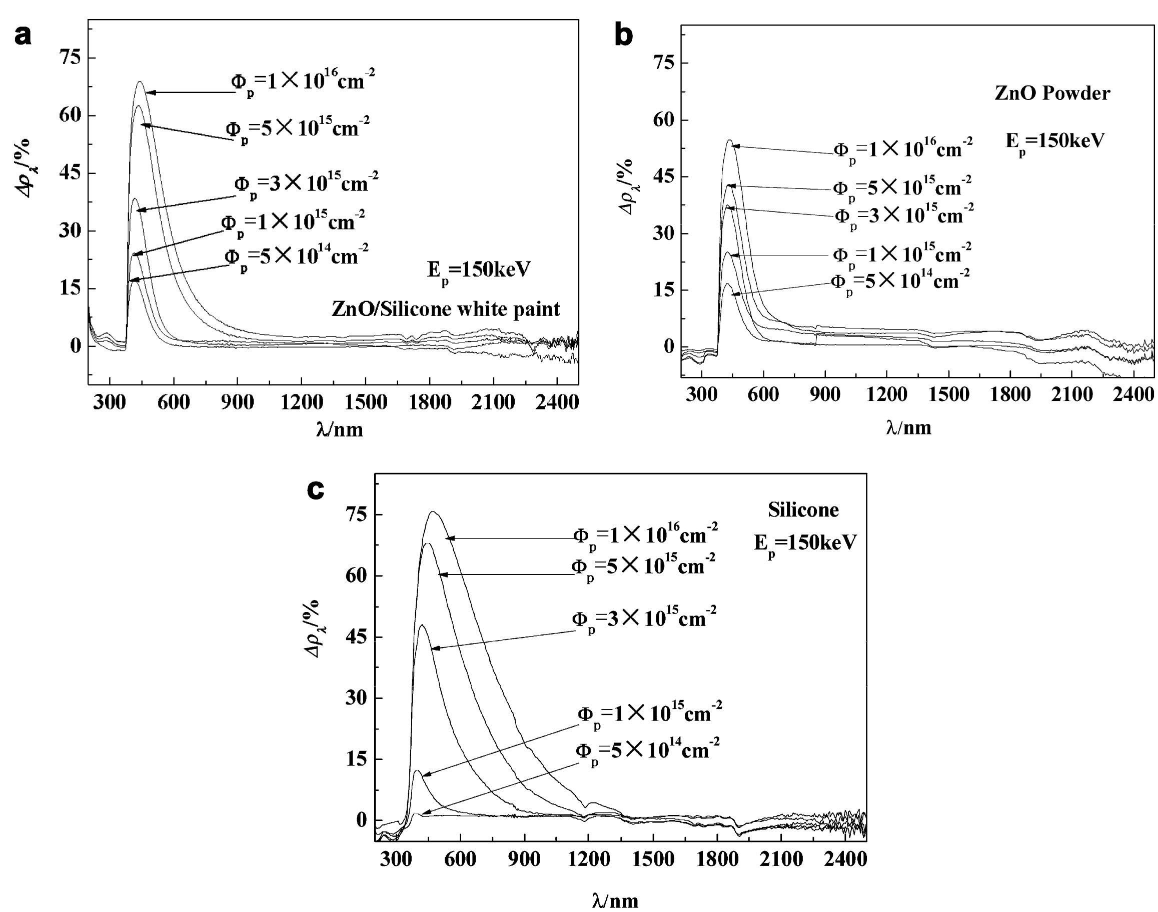

Fig. 1. The change in spectral reflectance $\Delta\rho_\lambda$ versus proton fluence for (a) the ZnO/silicone white paint, (b) the ZnO powders and (c) the silicone resin.