Mem. S.A.It. Suppl. Vol. 16, 130

Memorie della
Supplementi

Space weathering of asteroidal surfaces

Influence on the UV-Vis spectra

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Abstract. The surfaces of airless bodies in the Solar System are continuously altered by micrometeoroids bombardment and irradiation by solar wind, flares and cosmic particles. Major effects of this process - space weathering - are darkening and reddening of the spectra of surface materials. We have studied the changes induced by energetic ion irradiation, in the UV-Vis-NIR (0.2-0.98 μm) reflectance spectra of targets selected to mimic the surfaces of airless bodies in the inner Solar System. Chosen targets are olivine pellets, pure or covered by a transparent organic polymer (polystyrene). We have also measured the changes induced by ion irradiation in the absorption coefficient of the polymer. We have measured the variations of the absorption coefficient (0.25-0.98 μm) of polystyrene as a function of ion fluence. The diffuse reflectance spectra of irradiated samples covered by organics exhibit a much more significant variation than those of pure silicates. The spectra of targets made of olivine plus polystyrene can be fitted by using the measured absorption coefficient of polystyrene.

Key words. asteroids - methods: laboratory - techniques: spectroscopic

1. Introduction

The surfaces of airless bodies in the Solar System are continuously altered by micrometeoroids bombardment and irradiation by solar wind, flares and cosmic particles. Major effects of this process - space weathering are darkening and reddening of the spectra of surface materials, as well as 'degrading' of absorption features (Chapman 1996, Pieters et al. 1993). Up to now most of the laboratory simulations of space weathering, in particular ion irradiation, have been conducted by looking at changes in the spectra of relevant materials at visible and near IR (NIR) wavelengths (0.5-2.5 μm). Investigated materials include carbon based species such as frozen hydrocarbons (Brunetto et al. 2005), red bitumens (asphaltite and kerite) (Moroz et al. 2004), and different kinds of silicates (Brunetto and Strazzulla 2005, Brunetto et al. 2006, Sasaki et al. 2001, Strazzulla et al. 2005, Loeffler et al. 2008, 2009). However, UV wavelength region is suggested to be more sensitive indicator of weathering (and thus age), because the change in this spectral region should be more evident than that at longer

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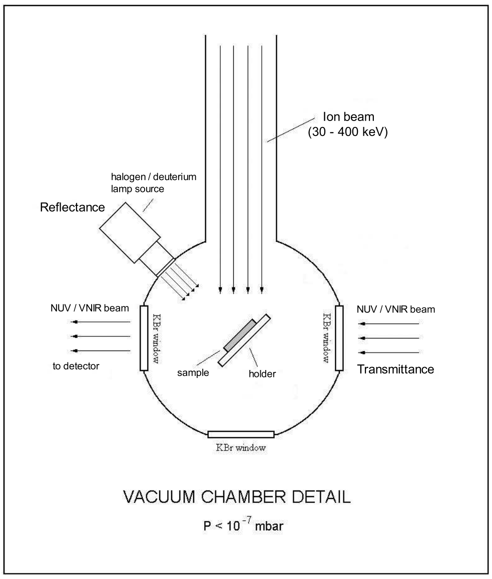

Fig. 1. A scheme of the vacuum chamber: solid samples are held at a finger. The chamber is interfaced to an ion implanter. Bidirectional reflectance spectra are acquired using an halogen/deuterium lamp source and NUV-VIS-VNIR spectrometer.

wavelengths for the same exposure to weathering processes (Hendrix and Vilas 2006). In our Laboratory for Experimental Astrophysics (LASp) in Catania (Italy) we started with a new series of experiments aimed at studying the effects of ion irradiation in solid materials in a spectral range that includes the NUV (0.2-0.98 μm) region.

2. Aims

We have studied the changes induced by energetic ion irradiation, in the UV-Vis-NIR (0.2 - 0.98 μm) reflectance spectra of targets selected to mimic the surfaces of airless bodies in the inner Solar System. Chosen targets are olivine pellets, pure or covered by a transparent organic polymer. We used polystyrene as a template for organics that can be present on asteroidal surfaces. Moreover we have measured the changes induced by ion irradiation in the absorption coefficient of the polymer.

The purpose is to have a tool to better compare laboratory with observed spectra and possibly distinguish between planetary objects having pure silicate surfaces from those whose surface are covered by organics exposed to cosmic ion bombardment.

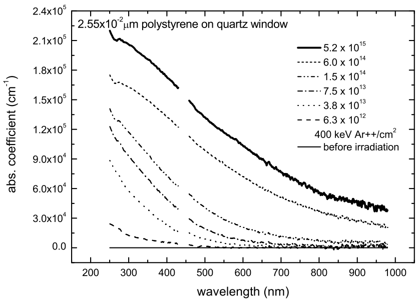

Fig. 2. Relative absorption coefficient of Argon irradiated polystyrene.

3. Experiments

We have prepared three olivine samples which consist of pressed olivine ($(Mg,Fe)_2SiO_4$) powder (milled olivine rocks) deposited on previously pressed KBr pellets; two olivine pellets with a polystyrene layer deposited over them and 5 polystyrene samples of different thickness deposited onto quartz. Irradiation experiments with 200 keV protons or 200-400 keV argon ions were carried out at room temperature inside a stainless steel vacuum chamber ($P<10^{-7}$ mbar), faced to NUV- VIS-NIR (0.2-0.98 μm) minispectrometer, or to a FTIR spectrophotometer (Bruker Vertex 70) working in the spectral range 8000 - 400 cm^{-1} (1.25 - 25 μm) (see Fig. 1). Before, during and after irradiation diffuse reflectance spectra of pellets, or transmittance spectra of polystyrene over quartz have been recorded.

4. Results

1. On the basis of transmittance measurements of polystyrene of thickness s, the relative absorption coefficient $\alpha(\lambda) = \tau(\lambda)/s\,[cm^{-1}]$ was determined as a function of wavelength for 200 keV proton and 400 keV Ar^{++} irradiation at

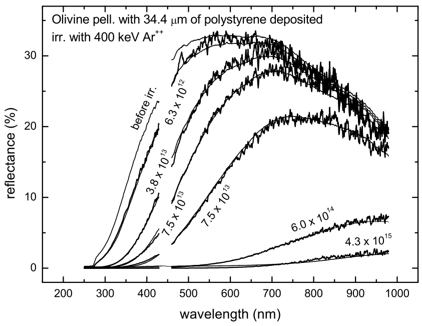

Fig. 3. Comparison between measured and expected reflectance of olivine with polystyrene layer deposited after 400 keV Ar^{++} irradiation. Absorption coefficient of polystyrene after Ar^{++} irradiation was used to simulate the effect expected after the absorption of certain amount of energy deposited by ions. A designation of each spectrum is an appropriate fluence in ions/cm^2.

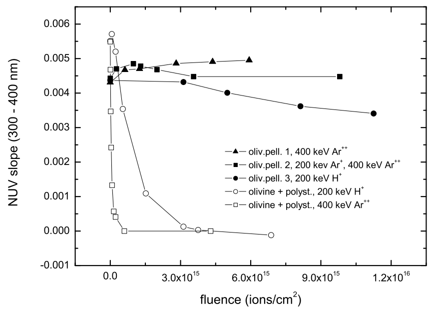

Fig. 4. Dependency of NUV spectral slopes of the samples on different ion fluence.

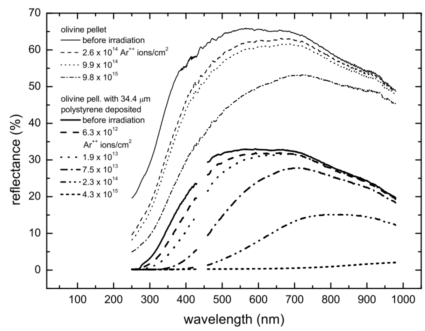

Fig. 5. Reflectance spectra of olivine pellet and olivine pellet with polystyrene deposited measured in situ during the irradiation.

different fluences. By relative absorption coefficient α we mean the coefficient expressing the amount of radiation transmitted by irradiated material relatively to the radiation transmitted by the unirradiated sample. The change of absorption coefficient of polystyrene after Ar^{++} irradiation is shown as an example in the Fig. 2.

2. The reflectance R^* of irradiated olivine + polystyrene samples can be expressed, in a first approximation, by the relation:

$$R^* = RT^2 \tag{1}$$

where R is the reflectance of the sample before irradiation, $T = e^{-\alpha s}$ is the transmittance of irradiated polystyrene of thickness s, which absorption coefficient is α. Simulated spectra (see Fig. 3) of the sample at several steps of argon irradiation well fit the measured spectra. In the equation 1 the absorption coefficient α of irradiated polystyrene at similar argon fluences was used.

The change in the reflectance spectrum of the irradiated sample is only due to the external layers since the thickness of polystyrene (about 34 μm) is much ticker than the penetration depth (0.4 μm) of 400 keV Ar^{++} into polystyrene achieved by SRIM calculation (Zeigler et al. 1996).

3. The spectral slope in NUV region (300-400 nm) is changing with increasing irradiation doses (see Fig. 4). The spectral slopes in units of reflectance nm^{-1} were computed by fitting a straight line to the reflectance data (method of linear regression) in the studied wavelength range. Looking at the Fig. 5, it is clear that the diffuse reflectance spectra of the sample covered by organics exhibits a much more significant variation than that of pure silicate due to the carbonization of the polystyrene layer. Taking into account the NIR part of the spec-

tra, and the lower ion fluence, the effectivity of the weathering

process is 10^2 times higher in the case of organics. In the experiment of Zhiyong et al. (2000) it was shown, that absorption edge of polystyrene shifts due to the carbonization of material (Compagnini et al. 1990) gradually from UV toward the visible with increasing fluence.

The results will be applied to give a contribution to the interpretation of the physico/chemical processes determining the colors of minor objects in the Solar System.

Acknowledgements. This research has been supported by Italian Space Agency contract n. I/015/07/0 (Studi di Esplorazione del Sistema Solare). We thank F. Spinella for his help in the laboratory.

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