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In-situ studies of ion irradiated materials relevant to planetary science

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Abstract

Bombardment by solar and galactic energetic particles influences the surface properties of atmosphereless bodies in the Solar System. Effects such as sputtering, chemical and structural modifications have been investigated in the laboratory with a view to their relevance in several astrophysical environments.

1. Introduction

Cosmic ion irradiation is believed to be one of the processes driving the evolution of surface materials on airless bodies. Fast ions passing through a solid release their energy in the target by elastic interactions with the target nuclei and by inelastic collisions causing ionisations and excitations. Many molecular bonds are broken along the ion-track and, in a very short time (one pico second or less), the radicals and molecular fragments recombine giving rise to a rearrangement in the structure. “Laboratorio di Astrofisica Sperimentale” at INAF – Osservatorio Astrofisico di Catania, has been active starting from the eighties in the experimental study of the effects induced by fast ions in solids (frozen gases, carbonaceous and organic materials, silicates etc.) of astrophysical interest. The "in situ" techniques used to analyze the effects of irradiation are Infrared, Raman (see Fig. 1) and UV-Vis-NIR spectroscopy. The results have been applied to various astrophysical scenarios. Some results relevant to planetary science are summarized here.

2. Experimental set-up

The in situ analyses are performed in a stainless steel high vacuum chamber ($P < 10^{-7}$ mbar). Inside the vacuum chamber a substrate is placed in thermal contact with a cold finger whose temperature can be varied between 10 and 300 K. The vacuum chamber is interfaced with an ion implanter (200 kV; Danfysik), from which ions with energy up to 200 keV (400 keV for double ionizations) can be obtained. We have studied both solid samples (e.g. meteorites) and frozen gases (ices). To prepare icy samples, a needle valve is used to admit pre-prepared gases (or mixtures) into the chamber, where they freeze on the substrate. Further details on the experimental set-up can be found elsewhere [4].

3. In-situ Raman spectroscopy

Raman spectroscopy gives valuable information on the vibrational transitions of molecules in the solid, liquid, and gas phase. In particular it is a powerful tool to investigate the structural properties of a given sample and so it has often been used to study the effects of ion-induced lattice damage in carbonaceous solids and organic compounds [4]. Carbonaceous materials can widely vary in chemical composition and structure (diamond, graphite, glassy carbon, hydrogenated amorphous carbon, etc.). Depending on the degree of order of graphitic (sp^2 hybridization) materials, one or two first order Raman bands are observed. In HOPG (Highly Ordered Pyrolitic Graphite) or natural graphite with large (>1 μm) micro crystals only one first order Raman band at about 1582 cm^{-1} is observed. This band is known as G (Graphitic) line. Spectra of micro-crystalline graphite and disordered carbons show an additional 1360 cm^{-1} line. This D (Disordered) line is attributed to phonons active in small crystallites or on the boundaries of larger crystallites. The intensity ratio (I_D/I_G) of the D and G lines varies as the inverse of the crystal planar domain size (L_a). In amorphous carbons and hydrogenated amorphous carbons, both G and D bands are present. These bands are broader than those observed in disordered graphite and the width of these bands corresponds to the degree of disorder of the amorphous carbon. In high disordered amorphous carbon the two bands become so wide that they can no longer be distinguished as individual peaks.

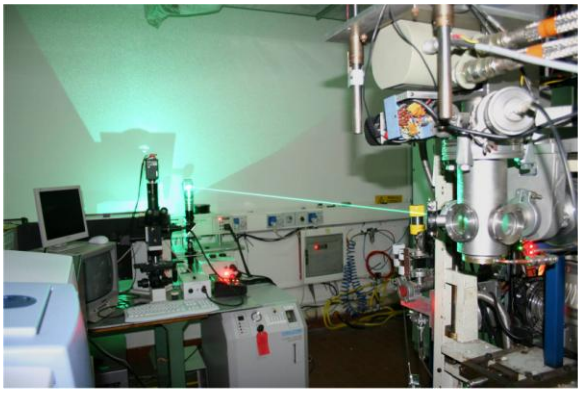

Figure 1: Raman in situ experimental set-up.

Ion irradiation can disorder the structure of well ordered carbonaceous materials. As an example, in situ Raman spectra of HOPG irradiated with 3 keV He^+ ions at different ion fluences (ions cm^{-2}) are reported in Figure 2. At low fluences, ion irradiation induces a damage in the crystal lattice, as evidenced by the appearance of an increasing D line. At higher fluences (> 10^{16} cm^{-2}) the damaged graphite crystal is fully converted into an amorphous carbon film. IDPs (Interplanetary Dust Particles) suffer, during their sojourn in the interplanetary medium, irradiation by solar energetic particles and solar wind particles. Based on the results presented above and on similar irradiation experiment carried out on well ordered amorphous carbon grains, it has been proposed that the different degree of order seen, by micro-Raman spectroscopy, in the amorphous carbon present in IDPs, could correspond to the different time, spent by IDPs in the interplanetary medium before collection in the Earth atmosphere [1]. By means of in situ Raman spectroscopy, it has been shown that amorphous carbon can be formed at low temperatures after ion irradiation of pure hydrocarbons and carbon bearing ice mixtures [2]. On the basis of these results it has been suggested that comets can develop an organic crust during ion irradiation at low temperature, i.e. while comets stay in the Oort cloud (T ≈10-20 K), without requiring a first passage by the Sun and its consequent heating.

The “Stardust” mission has recently given us, together with other several laboratories in the world, the unique opportunity to study cometary particles directly collected in space from comet Wild-2.

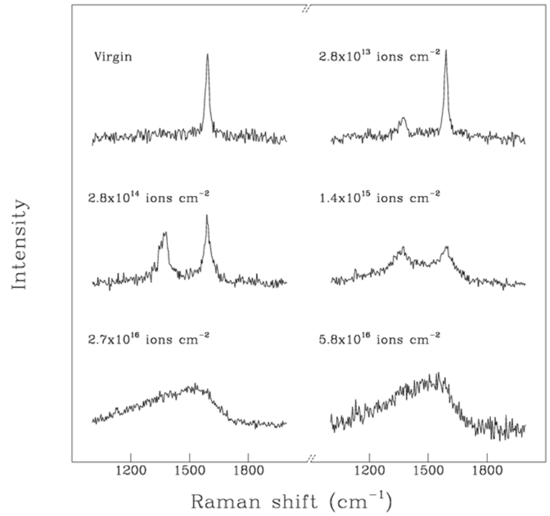

Figure 2: HOPG irradiated with 3 keV He^+.

The Raman analysis shows that the degree of order in different Stardust particles spread over a wide range, corresponding to that exhibited by all the IDPs examined so far. The “relatively” more disordered amorphous carbon observed in some particles, has been interpreted as an evidence of ion irradiation processing [3].

Acknowledgements

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References

[1] Baratta, G.A., et al.: Raman spectroscopy of ion-irradiated interplanetary carbon dust analogues, J. Raman Spectrosc., Vol. 35, pp. 487-496, 2004.

[2] Ferini, G., Baratta, G.A., and Palumbo, M.E.: A Raman study of ion irradiated icy mixture, A&A, Vol. 414, pp.757-766, 2004.

[3] Rotundi, A. et al.: Combined micro-Raman, micro-infrared, and field emission scanning electron microscopy analyses of comet 81P/Wild 2 particles collected by Stardust, MAPS, Vol. 43, pp. 367-397, 2008.

[4] Strazzulla, G., Baratta, G.A., and Palumbo, M.E.: Vibrational spectroscopy of ion-irradiated ices, Spectrochim. Acta A, Vol. 57, pp. 825-842, 2001.