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Processing by electron bombardment of a-C:H interstellar dust analogues grown by PECVD

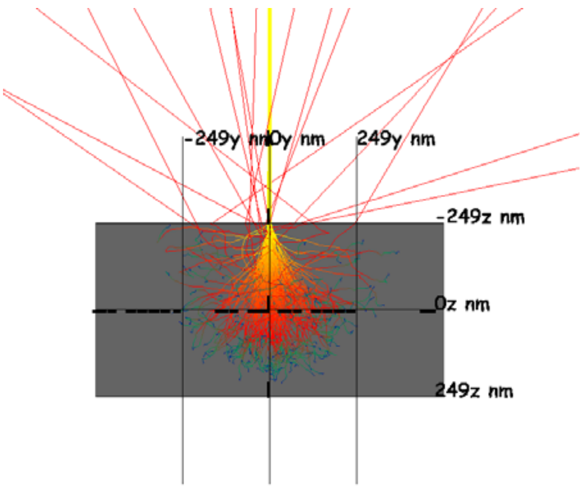
Germán Molpeceres[1], Miguel Jiménez-Redondo[1], Belén Maté[1], Víctor J. Herrero[1], Elena Lopez-Elvira[2], Javier Méndez[2], Isabel Tanarro [(*)1]

[1] *Instituto de Estructura de la Materia, CSIC, Serrano 123, 28006 Madrid, Spain*
[2] *Instituto de Ciencia de Materiales de Madrid, CSIC, Sor Juana Ines de la Cruz 3, 28049 Madrid,Spain*
[(*)] i.tanarro@csic.es

Carbonaceous compounds are found in very diverse astronomical regions [1]. Significant amounts are detected in small dust grains, which show characteristic IR fingerprints revealing the presence of different functional groups [2]. Among the various materials investigated as carriers of these IR bands, a-C:H compounds grown by PECVD have led to the best agreement with observations [3]. In this work, we study the stability of carbonaceous dust analogues generated as deposits in He+CH_4 RF discharges. To simulate the dust processing in the interstellar environments, the samples have been subjected to energetic electron bombardment. FTIR spectroscopy is employed to monitor the changes in the structure and composition of the carbonaceous films.

The experimental system has been described elsewhere [4]. It comprises two different setups: For film deposition, an inductively coupled RF (13.56 MHz) low pressure discharge reactor made of Pyrex (30 cm long, 4 cm diameter), with an external coil in the center of the tube, is employed. A gas mixture of CH_4 (5 sccm) + He (10 sccm) at 0.3 mbar is supplied as precursor. The dissociation of CH_4 and the production of new species like heavier hydrocarbons and H_2 are analyzed by a differentially pumped quadrupole mass spectrometer. Typical layer thicknesses of ~ 500 nm are grown on Si sustrates with 40 W discharges in ~ 15 min. AFM images of the deposits evince a granular distribution with average diameters ~ 250 nm and average roughness ~ 30 - 50 nm.

The proccesing of the deposits is performed in a high vacuum chamber, where a 5 keV electron gun is installed. The samples are proccesed at a background pressure ~ 10^{-7} mbar with electron fluxes of 100 nA/cm^2. During irradiation, the samples are maintained at ambient temperature or cooled down at 90 K by means of a liquid nitrogen trap with a temperature regulating system. The chamber is optically coupled to a Fourier Transform Infrared Spectrometer (FTIR) arranged to perform normal incidence transmission measurements. A rotatable vacuum flange allows positioning the sample towards the electron beam or towards the IR beam, alternatively. AFM images suggest a slight increase of the average grains size after irradiation.



The penetration of electrons into the films was numerically simulated with the CASINO code [5]. It is based on Monte Carlo calculations of electron trajectories considering the energy loss processes inside the solid. Input parameters are the energy of the electrons, the geometry of the sample, its composition and density. Fig. 1 displays the trajectories generated by 5 keV electrons impinging on a ~ 500 nm a-C:H layer, considering an average density of 1.5 g cm^{-3} and H/C = 25/75 [6]. As can be seen, the initial electron beam spreads, and electrons give their energy to the solid as they progress. The simulation of electron trajectories is stopped when the electron energy falls below 50 eV.

Fig. 2: CASINO simulation of the passage of 5 keV electrons through a 500 nm a-C:H layer.

Fig. 2 shows two IR absorption spectra centered in the 2900 cm^{-1} region of the a-C:H film, before processing, and after 367 min electron irradiation, at room temperature. This spectral region constitutes one of the most characteristic fingerprints in interstellar dust observations. The observed signals are composed of different CH stretching bands, whose assignments are indicated in the figure. The variations observed between both spectra evince the strong changes in total absoption and band structure, indicating a dehydrogenation of the carbonaceous deposit and a decrease in the amount of sp^3 bonds.

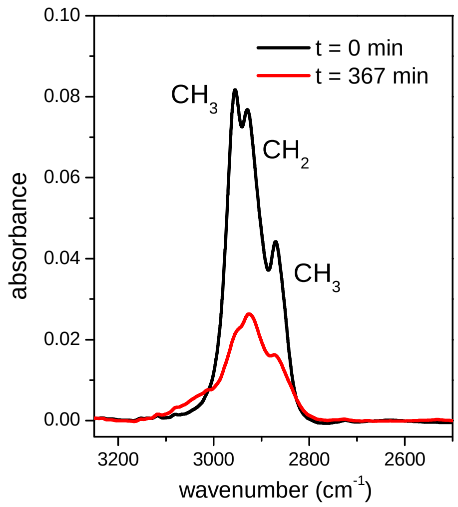


Fig. 2: IR spectra of a-C:H sample before and after 5 keV electron processing (see text).

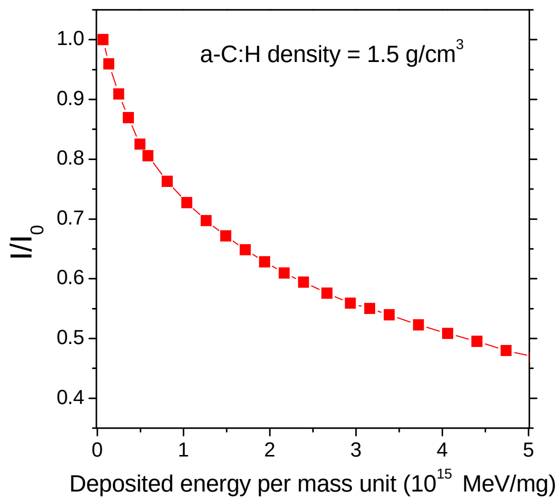


Fig. 3: Normalized intensity decay of the 2800-3100 cm^{-1} band of a-C:H with deposited energy per mass unit.

In Fig. 3, the decay of the normalized absorption intensity of this band system as a function of the deposited energy is displayed. Based on CASINO predictions, it was assumed that the electrons left all its energy on the samples irradiated and that they are processed practically in all their thickness. A comparison of this beaviour with laboratory studies of the effects of cosmic rays on carbonaceous interstellar analogues reported in the literature [7] suggests that the processing of this carbonaceous films by 5 keV electrons resembles quite reasonably well the behaviour observed for protons in the MeV range.

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