Growth, thermal desorption and low dose ion bombardment damage of C₆₀ films deposited on Cu(111)

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Abstract

Auger electron spectroscopy (AES), low energy electron diffraction (LEED) and reflection electron energy loss spectrometry (REELS) were used to characterize the growth and thermal stability of C₆₀ films deposited on Cu(111). By means of LEED we found that while C₆₀ grows in an ordered fashion up to the first monolayer (ML) at room temperature (RT), it turns amorphous beyond that point. On the other hand, when the substrate temperature is kept at 450 K, films up to two ML with crystalline structure are obtained. For substrate temperatures beyond 570 K thick films (more than 1 ML) do not grow at all. By using AES, we found that a thick C₆₀ film starts to desorb at a temperature around 470 K but the first ML remains stable up to temperatures as high as 900 K. A ML with a better crystalline order is obtained after desorption than that growth with the substrate at RT or higher temperatures. When the substrate is heated at 970 K, the first ML is not fully removed but the C₆₀ molecular structure is altered or molecules break up into smaller pieces. The ion induced damage on C₆₀ on Cu(111) films was studied for typical ions, incoming energies and irradiation doses used in low energy ion scattering (LEIS) experiments. The D-value of C(KLL) Auger spectra, the π*-plasmon of REELS and the evolution of the LEIS spectra, were monitored to characterize the damage caused to the film. We found that, at low doses (∼10¹⁴ ions cm⁻²), damage is only detectable for massive ions like Ar, but not for H and He in the 2–8 keV range.

1. Introduction

Fullerenes have been extensively studied since its discovery in 1985 [1]. Due to its applications in very diverse fields, like medicine, electronics, chemistry, etc [2], they have aroused the interest of the scientific community. Similarly, a large number of articles were dedicated to the fundamental properties of fullerenes, some of them focused on the growth of C₆₀ films on different substrates [3–8]. In particular, the growth of C₆₀ on semiconductor surfaces has been broadly investigated due to its applications in solar cell-based devices [9–12].

The literature on C₆₀ films growth on metal substrates is abundant [8, 13–24]. Particularly on Cu(111) substrates, STM experiments combined with theoretical calculations of bands structure [16], and photoemission [19] were used to demonstrate that electron transfer from the Cu(111) substrate to C₆₀ varies between 1 and 2 electrons per molecule. Sakurai et al [18], using field-ion STM (technique that combines an STM with field emission microscopy), show substantial differences in the C₆₀ growth on Cu (111) and Ag (111), mainly due to the strong C₆₀–Cu (111) interaction. Later, LEED [20] and STM [22] studies show that C₆₀ adsorption of molecules on a Cu(111) surface induces a reconstruction of the substrate, and a recent Auger study [8] shows that C₆₀ films on Cu(111) grow layer by layer (LbL).
Alternatively, only a few articles were devoted to the study of thermal desorption of fullerene films deposited on different substrates, e.g. polymers [25, 26]; alumina, silicon, graphite and carbon nanotubes [13, 27–29]; and some metal substrates like Ta, Ag, Au and Al [15, 30].

On the other hand, techniques based on the dispersion of slow ions (low energy ion scattering, LEIS) are widely used for chemical and structural surface characterization [31]. The technique has a high surface sensitivity, being possible to detect fractions of monolayer (ML) using low doses with minimal radiation damage. In particular, this is important for certain carbonaceous nanostructured surfaces, wherein the irradiation damage can be important for certain irradiation conditions. Recently [32], it has been shown that the technique is capable of checking the purity of graphene surfaces, demonstrating the benefits of the technique in screening the quality of the graphene during its fabrication process.

Despite damage on C60 films under ion bombardment having been previously studied, most of these works were focused on high incoming energies (>20 keV), high irradiation doses or different incoming projectiles [33–42]. The modification of fullerene films using ion beams in the LEIS regime (ion energy <10 keV) has barely been studied [43–47]; focusing mostly on Ar+ incoming projectiles. Among these articles, it is relevant to mention that a direct knock-out of a single carbon atom from C60 molecules have been observed for high impact energies (>13.5 keV) of Ar+ and He2+ collisions on C60 molecular clusters, leading this process to an efficient formation of new systems like C58+, C59+, C118+ and C119+ [42, 48].

In the present work we studied the growth and thermal stability of C60 films on Cu(111) as an extension of a previous research were we studied the growth of C60 on Cu(111) with AES and kinetic Monte Carlo simulations [8]. We use Auger electron spectroscopy (AES), for elemental composition information; reflection electron energy loss spectrometry (REELS), for molecular structural information; and low energy electron diffraction (LEED), for crystalline structural information. With these techniques, we are able to determine the effect of surface temperature on molecular stability and accommodation. On the other hand, we assess the optimal irradiation conditions (ion type, dose, and incoming energy) under which LEIS experiments can be carried on with minimum damage of C60 films deposited on Cu (111).

2. Experimental methods

Thick C60 films were deposited by vacuum sublimation of C60 powder (at 625 K) on a Cu(111) single crystal. The sample was positioned at a distance of 5 cm right in front of the Knudsen cell containing the C60 powder. The whole process was carried out under ultra-high vacuum (UHV) conditions (∼10−9 Torr).

Desorption measurements have been performed by using a commercial Auger spectrometer (SAM PHI 590 A) based on a UHV chamber and equipped with a cylindrical analyzer and a coaxial electron gun. The experimental setup and the sample preparation procedure were described in a previous paper [8].

The following procedure was used to study the C60 films thermal desorption. Starting from a thick C60 film deposited on Cu(111), the C(KL) and Cu (MVV and LVV) Auger spectra were monitored as the sample temperature was increasing from room temperature (RT) (300 K) to about 1000 K. The sample was heated by electron rear bombardment and the temperature measured by a chromel-alumel thermocouple. Auger spectra were acquired in differential mode (modulation: 4 Vp–p), by using a 3 keV (1 μA) electron beam. Alternatively, REELS spectra of the sample were taken in order to analyze the π-plasmon peak dependence with sample temperature. In this case, the electron incident energy was fixed to 100 eV.

Irradiation damage and LEED experiments were performed in a different UHV chamber equipped with a LEIS-TOF spectrometer, and a LEED/Auger system. Briefly, this system consists of: (i) a UHV chamber with a base pressure of 10−9 Torr; (ii) an ion gun (Colutron), equipped with a Wien filter, beam focusing lenses and beam pulsing plates; (iii) a time-of-flight (TOF) spectrometer; and (iv) a LEED/AES system based on a 4 mesh reverse view retrackable optics and a coaxial miniature electron gun (VG model RVL 900).

Before C60 evaporation, the substrate was carefully cleaned via several cycles of sputtering (6 keV Ar+, 30° incident angle) and annealing (850 K, 5 min). The sample cleanliness was checked by Auger measurements of the level of typical contaminants (carbon and oxygen).

Once the substrate was prepared, a thick C60 film was evaporated as above described. The thickness of the C60 film was controlled through the evaporation time. The deposition rate was estimated by LEED measurements for coverages under the first ML. The differences in the growth rate, produced by the change in the sticking coefficient, in going from C60 on Cu(111) to C60 on C60, has been already shown to be negligible [8].

In order to assess if typical LEIS experiments can be performed on this sample, i.e., to check the sample damage under typical irradiation doses in LEIS experiments; the sample was exposed to irradiation with various ions and range of incident energies (both usual in LEIS experiments). Ar+, He1+ and H1 were used as projectiles with energies of 2, 4 and 8 keV, and an incident angle of 22.5° (respect to the surface). The irradiation time was fixed to 8 h of a pulsed ion beam (average current density: 15 nA cm−2). To monitor the irradiation damage on
C₆₀ films, REELS spectra (100 eV primary energy) and AES (3 keV primary energy) were taken before C₆₀ deposition, immediately after C₆₀ evaporation, in regular 2 h time intervals during pulsed irradiation; and after continuous irradiation (∼1 μA cm⁻²).

LEIS-TOF spectra were acquired for 3 keV Ar⁺, 6 keV He⁺ and 5 keV H⁺ irradiation at a scattering angle of 45°. For Ar⁺ irradiation, three spectra (15 min acquisition time each) were sequentially acquired. For He⁺ and H⁺ irradiation, several spectra were consecutively taken (6 min each), compared and summed over time in order to gain information on time evolution and enhance the signal to noise ratio.

3. Results and discussion

3.1. C₆₀ growth on Cu(111), LEED results

The different growing stages of C₆₀ on Cu(111) were monitored via LEED images taken with 100 eV primary energy electrons at a fixed substrate temperature of 293 K (RT). In figure 1 we show the LEED images that describe the growth process, starting from a clean copper surface to a thin C₆₀ film.

The clean Cu surface is characterized by LEED immediately before starting the C₆₀ evaporation (figure 1(a)), showing the typical hexagonal Cu(111) LEED pattern. After 10 min of evaporation, corresponding to 0.4 ML according to the AES calibration, a more blurred spot pattern, consistent with the formation of an incomplete ML of C₆₀ molecules (figure 1(b)), is obtained. After 25 min of evaporation, a clear change in the original LEED pattern is observed (figure 1(c)). The symmetry (4 × 4) of the pattern reveals the formation of a commensurate ML of C₆₀ on the Cu(111) substrate [22, 49], showing the LbL growth, at least up to the first ML in agreement with previous measurements using AES [8]. Increasing the film thickness, (50 min of evaporation) produces the loss of the LEED pattern (figure 1(d)), indicating that the ordered structure is not preserved beyond the formation of the first layer. This result is also consistent with the formation of an amorphous-like C₆₀ film on the Cu(111) substrate.
We have already shown that C\textsubscript{60} grows in a LbL fashion at RT up to three MLs \cite{8} and that only one ML grows if the substrate is kept at a high temperature (570 K). However, we did not find any differences on how the first layer grows under both situations. This is not a surprising result since AES is not sensitive to the size of the growing island. LEED offers the possibility of gaining information in this sense. In figure 2 we show evolution of the grow of C\textsubscript{60} on Cu\textsubscript{(111)} at 570 K.

While the first three adsorption stages (images 2(a)–(c)) essentially reproduce the RT experiment, the LEED image corresponding to the fourth adsorption stage (evaporation time: 50 min) completely changed (figure 2). The pattern shown in figure 2(d) is similar to the one shown in figures 1(c) and 2(c) but with the diffraction spots more clearly defined, which confirms that when the substrate temperature is greater than 570 K only one ML grows on the copper surface. The higher definition of the LEED spots can be associated to the larger domains with crystalline order when the C\textsubscript{60} film is grown with the substrate kept at 570K.

We also explore the possibility of growing a thicker C\textsubscript{60} film with a long-range crystalline structure by heating the substrate at temperatures lower than 570 K. In this test, the substrate was kept at 470 K while C\textsubscript{60} was evaporated for the same deposition times as in figure 1. The corresponding LEED images obtained are shown in figure 3. The pattern obtained in figure 3(d) is clearly different from that shown in figure 1(d). Now the diffraction spots can be easily recognized, showing that the thick film deposited presents crystalline structure. The high substrate temperature is probably inducing a rapid rearrangement of the C\textsubscript{60} molecules leading to a long-range crystalline order.

### 3.2. Thermal desorption of C\textsubscript{60} films on Cu\textsubscript{(111)}

Figure 4 shows the evolution of the Auger peak to peak heights of C (KLL) and Cu (MVV and LVV) while the temperature of the sample is increased from RT (300 K) to 973 K. The experiment started with a thick C\textsubscript{60} film (~3 ML) deposited on the Cu(111) surface. The temperature dependence of the ratios C/Cu(MVV) and C/Cu (LVV) are shown in the inset of figure 4.

The amplitudes of the Auger signal do not significantly change until the substrate temperature reaches ~470 K, indicating the absence of any significant C\textsubscript{60} desorption in this temperature range. From that

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**Figure 2.** LEED image for C\textsubscript{60} evaporated on Cu\textsubscript{(111)} when the substrate temperature is kept at 570 K for clean Cu\textsubscript{(111)} (a); after 10 min of C\textsubscript{60} deposition (b); after 25 min (c); and after 50 min (d).
Figure 3. LEED image for C₆₀ evaporated on Cu(111) at 450 K: (a) clean Cu(111) surface, before C₆₀ evaporation, (b) after 10 min of C₆₀ deposition, (c) after 25 min, and (d) after 50 min. The pattern is different from that observed in figure 1(d), indicating a crystalline structure formation.

Figure 4. Auger peak to peak height for C(KLL) and Cu(MVV and LVV), for different substrate temperatures. The vertical dashed line ($T \sim 550$ K) denotes the temperature from which only one monolayer of C₆₀ is still remaining on the Cu(111) substrate. The ratios C/Cu(MVV) and C/Cu(LVV) are shown in the inset. The whole desorption process takes place at temperatures between 450 K and 550 K.
temperature on, until ca. 550 K, the C(KLL)/Cu Auger signal ratios start to decrease consistent with a C$_{60}$ desorption process. From 550 to 900 K, the C and Cu Auger signals remain constant, pointing out the absence of any kind of carbon desorption. This finding is probably linked to the stability of only one ML in this ample temperature range (550–900 K).

For temperatures higher than 900 K the Cu Auger signal ratios starts increasing while the C signal shows only a slight decrease, suggesting that the C$_{60}$ molecules are kept adsorbed on the Cu(111) surface, but undergoing some changes in their molecular structure (e.g. breaking of molecular bonds). A similar behavior was found by Hamza et al. [28] when C$_{60}$ molecules are desorbed from Si(100) at 900 K. They showed that C$_{60}$ molecules might start breaking into fragments that covers a large fraction of the silicon surface.

In order to gain information about this C$_{60}$/Cu(111) thermal desorption process, LEED images were taken. The starting point was a thick film (~3 ML) of C$_{60}$ deposited on Cu(111). In figure 5 we show the images taken at increasing temperatures: 290 (a); 450 (b); 570 (c); 770; and 970 K (e).

Different remarks can be made based on previous images: (i) the crystalline structure (order) starts to recover at temperatures close to 450 K; (ii) the typical LEED pattern of one C$_{60}$ ML on Cu(111) becomes sharper when the temperature is increased (c) and (d), (iii) while the C$_{60}$ crystalline order is lost at temperatures around 900 K, the LEED pattern of clean Cu(111) (figure 1(a)) is never recovered. From these findings, we can infer that: (i) the C$_{60}$ ML attached to the Cu(111) atoms (first ML) is not thermally desorbed (even at $T = 970$ K); (ii) up to temperatures of 450 K, the LEED pattern (figure 5(b)) is consistent with long-range crystalline order, indicating a reordering of C$_{60}$ molecules; (iii) second and upper layers are thermally desorbed between 450 and 770 K and, (iv) according to AES and LEED results C$_{60}$ molecules could break up into smaller fragments that might spread all over the substrate; explaining the important C/Cu Auger ratio and the absence of crystalline structure revealed by LEED.

In order to assess potential changes in the C$_{60}$ molecules structure, reflected electron energy loss spectra were taken during thermal desorption process. The $\pi$-plasmon, due to $\pi$-bonds of C$_{60}$ molecule, was monitored during the process (figure 6).

Three distinctive features can be recognized in the REELS spectra when the temperature is increased: (i) the $\pi$-plasmon gets broader mostly in the first stages of the C$_{60}$ thermal desorption; (ii) a slight shift (~0.8 eV) of the $\pi$-plasmon to a higher energy loss is observed when temperature rises from 670 to 1070 K indicating changes in the C$_{60}$ molecular structure and (iii) the clean Cu(111) spectrum is, even at the highest temperatures, never retrieved. The latter result is fully consistent with previous Auger and LEED observations.

### 3.3. Ion bombardment damage under low irradiation doses

With the purpose of determining whether it is possible to analyze C$_{60}$ thin films grown on Cu with LEIS, we performed a systematic study aimed to assess the potential irradiation damages produced with typical ions, irradiation doses and incoming energies used in LEIS experiments. The study essentially consisted on irradiating the sample during a fixed period of time (8 h) with a pulsed ion current (typical of LEIS-TOF experiments).

Auger and REELS spectra were taken every 2 h to monitor sample damage during the experiment. After the 8 h of pulsed ion-current irradiation, the sample was directly irradiated (non-pulsed current) during 10 min. The study was performed for different incoming energies (2, 4 and 8 keV) and various projectile ions (H$^+$, He$^+$, and Ar$^+$).

The bar charts plotted in figure 7 show the ratio of C(KLL)/Cu(MVV) Auger peak to peak signal for four different stages of the study: (i) clean Cu (black); (ii) thick C$_{60}$ film deposited on Cu(111) just before irradiation (red); (iii) after 8 h of pulsed irradiation (green) and (iv) after 10 min of direct irradiation (blue). Results are shown for H$^+$ (figure 7(a)), He$^+$ (figure 7(b)) and Ar$^+$ (figure 7(c)) for 3 different incoming energies: 2, 4 and 8 keV (indicated).

Similarly, in figure 8 REELS spectra are shown for the same experimental conditions as in figure 7. In these figures, the region corresponding to the $\pi$-plasmon is zoomed in.

As it can be clearly observed from figures 7 and 8, the comparison between the spectra obtained at different stages of the study, both techniques provide the same apparent result: changes are only detected (within the experimental error) when the sample was irradiated with Ar$^+$, regardless of the incoming ion energy.

An additional damage test was performed by using the D parameter of the C(KLL) peak [50–52] in order to determine whether the sp$^3$/sp$^2$ content was modified under ion irradiation. According to [50], the distance between the maximum and minimum value of the KLL carbon peak is linked to the sp$^3$/sp$^2$ C-bonding type ratio. In this way, compounds with molecular structure close to graphite (100% sp$^2$ bonds) have a D parameter close to 21 eV and compounds structurally close to diamond (100% sp$^3$ bonds) present a D parameter of the order of 13 eV. Analogously, amorphous carbon or carbon black pellets (what is expected when C$_{60}$ molecule is destroyed) present a D parameter closer to diamond. In figure 9 we show a comparison of C KLL spectra taken at different irradiation stages. The C$_{60}$ pristine film spectrum (red) is taken as a reference. For it, the D parameter is
of the order of 23 eV indicating a molecular structure with almost 100% of sp² hybridization. From the figure it is clear that the $D$ parameter of the films irradiated with H⁺ and He⁺ does not change even at high incoming energies. However, if Ar⁺ is used as the projectile, the Auger peak structure is strongly modified and the $D$ parameter cannot be straightforwardly obtained anymore. This issue is a clear sign of destruction at molecular level.

To check if knockout processes of single carbon atoms were prompted during irradiation, we perform a LEIS-TOF study. In LEIS, recoil carbon atoms generated during the collision, can be easily detected if the scattering angle is not too large. In figure 10 we show LEIS spectra for 3 keV Ar⁺, 6 keV He⁺ and 5 keV H⁺ ions colliding with a thick film of C₆₀ deposited on Cu(111) taken with a fixed scattering angle of 45°.
For 3 keV Ar\(^+\) irradiation, three successive spectra were taken, each with 15 min acquisition time. In the first spectrum (black) only the peak corresponding to C atom recoils is seen, showing that knockout processes are taking place during the irradiation.

For the subsequent spectra (red and green) the peak due to the elastic scattering of Ar\(^+\) ions from copper atoms is also appreciated, indicating that an important fraction of the C\(_{60}\) molecules were removed, and the pi-plasmon peak is broadened and shifted during the thermal desorption process. The clean Cu spectrum is never recovered, consistent with previous Auger and LEED results.

**Figure 6.** Reflected energy loss spectra (REELS) for different substrate temperatures. The \(\pi\)-plasmon (inset) is broadened and shifted during the thermal desorption process. The clean Cu spectrum is never recovered, consistent with previous Auger and LEED results.

**Figure 7.** C(KLL)/Cu(MVV) Auger peak to peak height ratio for the different situations of the experiment: before C\(_{60}\) evaporation or clean Cu (black); just after C\(_{60}\) deposition (red), after 8 h of pulsed irradiation (green), and after 10 min of direct irradiation (blue). The corresponding incoming energies are indicated. Only appreciable differences are observed when projectile Ar\(^+\) ions are used.
projectile already interacts with substrate atoms (Cu). This peak increases with time due to the steady sputtering of C60 molecules. The clean Cu(111) spectrum (gray) is shown for comparison.

For 6 keV He\(^+\) irradiation (center), and 5 keV H\(^+\) irradiation (right) the LEIS spectra is shown for 2 h acquisition time. Both spectra show the unique presence of the direct elastic peak due to the scattering of the projectiles with the C atoms of the C60 molecule. The total absence of the C recoil peak clearly indicates that knockout processes of single carbon atoms are not taking place under these irradiation conditions.

4. Conclusions

LEED results show that the first C\(_{60}\) ML adsorbed on the Cu(111) surface presents long range crystalline order that disappears as the C\(_{60}\) subsequent layers are formed. It is also revealed by LEED that when the temperature of the substrate is kept at about 600 K during the C\(_{60}\) deposition, only one ML grows on Cu(111). When the C\(_{60}\) is evaporated under desorption temperatures like 450 K, the second C\(_{60}\) layer grows with crystalline order. Rapid molecular reordering induced by the sample temperature might be responsible for this behavior.

Starting from a thick, amorphous like C\(_{60}\) film (3 ML or more), the molecules start to desorb at temperatures ca. 470 K, remaining only one ML at temperatures higher than 570 K. Auger, LEED and REELS measurements show that even at 800 K the first C\(_{60}\) ML does not desorb. However, results obtained by the three techniques at temperature higher than 950 K, indicate that even when some form of carbon always remains, the C\(_{60}\) molecules are structurally modified (possible breaking).

No damage was detected when the sample was irradiated with H\(^+\) or He\(^+\) with doses and irradiation times usual in LEIS experiments under pulsed irradiation conditions (fluence below \(3 \times 10^{14}\) ions cm\(^{-2}\)), or direct irradiation (\(4 \times 10^{15}\) ions cm\(^{-2}\)). On the other hand, Auger, REELS and LEIS spectra revealed that the C\(_{60}\) is damaged (altered) when the sample is irradiated with Ar\(^+\), even when using low projectiles incoming energies (2 keV) and low pulsed irradiation doses. Four independent methods (REELS spectra, Auger peak to peak ratio, Auger C(KLL) D-factor and LEIS spectra) consistently lead to previous conclusion. Our Ar irradiation results agree with previous work done on ion beam modification of fullerene films by 2 keV Ar ions [43]. They studied the induced amorphization of fullerene films using EELS and determined a cross section for the destruction of
Figure 9. Comparison of C (KLL) Auger spectra for the different situations analyzed (for the sake of simplicity, the 4 keV incoming energy case is omitted). The distance in energy between the maximum and the minimum of the spectrum (D-factor) is not modified when H\(^+\) and He\(^+\) are used as incoming ions. When Ar\(^+\) is used as a projectile, the spectra is strongly modified and the distance cannot be straightforwardly obtained.

Figure 10. LEIS-TOF spectra for 3 keV Ar\(^+\) ions (left), 6 keV He\(^+\) ions (center) and 5 keV H\(^+\) ions (right) colliding with a thick C\(_{60}\) film deposited on Cu(111). A clear sample modification is perceived during Ar\(^+\) irradiation. No signs of single C atoms knockout processes during He\(^+\) and H\(^+\) irradiation are observed (no peaks are observed in inset graphs).
the C$_{60}$ molecules of $8.5 \times 10^{-15}$ cm$^2$, value that corresponds closely to the geometric size of one C$_{60}$ molecule, and suggesting that each incident Ar ion destroys one molecule upon ion impact. Our result of no damage of C$_{60}$ for low energy He$^+$–C$_{60}$ collisions are in line with a previous gas-phase study$^{[47]}$ where small clusters of Polyclinic Aromatic Hydrocarbon and C$_{60}$ molecules are fragmented in 9 keV collisions with Ne, but not with He.

Our results are also consistent with sputtering coefficients calculated via SRIM code$^{[53]}$ (www.srim.org). For an ion beam with 4 keV incident energy impinging at 22.5° from the surface (geometry used in the present experimental setup) the following sputtering coefficients are obtained: 0.01, 0.06 and 0.86 for H$^+$, He$^+$ and Ar$^+$, respectively. Another relevant parameter also in line with our results is the deposition of nuclear energy (S$_{\text{nuc}}$, nuclear stopping power). For instance, the nuclear stopping power of 4 keV Ar$^+$ incident ions is 30 times higher than the corresponding one of He$^+$ and almost 300 times higher than H$^+$ nuclear stopping power. Regarding the role of the electronic energy deposition, the value of the electronic stopping power (S$_{\text{el}}$) does not change as much as the nuclear stopping power. For example for 4 keV ions $S_{\text{el}} = 11.3, 6.6$ and 6.2 eV Å$^{-1}$, for Ar$^+$, He$^+$ and H$^+$, respectively. Although for light ions (H$^+$ and He$^+$) $S_{\text{el}}$ is much greater than $S_{\text{nuc}}$ the deposition of electronic energy does not seem to be an important factor in the irradiation damage of C$_{60}$ thin films.

From these results, it is possible to conclude that H$^+$ and He$^+$ are suitable to be used as projectiles in LEIS analysis whereas Ar$^+$ projectiles are inappropriate to study C$_{60}$ films.

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