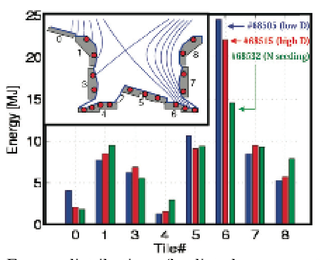
Thermal Desorption Spectroscopy investigation of co-implantation of Hydrogen with other species in graphite

Y.S Katharria, E. Aréou, J.-B. Faure, G. Cartry, J.-M. Layet, P. Roubin and T. Angot

Physique des Interactions Ioniques et Moleculaires, UMR CNRS-Université de Provence 6633, Centre de Saint-Jérôme, Case 241, Avenue de l'Escadrille Normandie-Niemen, 13397 Marseille Cedex 20, France

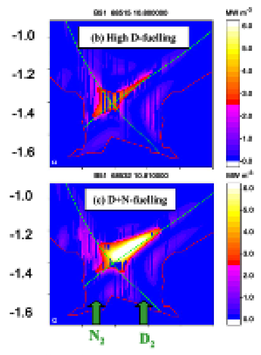
Motivation

In nuclear fusion research, impurity (N_2, Ne, Ar, Kr…) seeding is receiving a continuous attention because of its implication in plasma detachment and reduction of heat load onto the divertor tiles. Such studies mostly focused on power exhaust, plasma stability and impurity transport.



Energy distribution of radiated power on the divertor tiles.

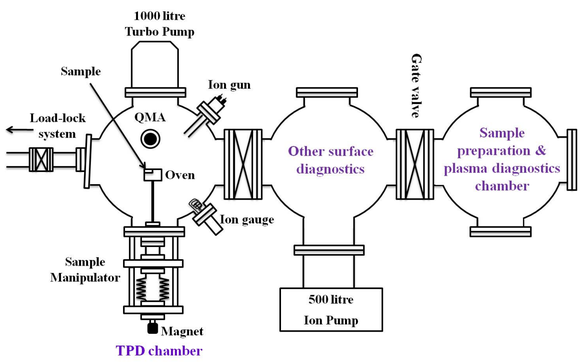
Y. Corre et al. Plasma Phys. Control. Fusion 50 (2008) 115012

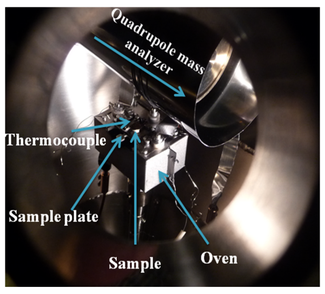


Radiated power

However, little attention is given to the possible synergistic effects resulting from simultaneous bombardment of the impurity with hydrogen or its isotopes on plasma facing components. Therefore, we have undertaken particle beam experiments in order to investigate these fundamental mechanisms.

Experimental Details





After transfer to UHV, graphite sample is cleaned by degassing it twice using a temperature ramp up to 1300 K.

Chamber base pressure : < 6×10^{-10} torr

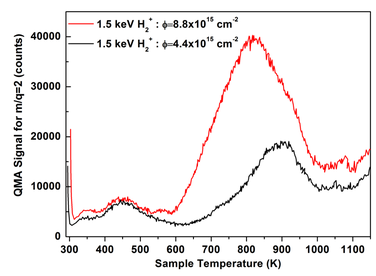
TPD : Heating rate : 1 K/s Temperature range : 300 – 1300 K (sample temperature)

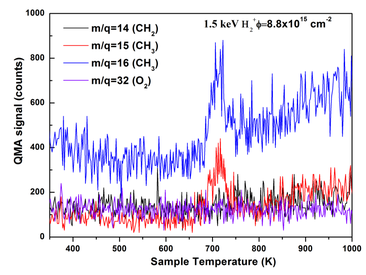
QMS : Hiden Analytical - Triple mass Filter - pulse ion counting Channeltron

Ion gun : ISE 10, Omicron nanotechnology

Typical bombardment pressure : ~ 6×10^{-7} torr; Typical ion currents : ~ 1-5 µAmp (6×10^{12} - 3×10^{13} cm^{-2}-s^{-1})

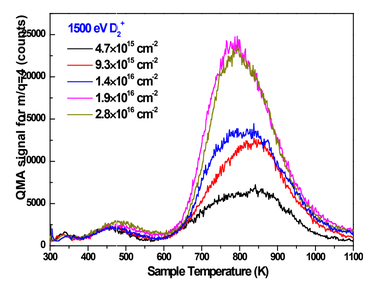
H_2^+ bombardement





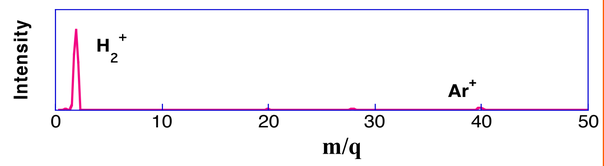
- Increase in retained H (or D) with increasing ion fluence.
- Hydrogen is desorbed essentially in the form of H_2, and methane molecules (CH_4 and CH_3) with corresponding peaks at ~ 800 K and 700K, respectively. *Yamaguchi et al., Fusion Enginering and Design. 16, 387 (1991)*
- Methane molecules are formed even at room temperature near ion range during ion bombardment and their desorption is governed by thermally assisted diffusion process. However, implanted hydrogen is chemically bound to C atoms and its emission occurs by detrapping, recombination followed by thermal diffusion, reason for appearance of methane peak at lower temperature than H_2 peak. *J. Roth, and J. Bohdansky, Appl. Phys. Lett. 51 (1987) 964.*

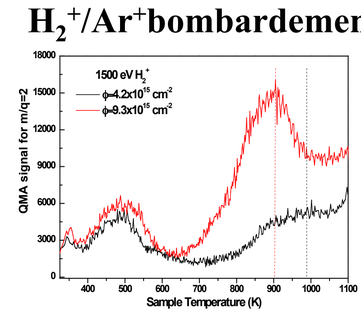
D_2^+ bombardement



H_2^+/Ar^+bombardement

With a little fraction of Ar

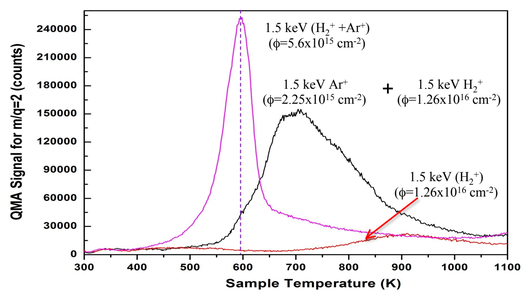




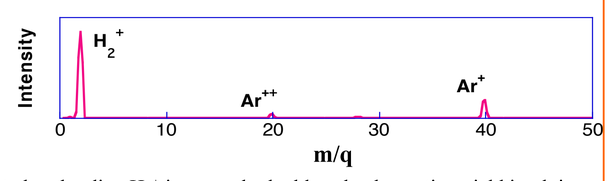
When the sample has gone through many cycles of bombardment and thermal ramps

- Change in the emission behavior of hydrogen: less retention
- No methane formation probably because of less H retention

Desorption energy ~ 1.52 eV (Peak area analysis)
Typical H desorption energy ~ 2eV
Ashida et al. J. Nucl. Mater. 128-129, 792 (1978)



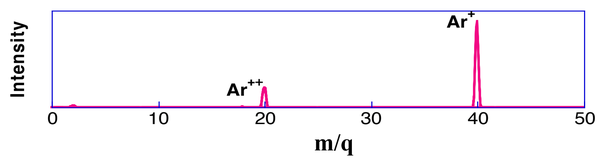
With more Ar

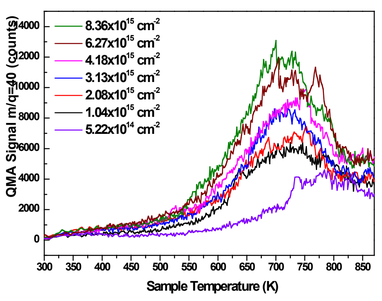


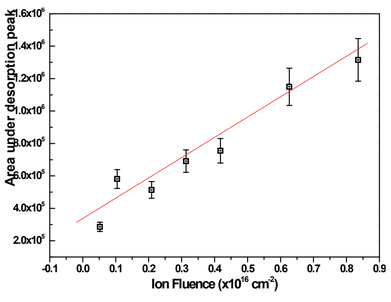
- A little addition of Ar^+ to bombarding H_2^+ ions nearly doubles the desorption yield implying a higher H retention. Addition of Ar further lower the desorption temperature
- Bombardments up to 500 K bring very little although slightly higer desorption temperature
- The effect of Ar impurities is similar to that of increasing ion fluence except a simultaneous shift peak (~500K) to lower desorption temperature.

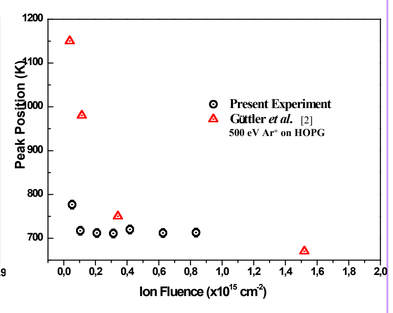
Ar ions bombardement

- Both Ar+ and Ar++ species









[2] Güttler et al., Surf. Sci. 570, 218 (2004)

- Ar desorption from graphite takes place at temperature ~700 K depending on the implanted ion fluence.
- Quantity of desorbed atoms varies nearly linearly in the fluence range 5.22x1014 – 8.36x1016 cm-2 .for 1.5 keV implanted Ar+.
- The amount of Ar atoms remaining in a target material is controlled by four factors:

  density of the ion current, bombardment duration, sputtering rate, and trapping efficiency (escape rate).

- Sputtering yield ~1.4 atoms per ion (TRIM) for 1.5 keV Ar incident at 45°

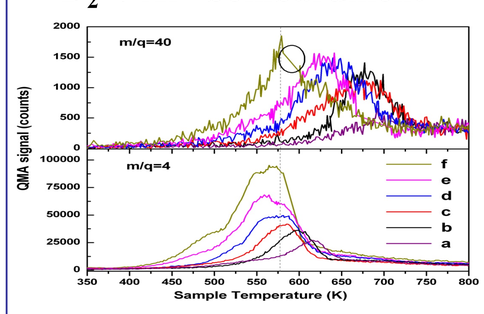
(~0.7 nm sputtered, range of ions ~ 2.7 nm ... *therefore no saturation of retained Ar is observed)*

- Ar generates vacancy (VD) and Ar interstitial (ID) defects.

These VDs assist in detrapping of Ar atoms and as a consequence, lower is the desorption temperature with increasing ion fluence.

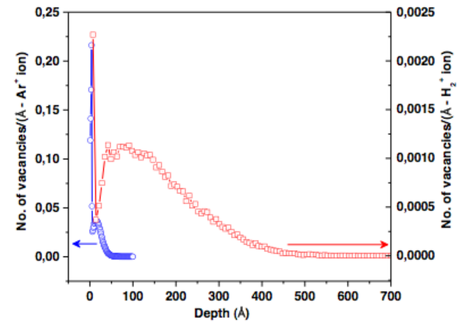
Desorption energy ~ 0.5 eV (Redhead Fit), ~0.7 eV (~16 kcal/mol.) (Peak area analysis)

D_2^+ / Ar^+ bombardment



(a) 1.2×10^{16} ions-cm^{-2} (Mo sample holder)
(b) 9.3×10^{15} ions-cm^{-2},
(c) 1.2×10^{16} ions-cm^{-2},
(d) 1.68×10^{16} ions-cm^{-2},
(e) 2.53×10^{16} ions-cm^{-2}, and
(f) 3.38×10^{16} ions-cm^{-2}.

- Desorption peaks of both the species shift to lower temperatures with ion fluence
- Additional desorption peaks seems to appear with increasing fluence.



- Depth variation of vacancies produced by 1.5 keV ions (SRIM)
- nearly 33 times more vacancies are produced by Ar ions but in the near surface region (up to 30 Å)

Conclusion

In this work, 1.5 keV hydrogen (or deuterium) and argon ions were co-implanted in graphite material, by simultaneously feeding a unique ion gun with both species. Several experiments were performed by varying the partial pressure of gases, as well as the ion fluence. Temperature programmed desorption (TPD) was performed and desorption products were compared to those resulting from single ion bombardment. It is found that the presence of Ar ions during H bombardment increases the hydrogen desorption yield and also result in a strong downshift of the desorption temperature by nearly 300 K. It is proposed that Ar ions modify the H_2^+ ion range implantation and that defects created by Ar ions assist trapping of H species. A full scale comparison of our results with those reported by *C. Hopf, A. von Keudell and W. Jacob, Nucl. Fusion 42 (2002) L27–L30* may not be possible. Indeed, using energetic ions (1 keV Ar+) and atomic H (instead of energetic H ions) cause most of the interactions (leading to methane molecule formation and chemical sputtering) to occur in the surface region (sub-surface contribution to methane formation may be ignored). In our experiment both Ar and H_2 ions have 1.5 keV energy. Therefore, H essentialy interact with C atoms lying below surface. However, the mechanism of bond breaking by Ar ions and then their passivation by H (to form CxHy type clusters), as reported by these authors, may be functioning during our experiment. However the low amount of methane desorbed during TPD in mixed Ar/H_2 (or D_2) bombardment as compared to that in H_2 bombardment seems difficult to understand if only the mechanism reported by Hopf et al., is considered. Depth profiling of H_2 after H_2+ and mixed H_2+/Ar+ bombardment (using SIMS for instance) may clarify a bit more about the possible mechanisms.

Acknowledgments

This work, supported by the European Communities under the contract of Association between EURATOM, CEA and the French Research Federation for fusion studies, was carried out within the framework of the European Fusion Development Agreement. Financial support was also received from the French Research Agency (ANR) under grant CAMITER (ANR-06-BLAN-0008-01).