

SCATTERING OF HYDROGEN ION BEAM FROM TUNGSTEN FUZZ

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1 Introduction

Tungsten is the main candidate for plasma facing material in the divertor zone of a thermonuclear reactor due to high melting temperature, high thermal conductivity and low sputtering erosion yield. However, its surface can be modified by "fuzz" nanostructure, which can form in linear simulators and tokamaks [1] under helium irradiation fluence as high as $\sim 10^{25} \text{ m}^{-2}$, sample temperature in the range of 1000-2000 K and energy $> 20 \text{ eV}$. Such structure significantly changes the plasma-wall interaction balance, especially the interaction of plasma components with the surface.

The fuzzy structure was investigated by means of hydrogen and argon ion scattering spectroscopy with energies in the range of 5-25 keV. The analyzed depth for bulk tungsten is from 5 to 20 nm for such energy range, but for thin porous structure it can be much deeper.

2 Experimental setup

The scheme of experiments is shown in fig. 1. Monoenergetic ion beam generated by duoplasmatron ion source 1 and mass-separated by electromagnet 2 in "Large MEPhI mass-monochromator" setup [2] interacts with the fuzzy sample 4. Scattered on 38° ion beam is separated by energy with energy analyzer 5 and detected with SEM 6. The interaction chamber 3 is pumped by turbomolecular pump with an output of 800 l/s that allows obtaining the pressure of $\sim 10^{-8}$ Torr during target irradiation. Ion current density varied from several nA/cm² to 1 $\mu\text{A/cm}^2$ depending on type of the ion beam: H^+ , H_2^+ , H_3^+ and Ar^+ . Ion current to a target is controlled by Keithley 6485 picoammeter and recorded during experiment for ion fluence calculating.

Fuzzy samples were prepared by irradiation of tungsten sample in helium plasma with fluence $\sim 10^{21} \text{ cm}^{-2}$ when at the surface 1000-2000 K. Scanning electron microscope analysis showed that diameter of fuzz nanostructures is $\sim 20\text{-}80 \text{ nm}$ and thickness of fuzzy layer is $\sim 1 \mu\text{m}$. As it was shown in [3] the density of the fuzzy structure is about 5% of bulk tungsten density.

3 Experimental results

Energy spectra of scattered protons for several ion beam energies is shown in fig.2. One can

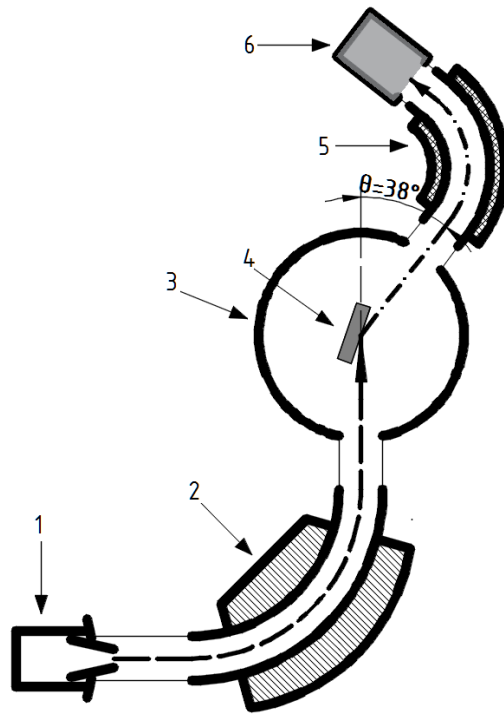


Fig. 1 Scheme of the experiment :

- 1 - ion source
- 2 - Separating electromagnet
- 3 - interaction chamber
- 4 - sample
- 5 - energy analyzer
- 6 - secondary electron multiplier as ion detector

see that with the increasing of ion beam energy the spectra transform to two-peak structure. One of the reason could be the transition of the protons through the fuzzy layer and their scattering from the bulk tungsten: with increasing beam energy there is more bulk tungsten contribution to the spectrum. It is interesting to note, that even as low as 13 keV protons beam can pass through $\sim 1 \mu\text{m}$ fuzzy layer (a low energy shoulder in spectrum) that corresponds to $\sim 6 \mu\text{m}$ total path in fuzz for the geometry of experiment, while maximum analyzed depth for bulk tungsten layer is about 10 nm.

Since the growth of fuzzy structures on plasma facing surface in fusion devices may lead to negative consequences, some methods of tungsten surface recovery are developed [4]. In this work the fuzzy sample was sputtered by 18 keV Ar^+ ion beam with fluence $2 \cdot 10^{16} \text{cm}^{-2}$. This fluence is enough for the sputtering of 10 nm bulk tungsten layer, but, taking in account high porosity of the fuzz, the fluence was enough for sputtering of $1 \mu\text{m}$ fuzzy layer. In fig. 3 one can see the evolution of the double peak spectrum from fuzz to ordinary energy spectrum of protons scattered from tungsten surface. The position of the peak corresponding to scattering from the bulk tungsten practically has not changed during the destruction process, that means that energy losses in fuzzy structures for protons with 25 keV is about $500 \text{ eV} / 6 \mu\text{m} \approx 0,1 \text{ eV/nm}$, while energy losses in bulk tungsten are 150 eV/nm . This allows evaluation of the average tungsten fuzz target density as compared with bulk tungsten as $\sim 1/1500$.

The energy spectra of scattered Ar^+ ion beam from fuzz and bulk tungsten are shown in fig. 4. The spectra are rather similar except of the scattered Ar^+ peak region. The right part of the peak corresponds to multiple scattering and this parts are very similar for fuzz and bulk

tungsten, while the left part correspond to single scattering and this process not so probable for fuzzy structure.

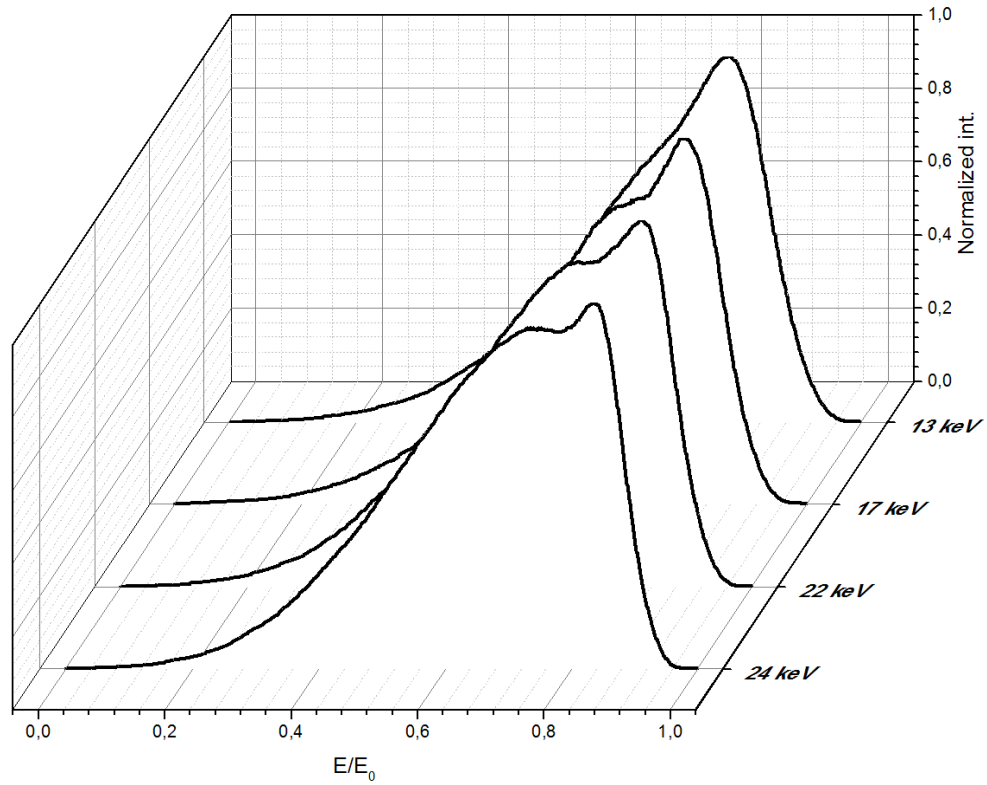


Fig. 2. Normalized energy spectra of scattered H^+ for several initial energies.

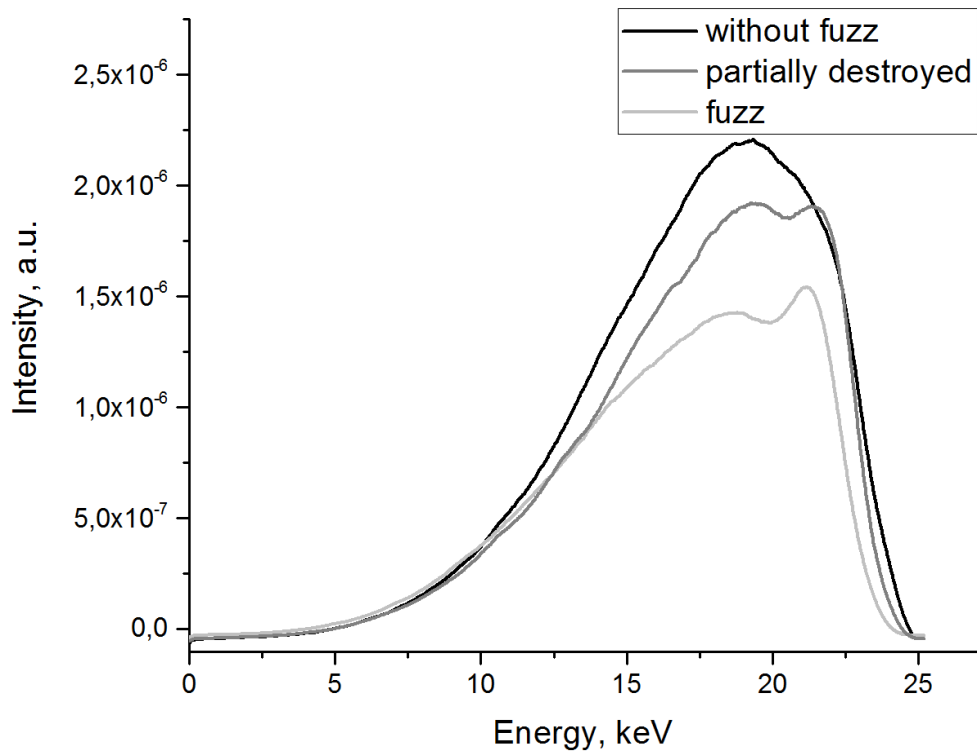


Fig. 3. Evolution of scattered H^+ energy spectra during fuzz destruction by Ar^+ beam.

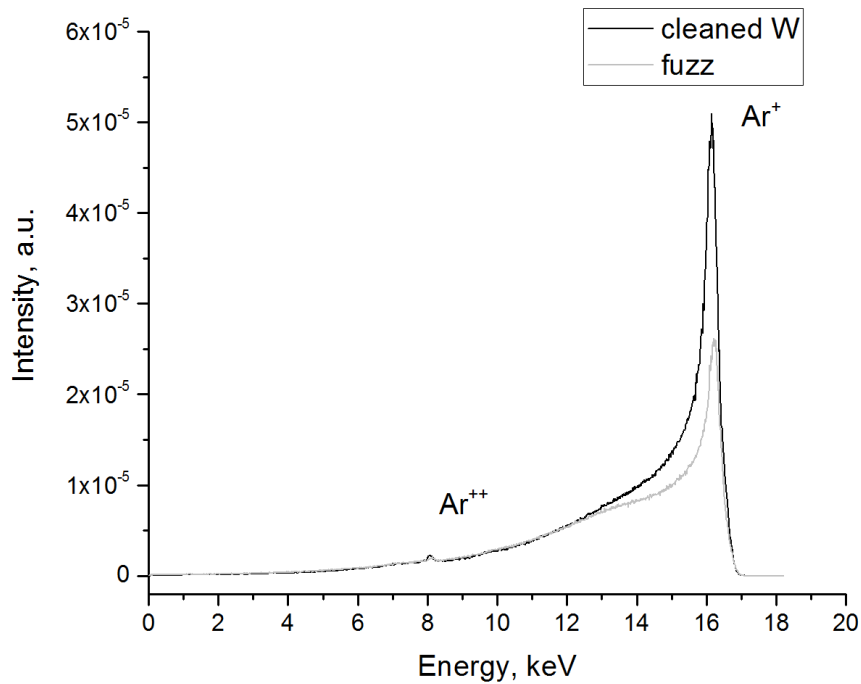


Fig. 4. Energy spectra of scattered Ar ions before and after fuzz destruction.

4 Conclusion

It is shown that spectra of protons scattered from fuzzy tungsten sample have two peak structure: corresponding to scattering from fuzz layer and from the bulk material under fuzz layer. It is shown that energy losses of protons in fuzzy tungsten structure is by three orders of magnitude lower than in bulk tungsten. The scattering of Ar^+ ions showed that single scattering from the fuzz is less probable in comparison with bulk tungsten sample, nevertheless, the spectra of particles multiple scattered from fuzz and bulk tungsten are very similar.

5 Reference

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