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Angle resolved velocity distributions of sputtered medium *Z* atoms

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Abstract

Measurements of angle resolved velocity distributions of sputtered atoms by the laser Doppler shift method are reported. The influence of the emission angle (as well as the angle of incidence) on the velocity distribution is studied by directing the laser beam along selected emission angles and scanning the laser wavelength over the Doppler broadened resonance. The new version of our sputtering apparatus allows us to study nine different ejection angles. We report on first measurements with aluminum and titanium atoms.

Keywords: Physical erosion; Impurity source

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1. Introduction

The understanding of sputtering of particles from the wall of a fusion reactor — one of the most important processes in plasma-wall interaction — and the development of correct models to describe the penetration of bombarding particles as well as energy losses requires information on velocity distributions and relative yields as a function of the emission angle of sputtering. The experiment described here is intended to allow the systematic study of the emission of sputtered atoms as a function of the emission angle (with the angle of bombarding ions kept fixed) with special emphasis on effects connected with anisotropy effects originating from deviations from the ideal case of isotropic collision cascades [1].

We are continuing our previous experiments with aluminum atoms [2] with an improved experimental set-up. The diagnostic tool to investigate velocity distributions is Doppler-shifted laser induced fluorescence (DSLF [3]) by which the atoms emitted in a specific direction and having a velocity in a specific interval are excited by a pulsed narrow bandwidth dye laser beam. The fluorescence photons resulting from this velocity dependent excitation are collected and detected. The resulting Doppler-broadened fluorescence spectrum reflects directly the velocity distribution provided the laser linewidth is narrow enough and saturation broadening is negligible.

First results obtained at the new set-up both for aluminum and titanium will be outlined below. Titanium was chosen because in this case both neutral and metastable atoms and also ions are amenable to LIF spectroscopy [4], and because interesting angle dependent effects may be expected for the various levels of excitation. For both species excitation schemes were adopted allowing the observation of the LIF signals with a frequency offset so that straylight could be circumvented by spectral filtering.

2. Experiment

Fig. 1 shows a schematic view of the experiment.

The target and the ion source are mounted in a rotatable vacuum chamber (base pressure $P = 3 \times 10^{-8}$ mbar). The latter has fifteen O-ring sealed Brewster windows on the circumference, displaced by 20° from each other.

The laser beam enters through a slit in the target (Johnson Mattey, 99.995% Al and 99.98% Ti). The free target diameter (8 mm) is defined by a stainless steel mask.

Rotation of the vacuum chamber (with the turbo- and water-cooled titanium sublimation pumps attached) relative to the observation optics (viewing a fixed scattering volume of dimensions $5 \times 3 \times 2$ mm^3 sited 20 mm in front of the target surface) mounted on a separate stand allows us to select nine different directions of observation. The

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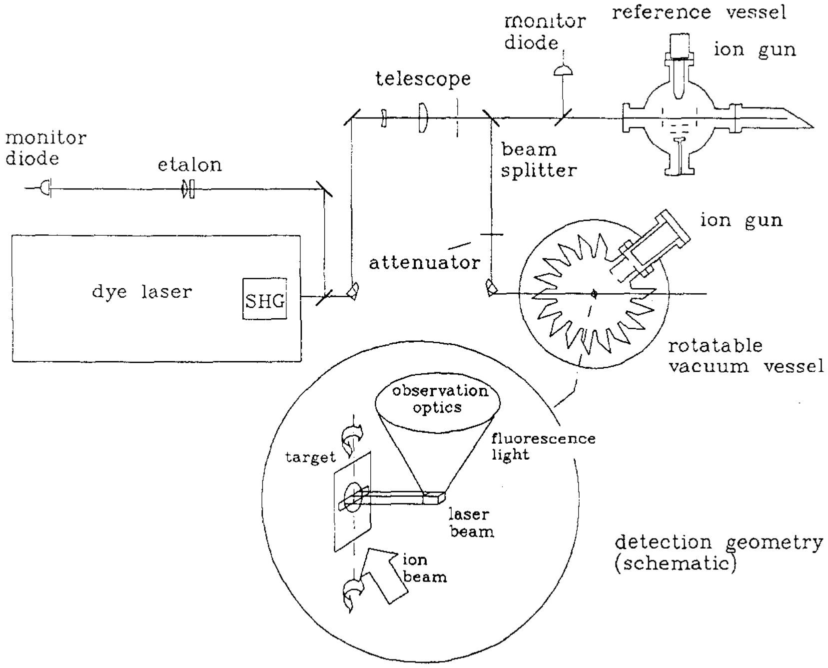

Fig. 1. Experimental set up. Details of the detection geometric are depicted in the insert.

angle of incidence can be varied 'in-situ' independently by rotation of the target alone with the aid of a stepper motor.

The diameter (8 mm) and the direction of incidence of the ion beam are defined by apertures. A lens combination (solid angle of detection $\Delta\Omega \approx 0.17$ sr) images the scattering volume through an interference filter onto a Hamamatsu R928 photomultiplier tube followed by a multichannel scaler (SR 430) in the photon counting mode. Since in case of titanium the upper fluorescence levels are extremely short-lived, the fluorescence signals were recorded in this case — in order to avoid saturation of the multichannel scaler — with a gated integrator (SR 250, gate width 40 ns) and were summed over typically 150 events.

The majority of these experiments were performed with 5 kV argon ions extracted from a Penning type ion source (Fisons AG 5000, current density typically 50 $\mu A/cm^2$). A modified Kaufman ion source was applied for measurements at smaller energies ($E_p \leq 1.5$ kV, current density typically 200 $\mu A/cm^2$). In order to remove the outermost contaminated surface layers the targets were sputtered with the argon ion beam for at least 20 minutes before actually collecting LIF-data.

Unlike the situation of isotropic particle motion the spectral position of zero velocity is not provided from symmetry in this type of measurements. In order to overcome this problem, we derived a small amount of the laser light by a beam splitter and generated a second LIF signal by exciting particles sputtered in a reference chamber with normal incidence of the ion beam supplied from a small electron collision ion source (3 keV Ar^+, Varian Mod. 2046). The laser light is irradiated parallel to the target surface thus exciting only sputtered particles moving normal to the laser beam and defining by the associated LIF signal the zero position of the velocity scale.

In case of aluminum the UV transition (3p → 4d) at 257 nm is excited with observation of the following transition 4s → 3p at 396 nm.

The tuned radiation is generated by an excimer laser-pumped dye laser (Lambda EMG 200 + Lambda FL 2002) and a SHG crystal (BBO).

In the case of detection of sputtered titanium atoms we applied the excitation scheme recommended by Dullni [4], namely the transition $a^3F_J \rightarrow v^3F_J$ requiring radiation of

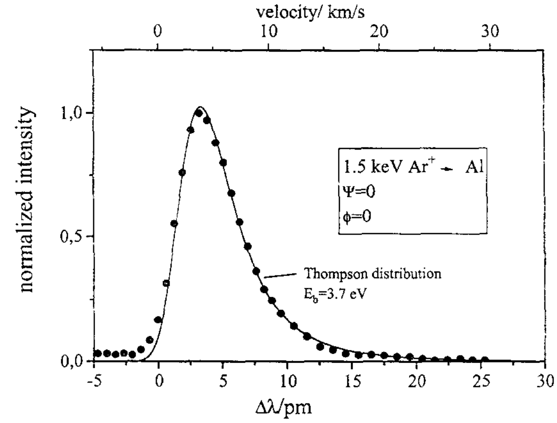

Fig. 2. Velocity distribution of sputtered aluminum atoms (1.5 keV Ar ions at normal incidence, observation parallel to target normal). The solid line represents the Thompson distribution.

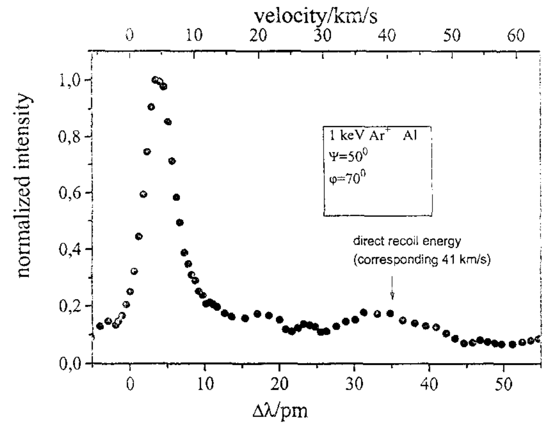

Fig. 3. Velocity distribution of sputtered aluminum atoms observed in forward direction.

wavelength $\lambda \approx 294$ nm. The observation can take place at 445 nm (transitions $v^3F_J \rightarrow b^3F_J$). In this case the pump radiation is generated in a Nd:YAG-pumped (532 nm) dye laser (Lambda FL 3002E) with frequency doubling (KDP). The laser linewidth is narrowed to about 0.04 wavenumbers (in the visible) by use of an intracavity etalon. The line width is monitored continuously by an etalon analyzing part of the radiation coupled out by a suprasil flat.

3. Results

The results obtained so far with this improved arrangement are still preliminary in character but can demonstrate the potential of this new set-up.

In the case of bombardment of an aluminum target with 1.5 keV Ar^+ ions (angle of incidence $\Psi = 0$ and angle of emission $\phi = 0$) the fit procedure of the measured velocity distribution with a profile calculated on the basis of a Thompson distribution (i.e. of the type $f(E) \alpha E/(E + E_b)^3$ with the surface binding energy E_b) yields a value for E_b (3.7 eV) close to that obtained by Dullni [5] for bombardment of aluminum with 1 keV argon ions (3.6 eV) (Fig. 2).

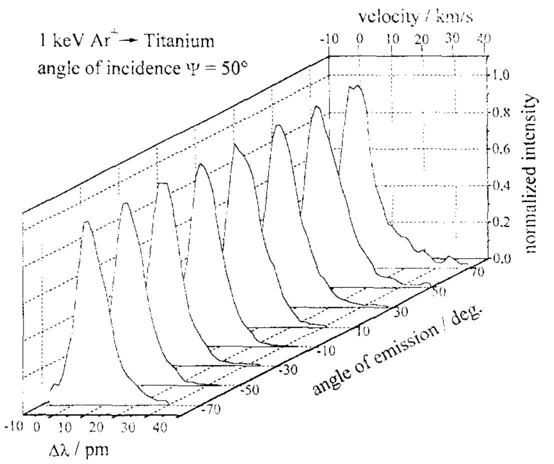

Fig. 5. Velocity distributions of sputtered titanium atoms observed for different ejection angles.

Fig. 3 shows an example of a distribution recorded for bombardment of an aluminum target with 1 keV argon ions. The angle of incidence is 50°; the angle of emission 70°. The behavior in the high energy tail — clearly different from the standard Thompson distribution — is of main interest in this case. The slight hump in the high energy tail may be caused by direct recoil particles.

The influence of different ejection directions is more pronounced for smaller projectile energies and steeper angles of incidence. Fig. 4 shows as an example the normalized distributions obtained with bombardment of aluminum with 0.5 keV argon ions at an angle of incidence

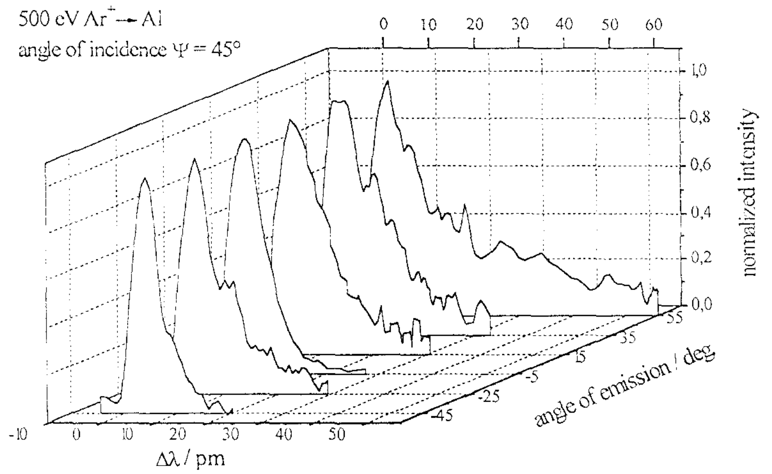

Fig. 4. Velocity distributions of sputtered aluminum atoms observed for different ejection angles.

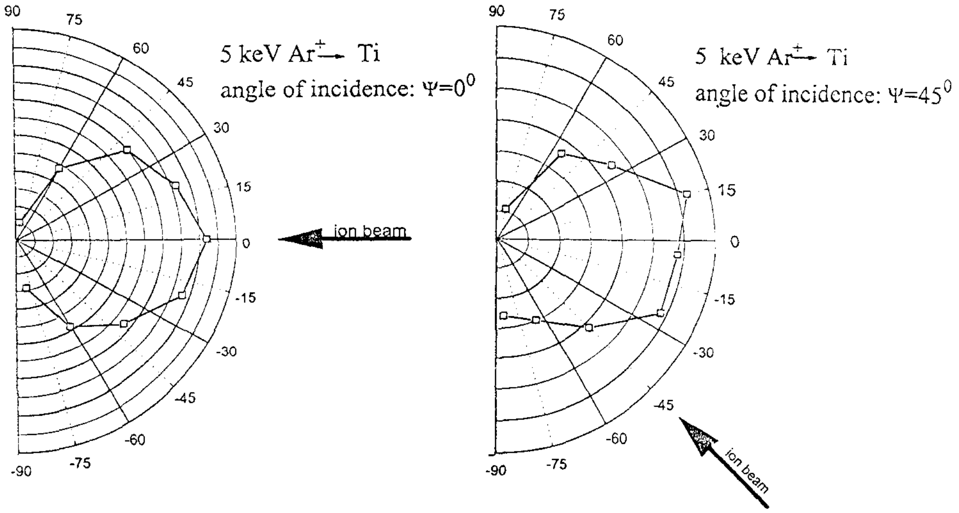

Fig. 6. Relative angular distributions measured with the laser wavelength fixed at the peak of the velocity distribution.

of 45°. Considerable broadening in forward direction is observed.

In Fig. 5 spectra of sputtered titanium atoms are depicted, taken with 1 keV ion energy at an angle of incidence $\Psi = 50°$ and beam current density of 0.2 mA/cm^2.

In this case additional deviations in the low energy part centered around zero velocity are significant. The contributions with negative velocities may be caused by reflected particles. Artefacts through power broadening were excluded by careful reduction of the laser intensity into the linear part of the saturation curve.

The comparison of the these distributions with a theoretical Thompson distribution yields values for the parameter E_b far higher than the values found in the literature for the sublimation energy [6]. The broad character of the distributions may be caused by a surface reaction at the target with oxygen or nitrogen molecules from the residual gas as invoked by Dullni [5] who investigated these influences systematically. This interpretation is supported by the additional observation that the intensities of the three ground state fine structure components ($J = 2,3,4$) yield an excitation 'temperature' around 1400 K, which is characteristic — as Dullni pointed out — for an oxidized surface. On the other hand a simple estimate of the surface coverage with impurity atoms in the dynamic equilibrium established under the influence of residual gas adsorption and sputtering by ion bombardment [7] yields a value of only 1% based on a sticking coefficient $S = 1$ and sputtering yield $Y = 1$, $J = 50$ μA/cm^2 and a residual pressure $P = 10^{-8}$ mbar. The last example (Fig. 6) is devoted to the demonstration of the capability of the new installation to measure relative angular distributions with angular displacement of the chamber viewing at a fixed velocity (e.g. the maximum) i.e. keeping the laser excitation wavelength fixed.

The distribution obtained with normal incidence exhibits good agreement with a cos ϕ distribution whereas the distribution recorded for 45° incidence show anisotropy effects as expected.

4. Conclusions

The first measurements at the new sputtering installation, designed for the measurements of angular distributions in connection with Doppler-shifted laser induced fluorescence (DSLF), are encouraging. Application of this method to medium Z targets demonstrates several anisotropy effects for which explanations are only partly available so far. Several obvious limitations can be overcome in the near future (e.g. by improvement of the base pressure and increase of the ion beam current, improvements in target preparation). Extension of the experimental program in the direction of high Z targets (e.g. tungsten) is in preparation.

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