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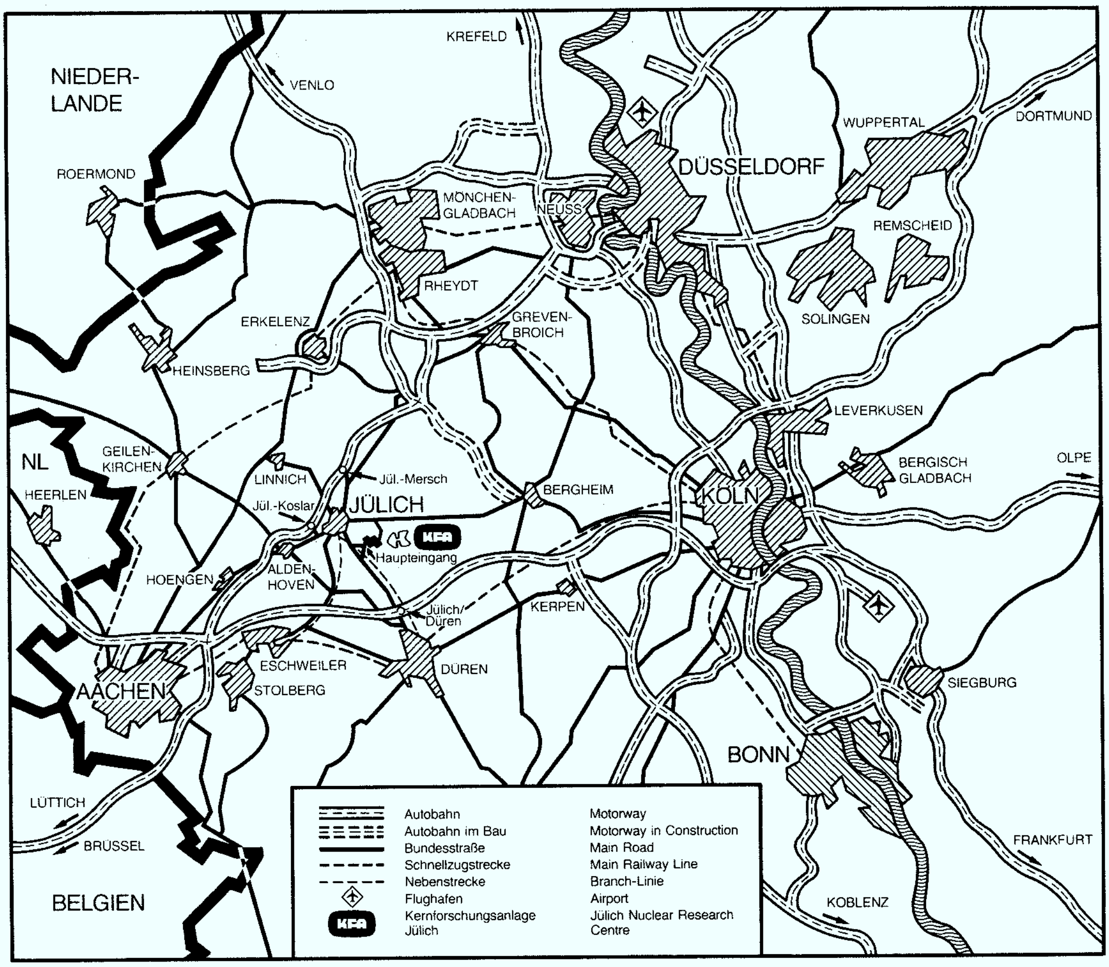

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Abstract

The velocity distribution of sputtered Fe-atoms has been measured for low-energy light-ion irradiation at normal incidence using laser induced fluorescence. Together with previous data the results are discussed in view of a linear cascade theory. The change in the velocity distribution for decreasing ion mass and energy is related to the change in the recoil density distribution in the target and the collision cross section.

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Introduction

The energy distribution of sputtered atoms is a direct probe of the recoil distribution inside the solid target under energetic particle bombardment. For heavy-ion irradiation the expected E^{-2}-distribution has been verfied by several investigators /1-4/. Recent results on low-energy light-ion sputtering of Ti and Zr, however, have shown a shift in the velocity distribution towards lower velocities as a function of ion type and energy /5-6/. Also anisotropic effects have been found /6,7/.

In the present work the velocity distribution of sputtered Fe-atoms for low-energy light-ion irradiation has been measured by means of laser induced fluorescence /8-10/. The irradiations were performed at the high current irradiation facility EVITA II, and the experimental set-up is shown in Fig. 1. The experimental set-up with an excimer-laser pumped dye-laser system and the observation system was identically to the one used in ref. 5. and has been discribed in detail therein. The iron targets were made of VP grade rolled iron mechanically polished with 3 μm diamond paste. The neutral sputtered Fe-

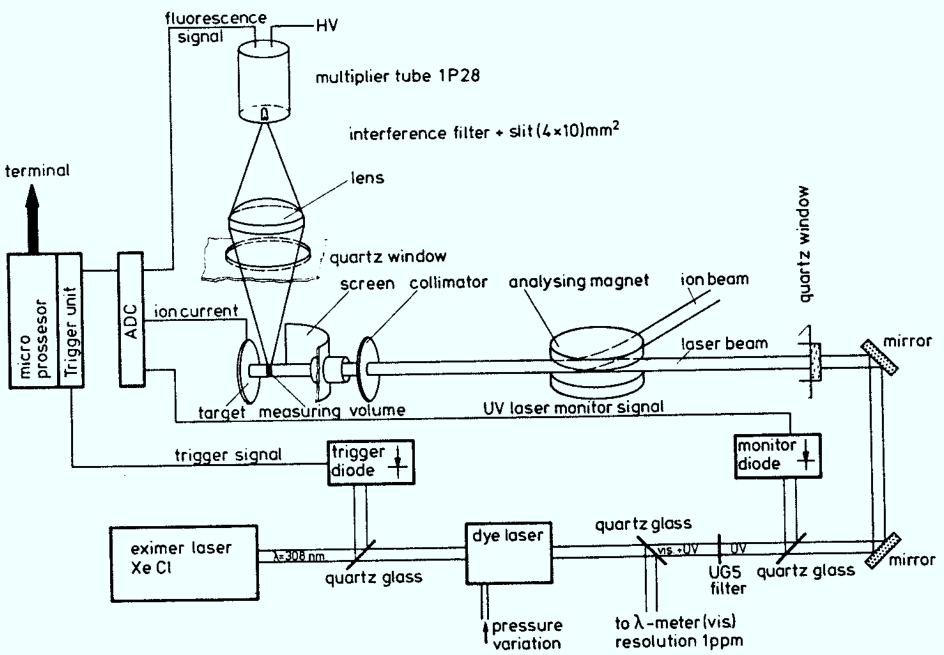

Fig. 1: Experimental geometry. The laser beam is hitting the target at normal incidence coaxially with the ion beam. The fluorescence light is observed normal to the laser beam.

atoms were excited by the laser light from the groundstate a^5D_4 to the state y^5D_4 (λ_e = 302.064 nm) and the fluorescence line to the metastable state a^5F_4 (λ_f = 382.04 nm) was observed.

Theory

In the collision cascade theory the energy distribution of the sputtered atoms (f(E) can be calculated using the power potential approximation /1,2/. Assuming a planar surface barrier of height U_0 one finds:

$$f(E) \propto E/(E + U_0)^{3-2m} \qquad (1)$$

for $E \ll T_m$, where T_m is the energy transfer in an elastic head-on collision ($T_m = 4\ M_1 \cdot M_2/(M_1 + M_2)^2 \cdot E_{ion}$) and m is defined by the power cross section /1/

$$d\sigma(T) = C \cdot E_{ion} \cdot T^{-1-m}\ dT \qquad (2)$$

where T is the transferred energy and E_{ion} the incident ion energy. In sputtering low-energy collisions are dominating and m is normally chosen close to zero ($m \gtrsim 0$) /1/.

For low-energy light-ion irradiation $T_m \gtrsim U_0$ and eq (1) is only valid for the very lowest energies $E \ll U_0$. In the limit $E \lesssim T_m$ Thompson /2/ showed f(E) to be given by

$$f(E) = K \cdot E \cdot (1 - ((E + U_0)/T_m)^p)/(E + U_0)^{3/2m} \qquad (3)$$

where p = 1 - m and K and normalization constant. For high-energy sputtering of gold Thompson used m = 1/2, but in our case it would be more reasonable to choose m closer to zero. The distribution (3) is rather insensitive to p in the interval $1/2 < p < 1$, and p = 1 will be used in this paper.

In the case of low-energy light-ion sputtering the collision cascade theory is not expected to give reliable results, and a single collision model would be more appropriate. However, using the model by Littmark and Fedder /11/ with the power cross section (2) yields approximately the same distribution as eq(3). In the following discussion, therefore, the distribution (3) will be used in the form

$$f(E) = K\cdot E\cdot(1 - (E + U_0)/T_m)/(E + U_0)^{1+n} \qquad (4)$$

Due to the refraction of the sputtered atoms by passing the planar surface barrier /2/, this spectrum corresponds to an isotropic recoil density energy distribution $G(E_{ion}, E)$ inside the target given by

$$G(E_{ion}, E) \propto (1 - E/T_m)/E^n \qquad (5)$$

Thus the energy distribution of the sputtered atoms gives directly the recoil distribution in the solid, which again is related to the scattering cross section. This is true for isotropic recoil distributions only, and anisotropic effects /12/ as found for light-ion sputtering of Zr /7/ will of course complicate this relation.

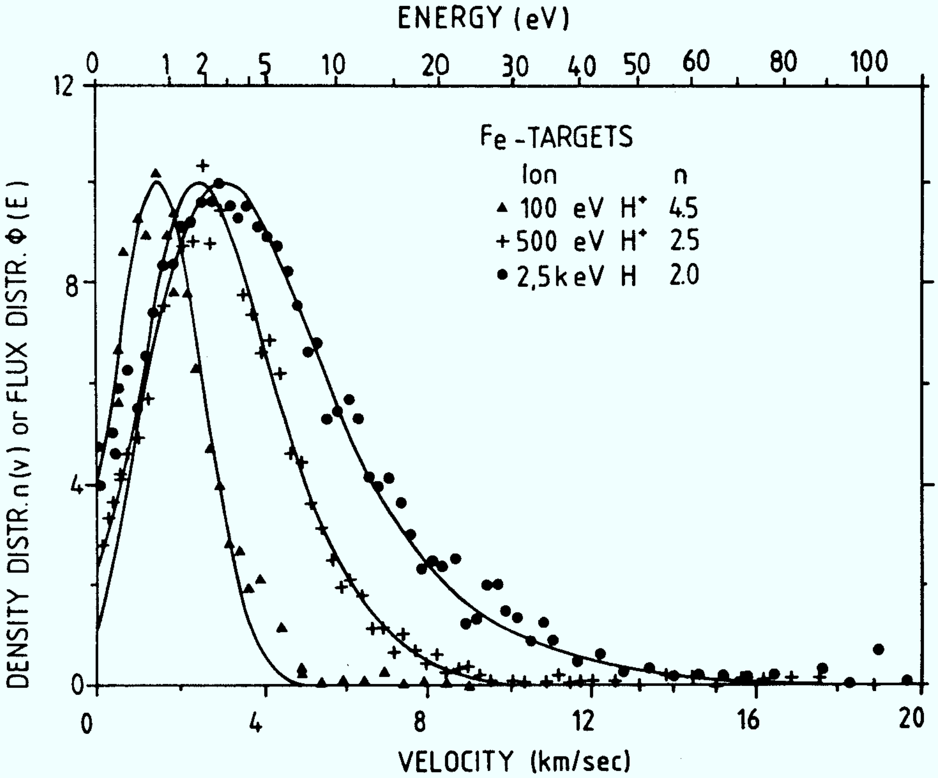

Fig. 2: Experimental velocity distributions of sputtered Fe-atoms for hydrogen irradiation. The curves are calculated from eq(4) using n as fitting parameter and folded with the laser profile (Gaussian)

Results and discussions

Some of the results for hydrogen irradiation are shown in Fig. 2. The shift in the velocity distribution for decreasing H-ion energy is clearly seen. The fluorescence signal is proportional to $n(v)dv = f(E)dE$, where $n(v)$ is the density velocity distribution. The curves are $f(E)$ from eq(4) with n as a fitting parameter. This procedure has previously been used to fit velocity distributions e.g. by Pellin et al /10/. In order to give a realistic fit distribution (4) was folded with a gaussian whose half-width was determined by the laser band width. As an example, the effect of the folding and of changing the power n is shown in Fig. 3 for 200 eV $H^+ \rightarrow Fe$. The same analysis has also been applied to our old data for Ti-sputtering /6/ as shown in Fig. 4. The resulting powers n are depicted in Fig. 5 and Table I as a function of the normalized energy $E' = T_m / U_0$ /13/.

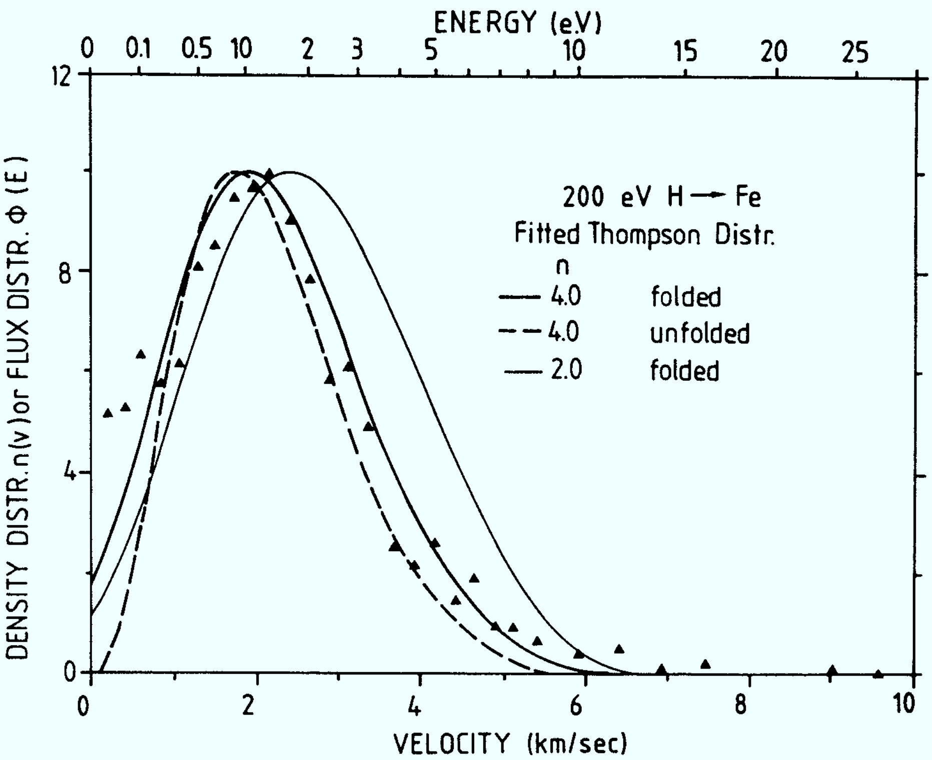

Fig. 3: The experimental velocity distribution of sputtered Fe-atoms for 200eV H^+ irradiation. The thick curve is the best fit of eq(4) to the data (n = 4). The dashed curve is the same but without folding with the laser profile. The thin curve is eq(4) for n = 2, and folded with the laser profile.

Table I : Experimental and calculated parameters for the velocity distribution measurements of sputtered Fe and Ti. $\langle v \rangle$ is the mean velocity of the sputtered atoms, as calculated from the fitted Thompson-distribution, with the n-values eq(4) given in the last column.

TARGET	U_o (eV)	ION	ENERGY (keV)	M_2/M_1	T_m (eV)	E'	$\langle v \rangle$ (km/s)	n
Fe	4.3	^{40}Ar	8.0	1.4	7778	1809	10.9	1.8
Fe	4.3	^{4}He	8.0	14.0	1996	464	8.1	2.0
Fe	4.3	H	2.5	55.9	173	40,2	6.2	2.0
Fe	4.3	H	0.5	55.9	34.6	8.0	4.0	2.5
Fe	4.3	H	0.2	55.9	13.8	3.2	2.6	4.0
Fe	4.3	H	0.1	55.9	6.9	1.6	1.8	4.5
Ti	4.9	^{4}He	8.0	12.0	2276	465	8.5	2.1
Ti	4.9	^{4}He	8.0	12.0	28.5	5.8	4.1	2.8
Ti	4.9	^{2}D	2.5	24.0	385	78.5	7.1	2.2
Ti	4.9	^{2}D	0.5	24.8	77	15.7	5.7	2.6
Ti	4.9	H	2.5	47.9	200	40.9	5.9	2.5
Ti	4.9	H	0.5	47.9	40.1	8.2	4.1	3.2
Ti	4.9	H	0.2	47.9	16.0	3.3	2.9	4.5

Although the powers for Ti in general appears to be a little bit higher than for Fe, the data points seem to define a universal dependence on E. It is interesting that large discrepancies from the high energy value for n, here

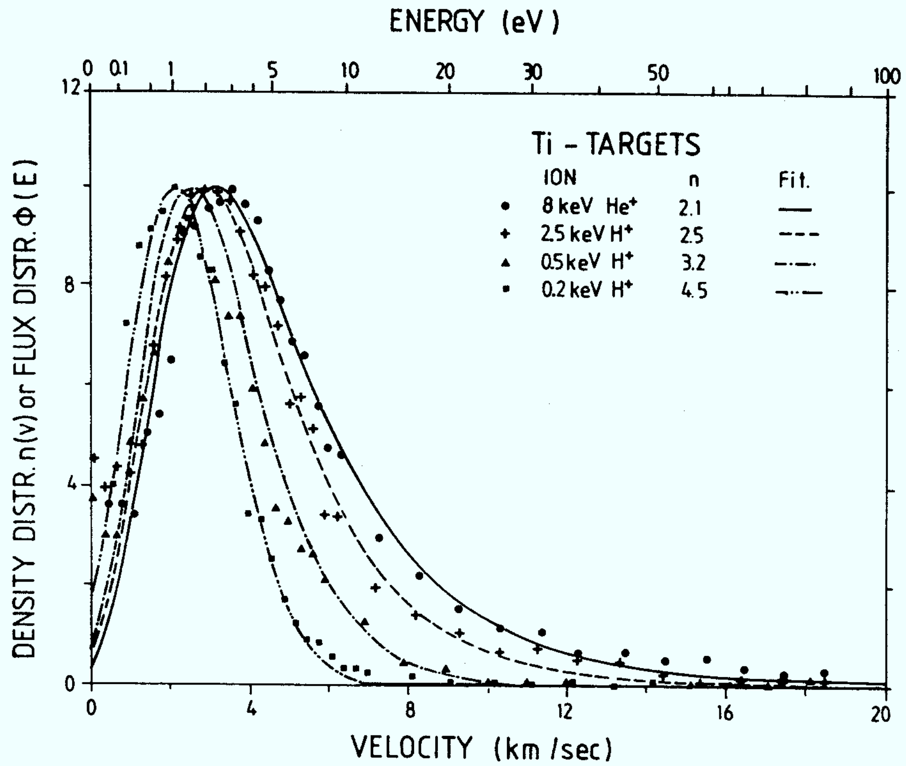

Fig. 4: Experimental velocity distributions of sputtered Ti-atoms for He^+- and H^+-ion irradiation at normal incidence. The curves are the best fit to the data from eq(4) folded with the laser profile (Gaussian).

represented by n = 1.8 for 8 keV Ar^+-Fe, appears for $E' \lesssim 20 - 30$. This is the same region where a scaling law for light-ion sputtering yields could be defined /13/. At small E-values the power n increases to $n \geq 4$. Unless this increase can be explained by anisotropic effects /7,12/, the steep falling tail in the velocity distribution cannot be described by using the usual power cross section with $0 \leq m \leq 1$. This is the more surprising because the reason for the change in the velocity distribution seems intuitively clear, namely the energy conservation in elastic collisions, i.e. no recoils with energy $\geq T_m$. Neither the approach by Roosendaal and Sanders /14/ taking the anisotropy of the collision cascade into account, nor the single collision

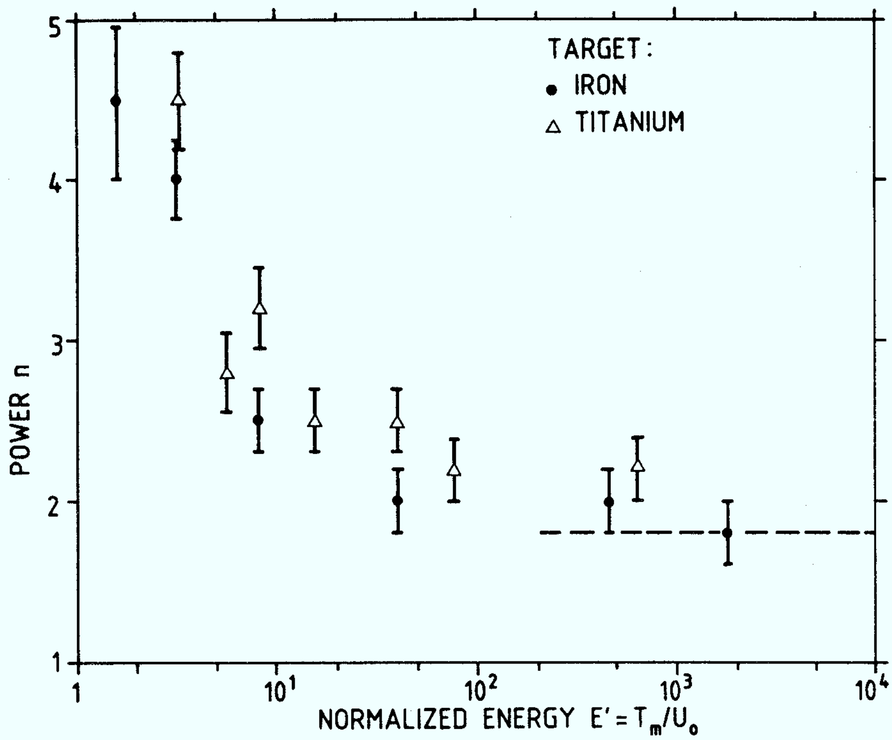

Fig. 5: The power n in eq(4) as a function of the normalized energy E'.

calculation by Falcone and Oliva /15/ have been able to discribe the experimental data /7/. In conclusion simple analytical collision theory seems not to be able to give a reasonable quantitative discription of the present experimental distributions, unless another cross section is introduced, and the whole problem of low energy collisions in solids still has a number of "Open Ends" waiting for satisfactory solutions.

Acknowledgement

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