Thermal Spike Effect in Sputtering of Metals with Energetic Heavy Ions ◇

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Sputtering experiments on metals have been performed using heavy ion projectiles up to the highest energies which are available at the Munich tandem accelerator. During one experiment the tandem was running even at 15 MV terminal voltage (the highest terminal voltage ever used for experiments in Munich) delivering 285 MeV Au^{18+} ions. Sputtering with heavy ions in the 100 MeV–range is, contrary to the keV–range, much less studied and may be influenced by electronic effects which dominate the slowing down of energetic ions. Measurements on insulators at MeV–energies had shown strong electronic effects but till now it was an open question whether the underlying physical mechanisms are also effective in conducting materials. Our experiments have given for the first time clear indications of electronic effects in sputtering of metals which we explain by a thermal spike mechanism [1].

Because of the extreme surface sensitivity of the sputtering process all measurements had to be made at UHV–conditions. We used a special setup which included a low energy sputter cleaning device and a UHV–compatible ERDA detector for in–situ surface analysis [2,3]. Sputtered atoms were collected on Si catchers at 90° to the surface which were afterwards analyzed by 1.5 MeV C channeling RBS. Additionally angular distributions were measured in certain cases [4]. I and Au ions at different energies were used in order to vary the electronic stopping power of the incoming ions. Sputter experiments have been performed on Ti, Mn, Zr and Au targets. A removable C–foil in front of the sputter targets allowed post-stripping to increase the ion charge state to the equilibrium charge state, typically by a factor of 2. Thus the charge state dependence of the sputtering yield could be tested. Reproducibility measurements had shown that the total errors of the sputtering yields are within 20%.

A common experimental finding in Mn, Ti and Zr was a distinct charge state dependence of the measured sputtering yields which shouldn't exist for pure nuclear sputtering and is a clear indication for electronic contributions (see Fig. 1a). This charge state dependency was not observed for Au targets. Another signature of electronic effects was found in the energy dependence of the Ti sputtering yield by a threshold-like increase at energies where the calculated nuclear yield decreases (at around 15 keV/nm energy loss). For Zr, the difference of the sputtering yields between Au at 230 MeV and I at 55 MeV is a clear indication for electronic effects. Both ions have similar nuclear stopping power at these energies and therefore the difference of the measured yields has to be caused by the different electronic stopping power. This behavior could be reproduced within a thermal spike model [5] which has been extended to calculate the number of evaporated (sputtered) atoms. The charge state dependence of the sputtering yield could be explained in the thermal spike model, too, by the charge state dependence of the electronic energy loss, at least near the surface.

Contrary to Ti the thermal spike model calculations for Zr were only successful after including the electronic *and* nuclear energy loss contribution to the heating process. An experimental hint for the importance of the nuclear component can be deduced from Fig. 1b by comparing the yields for 210 MeV I and 109 MeV Au ions. In spite of the higher electronic stopping power of I at this energy the corresponding yield is lower due to the lower nuclear heating. Although the absolute value of the nuclear energy loss is small, the coupling of the nuclear component to the lattice is much more effective than for the electronic component. Therefore the nuclear energy loss has to be considered in future thermal spike calculations.

Of course it cannot be expected from these first thermal spike calculations for sputtering to give more than a qualitative agreement. Some parameters are not well enough known and therefore a factor of 2 to 3 difference to the experiments can be accepted. It should be noted that even nuclear sputtering calculations based on collision cascades differ by about the same factor.

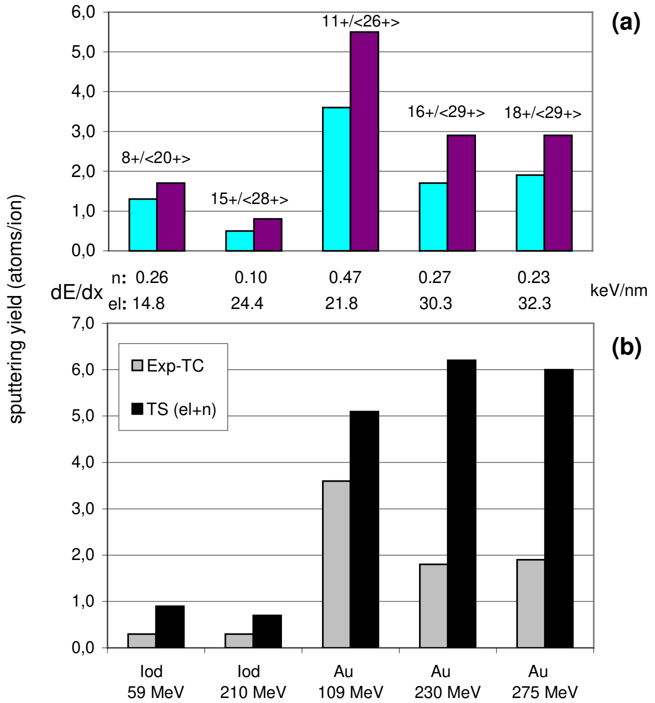

Fig. 1: (a) ion charge state dependence of measured sputtering yields for Zr with different ions and energies. (b) Thermal spike calculations compared with experimental sputtering yields. To remove the nuclear sputtering contribution calculated nuclear sputtering yields (by TRIM.CASCADE) are subtracted from the experimental values with incoming ions in charge state equilibrium.

References

[1] H.D. Mieskes, Ph.D. thesis, LMU München, 1999
[2] H.D. Mieskes *et al.*, Jahresbericht 1997, p. 43 and 104
[3] H.D. Mieskes *et al.*, Nucl. Instr. Meth. **B146** (1998) 117
[4] H.D. Mieskes *et al.*, Jahresbericht 1998, p. 40
[5] Z.G. Wang *et al.*, J. Phys. Condens. Matter **6** (1994) 6733

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