

ACCUMULATION OF GOLD IONS ON A GOLD COATED QUARTZ CRYSTAL

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Abstract: A new experiment has been started to determine the atomic mass of gold in the unit kilogram. For this purpose, gold ions have to be accumulated to a weighable mass and the ion current has to be measured and integrated over the accumulation time. In a first accumulation experiment gold ions have been accumulated on a gold coated quartz crystal. A gold ion beam with a current of 5 mA and a range of ion energy between 25 eV and 300 eV has been used. As a result of the interaction of the gold ions with the surface of a gold coated quartz crystal, the ratio of the change of mass per time and the ion current multiplied with the elementary charge has been determined as a function of the ion energy. The transition between the mass loss and the mass increase at the oscillator quartz, mainly resulting from the sputtering effects, has been observed. The measurements have shown a reasonable agreement with the expected value of the mass of a gold atom in the unit kilogram for low ion energies.

Keywords: gold ion beam, quartz crystal microbalance, ion accumulation

1 INTRODUCTION

A proposal for an experiment for direct measurement of the atomic mass unit and the concept of monitoring and realizing the kilogram at an atomic level was described earlier [1]. The experiment is based on the idea that the ratio between the mass and the charge of a simply charged ion is equal to the ratio between the mass and the total charge of accumulated ions.

The experiment could be realized by generating a high current ion beam of a specified nuclide, accumulating the ions by a collector up to a weighable mass and measuring the ion current integrated over the accumulation time. This integral represents the total charge of the accumulated ions. Gold, ^{197}Au , will be an appropriate nuclide because of its natural isotopical purity, chemical inactiveness and large atomic mass. The realization of this experiment has been started at the Physikalisch-Technische Bundesanstalt by measuring the mass of a gold atom in terms of the kilogram.

As an important step for this purpose, in a first accumulation experiment, the change of mass per time during the bombardment of a gold coated quartz crystal of a quartz crystal microbalance with gold ions and the ion current have been determined as a function of the ion energy. The gold ions have been extracted out of the ion source with an ion energy of 18 keV. In a deceleration system which is installed in front of the quartz crystal balance the gold ions are decelerated to an ion energy between approx. 30 eV and 300 eV. The ion energy has been varied by changing the potential difference between the ion source and the quartz crystal. The measured difference of mass per time as a function of the ion energy depends on sputtering and reflection effects, on secondary electron emission as well as on the influence of neutral particles and electrons which possibly exists due to scattering effects at the screens, limiting the lateral size of the ion beam.

2 EXPERIMENTAL SET-UP

The experimental set-up is composed of a CHORDIS [2] (Cold or HOt Reflex Discharge Ion Source) ion source, a quadrupol triplet lens, a beam monitor, a dipole magnet and a quartz crystal microbalance with a gold coated quartz crystal. The sputter Version of the CHORDIS ion source was used which comprises a gold electrode as sputter electrode.

Positive ions are extracted out of the CHORDIS ion source. The parameters of the ion source have previously been investigated in [3]. The gold ions are focused with a quadrupole triplet lens. A beam monitor checks this focus. The mass separation is done with a dipole magnet. The pressure within the beam transport chamber is normally around 10^{-4} Pa and below 10^{-6} Pa with and without the presence of ion beam, respectively. The arrangement is schematically shown in figure 1.

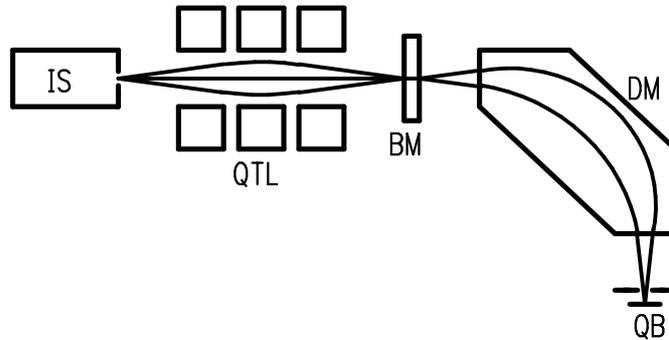


Figure1. Scheme of the experimental system. IS ion source, QTL quadrupole triplet lens, BM beam monitor, DM dipole magnet and QB quartz crystal microbalance.

A commercially available quartz crystal balance (XTM/2 from Leybold inficon inc.) has been used for the measurements. The quartz crystal was coated with a gold layer and the quartz crystal balance was screened with an isolated screening electrode (see Fig. 2).

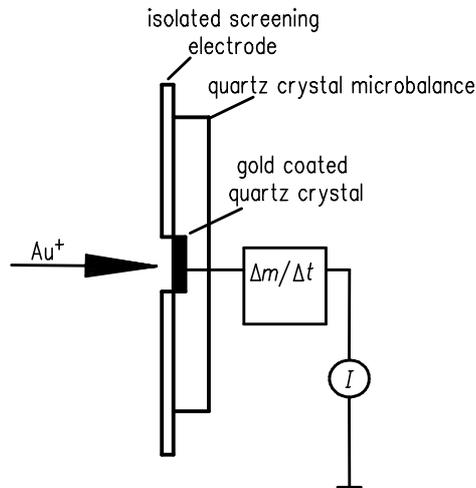


Figure 2. Scheme of the quartz crystal microbalance. The change of mass per time $\Delta m/\Delta t$ and the beam current I were measured.

This screening is necessary for the measurement of the beam current, because only the current of the gold ions, which are neutralized at the gold coated quartz crystal should be measured. The accumulation with this quartz crystal balance can only be done with a low beam current of gold ions of a few microampere. With high ion current, the isolation of the screening electrode will also be coated with gold after a short time. In this case, the measured ion current will be too high, because the beam current of the screening electrode will also be measured. Space charge effects are responsible for an expansion of the ion beam.

Changes of mass per time were measured in the range of nanogram per second and the ion current was measured in the range of microampere. The ion current was measured with an amperemeter, which is installed between the isolated quartz crystal and the ground potential.

The ion energy was fixed by the potential difference between the ion source and the quartz crystal. The ion current depends on the potential difference between the ion source and the beam transport area [3]. For the required ion current, it was necessary to extract the positive ions from the ion source with a potential difference of 18 kV, which leads to an ion energy of approx. 18 keV. At the quartz balance the ions were decelerated to energies below 300 eV. With this arrangement it is possible to decelerate the gold ions down to a few electron volt. A scheme of the deceleration system is shown in figure 3.

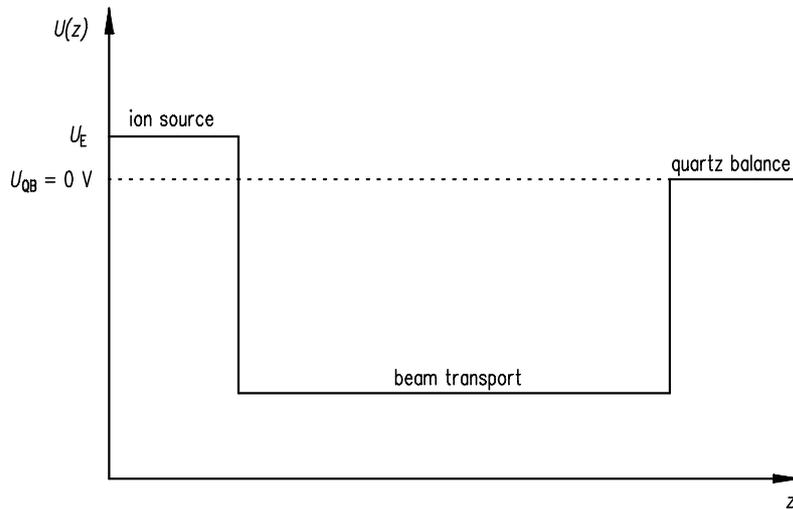


Figure 3. Scheme of the deceleration system

3 RESULTS AND DISCUSSIONS

During the bombardment of the gold coated quartz crystal with decelerated gold ions the quotient $\Delta m/\Delta t$ and the beam current I were measured as a function of the potential difference $U_E - U_{QB}$ between the ion source and the quartz crystal. This potential difference is somehow a measure of the ion energy. First measurements have shown that the distribution of the ion energy has a non-negligible width of some tens of electron volt, which is probably due to the Boersch effect [4] at most part.

The measured curve (see figure. 4) was influenced by sputtered target particles, the reflection of incident gold ions, the emission of secondary electrons as well as by neutral particles and electrons, which have been developed during the deceleration of the gold ions by scattering effects at the screens.

For the potential difference $U_E - U_{QB}$ between 100 V and 300 V the quotient $e (\Delta m/\Delta t) I^{-1}$ is negative and falls with rising potential difference. Within this potential range a mass loss at the gold-coated quartz crystal was measured and becomes larger with increasing ion energy. The main reason for this effect is the increase of the sputtering yield with increasing energy [5]. For a decreasing potential difference $U_E - U_{QB}$ the quotient $e (\Delta m/\Delta t) I^{-1}$ increases from negative to positive values. The change from negative to positive values shows the transition of the mass loss to the mass increase. Previous measurements with xenon – ions on gold have shown, that below a threshold energy no further target atoms are sputtered [6].

The particle reflection coefficient is reduced towards lower energies of the incident ions, if between the projectile and target particle chemical binding forces exist [7]. The decrease at low energies depends, apart from the binding energy, on the surface structure as well as on the mass of the projectile and target particles.

The secondary electron emission doesn't have a crucial influence on these measurements at energies of the incident ions of a few 100 eV [8]. Measurements of Eder [9] have shown for the bombardment of gold with gold ions at an ion energy of 1 keV a total electron yield smaller than 0,01.

The mentioned effects of sputtering, reflection and electron emission should decrease to zero at sufficiently small ion energies. Only the rates of charged or neutral particles generated by collisions of the gold ions with particles of the residual gas or with screening devices are not reduced considerably with the experimental arrangement used here.

For low ion energies promising results for the experimental determination of the atomic mass of gold in the unit kilogram in the frame of this new experiment have been attained.

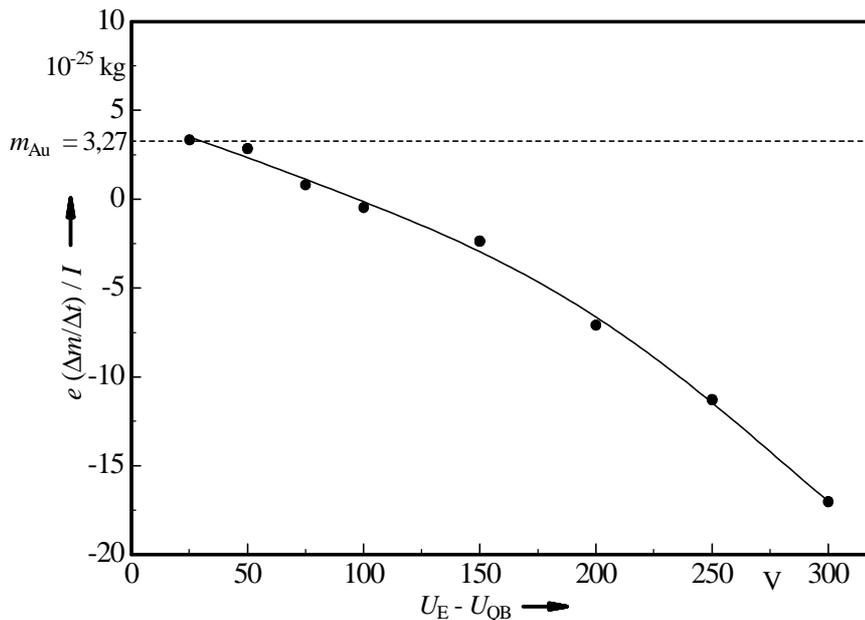


Figure 4. Results of the quotient $e(\Delta m/\Delta t) I^{-1}$ as the function of $U_E - U_{QB}$. The quotient $\Delta m/\Delta t$ and the ion current I were measured experimentally. m_{Au} is the atomic mass of gold and e is the elementary charge. For small values of $U_E - U_{QB}$ the quotient $e(\Delta m/\Delta t) I^{-1}$ should converge against the atomic mass of gold m_{Au} in the unit kilogram. The experimental value for m_{Au} in the unit kilogram is $3,35 \cdot 10^{-25}$ kg for $U_E - U_{QB} = 25$ V.

4 CONCLUSION

Experimental results for the change of mass per time $\Delta m/\Delta t$ of a gold coated quartz crystal during the bombardment with gold ions as well as for the ion current I as a function of the the potential difference between the ion source and the quartz crystal $U_E - U_{QB}$ have been presented. The ion beam was decelerated to energies of a few electronvolts. The transition between the mass loss and the mass increase was observed experimentally. The measurements have shown a reasonable agreement with the expected value of the mass of a gold atom in the unit kilogram for low ion energies. In the future further important effects like the sputtering of target particles, the energy distribution of the incident gold ions, the reflection of incident gold ions as well as the secondary electron emission have still to be investigated and possibly to be reduced.

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