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AN ARRAY OF QUARTZ CRYSTAL MICROBALANCES FOR MEASURING TWO-DIMENSIONAL MASS-DISTRIBUTIONS

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Abstract: A special collector is being developed to determine the two-dimensional mass distribution of ions from a low energy ion beam and of the particles backscattered from a target by using an arrangement of an array of quartz crystal microbalances.The distribution of the scattered particles during the bombardment of a collector surface with gold ions will be of special interest for the experimental determination of the atomic mass of gold in the unit kilogram, where decelerated gold ions are to be accumulated in a collector to a weighable mass. The current state of the research work is presented.

Keywords: quartz crystal microbalances, mass distribution, scattered particles

1 INTRODUCTION

A proposal for an experiment for direct measurement of the atomic mass of gold and a concept of monitoring and realizing the kilogram has been described in [1]. A corresponding set-up and preliminary measurements have been realized at Physikalisch-Technische Bundesanstalt [2]. The aim of the experiment is to accumulate Au^+ ions from an ion beam to a weighable mass and to measure the ion current integrated over the accumulation time. In order to reduce the sputtering and reflection effects occuring when the ions encounter the collector surface, the ions are decelerated to low energy, but also the remaining effects of sputtering and reflection have to be measured. Therefore, an array of quartz crystal microbalances will be developed to measure the two-dimensional mass distribution of the scattered particles to determine the number of scattered particles, which can leave the ion collector during the accumulation possibly.

2 SCATTERED PARTICLES

During the accumulation of Au^+ ions in an ion collector, sputtering and reflection effects can be possibly falsificate the experimental determination of the atomic mass of gold. This is the case if particles can leave the ion collector, which have a mass to charge ratio which is not equal to that of a simply charged gold ion. It is necessary to minimize the sputtering and reflection effects, but also to quantify the possible loss with sufficient accuracy. A minimization of this effect can be achieved by decelerating the incident gold ions to an energy where nearly no particles will be sputtered and reflected.

Above a certain threshold energy [3] which depends on the surface structure, on the binding energy of the target atoms in the collector surface and on the mass of the projectile and target particles, target atoms are sputtered by incident ions. The sputtering yield rises with increasing ion energy [4], attains a maximum and drops with further rising ion energy due to increasing ion implantation. With the Monte Carlo program TRIM.SP the sputtering yield and the energy of the sputtered target atoms as a function of the ion energy was simulated [5]. The results show that with an ion energy of less than 17 eV no more target atoms are sputtered. With energies of the incident ions between 17 eV and 1000 eV the mean energies of the sputtered particles range from 0,3 eV to 12,7 eV. One of the few experiments for the determination of the threshold energy was accomplished by Stuart and Wehner [3]. They determined a threshold energy of 20 eV for the bombardment of gold with Ne^+, Ar^+,Kr^+ - ions and of 18 eV with Xe^+ - ions.

The particle reflection coefficient decreases towards small energies of the incident ions, if between the projectile and target particles chemical binding forces exist, which is the case for a bombardment of a gold surface with gold ions. The decrease towards low energies depends apart from the binding energy on the surface structure as well as on the mass of the projectile and target particles. TRIM.SP simulations [5] of the particle reflection coefficient as a function of the energy of the incident ions have shown that below 35 eV ions will be reflected no more and that at energies of the incident particles

between 35 eV and 1000 eV the mean energy of the reflected particles is between 0,27 eV and 34,5 eV.

3 ARRAY OF QUARTZ CRYSTAL MICROBALANCES

An array of quartz crystal microbalances is being developed to measure the two-dimensional mass distribution of low energy particles. The aim is to measure the distribution of the scattered particles during the bombardment of the collector surface with low energy gold ions and to fit the experimental results for a two-dimensional mass distribution to a theoretical model in order to determine the number of scattered particles into the area of the ion aperture. It is also intended to measure the two-dimensional mass distribution of the incident gold ions.

Figure 1 shows the ion collector for accumulating the gold ions and for determining the two-dimensional mass distribution of the sputtered and backscattered particles as well as that of the incident gold ions. Both have an energy of a few electron volts.

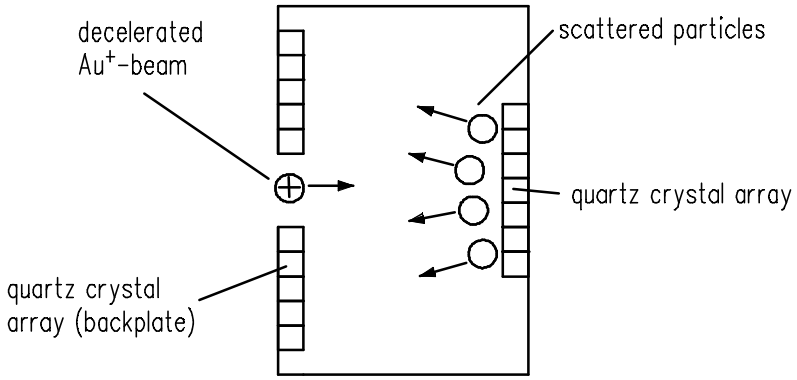

Figure 1. Detector to measure the two-dimensional mass distribution of the sputtered and backscattered particles and that of the incident gold ions

Until now, there have been limits in the realization of this concept since in particular the common quartz crystals and the crystal holders are too large for arranging them in an array. Therefore, an array of quartz crystals have been manufactured by etching the array structure in a quartz blank [6] and covering their electrodes with a gold layer afterwards. Using this technique, there is the oppportunity to manufacture quartz crystals in very different sizes from a few millimeter in diameter to a few centimeter and to arrange them as near as possible inside the array. In addition, this method offers the opportunity to use large quartz crystals for calibrating the crystal´s signal by weighing on a ultra-micro balance. If the quartz crystal is electrically isolated from the ground potential, the measurement of the ion´s current can be carried out too. Measuring both the accumulated mass and the current, it will be possible to determine the atomic mass of gold [2].

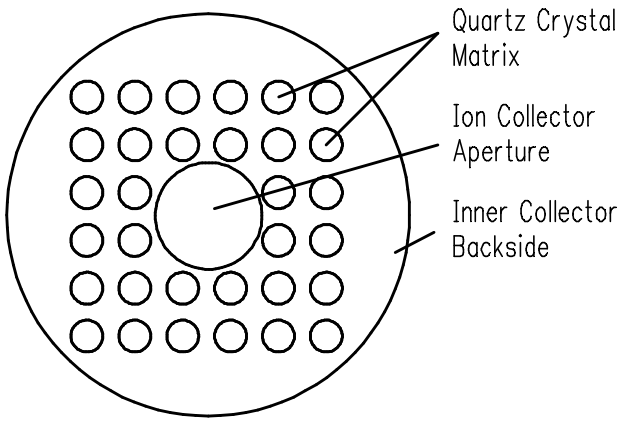

Figure 2. Ion collector backplate with a quartz crystal array

Figure 2 shows an example of the arrangement of the quartz crystals on the backplate of the ion

collector for the measurement of the two-dimensional mass distribution of sputtered and backscattered particles.

The number of the quartz crystals of the array could be varied in dependence of their diameter used. Finally, it is intended to decrease the quartz crystal diameter as small as possible to use a greater number of crystals. This improves the opportunity to fit the experimental results for a two-dimensional mass distribution to a theoretical model.

The use of quartz crystals for the determination of mass and thickness of an adsorbed layer was first investigated by Sauerbrey in 1957 [7]. Sauerbrey found out that a layer which is applied on an oscillating quartz crystal plate carrying out thickness shear modes changes the resonance frequency of the plate due to enlargement of the vibrating mass. Sauerbreys´ fundamental equation is given as follows:

$$-\Delta f = \frac{f_0 \cdot m_f}{d_q \cdot r_q} \qquad (1)$$

$$= \frac{f_0^{\,2}}{F_q \cdot r_q} \cdot m_f$$

$$= c_f \cdot m_f$$

with Δf - frequency shift due to mass change, f_0 - resonance frequency of the quartz only, m_f - areal density of a layer, d_q - quartz crystal thickness, c_f - specific mass sensitivity, F_q - frequency constant of a quartz crystal, r_q - quartz density.

The validity of the equation has been confirmed for a mass allocation of not more than 2% of the quartz crystal's mass for rigid materials like metals. With greater layer thicknesses or softer layer substances the acoustic characteristics of the applied layer must be considered additionally [8].

According to equation (1), the theoretical detection limit depends on the resonance frequency of the quartz crystal and the minimum resolvable frequency change of the detector. Therefore, in the context of these investigations it is intended to use quartz crystals with resonance frequencies up to 50 MHz which leads to an increase of the detection response. Because it is possible to determine the frequency shift of an oscillating quartz crystal with high precision, we have a very sensitive method for the determination of the mass of very small adsorbed layers. The accuracy of this measurement method is essentially limited by the temperature dependence of the quartz resonance frequency and by the layer distribution on the quartz crystal. Figure 4 shows the measurement set-up for experimental investigations.

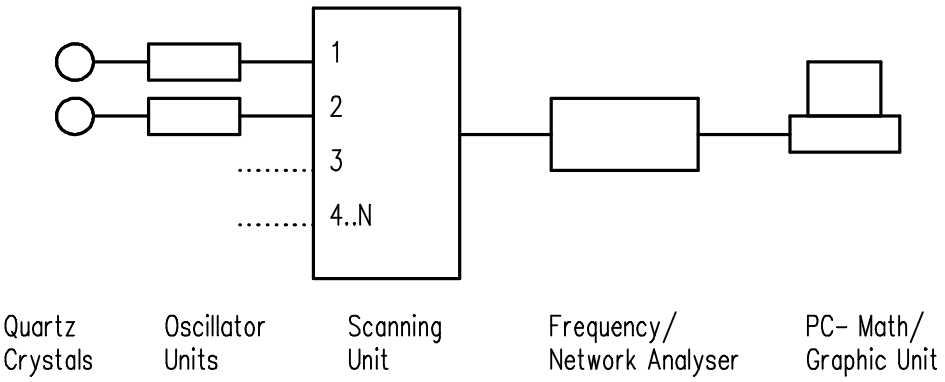

Figure 4. Scheme of the measurement equipment

Each quartz crystal will be driven with a separate oscillator circuit. Using a scanner unit, the RF

signals are supplied to a frequency/network analyzer serving for the measurement of the frequency shift of the signal. A following arithmetic and graphic unit takes over the evaluation of the experimental results and the diagram of the profile.

4. CONCLUSION

An array of quartz crystal microbalances for determining the two-dimensional mass distribution of low energy particles has been presented. It is aimed at investigating sputtering and reflection effects during the bombardment of a collector surface with gold ions. Because the number of scattered particles should be quantified as exactly as possible, investigations on the calibration ability of the quartz crystals are to be accomplished. The described method offers the opportunity to compare the change of the mass of the quartz measured by the resonant frequency shift with the change of mass measured with an ultra-micro balance directly.

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