SPUTTERING NEGATIVE ION SOURCE

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Ion sources based on the sputtering process proved to be versatile and capable of producing a large variety of negative ion beams for Tandem accelerators. Although the mechanism of the sputtering process is not yet fully understood, some present models for secondary ion emision give good agreement with experiments [1] carried out so far. The ion source of this type is mounted at the Tandem accelerator of the Ruđer Bošković Institute in Zagreb. The general layout of the source and its principle of operation are presented, as well as some further modifications for the application in the Accelerator Mass Spectrometry. The expected negative ion yields are listed [2].

1. Sputtering process

Sputtering process can be defined as the emission of ions and/or neutrals from material bombarded by beam of ions or neutrals. In the first step surface atoms are dislodged with several eV of energy from the surface. Then, in the second step, ionization of sputtered atoms can occur. Fraction of the ionized atoms range from 10^{-4} to one. Phenomenologically, the secondary ion yield of element A is given with

$$Y_A \propto \sum_{\gamma} P_A^{\gamma} C_A s_A^{\gamma} I_p$$

where P_A^{γ} . C_A . s_A^{γ}. and I_p are the ionization probability. concentration. the sputtering coefficient and flux of the primary ions. Sum goes over different bonding configurations γ [1].

Clearly when neutral atom strikes and bounces of a surface having a work function less then or comparable with the electron affinity of the atom. there is a high probability that the atom will emerge as a negative ion. In 1962 V.E. Krohn showed that when a large range of solid surfaces are sputtered by cesium ions a fairly high fraction of the emitted particles are negative ions of the surface. He further showed that the addition of neutral cesium to the surface increased the fraction of emitted negative ions by as much as an order of magnitude [3]. Undoubtedly. the efect of the neutral cesium is to depress the exit work function of the surface. Broadely speaking. an oxidation of metallic samples leads to higher positive ion yields whereas deposition of alkaline atoms on the surface induces a strong increase of the negative ion emission for all elements having high electron affinities. The experiments established that ionization probabilities for negative ion creation varies through an exponential relation :

$$P^{-} \sim \exp\left[- \frac{W - A}{v_{\perp}}\right]$$

where W. A. and $v_\perp$ are exit work function of the surface. electron affinity and normal velocity of the ejected particle [4]. This exponential dependence on the inverse of $v_\perp$ arises from transit time of the sputtered atom through the interaction region [1]. Since many of the negative ions observed by investigators have electron affinities less than 2 eV. and because it is hardly likely that layer of neutral cesium will reduce work function of the surface below about 2 eV. there must be some other mitigating factor for secondary ion emission. That might be electrical image potential between surface and sputtered atom. which lowers exit work function. increasing probability for electron tunneling from surface to atomic levels [1], [5].

Another effect which have to be mentioned is increase of the yield of the sputtered negative ions when oxygen is sprayed onto sputtered surface. A straightforward explanation could be that Cs_2O which has a lower exit work function as compared to Cs forms a layer on the sputtered surface [2], [3]. With this type of processes is possible to get significant negative ions yields even from electropositive elements. Also. negative ions of various gasses can be produced by sputtering of the gass sprayed in front of the solid surface (as example Ti) [2], [3], [6].

2. Sputtering negative ion source in Zagreb

The sectional diagram of the sputtering ion source in Zagreb.

is shown in fig. 1.a and 1.b. The primary beam of positive cesium ions is produced by surface ionization of cesium vapor on a hot. porous tungsten surface (3). The porous tungsten allows cesium vapor from a boiler (1) to pass through into the vacuum region of the source. Temperature of the cesium boiler varies about 300°C and is controled via termocouple (2). Increase of the temperature of the cesium boiler causes increase of pressure of the cesium vapor. so ionizer temperature would be sufficiently high (up to 1200°C) to ionize all incoming cesium. The ionizer temperature is can be measured with a pyrometer viewing the top of the ionizer by a removeable mirror on the beam axis. Ionizer and cesium boiler are on ground potential. Positive ion extractor (5) accelerates and focuses cesium ions toward a sputtering cone (8) made of material to be sputtered and ionized to produce secondary negative output beam. Sputter cone holder (10) is capable of carrying 12 different cones which can be rotated into the target position without breaking the vacuum. The inner shield tantalum tube (7) located in front of sputtered cone accumulates cesium on its inner surface to promote deposition of neutral cesium on sputtered surface [6]. Gas line (9) enables spraying of various gasses onto sputtered surface.

The positive ion extractor and the sputter cone holder are maintained at a high negative potential (-30 kV). In front of the positive ion extractor is deccel electrode (6) operated up to 2kV more negative than extractor to suppress the bombardment of the ionizer by sputtered negative ions and electrons [6]. The negative ions formed at the sputtering cone are extracted through a circular hole at the rear side of the cone by a negative ion extractor (11), maintained at ground potential. The sputter cone with the positive ion extractor is shown in fig 2.a. The deflection magnet (12), placed inside of the negative ion extractor, removes electrons from the negative ion beam, to improve focusing of the negative ion beam. The beam is focused by grid (13) and einzel (14) electrostatic lenses whose active elements are operated on high positive (up to +20 kV) and high negative (up to -30 kV) potentials.

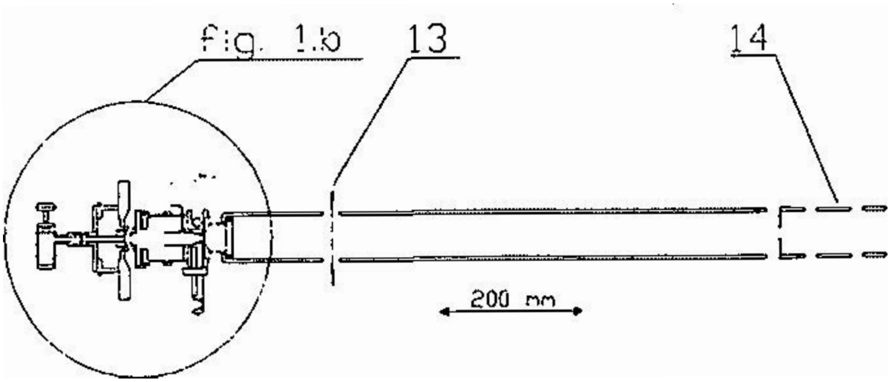

Fig. 1.a. The sectional diagram of the sputtering ion source in Zagreb

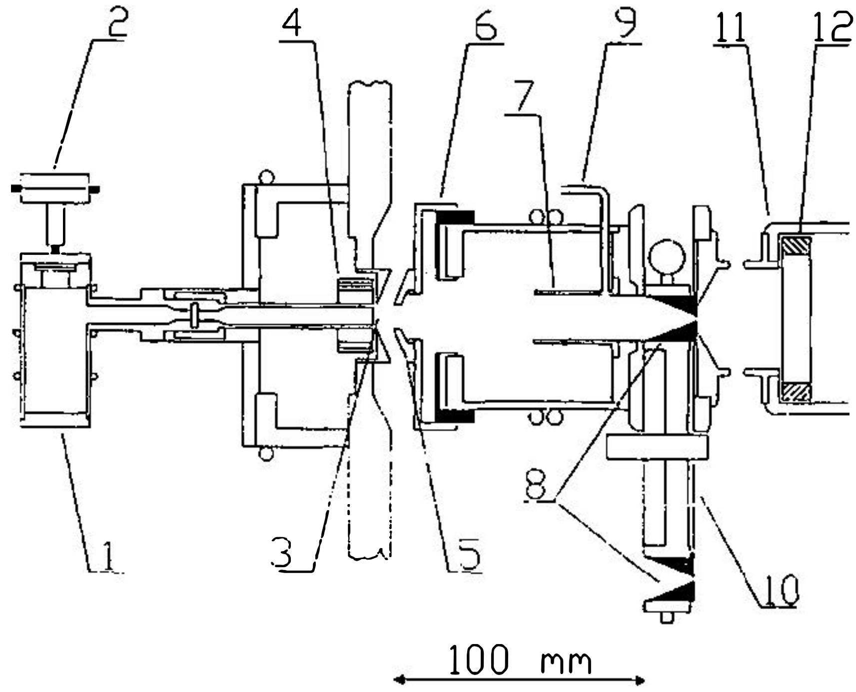

Fig. 1.b. The sputter cone and the negative ion extractor in the normal configuration

The greatest number of the negative ions produced in the sputtering process have only one excess electron. With maximum extraction potential of -30 kV. that gives maximum negative ion beam energy of 30 keV. The absolute yield of certain negative ion species can be influenced strongly by many factors. The most relevant are : the shape of the sputtered surface. cone preparing process and the residual gass pressure [2], [3]. The operating vacuum in the system would be below one times 10^{-9} Pa. A variety of the sputter cone shapes have been tried by Middleton [3] and the other investigators in order to obtain the most efficient shape. The highest intensity was found with the standard cone of 40° opening angle and 2 mm ∅ exit hole. The expected negative ion yields are listed in the Table 1.

Table 1.

The expected yields of the negative ions

Ion	Target (sprayed gas)	Yield (10^{-6} A)
H^-	Ti (H_2)	6.
Li^-	Li (O_2)	1.
BeO^-	$CuBe_3$ (O_2)	1.
BO^-	BN TiB_2 AlB_2 (O_2)	3.
C^-	graphite	23.
O^-	Ti (O_2)	27.
AlO^-	Al (O_2)	2.
Si^-	monocryst.	15.
S^-	FeS	20.
Ni^-	Ni	1.
Au^-	Au	4.

For applications in the Accelerator Mass Spectrometry certain modifications are necessary. For that purpose the sputtering source would work in so called "reflecting" configuration as is shown in fig. 2. The "reflecting" configuration allows use of the much smaller sample sizes without penalty in the beam intensity. The Cs^+ beam drifts through the openings in the sample holder. The beam is reflected back by a positive ~ +100 V bias on the front section of the negative ion extractor to strike the small pit containing the sample to be sputtered [7], [3]. The negative ions are then extracted as for the normal configuration.

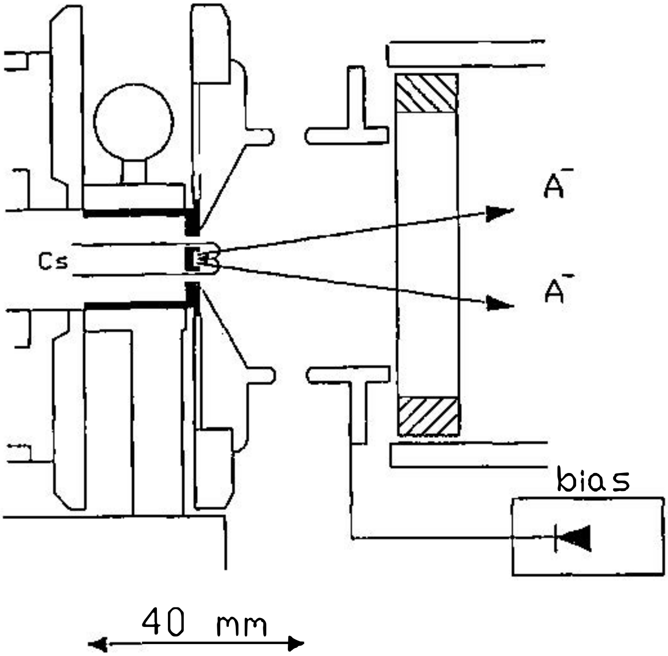

Fig. 2. The "reflecting" configuration

R E F E R E N C E S

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