

Research Paper

Fabrication of Potassium Ion Source and its Emission Characteristics

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Abstract In this study, we fabricated the K^+ ion source for the various purposes and investigated the emission characteristics. The fabricated K^+ ion source was painted in the tungsten filament to make filament type ion source. The RGA spectra show that the filament type K^+ ion source has a good out gassing character, so it can be used in the ultra-high vacuum system. The maximum K^+ ion current was 20 mA when filament temperature was 1410 K and filament potential was 50 V. When the filament temperature was 1070 K, the initial beam current was 50 mA and decreased only by 2% during 4 hours. The emitting energy was measured to be 2.04 eV. This low value means that the fabricated specimen is a good K^+ ion source. We conclude that this filament type ion source can be used in various fields, including the LEIS research.

Keywords: K^+ ion source, RGA, Filament type, LE IS

I. Introduction

There are many kinds of ion sources, such as an electron impact ionization ion source [1], an ion attachment ion source [2], a cold cathode ion sources [3], and a liquid metal ion source [4]. These ion sources are used for various purposes. The ion gun with the electron impact ionization source is widely used in the surface studies of the materials. LEIS is a good tool for the analysis of the composition and structure of solid [5-7]. Typically, He^+ ion with energy E between 500 eV and 10 keV and Electrostatic Analyzer (ESA) or Time of Flight (TOF) analyzer is used in the LEIS study. The TOF analyzer can detect both ions and neutral atoms; however, the ESA can detect only ions, but not neutral atoms. Due to the neutralization effect of the incident ion on the target materials, the efficiency of the detecting the scattered ions of the ESA is lower than that of the TOF analyzer. Therefore, when ESA is used in the LEIS study, low neutralization probability ions are more effective than high neutralization probability ions. It is known that the neutralization of the ions scattered from solid is due to the Auger-neutralization and resonance neutralization [8]. In Auger-neutralization, a single electron tunnels from a metal to an ion state of equal energy. Therefore, the Auger-neutralization heavily depends on the ionization energy of the incident atom and the work function of the target solid. The ionization energy He^0 is 24.6 eV, while the elements in Group I have much lower ionization energies. Therefore, the neutralization probabilities of the

elements in Group I are lower than those of the inert gases and we can infer that the neutralization probability of He^+ ion is much higher than alkali ions. Geobl and co-authors[8] reported that the neutralization probabilities of the He^+ ion scattered from Ag surface are ~70~80% depending on the Ag crystal surface and the energy of the incident H^+ ion, while the neutralization probabilities of the Li^+ ion is 20~50% [9] depending on the work function of the target materials. Although the experimental conditions are different, if we consider the ionization energies and the experimental results, we can infer that the neutralization probability of He^+ ion is much higher than alkali ion. The good ion sources should satisfy with (1) no outgassing in the ultra-high vacuum system, (2) high purity of emitted ion, (3) stable for a long time.

In this study, we fabricated the K^+ ion source which satisfies with the above good ion source conditions and is effective to the ESA-LEIS, and has a simple process to emit ions; furthermore, its emission characteristics were investigated. To get the K^+ ion, we heated the tungsten filament painted with the powder of the fabricated specimen and applied positive potential with respect to the plate or grounded vacuum chamber. The alkali ions are widely used for the study of the adsorption on metal surface [10], the charge exchange or the neutralization [11-14], the growth on metal surface [15], and ion implantation [16-17]. Potassium is an important element used for the various fields. K^+ ion also used for the various doping studies in the LEIS study [18] and the other doping studies [19-20]. The ion gun or the equipment installed our ion source does not need a differential pumping system and the control power supply shall be more simple than the power

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supply for the conventional inert gas ion gun. Our fabricated K^+ ion source will be useful for the various studies listed above.

II. Experiment

It is known that β -eucryptite ($Li_2 \cdot Al_2O_3 \cdot 2SiO_2$) [20] has highly one dimension Li^+ conductivity [22,23] and a negative coefficient of thermal expansion and its linear coefficients of the crystallographic directions α_a and α_c are $8.21 \times 10^{-6} / ^\circ C$ and $-17.6 \times 10^{-6} / ^\circ C$ respectively [24]. This net effect of the anisotropic expansion is sufficient to enlarge the central openings of the crystal lattice where the Li^+ ions are readily emitted from this type crystal lattice. The elements in group I have similar chemical properties. Therefore, if Li atoms in the β -eucryptite could be substituted by elements in Group I, those elements in the β -eucryptite-like materials also could be emitted.

Potassium is the element in Group I and Li atoms in the β -eucryptite could be substituted by potassium atoms.

For fabrication of the K^+ ion source, we carry on the following steps;

(1) K_2CO_3 , Al_2O_3 and SiO_2 powders are uniformly mixed with the molecular proportions of 1, 2, and 2.

(2) The mixed powder is made into briquettes, 1 cm in diameter and 0.5 cm thick, by compressing with the pressure of 1 ton/cm².

(3) Briquette is heated up to 1800°C using tungsten filament in the vacuum chamber. After several minutes of heating this briquette at this temperature, it cools down slowly. We used the vacuum chamber to prevent from the contamination of the specimen from oxygen, nitrogen, and other gases in the atmosphere. In this process, we can observe the melting of the briquette. This process reduces the carbonate to the oxide (see Eq. (1)).



To investigate the emission characteristics of the β -eucryptite-like material ($K_2O \cdot Al_2O_3 \cdot 2SiO_2$), we grounded the β -eucryptite-like material ($K_2O \cdot Al_2O_3 \cdot 2SiO_2$) and painted it on the tungsten filament.

The tungsten filament painted with specimen was inserted in the vacuum chamber with the base pressure is $\sim 10^{-10}$ torr. To measure the emission current, we placed a copper plate in front of the filament. The distance between the filament and the plate was 5 mm. A residual gas analyzer (RGA) was used to measure the emitted elements, as well as to distinguish ions from neutral atoms.

III. Results and Discussion

The dimensions of the spiral type filament were as follows: 0.5 cm in length and 1 mm in diameter. The resistance of the filament was 0.06 W at room temperature

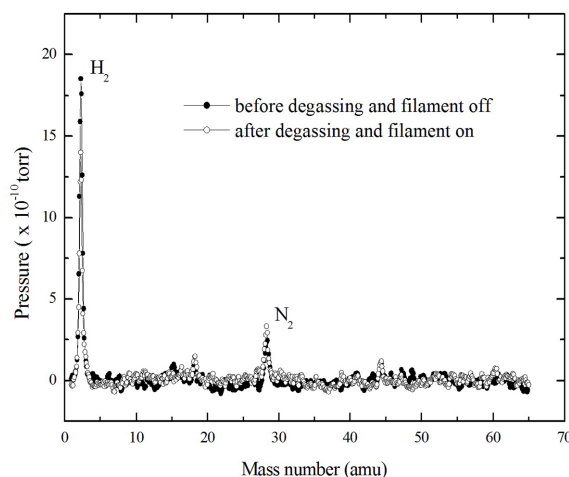


Figure 1. The RGA spectra (1) closed circles: before filament degassing and the filament current is 0 V and (2) open circles: after filament degassing and the filament current is 3A (filament temperature is 1360 K).

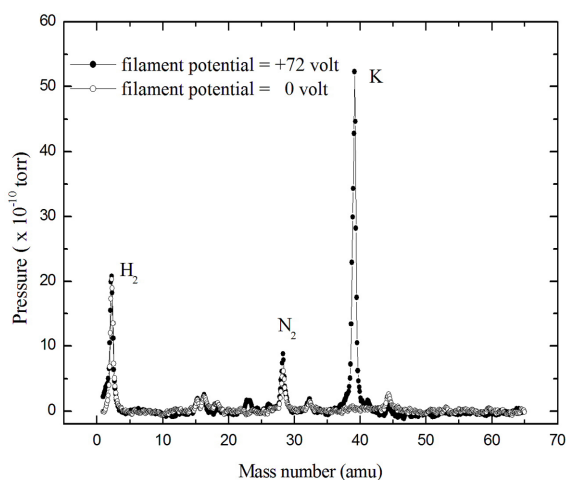


Figure 2. The RGA spectra when the filament temperature is 1310 K and (1) open circles: the filament potential is 0 V and (2) closed circles: the filament potential is 72 V. Note, when positive potential is applied to the filament, the strong K peak appeared.

and the temperature of the filament was estimated using R-T relation, $R=R_0(1+\alpha(T-T_0))$. The filament resistances during heating were estimated by measuring the filament current and the filament voltage.

Fig. 1 shows the RGA spectra when the filament painted with specimen was set up in the vacuum chamber. The degassing procedure was performed before the RGA experiment. During degassing process, CO_2 , H_2O , and O_2 peaks became stronger; however, after finishing degassing, these peaks became smaller or disappeared. The closed circles denote the spectrum when the filament was not degassed and filament current was off. The open circles denote the spectrum when the filament was degassed and filament temperature was 1360 K. As shown in Figure 1, the shapes of two spectra are almost same, i.e., the prepared ion source has no out gassing in the ultrahigh vacuum chamber even at a high filament temperature.

Fig. 2 shows the RGA spectra when the filament temperature was 1310 K. The closed circles denote the spectrum when the filament potential was 72 V with respect to the chamber ground and open circles denote the spectrum when the filament potential was 0 V. As shown Figure 2, H₂, N₂, and other small peaks appeared independently on the filament potentials. However, strong K peak appeared when positive potential applied to the filament. Note this peak did not appear when the filament potential is 0 V. Particularly, we could not find the other peaks that appeared after applying the potential. This phenomenon means that only K⁺ ion emitted by the positive potential of the filament and the emitted K⁺ ion spread into the vacuum and was detected by the RGA.

Although K⁺ ion is ready to emit, it still remains in the bulk of the β-eucryptite-like material as an ion state. The K⁺ ion needs some energy to emit from the level in the bulk to the vacuum level. Thermionic emission is a term used to describe the emission of electron (and/or ions) from a solid when it is heated in vacuum. The emission current is described by the Richardson equation [25] (see Eq. (2)):

$$I=A(1-r)T^2 \exp(-e\phi/kT) \quad (2)$$

where I is emission current, A is emission constant, $(1-r)$ is the transmission coefficient of the surface barrier, T is the temperature in Kelvin unit, and $e\phi$ is the work function. In the case of an ion, the work function $e\phi$ should be substituted by another physical quantity which the emitting energy E_e needs to emit an ion from a solid to vacuum. Then, the equation can be modified as follows (see Eq. (3)):

$$I=A(1-r)T^2 \exp(-E_e/kT) \quad (3)$$

If we rearrange this equation, we obtain Eq. (4):

$$\ln(I/T^2)=\ln B-(E_e/k)/T \quad (4)$$

where B is $A(1-r)$. If we plot $\ln(I/T^2)$ versus $1000/T$, we can calculate E_e from the slope of this plot.

Fig. 3 shows the plot $\ln(I/T^2)$ versus $1000/T$ when filament potential is 50 V. The slope of this graph is -23.72. The emitting energy E_e obtained using this slope is 2.04 eV. This small energy means that K⁺ ion can easily be emitted. Note that the work function of LaB₆ is 2.4~2.7 eV [26] and it is used for a good electron source. If we compare this K⁺ ion source with a LaB₆ electron source, we can conclude this β-eucryptite-like material is a good K⁺ ion source.

Fig. 4 shows the change of the K⁺ ion beam current versus emitting time for the various filament temperature values. In Figure 4, the filament potential is fixed at 50 V. When the filament temperature was 1410 K, the initial ion beam current amounted to 20 mA and the ion beam current decreased rapidly. It decreased by about 50% of the initial

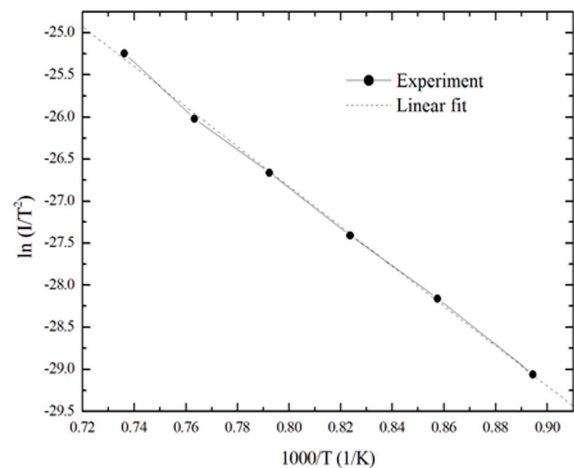


Figure 3 Plot of $\ln(I/T^2)$ versus $1000/T$ when the filament potential is 50 V. The plot shows the straight line.

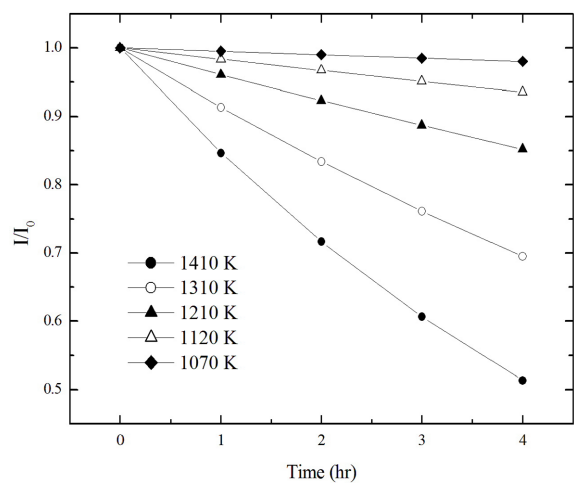


Figure 4 Decrements of the K⁺ ion beam currents versus time. Decrement rates increase dramatically with the increase of the filament temperature.

current during 4 hours. When the filament temperature was 1070 K, the initial emission current was 50 μA and decreased by only 2% during 4 hours. The intensity of the ion current was stable for longer than two hours with the instant fluctuation below 5%. Although the emission current was measured to be 20 mA, it could be increased by adjusting the filament potential, filament temperature, or filament size. If this beam is focused in the 1 mm diameter, the beam flux density is 20 mA/mm². It is a very strong beam flux density. Particularly, this beam current was obtained by the small size filament. Therefore, we can choose the filament temperature according to the object of the experiment. For example, if we want to make a high K doping material in a short time using the ion implantation method, we may choose a high filament temperature and, if we want to use this ion source for the ion scattering study, we may set the filament temperature to be low, because LEIS does not need a high ion beam current.

The decrements of current can be explained as follows. If we set number of K atoms in the specimen as N and the

number of emitted K^+ ion per unit time as dN/dt , that is K^+ ion current, then dN/dt is proportional to N . If we set the proportional constant (decay constant) as α , then, the number of K atoms in the specimen after the time t is as follows (see Eq. (5)):

$$N=N_0 \exp(-\alpha t) \quad (5)$$

where N_0 is the initial number of K atom in the specimen. As the number of the emitting K^+ ion (current) is proportional to N , emitting current I can be expressed by the decay equation (see Eq. (6)):

$$I=I_0 \exp(-\alpha t), I/I_0=\exp(-\alpha t) \quad (6)$$

I/I_0 versus time graphs shown in Fig. 4 follow this decay equation. The calculated decay constants using fitting the plots and Eq. (6) for the plots of 1070 K, 1120 K, 1210 K, 1310 K, and 1410 K were 1/200, 1/60, 1/25, 1/11, and 1/6, respectively. Here, the unit of the decay constant is hr. As shown by this result, the decay constants heavily depend on the specimen temperature. The calculated relation between decay constants and the specimen temperature is given by the following (see Eq. (7)):

$$\alpha_T=6.3 \times 10^{-6} \exp(1/138 T) / \text{hr.} \quad (7)$$

Using this decay constant- temperature relation, we can determine the life time of the K^+ ion source.

IV. Conclusions

To fabricate the K^+ ion source, we substituted the Li atoms in the β -eucryptite by the K atoms. The fabricated specimen (β -eucryptite-like K^+ ion source) has a good out gassing character so it can be used in the ultra-high vacuum system. When the ion source was heated and the positive potential was applied to the filament, only K^+ ion emitted and the other ions were not emitted. The maximum K^+ ion current was 20 mA when the filament temperature was 1410 K and the filament potential was 50 V. When the filament temperature was 1070 K, the initial beam current was 50 μ A and decreased by only 2% during 4 hours. If we set the filament temperature below 1070 K, the decrement of the beam current shall be less than 2% during 4 hours. The decay constants of the emission current heavily depend on the filament temperature. Using the decay constants, we can determine the life time of the K^+ ion

source. The K^+ ion emitting energy was measured to be 2.04 eV. This low value means that the fabricated specimen is a good K^+ ion source. Therefore, we conclude that this ion source can be used for in various fields, including the LEIS research.

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