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Direct Extraction of a Na^- Beam from a Sodium Plasma

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Abstract

Negative sodium ions (Na^-) were extracted from a small multi-cusp ion source. A steady state sodium plasma was produced by primary electrons in a sodium gas evaporating from a metal sample placed in the discharge chamber. The Na^- current density of 1.5 $\mu A/cm^2$ was obtained from a single aperture of 1.5 mm diameter at relatively low discharge power of about 0.4 W and filament power of 50 W. Extraction characteristics were studied by changing the plasma electrode bias. The extracted Na^- current showed dependence on the bias voltage similar to that of H^- or Li^- volume production.

Keywords
negative ion, sodium, volume production, hydrogen, lithium, ion source

1. Introduction

Volume production of H^- and that of Li^- are currently attracting considerable interest, not only from a viewpoint of applying them to high energy neutral beam heating and diagnostic systems for the fusion plasma[1,2,3], but also from a viewpoint of studying the production mechanism of negative ions in a plasma volume[4,5]. The H^- and Li^- ions are considered to be produced in the plasma volume by dissociative attachment (DA) of low energy electrons to diatomic molecules. In the case of H^- production, the DA process is strongly enhanced when hydrogen molecules are highly excited to vibrational and/or rotational states, dominantly through collisional excitation with fast electrons. However, the main destruction process of the H^- and Li^- ions in the plasma volume is detachment in collision with high energy electrons. Suppression of high energy electrons in the extraction region by applying a filter magnetic field or by shaping the main plasma into a sheet is effective to increase the output current. It is also known that the negative ion current takes the maximum when the plasma electrode facing the extraction region plasma is biased to a few volts positive against the anode potential[1,3].

In a volume of a plasma, Na^- ions are presumed to be formed under more severe condition than H^- or Li^- : the electron affinity of Na is only 0.54 eV, smaller than that of hydrogen (0.76 eV) or lithium (0.62 eV). In the present paper an evidence of direct extraction of Na^- ions from a sodium plasma is shown, and the dependence of extracted current on discharge voltage and the plasma electrode bias voltage are described. The effect of the magnetic filter is examined. The results are compared with the extraction characteristics of H^- and Li^- volume production sources.

2. Experimental arrangement

Figure 1 shows a schematic diagram of the ion source and the geometry of the extraction and measurement of the negative ion current. The ion source consists of a cylindrical stainless-steel chamber (6 cm diameter by 7.5 cm long) surrounded externally by 8 columns of samarium-cobalt magnets. Inside the chamber is a stainless-steel heat shield of 4.8 cm inner diameter. A plasma is produced by primary electrons emitted from a tungsten filament of 0.35 mm diameter and 80 mm long. The wall of the heat shield serves as an anode. A piece of sodium metal , placed in the heat shield evaporates dominantly due to the radiation from the filament which is heated with a typical power of 50 W. The heat shield temperature is monitored by a thermo-couple at a position away from the filament. Only at the beginning of the operation argon gas is introduced to initiate a discharge. When the heat shield temperature reaches above 230^0 C, the gas introduction is terminated and the steady state sodium plasma is sustained with sodium vapor. A pair of external permanent magnets is fixed in the region adjacent to the plasma electrode. The maximum strength of the magnetic filter field is 207 Gauss and this peak field is located 0.9 cm apart from the plasma electrode hole.

The beam is extracted from the open end of the chamber by a two-electrode extraction system (a plasma electrode and an extraction electrode). The extractor aperture of each electrode is 1.5 mm in diameter. The extracted beam is detected with a Faraday cup after 60^0 bending with an electromagnet. In order to keep enough resolution in momentum spectrum, two defining slits, S1 and S2, of 1.1 mm width each are inserted at the entrance of the bending section and that of the Faraday cup.

3. Experimental results and discussions

(3.1) Characteristics of Na^- extraction

The extraction of a Na^- beam is examined on the momentum spectra. In this experiment, lumps of sodium and lithium metal are placed in the heat shield together. When the heat shield temperature reaches above 215^0 C, a signal of Na^- beam can be seen as shown in Fig. 2(a). It disappears when the sodium is all consumed. Meanwhile, a peak of Li^- beam starts to appear as shown in (b), when the temperature is above 300^0 C . The momentum of the peak in Fig.2(a) is defined to be that of Na^- by comparison with those of $^6Li^-$ and $^7Li^-$, and the mass of the ion species is confirmed by changing the acceleration potential from 200 V to 500 V. In Fig. 2(a), a small peak of mass number = 46 is seen, indicating a possible existence of Na_2^- in the extracted beam.

In Fig. 3 is plotted the Na^- beam current as a function of the heat shield temperature. If the thermal equilibrium is assumed in the heat shield, the vapor pressure dependence of the extracted Na^- current is roughly obtained to be I^- $P^{1.2}$, and it can be scaled almost independently from the discharge voltage and the amount of introduced argon gas.

The dependence of the Na^- beam current on the discharge voltage is shown in Fig. 4. Here, the discharge current and the heat shield temperature are kept almost constant, to be 5 mA and 550 K, respectively, and the plasma electrode bias is fixed at 0.5 V. The output current increases as the discharge voltage (Vd). There is a tendency that it saturates at higher Vd.

The total beam current has been measured when the two slits S1, S2 are removed, and the most of the beam is detected with the Faraday cup of 3.5 cm inner diameter. The Na^- current density of 1.5 $\mu A/cm^2$ was obtained at relatively low discharge power of about 0.4 W and filament power of 50 W.

(3.2) The effect of the magnetic filter

In order to investigate the similarity with H^- and Li^- volume production, the dependence of the plasma electrode bias voltage (Vb) and the effect of the magnetic filter are examined. In Fig. 5 are shown the Vb dependence of the Na^- beam current (I^-) measured without the filter magnets(a) and with them(b). The drain current to the plasma electrode, Ib, is also shown in the figures . The I^- dependence on Vb is similar to those of H^- and Li^- extraction experiments[1,3]. Except that the current to the plasma electrode in the electron saturation region is suppressed by the filter field in (b) and the plasma potential to the anode is slightly different, overall features are same in both cases. From the Ib-Vb trace, estimation of the electron temperature and the density of the plasma in the extraction region can be made[6]. The electron temperatures are about 0.15 eV for both cases and the ion saturation currents are almost same. These similarity may explain the fact that the extracted currents are same at the maximum or when Vb is negative. On the other hand I^- in the electron saturation region without the filter field is less than a half of that with filter, indicating possibility of destruction of Na^- by electrons near the extraction region.

The comparison of the dependence of I^- normalized to the discharge power upon the discharge voltage can be seen in Fig. 6. They are almost same and the magnetic filter effect cannot be seen at Vd less than 15 V. While the normalized I^- measured with filter gradually decreases as the Vd increases, it is constant at higher Vd value when the filter magnets are removed.

4. Conclusions

Negative sodium ions (Na^-)were directly extracted from a self-sustained sodium plasma confined in a small multi-cusp ion source. The extracted Na^- current shows dependence on the plasma electrode bias voltage similar to that of H^- or Li^- volume production. When the plasma electrode voltage is in ion saturation or in the transition region, the effect of the magnetic filter on the extracted current is not observed, because the plasma in the extraction region is not affected by it within the present operation conditions. The Na^- beam current is almost proportional to the discharge voltage without the magnetic filter. The Na^- current density of 1.5 $\mu A/cm^2$ was obtained from a single aperture of 1.5 mm diameter at relatively low discharge power of about 0.4 W and filament power of 50 W.

References

[1] K. N. Leung, K. W. Ehlers, and M. Bacal, Rev. Sci. Instrum. 54, 56(1983)

[2] S. R.Walther, K. N. Leung, and W. B. Kunkel, Appl. Phys. Lett. 51,566(1987)

[3] M. Wada, H. Tsuda and M. Sasao, Rev. Sci. Instrum.61, 433(1990)

[4] M. Bacal, Phys. Scripta 2/2 (1982) 467

[5] M. W.Mcgeoch and R.E.Schlier, Phys. Rev. A33, 1708 (1986)

[6] M. Wada, H. Tsuda and M. Sasao, to be submitted.

Figure captions

Fig. 1. Schematic diagram of the experimental apparatus.

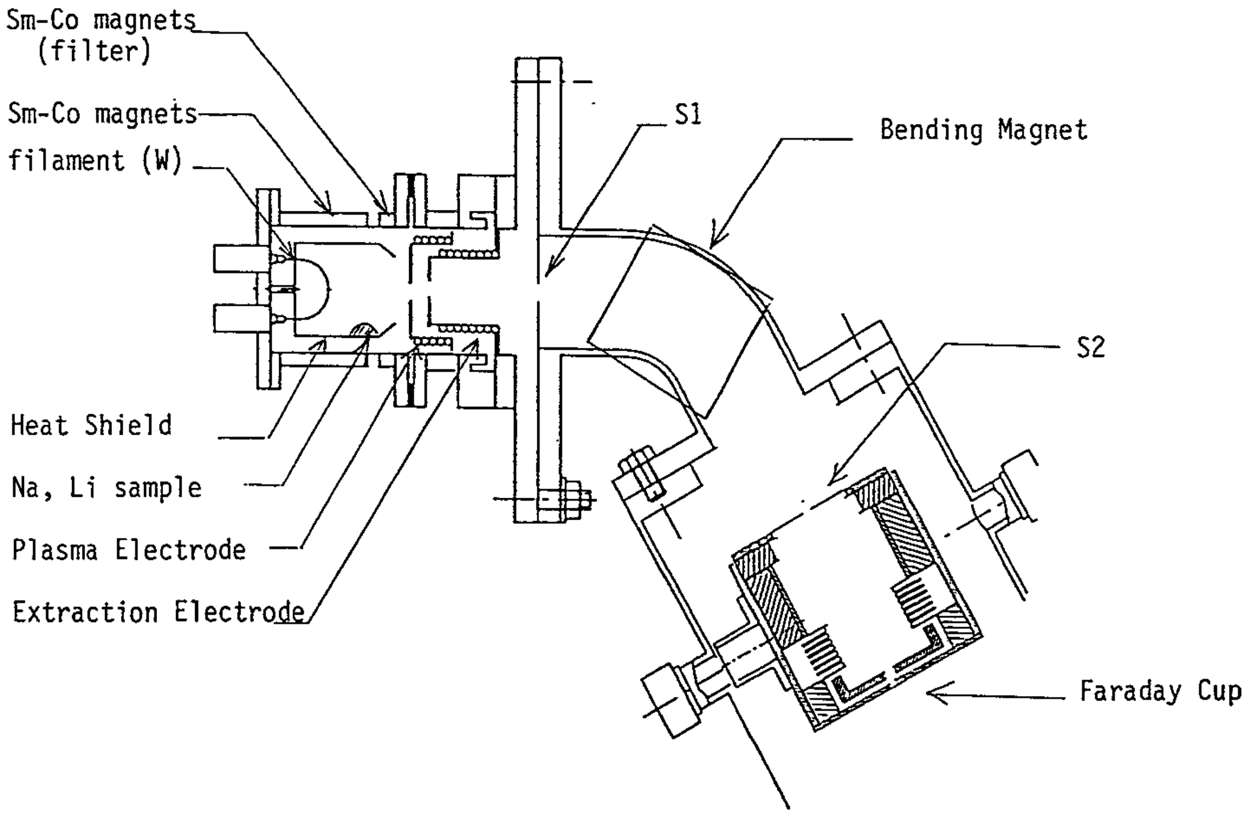
Fig. 2. Momentum spectra of Na^- (a) and of $^6Li^-$ and $^7Li^-$ (b). In Fig.(a), a small peak of mass number = 46 is seen, indicating a possible existence of Na_2^-.

Fig. 3 The dependence of the Na^- beam current upon the heat shield temperature.

Fig. 4 The dependence of the Na^- beam current on the discharge voltage measured with the magnetic filter.

Fig. 5 The dependence on the plasma electrode bias voltage (Vb) of the Na^- current and the drain current of to the plasma electrode, without the magnetic filter (a) and with it (b).

Fig. 6 The normalized Na^- current (I^-) by the discharge voltage (Vd) as a function of Vd. Open circles indicate those with the magnetic filter and closed without it.



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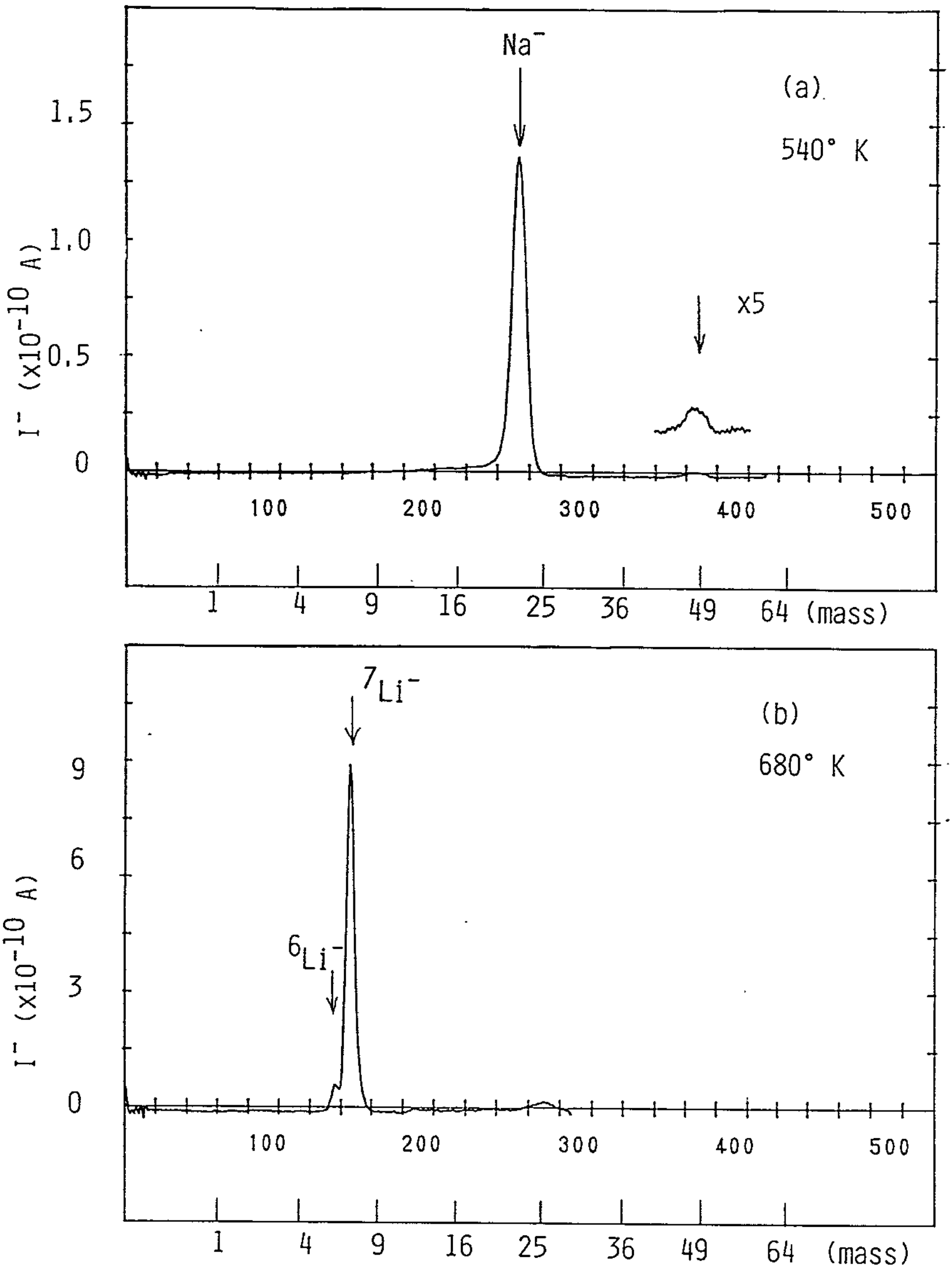

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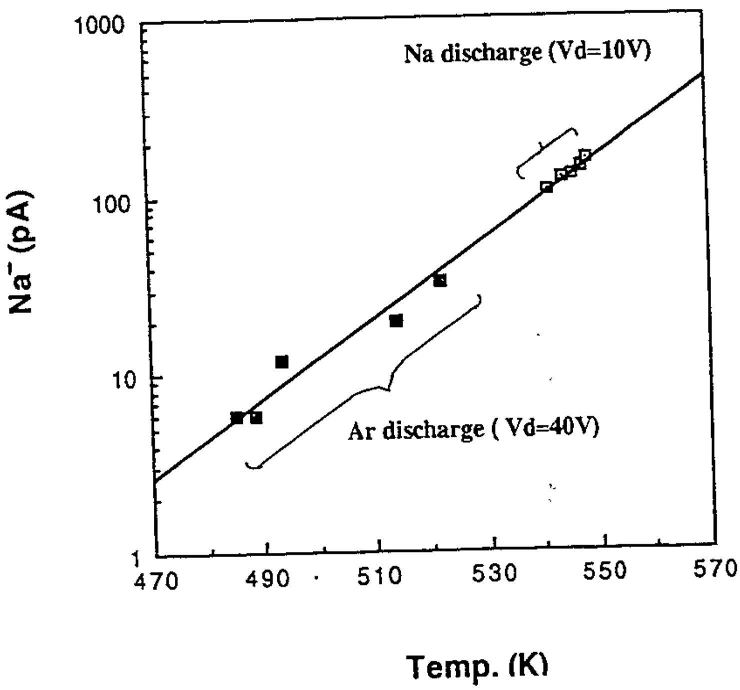


Fig. 3 The heat shield temperature dependence of the Na^- beam current .

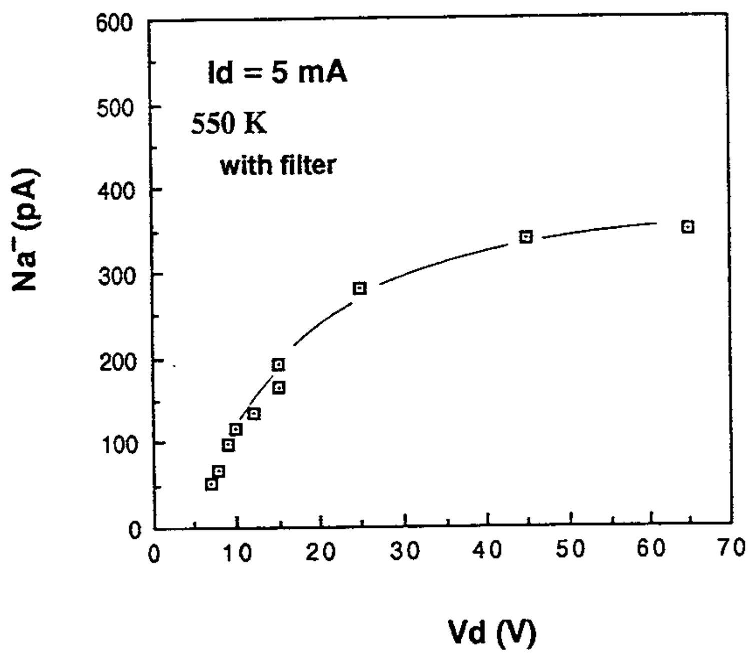


Fig. 4 The dependence of the Na^- beam current on the discharge voltage measured with the magnetic filter.

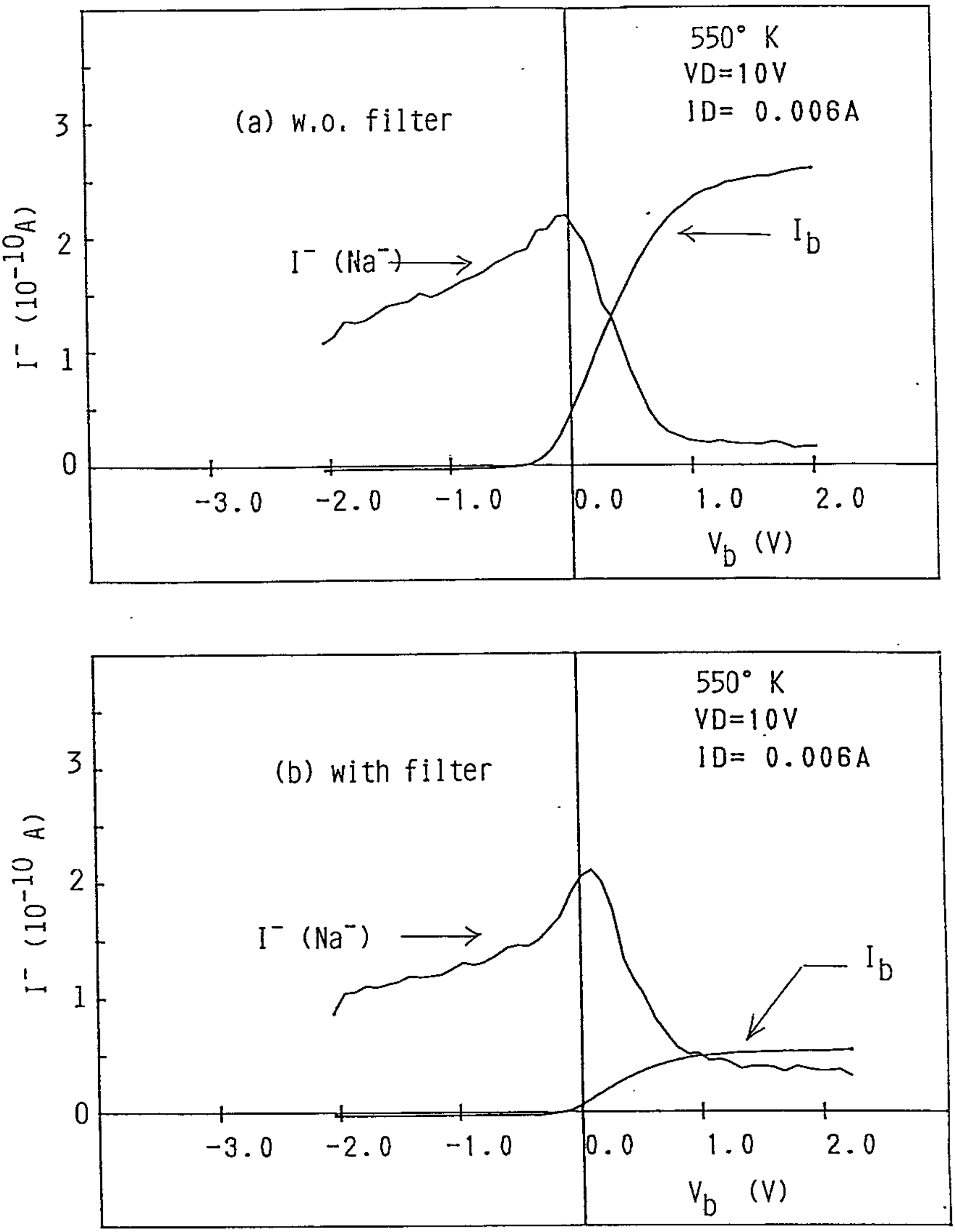
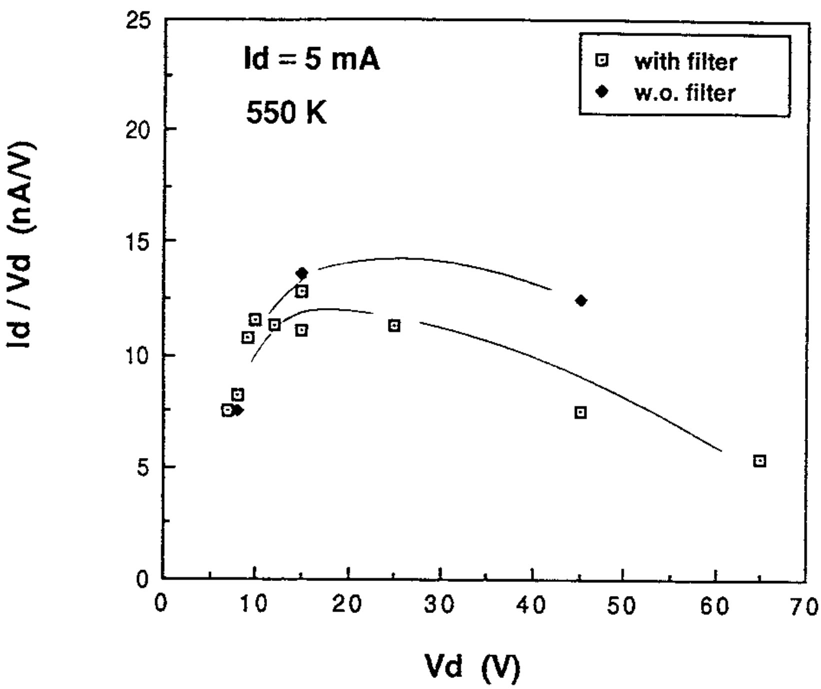


Fig. 5 The dependence on the plasma electrode bias voltage (Vb) of the Na^- current and the drain current of to the plasma electrode, without the magnetic filter (a) and with it (b).



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