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Publication Date
1990-05-01

LBL-29226
Preprint

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Accelerator & Fusion Research Division

Submitted to Physical Review Letters

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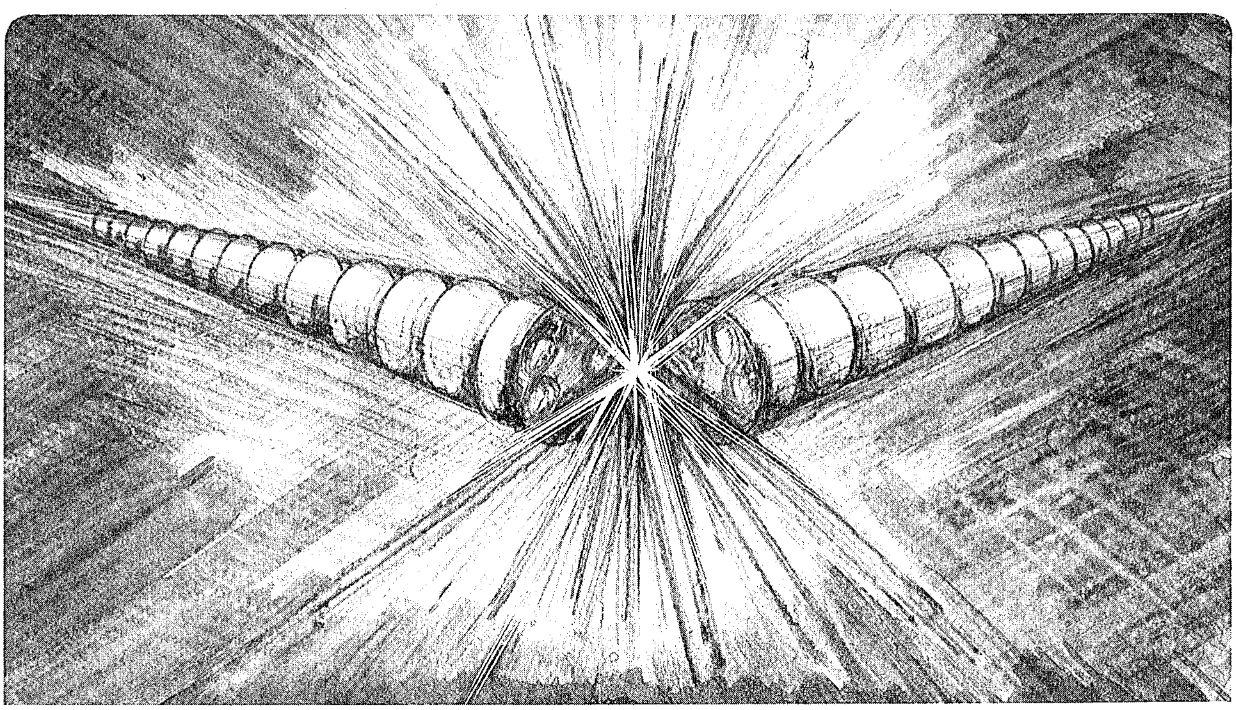
May 1990



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

H^- Enhancement Process in a Multicusp Ion Source Operated with a Barium Insert Structure

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Abstract

It has been demonstrated that the H^- output current from a small multicusp source can be substantially enhanced if the hydrogen plasma is seeded with barium. Operating with a barium washer insert at the extraction aperture, it is found that the extractable H^- current is increased by a factor of three if the insert bias potential is optimized. By use of a mixture of xenon and hydrogen gas, it is further demonstrated that the positive hydrogen ions are responsible for the observed H^- enhancement.

Future neutral beam systems as well as many high energy accelerators will require an ion source that can deliver high current and high brightness H^- or D^- beams. Recent experimental investigations show that the addition of cesium or barium to a hydrogen discharge can enhance the H^- output current by a large factor together with a substantial reduction in the electron-to-H^- ratio in the extracted beam.[1-4] As a result, H^- beams with current densities exceeding 1 A/cm^2 can now be easily generated from a multicusp source when the plasma is seeded with cesium.[2]

Both cesium and barium are low work function metals. They can reduce the surface work-function when condensed on a substrate. However, barium is much preferred over cesium in ion source operation for the following reasons. First, barium has a vapor pressure which is more than five orders lower than cesium. Therefore, much less of its vapor effuses from the source, and voltage breakdown problems in the accelerator structure can be minimized. Second, barium has a higher melting point than cesium (725^{o}C as compared to 28^{o}C). Accordingly, it can be machined or cast to form the proper shape and geometry for ion source applications.

In a previous study, seeding of the multicusp source with barium was accomplished by placing some solid samples of barium on the liner of the source chamber.[2,4] The barium evaporated during discharge operation and deposited on all surfaces of the chamber. As a consequence of this deposition process, a large factor in the improvement of the H^- output was achieved. Further experimental studies indicate that the overall enhancement is due to the additional H^- ions formed on the anode walls.[4]

For a pure-hydrogen discharge, the H^- ions extracted from a multicusp source are produced in the plasma volume via electron-molecule or electron-ion collisional processes.[4,5] However, when barium is mixed with hydrogen in the source discharge, the majority of the H^- ions are generated on the anode surfaces[4] which include the entire chamber wall as well as the first or plasma electrode of the accelerator. In this letter, we report the first experimental investigation which identifies the most effective region for surface H^- production when the source is operated with barium. In addition, it is shown that the positive hydrogen ions, not the neutral atoms or molecules, are mainly responsible for the formation of H^- ions on the anode surfaces.

The experiment was performed in a small multicusp source which is shown schematically in Fig. 1. The source chamber is a thin-walled copper cylinder (7.5 cm diam by 8 cm long) surrounded by fourteen columns of samarium-cobalt magnets which form a longitudinal linecusp configuration for primary electron and plasma confinement.[6] The magnets are enclosed by an outer anodized aluminum cylinder, with the cooling water circulating around the source between the magnets and the inner housing wall. The back flange has four rows of samarium-cobalt magnets which are also cooled by drilled water passages.

A steady-state hydrogen plasma was produced by primary electrons emitted from a hairpin tungsten filament. The entire chamber wall served as the anode for the discharge. In order to enhance the H^- yield, a pair of water-cooled permanent magnet filter rods was installed about 5 cm apart. The filter rods provided a narrow region of transverse magnetic field (B_{max} $\approx$ 125 G) which divided the entire source chamber into an arc discharge and an extraction region. The filter field was strong enough to prevent primary electrons from entering the extraction chamber. Excitation and ionization of the gas molecules were performed by the primaries in the discharge region. Both positive and negative ions, together with cold electrons were present in the extraction region, and they formed a plasma with very low electron temperature ($T_e \leq 1$ eV), which is favorable for H^- formation and survival.[7]

The open end of the source chamber was enclosed by a two-electrode extraction system. Positive or negative hydrogen ion beams were extracted from the source through a 2-mm-diam aperture. A compact magnetic-deflection mass spectrometer,[8] located just outside the extractor, was used for relative measurement of the extracted H^- ions as well as for the analysis of positive ion species. Plasma parameters were obtained with a small Langmuir probe located near the center of the source chamber.

The source was initially operated with a 0.8 mm thick copper washer attached to the plasma electrode at the exit aperture as illustrated in Fig. 1. The outer and inner diameter of the washer were 18 mm and 3 mm respectively. A hydrogen plasma with a density of 4.8×10^{11} cm^{-3} and electron temperature of 1.4 eV was maintained by a discharge voltage of 80 V and a discharge current of 1.1 A at a background pressure of 10^{-2} Torr. The plasma potential V_p measured at the center of the source chamber was about 3.5 V positive with respect to the anode or chamber walls. The distribution of $H^+ : H_2^+ : H_3^+$ in the positive ion beam was found to be 15 : 3 : 82. Thus, the majority of the positive hydrogen ions in the extraction region were H_3^+ ions.

The copper washer together with the plasma electrode were electrically isolated from the source chamber. Therefore, they could be biased at a potential V_b either positive or negative with respect to the anode (chamber walls). A plot of the H^- signal amplitude versus V_b is presented in Fig. 2. For the range of V_b considered, the H^- signal peaked at $V_b \approx 0$. The signal decreased when a positive potential was applied on the copper washer. A positive bias would impede the flow of positive ions and cold electrons to the extraction and filter regions.[9] As a result, production of H^- ions via dissociative attachment process was reduced. On the other hand, the flow of H^- ions to the exit aperture was also reduced when the washer was biased negatively with respect to the anode.

With the copper washer replaced by a barium washer, the above measurements were repeated under the same discharge conditions and at the same source pressure. For $V_b > 1$ V, the H^- output was very similar to the case with the copper washer (Fig. 2). However, as the bias voltage V_b became negative, the H^- output current increased rapidly. It reached a maximum at $V_b \approx -5$ V and then decreased again for higher negative bias voltage. At the optimum bias voltage, Fig. 2 shows a factor of about 2.5 increase in H^- current when the source was operated with a barium washer. On the other hand, Langmuir probe characteristics did not show any change in plasma density, electron temperature and plasma potential in the discharge chamber. In fact, the extracted positive ion beam contained approximately the same proportion of positive hydrogen ion species as in the case when the copper washer was used.

The above result clearly demonstrates that the observed enhancement Is due to additional H^- production on the barium surface. Immediately after the barium washer was cleaned up by high energy (~200 eV) ion sputtering, the H^- signal could be three times higher than that of the copper washer. Since the same factor of enhancement was found when vapor deposition was employed to coat the entire chamber surface with barium,[4] one can conclude that the present location of the washer is indeed the most effective area for surface enhancement of H^- ions.

H^- ions can be generated on the barium surface by reflection of the positive-hydrogen-ions species,[10-12] or they can be formed by reflection of neutral hydrogen atoms.[13,14] H^- ions can also be generated if incoming projectiles have enough energy to desorb the hydrogen atoms that are adsorbed on the barium surface.[15,16] In oder to identify which is the dominant H^- production process, the source must be operated with either positive hydrogen ions or neutral atoms in the extraction chamber. The former condition is difficult to achieve, but the latter can be accomplished by using the gas-mixing technique,[5] that is, by introducing a gas which has a threshold ionization energy lower than that of H_2 (E_i = 15.4 eV). If a plasma can be generated with primary-electron energy lower than 15.4 eV, then only H^o and $H_2{}^o$ but no H^+, $H_2{}^+$ or $H_3{}^+$ ions will be present in the source. However, low energy electrons together with the ions of the supporting gas will form the plasma in the extraction region.

Xenon was chosen as the supporting gas becasue it has a relatively high ionization cross section even at an electron energy as low as 13 eV, and it does not react chemically with barium. The source chamber was filled with hydrogen and xenon to partial pressures of 10^{-2} Torr and 4×10^{-4} Torr respectively. When the source was operated with a barium washer and with a discharge voltage of 9.5 V and discharge current of 1.2 A, no positive hydrogen ion species were detected. However, the mass spectrometer showed the presence of H^- ions. The dependence of the H^- output as a function of V_b is presented in Fig. 3. It can be seen that the result is similar to that of the experiment with the copper washer. The extracted H^- ions in this case can only be generated from neutral H_2 in the plasma volume via the dissociative attachment process.[5]

When the same experiment was performed with the source operated at a similar discharge power (11 W) but with a discharge voltage of 40 V, the H^- output increased when $V_b \leq +1$ V. The H^- current again reached a maximum at $V_b \approx -5$ V. This result, therefore, resembles the barium washer data presented in Fig. 2. Thus, the enhancement of H^- with negative bias on the plasma electrode under this discharge condition (40 V, 0.27 A) must originated from the positive hydrogen ions, presumably the H_3^+ ions.

For a bias voltage that is negative with respect to the plasma potential, the barium washer is bombarded by the H_3^+ ions with an energy equal to $e(V_p + |V_b|)$, where e is the electronic charge. Energetic H_3^+ ions (E > 50 eV) incident on a metal surface will dissociate into three H atoms each with ~1/3 of the incident energy. Van Os, van Pinxteren and Los showed that these H atoms, upon reflection from a barium surface, can be converted into H^- ions with a reasonable probability.[17] At lower incident energies, Hiskes and Karo showed that the incident H_3^+ ion can form an H atom and a vibrationally excited $H_2(v'')$ molecule upon interaction with a surface.[18] After reflection, the low work-function barium surface provides two additional sources of H^- production: Direct H^- production by fragment H atoms rebounding from the surface, and dissociation of H_2^- formed in the surface selvage into H + H^- fragments. For an incident energy of 6 eV, Hiskes and Karo[18] found that the contribution from the low-work-function barium ($\phi_W \approx 2.7$ eV) is 0.26 H^- per H_3^+. Since the work function of copper ($\phi_W \approx 4.5$ eV) is high, no significant surface production of H^- ions is expected when a copper washer is employed which therefore explains the difference in H^- yield shown in Fig. 2.

In this experiment, the H^- enhancement is optimized at $V_b \approx -5$ V. With $V_p \approx 3.5$ V, the incident H_3^+ ions arrive with energy $\approx$ 8.5 eV. As pointed out by Seidl et al.,[17] the H^- ions formed at the surface must posses enough translational energy to overcome the image force. If ϕ_W is the work-function of the surface and E_a is the electron affinity energy of the H^- ion, then the minimum translational energy is ($e\,\phi_W - E_a$) which is 1.95 eV for barium. This sets a minimum incident energy for the H_3^+ ion of ~ 6 eV.

One would expect that this surface production process is more pronounced for higher negative bias voltages on the barium washer. If the plasma potential is more positive than the barium surface, the surface-produced H^- ions will be accelerated across the plasma sheath, through the filter into the discharge region. Only low energy H^- ions ($E < 3$ eV), will be reflected by the magnetic field of the filter and are subsequently extracted through the exit aperture. As a result, the H^- enhancement decreases for more negative bias voltages.

In conclusion, we have demonstrated that in a multicusp source[2], a substantial H^- enhancement can be achieved with a barium washer insert operated with the proper bias potential. This enhancement is due to surface conversion of low-energy positive hydrogen ions rebounding from the barium washer. This simple configuration can be used to improve the brightness of multicusp volume H^- sources.

We would like to thank D. S. McDonald, D. Moussa, S. Wilde and M. D. Williams for techanical assistance. This work is supported by AFOSR, Grumman Space System, USASDC, and the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

1. S. R. Walther, K. N. Leung, and W. B. Kunkel, J. Appl. Phys. 64, 3424 (1988).
2. K. N. Leung, C. A. Hauck, W. B. Kunkel, and S. R. Walther, Rev. Sci. Instrum., 60, 531 (1989).
3. S. R. Walther, K. N. Leung, and W. B. Kunkel, Appl. Phys. Lett., 54, 210(1989)
4. K. N. Leung, S. R. Walther, and W. B. Kunkel, Phys. Rev. Lett., 62, 764 (1989).
5. K. N. Leung and W. B. Kunkel, Phys. Rev. Lett., 59, 787 (1987).
6. K. N. Leung, T. K. Samec, and A. Lamm, Phys. Lett. 51A, 490 (1975).
7. J. R. Hiskes and A. M. Karo, J. Appl. Phys. 56, 1927 (1984).
8. K. W. Ehlers, K. N. Leung, and M. D. Williams, Rev. Sci. Instrum. 50, 1031 (1979).
9. K. N. Leung, K. W. Ehlers, and M. Bacal, Rev. Sci. Instrum. 54, 56 (1983).
10. J. R. Hiskes, A. M. Karo, and M. Gardner, J. Appl. Phys. 47, 3888 (1976).
11. P. J. Schneider, K. H. Berkner, W. G. Graham, R. V. Pyle and J. W. Stearns, Phys. Rev. B 23, 941 (1981).
12. J. N. M. van Wunnick, J. J. C. Geerlings, E. H. A. Granneman, and J. Los, Surf. Sci. 131, 17 (1983).
13. W. G. Graham, Phys. Lett. 73A, 186 (1979).
14. S. T. Melnychuk, M. Seidl, W. Carr, J. Isenberg, and J. Lopes, J. Vac. Sci. Technol. A 7, 2127 (1989).
15. M. L. Yu, Phys. Rev. Lett. 40, 574 (1978).
16. M. Seidl and A. N. Paragellis, Phys. Rev. B 26, 1 (1982).
17. C. F. A. van Os, H. M. van Pinxteren, and J. Los, in Proceedings of the Third European Workshop on the Production and Application of Light Negative Ions, Amersfoort, The Netherlands, Feb, 1988 (published by FOM-Institute for Atomic and Molecular Physics, Amsterdam, the Netherlands) p.166.
18. J. R. Hiskes and A. M. Karo, J. Appl. Phys. 67, 6621 (1990).

Figure Captions

Fig. 1 A schematic diagram of the multicusp H^- ion source.

Fig. 2 H^- signal amplitude as a function of bias voltage when the source is operated with a barium or a copper washer insert and with the same discharge conditions.

Fig. 3 H^- signal amplitude as a function of bias voltage when the source is operated with a barium washer insert and with two different discharge parameters.

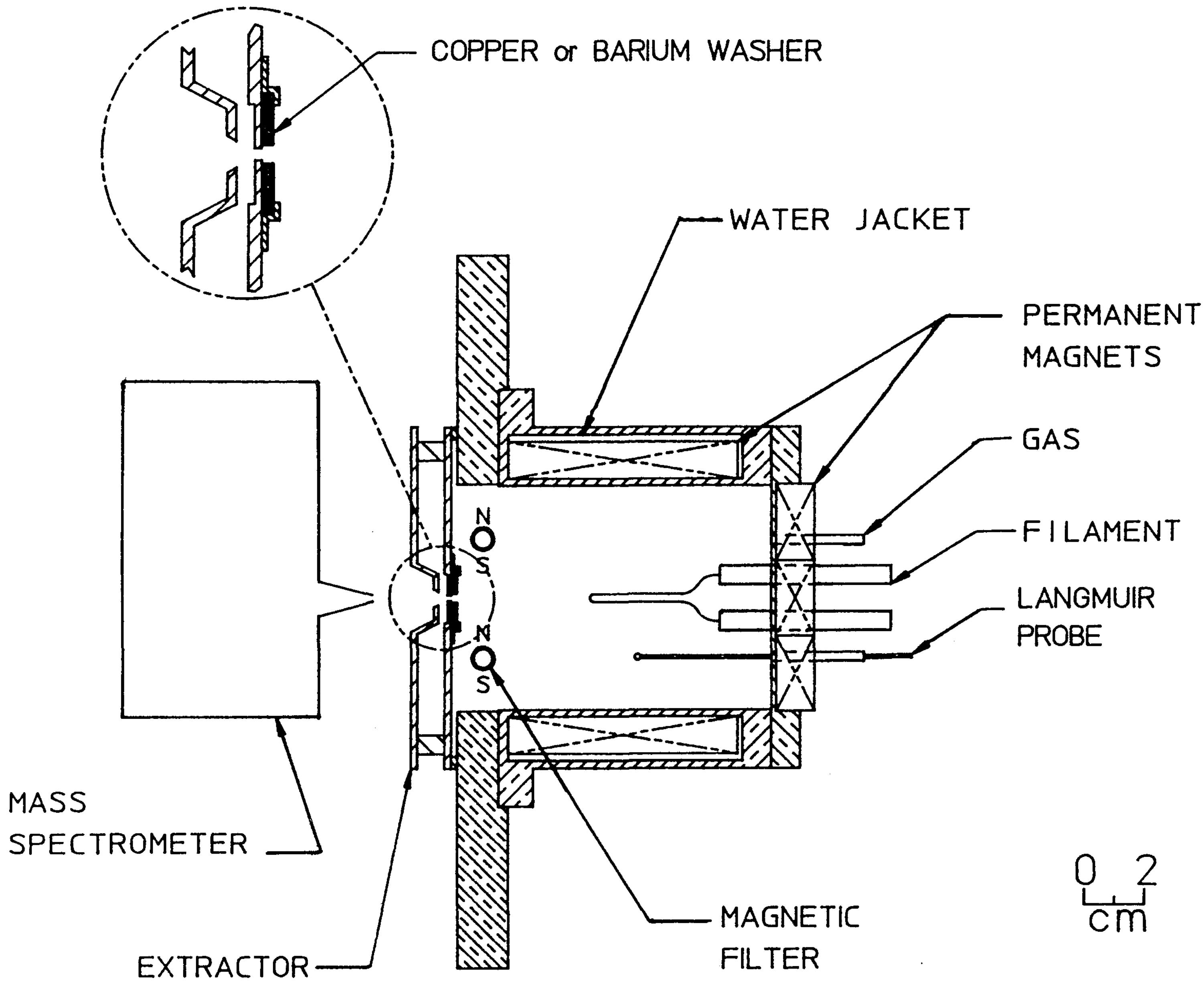

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Fig. 1

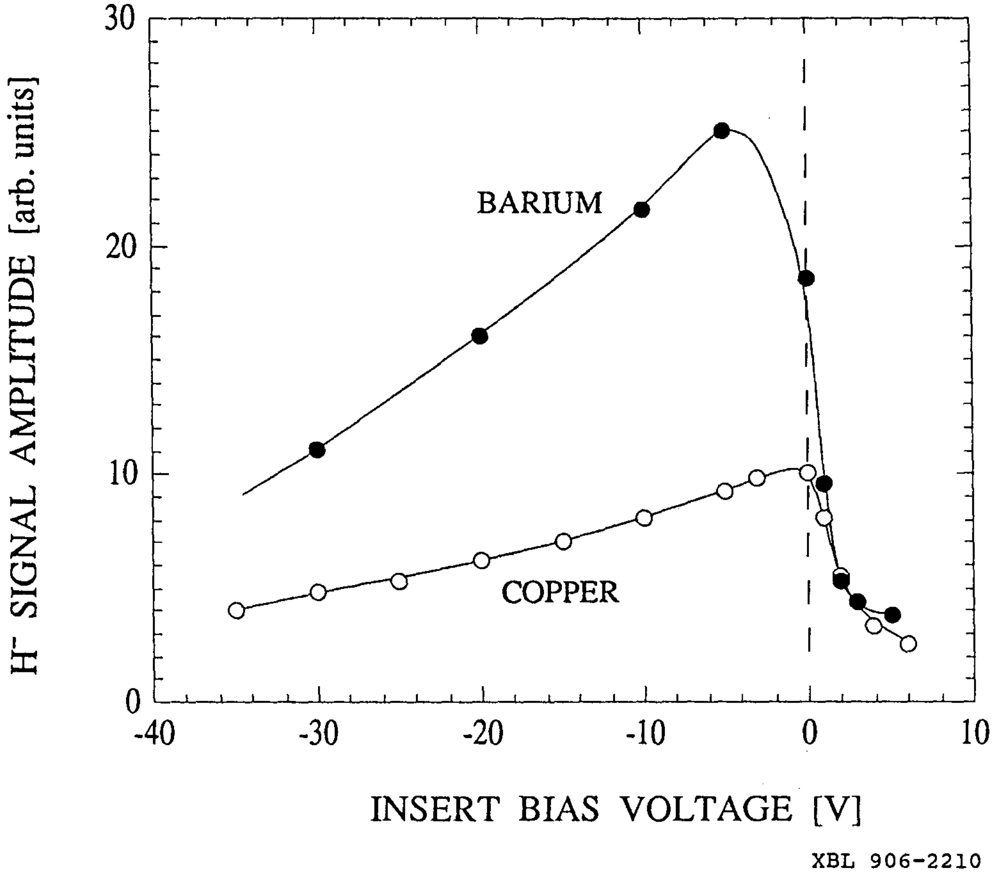
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Fig. 2

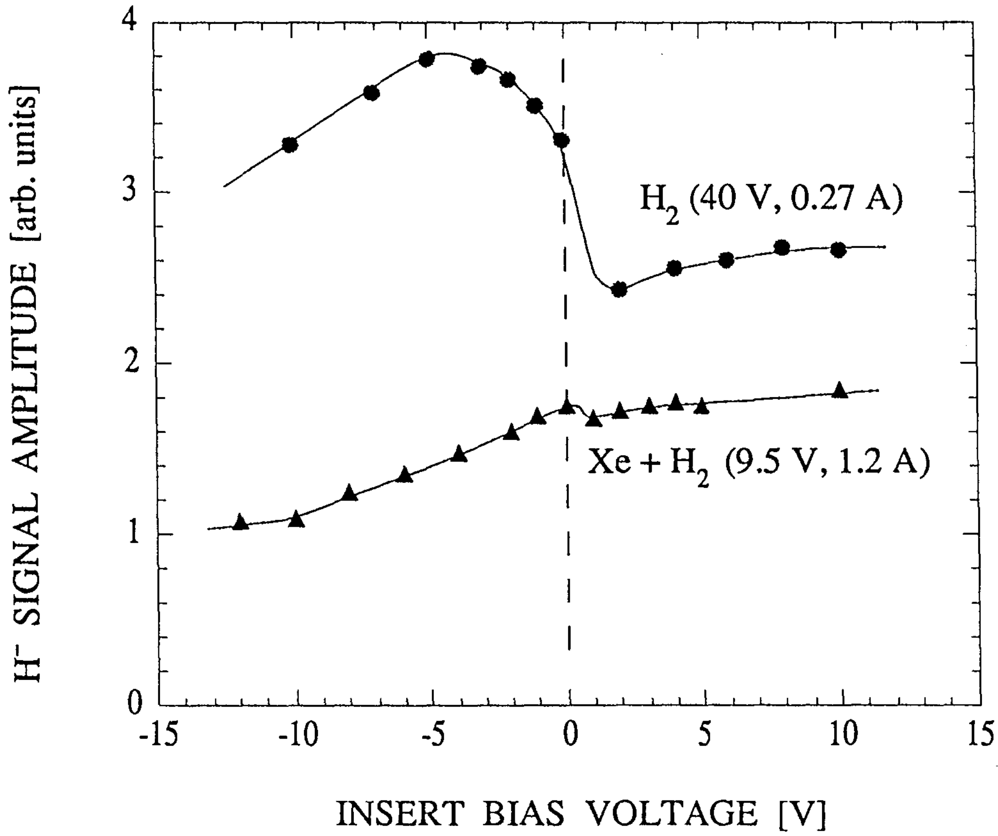

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Fig. 3