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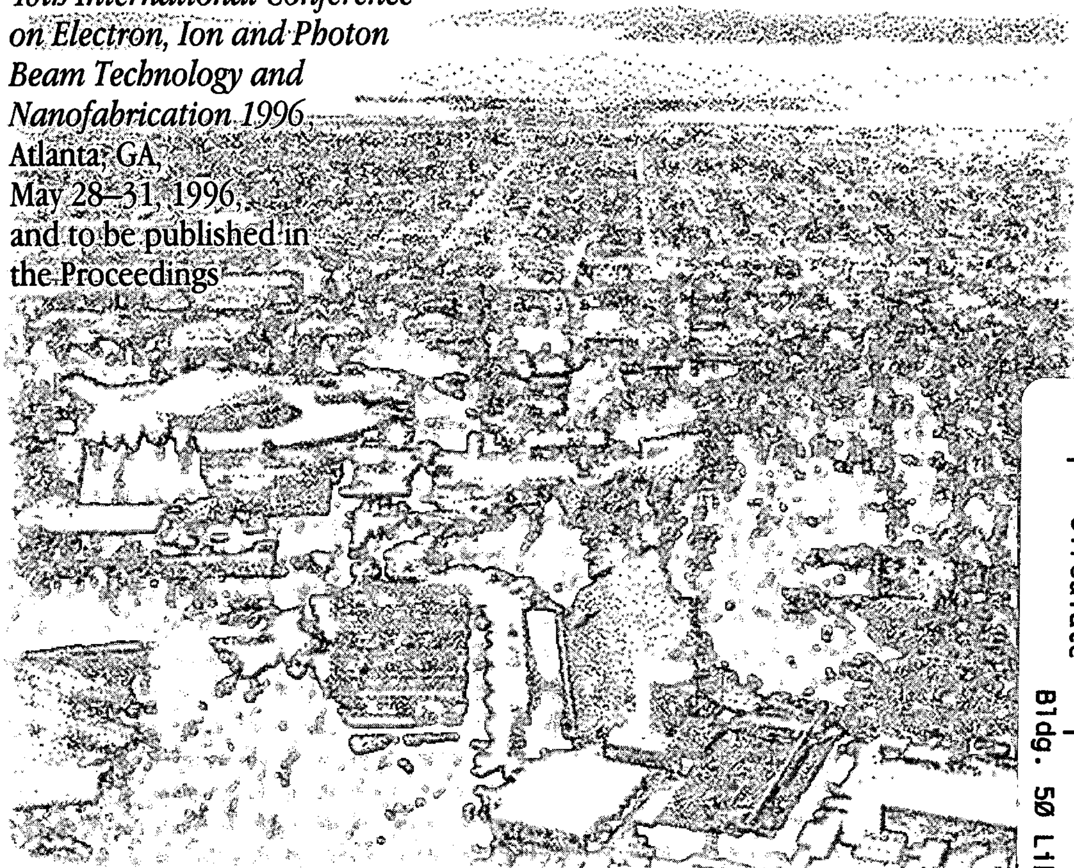

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Development of Ion Sources for Ion Projection Lithography*

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Abstract

Multicusp ion sources are capable of generating ion beams with low axial energy spread as required by the Ion Projection Lithography (IPL). Longitudinal ion energy spread has been studied in two different types of plasma discharge: the filament discharge ion source characterized by its low axial energy spread, and the RF-driven ion source characterized by its long source lifetime. For He^+ ions, longitudinal ion energy spreads of 1 - 2 eV were measured for a filament discharge multicusp ion source which is within the IPL device requirements. Ion beams with larger axial energy spread were observed in the RF-driven source. A double-chamber ion source has been designed which combines the advantages of low axial energy spread of the filament discharge ion source with the long lifetime of the RF-driven source. The energy spread of the double chamber source is lower than that of the RF-driven source.

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a) Also with the Nuclear Engineering Department, University of California Berkeley.

I. INTRODUCTION

Ion projection lithography (IPL) aims at projecting sub-0.18 μm patterns of a stencil mask onto a wafer substrate with minimum chromatic aberrations [1]. For this purpose, an ion source that delivers a beam with low axial or longitudinal energy spread (< 3 eV) is required. The filament discharge multicusp ion source is capable of producing large volumes of uniform, quiescent, and high density plasmas with low axial energy spread (~ 1 eV) as reported previously [2]. However, the limited filament lifetime will ultimately limit the usefulness of the filament discharge ion source for this and many other applications.

An alternative ion source that has a longer lifetime than the filament discharge source is available and has been tested. The RF-driven multicusp ion source has a longer life span than the filament discharge ion source. However, the axial energy spread for the RF-discharge case has been found to be larger than that of the filament discharge due to the RF-coupling. In this paper the results on the energy spread of the two ion sources will be presented, and a double chamber ion source which combines the low axial energy spread characteristics of the filament driven source with the long lifetime of the RF-driven source will be examined.

II. EXPERIMENTAL SETUP

The experimental set-up consists mainly of the ion source and the energy analyzer which is used to obtain the axial energy spread at the exit aperture. Three different multicusp ion source schemes have been tested: a filament discharge source, an RF driven source and a double chamber

source. The filament discharge source chamber was 10 cm diameter by 10 cm long. The surface of the chamber was surrounded by 20 columns of samarium-cobalt permanent magnets with alternating polarity to generate longitudinal line-cusp magnetic fields that confine the primary ionizing electrons and the plasma.

One end of the chamber was terminated by an end flange which was covered with rows of permanent magnets to complete the line-cusp arrangement. The other end contained the extraction aperture, as shown on Fig. 1. A steady-state plasma was produced by primary electrons emitted from a tungsten filament, and the entire chamber wall, except the plasma electrode, served as the anode for the discharge. A magnetic filter system was used to provide a limited region of transverse magnetic field which prevents the energetic electrons in the discharge chamber from crossing over into the extraction region (between the aperture and the filter).

The second source tested was the RF-driven multicusp ion source, as shown in Fig. 2. It was similar to the filament discharge source except the tungsten filament was replaced by an RF-antenna operating at a frequency of 13.56 MHz.

The third source was composed of two 10 cm diameter by 10 cm long chambers with the first chamber used as a plasma cathode, as shown in Fig. 3. The two multicusp source chambers were electrically isolated from each other by a three-grid electrode system which worked as an accel-decel extraction system. The first grid was electrically connected to the first chamber while the third grid was connected to the second chamber. The middle grid was biased positively with respect to the second chamber to suppress the backstreaming of positive ions. Plasma is generated by an RF-discharge in the first chamber.

The axial energy spread was measured at the exit aperture for these three multicusp ion sources. A retarding field energy analyzer was used [2]. The energy analyzer has a grid which is biased negatively for electron suppression, and a collector (connected to a variable power supply and a resistor) for energy distribution measurement. The analyzer is connected to a computerized data acquisition system. The entire assembly is illustrated in Fig. 4.

III. EXPERIMENTAL RESULTS

A. Filament discharge ion source

Positive helium ions with low axial energy spread were measured with the use of filter magnets. The filter creates a relatively uniform plasma potential in the discharge side where ionization takes place [2]. Since all the ions arriving at the exit aperture start out with about the same potential energy, their energy spread is expected to be small.

For helium, at a discharge voltage of 70 V and discharge current of 2A, the axial energy spread was found to be approximately 1.2 eV. Fig. 5b is the differentiated curve of the I-V characteristic curve of Fig. 5a.

B. RF-driven ion source

Using helium as the working gas, an axial energy spread of 7.3 eV (as shown in Fig. 6) was measured with RF input power of 50 W. The axial energy spread for the RF-driven source is substantially larger than that of the filament case, and it increases with RF-power. The high axial energy spread is due to the penetration of the RF-induction fields into the other side of the filter.

This causes ionization to take place in the extraction region [3]. The magnetic filter is therefore ineffective and the energy spread is comparable to the case without filter for a filament discharge which was previously reported to be approximately 8 eV [2].

The purpose of the magnetic filter is to achieve a production of ions with low axial energy spread by preventing ionizing electrons that are present in the discharge side from crossing over to the extraction side. This ensures that no ionization takes place in the extraction region. However, in an RF-driven source, some RF-induction field can reach the extraction chamber. The B-field of the magnetic filter cannot prevent the generation of energetic or ionizing electrons in the extraction region where the plasma potential falls off rapidly. Ions are produced in the source chamber where the plasma potential is uniform and also in the extraction chamber where the plasma potential has a large gradient, leading to a larger longitudinal energy spread.

The penetration of RF-induction field into the extraction chamber could be minimized. This was accomplished by reducing the antenna size, by setting the axis of the antenna loop perpendicular to the axis of the source body or by increasing the distance between the antenna and the magnetic filter[3]. These different source arrangements reduced the axial energy spread in this source by approximately a factor of 2. However, they did not completely prevent the penetration of the RF-induction field into the extraction region, and hence ion production in the extraction region.

C. Double-chamber ion source

The double-chamber ion source was tested by using an RF-antenna discharge plasma as the cathode. The three grid system served as an accelerator for electrons and also as a shield for

RF-induction field. Plasma was generated in the second chamber by the electrons extracted from the first chamber.

As shown in Fig. 3, a magnetic filter system is used to divide the second chamber into two regions (discharge and extraction). A complete plasma potential profile within the chamber has not yet been determined. However, a relatively uniform plasma potential distribution near the filter in the discharge region and a rapid fall off in the extraction region is expected. As a result, an axial energy spread of 1 ~ 3 eV should be measured. The measured longitudinal energy spread for the source was found to be approximately 2.1 eV, as shown in Fig. 7, which is significantly lower than the RF-driven single chamber case.

CONCLUSION

The filament discharge ion source with magnetic filter is capable of producing ion beams with low axial energy spread. For He^+ ions, a longitudinal ion energy spread of 1.2 eV was measured for a filament discharge multicusp ion source. The RF-driven multicusp ion source has a much longer lifetime but the axial energy spread was found to be larger due to RF-coupling. The energy spread for the RF-driven source (same size as the filament source) was found to be as high as 7.3 eV. The double chamber ion source, on the other hand, combines the low axial energy spread characteristic of the filament source with the long lifetime of the RF source. This source is capable of producing ions with an axial energy spread of about 2.1 eV.

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FIGURE CAPTIONS

Fig. 1 Schematic of a multicusp ion source operated with a filament cathode.

Fig. 2 An RF-driven source has the same arrangement as the filament discharge source except the filament is replaced by an antenna.

Fig. 3 The filament cathode in Fig. 1 is replaced by a plasma cathode in the double-chamber ion source. The three grid system separates the two chambers.

Fig. 4 Schematic of the energy analyzer set-up. Energy spread measurements are taken at the exit aperture of the source.

Fig. 5a The I-V characteristics of the energy analyzer the filament discharge source,

Fig. 5b The I-V curve of Fig. 5a is differentiated to obtain the axial energy spread which is defined as the full width at half maximum.

Fig. 6 The axial ion energy spread for the RF-driven source.

Fig. 7 The axial ion energy spread for the double-chamber source arrangement.

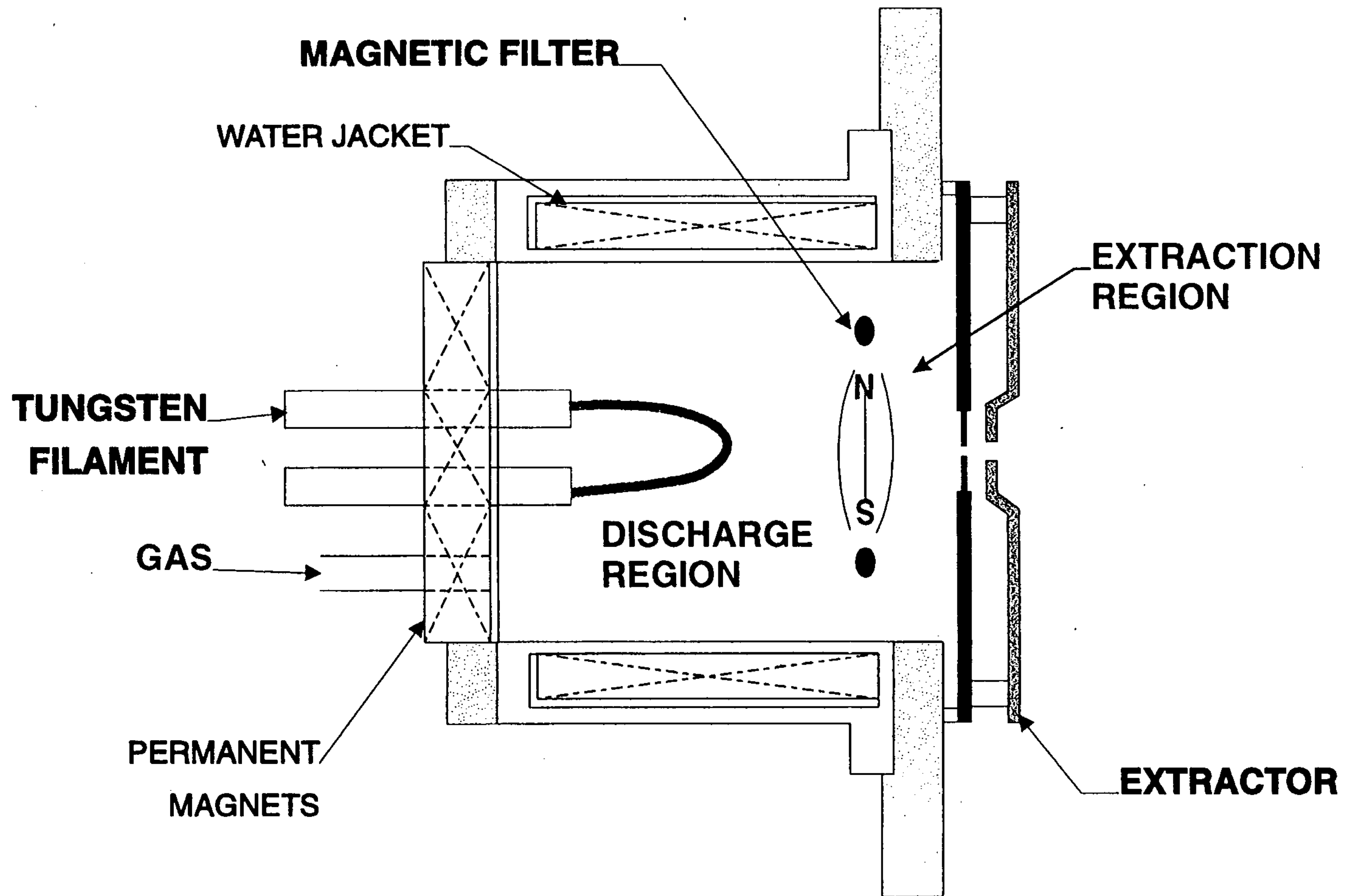

FIGURE 1

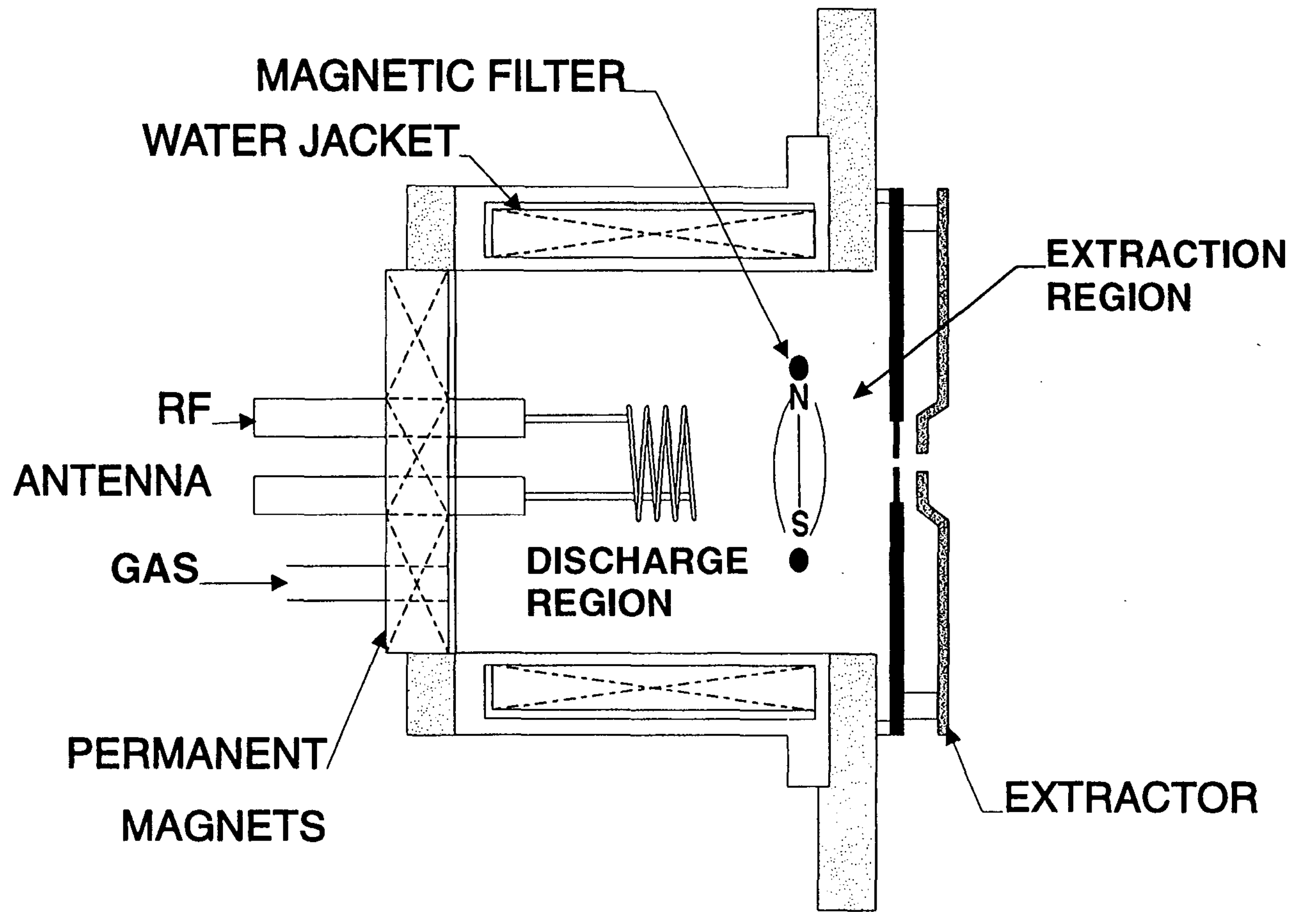

FIGURE 2

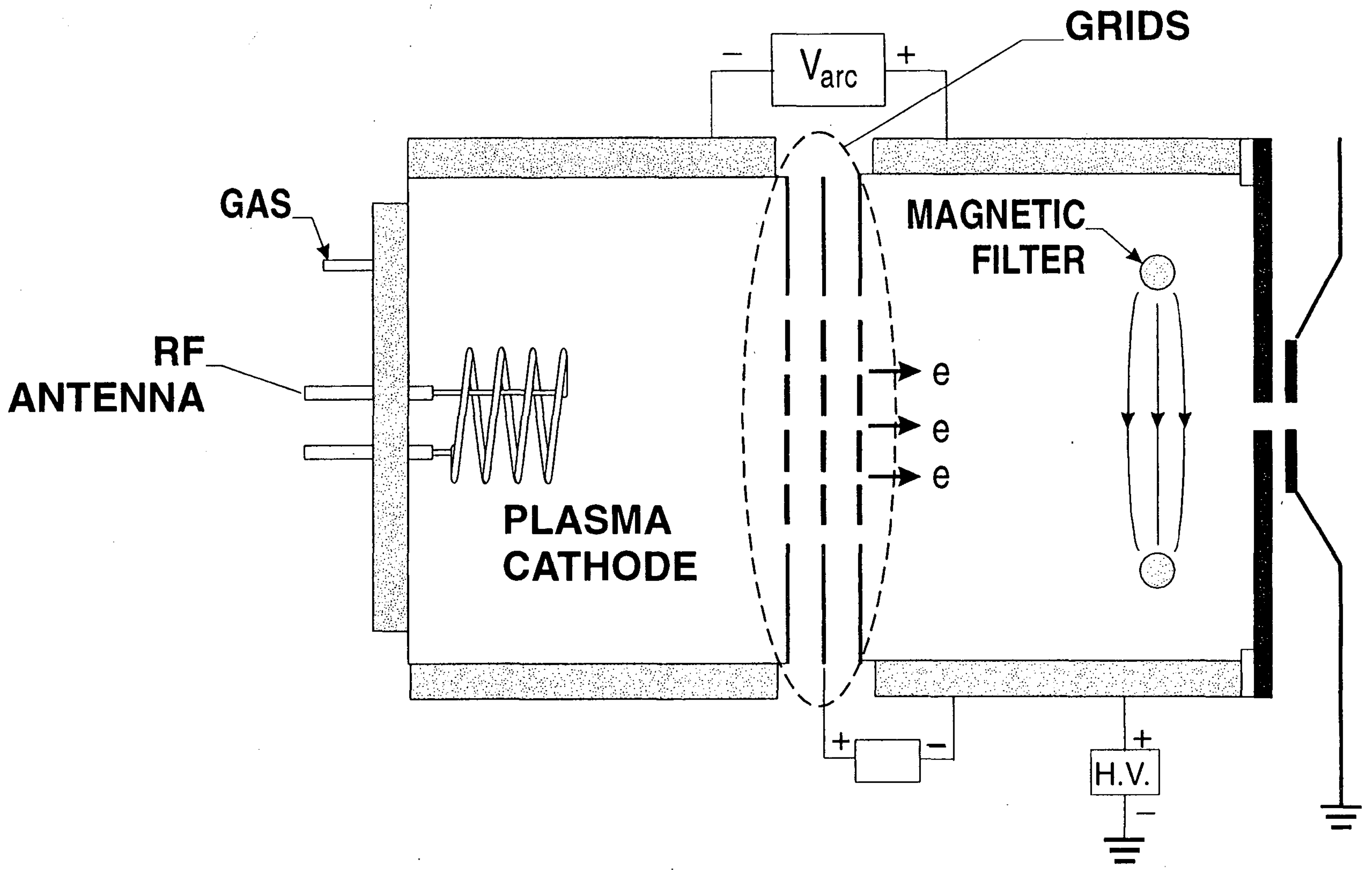

FIGURE 3

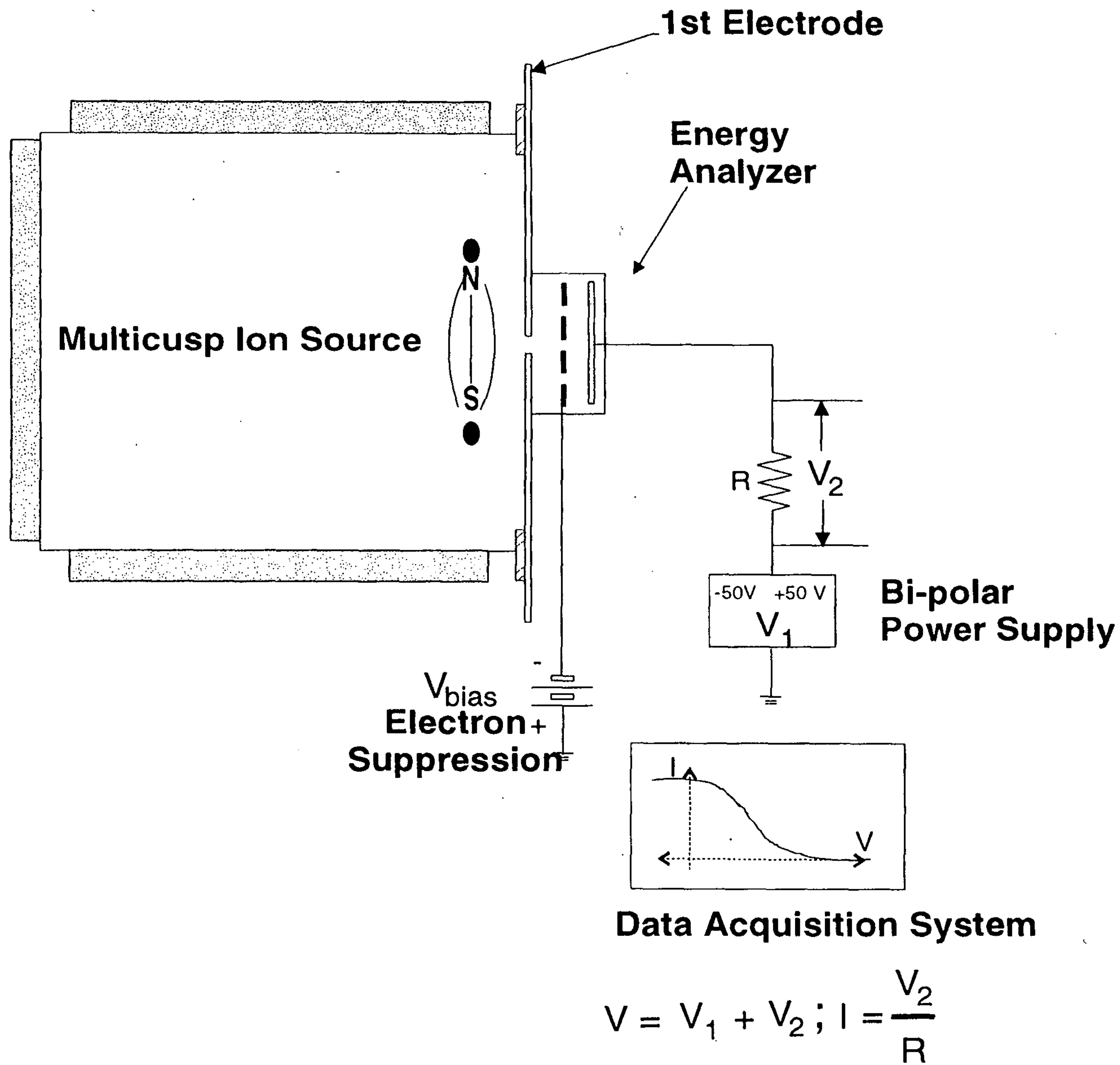

Fig. 4

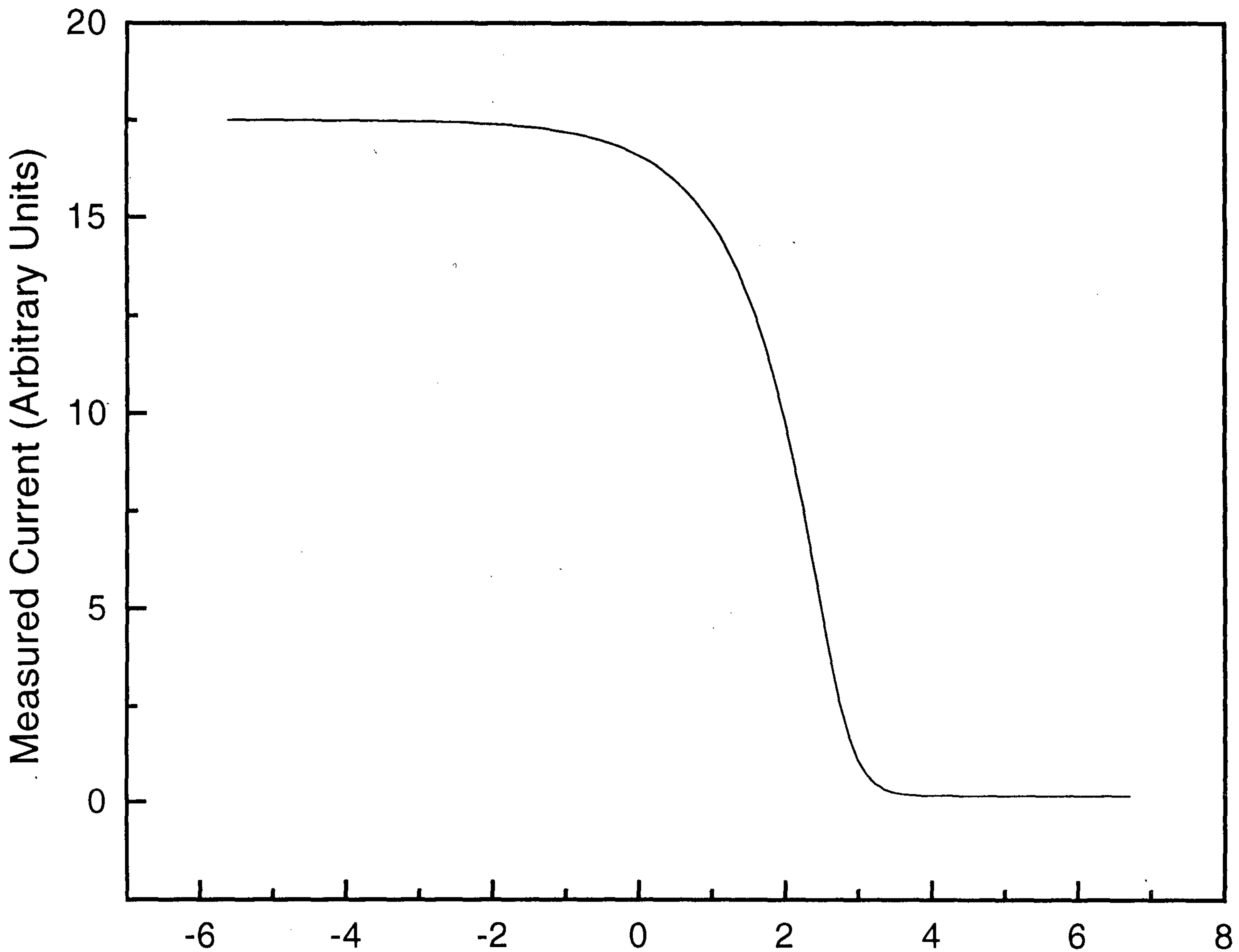

Fig. 5a

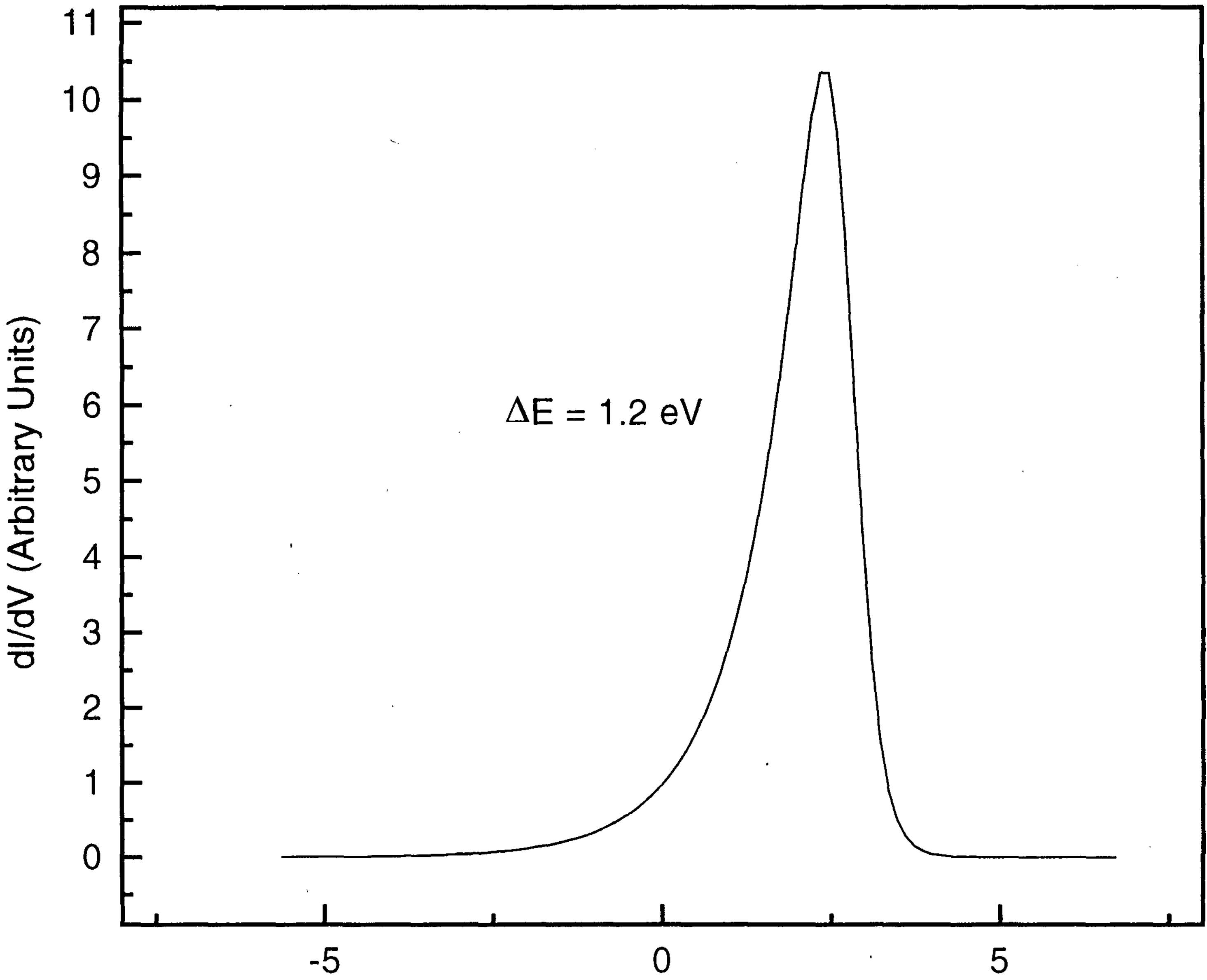

Fig. 5b

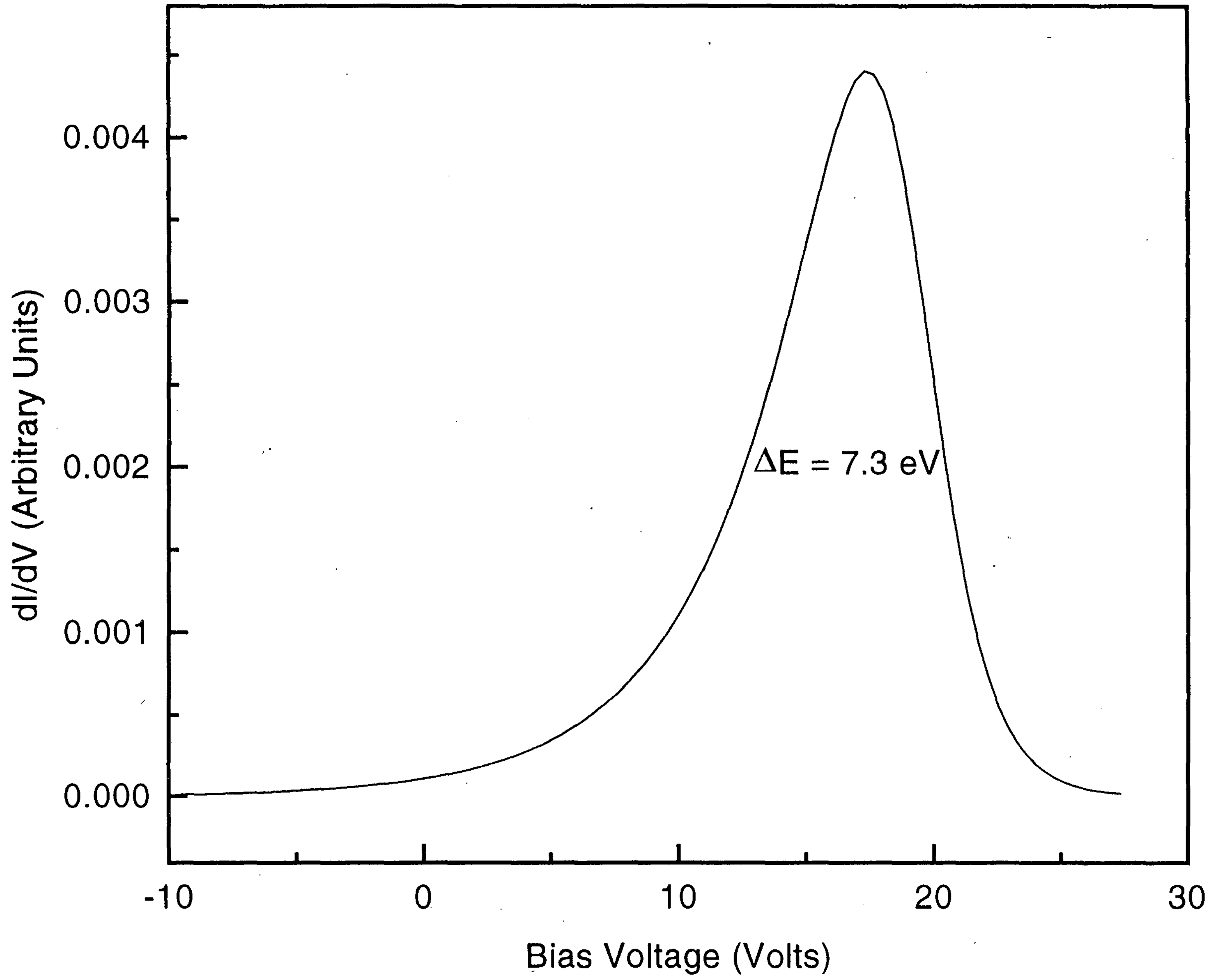

Fig. 6

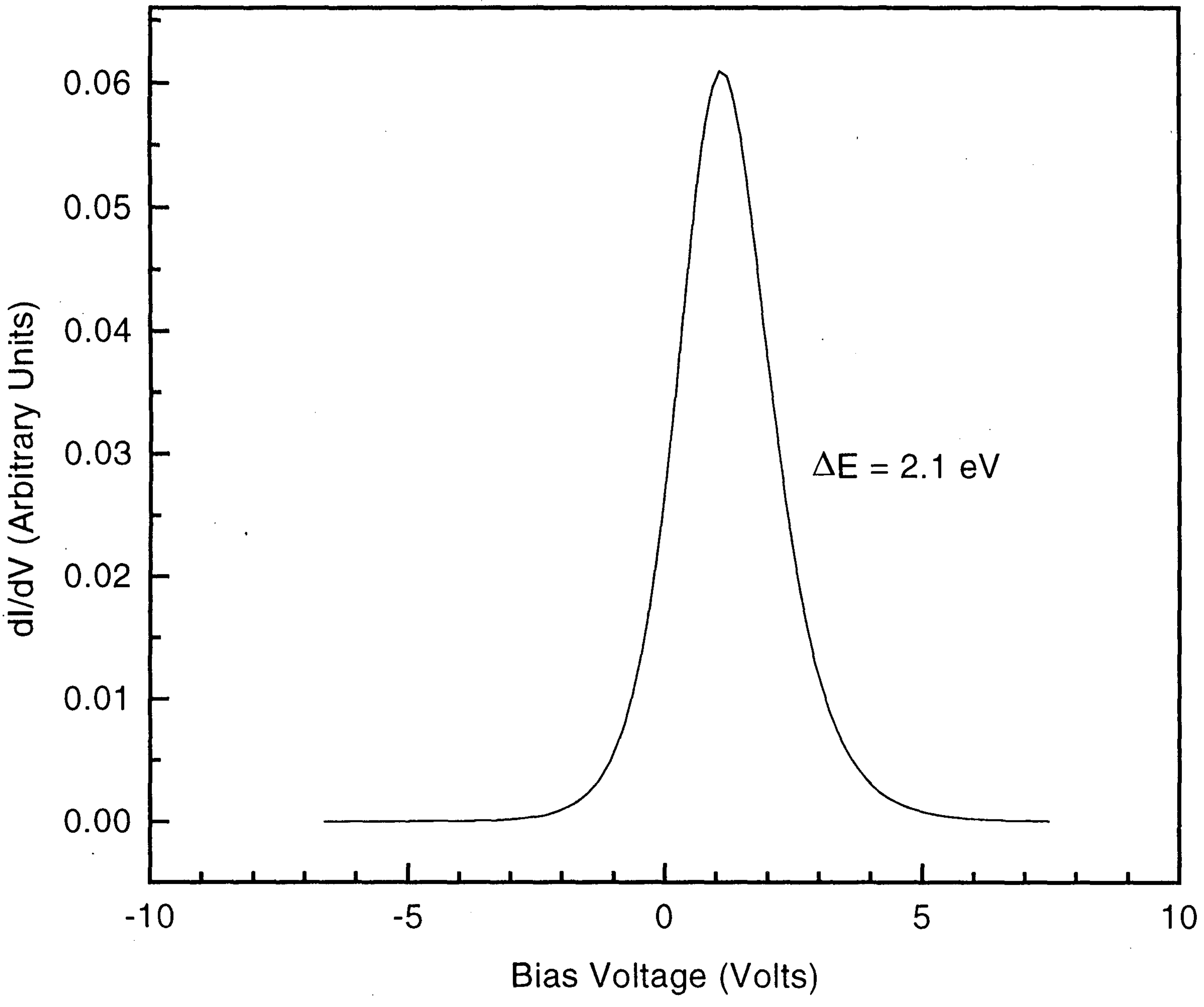

Fig. 7

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