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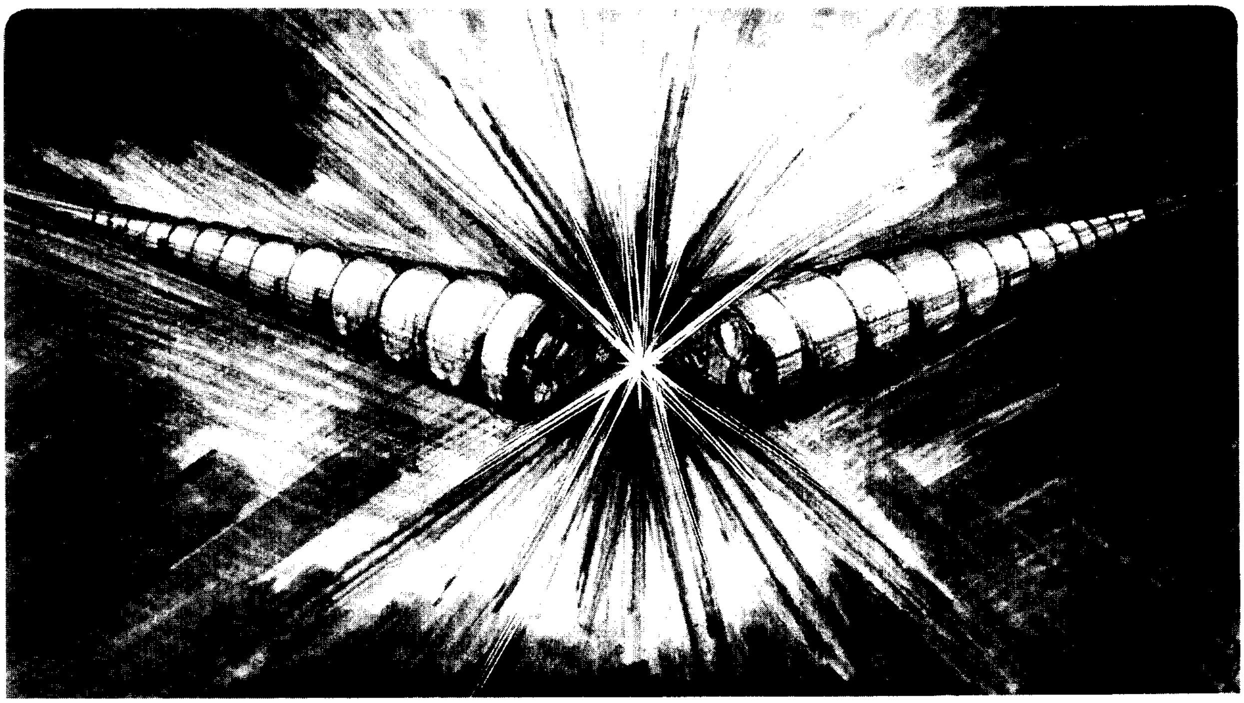

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Accelerator and Fusion Research Division
Lawrence Berkeley National Laboratory
University of California
Berkeley, California 94720

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Beam Emittance Measurements on Multicusp Ion Sources *

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Abstract:

Multicusp ion sources are used for various applications. Presently, the implementation of this type of ion source is planned for the development of an ion beam lithography machine, which will be used for the projection of sub-0.2 μm patterns onto a wafer substrate. Since, for this application, a very good beam quality and a small ion energy spread are required, emittance measurements have been performed on a multicusp ion source for various source conditions. It is shown that the installation of proper capacitors between the extraction electrodes is necessary to avoid rf-pickup, which otherwise leads to a distortion of the beam emittance. The influence of the magnetic filter field on the beam emittance has been investigated, and the beam emittance of a dc filament-discharge plasma has also been compared to that of an rf-generated plasma.

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1. Introduction

For the production of microelectronics devices a lithography step is needed for the projection of structures onto a wafer. The presently used optical lithography is limited in its resolution capabilities and work is being done to find a substitute for it. Therefore, the Advanced Lithography Group (ALG) is currently developing an Ion Projection Lithography machine (IPL) [1], which uses a multicusp source for the ion production.

In multicusp sources, plasma confinement is achieved by a number of cusp-magnets placed around the plasma chamber. The polarity of the magnets is alternated, so that the magnetic field screens off a major part of the chamber walls, thus reducing the loss of primary electrons in the radial direction. For plasma generation, either a filament-discharge or rf-induction discharge can be used [2]. The multicusp sources used at LBNL usually have the option of placing permanent magnets, acting as a magnetic filter for high-energy ionizing electrons, inside the source chamber near the extraction area [3]. Fig. 1 shows a schematic of such an rf-driven multicusp ion source with a magnetic filter in front of the extraction system, dividing the source chamber into a plasma generation region and an extraction region.

In this experiment, we have measured the emittance of a beam generated in such a multicusp ion source. For beam formation, a triode extraction system was attached to the plasma chamber. Emittance measurements have been performed on a beam generated with a filament-discharge plasma as well as with an rf-generated plasma. In the latter case, the use of capacitors in the extraction system was tested, to filter out possible rf components in the extraction voltage. Additionally, a qualitative comparison of the emittance of the beam with and without the use of the filter magnets has been performed.

2. Numerical Calculation of the Extraction System

For measurement of the beam emittance in all these cases, a triode extraction system was employed. In Fig. 2 a numerical simulation of this extraction system is shown. The calculation was performed with the computer code IGUNE [4]. The aperture diameters are 3 mm, 3.4 mm and 3.4 mm and the first and second gap widths are 6.5 mm and 1 mm, respectively.

A 2 keV helium beam is formed in the extraction system with the second electrode at -4 kV. Helium was chosen as the working gas, since any deflection of the beam in the magnetic field would depend on the ion mass, with a higher deflection for lighter ions. Hydrogen would result in atomic as well as molecular ions in the beam, confusing the interpretation of the emittance measurement.

3. Experimental Set-Up

Fig. 3 shows a schematic of the experimental set-up. For beam formation an ion source, consisting of a multicusp plasma generator and a triode extraction system, is used. An emittance scanner, together with a profile monitor, is placed inside a diagnostic chamber. This scanner is moved on a spindle across the beam. Additionally, the whole unit can be rotated, so that emittance and profile measurements in x- as well as in y-direction are possible. At the end of the vacuum chamber, a Faraday cup of 10 cm diameter is placed.

The beam emittance is obtained by use of a slit-slit emittance scanner. The scanner, built by Grumman Corporation, is of the Allison type [5], consisting of two parallel plates containing the entrance and exit slits, with a pair of electrostatic deflection plates in between. The first slit separates part of the beam at a certain position x. The particles are then deflected into the second slit by a voltage on the deflection plates U_D which is proportional to x', the derivative of the particle trajectory, and inversely proportional to the particle energy U_0. In our case, the widths and lengths of the two slits are 25μm and 6 cm, respectiveley, the distance between the slits is 6 cm, the gap between plates and slits is 0.5 cm, and the aperture between the plates is 2 mm. This allows a range of measurement of ±2.5 cm in spatial and ±57mrad in angular direction. Behind the second slit a collector is used to measure the intensity distribution as function of x and x'. In front of the collector an electrode is placed, allowing the suppression of secondary electrons.

For plasma generation a 10 cm diameter multicusp source with a length of 10 cm is used. The measurements are done with a filament- as well as an rf-driven plasma, with a frequency of 13.56 MHz in the latter case. In both cases, for a certain current density in the extraction area, the required discharge power is dependend on the use of the magnetic filter which reduces the plasma density in the extraction region of the source.

The electrodes of the extraction system are made of copper. The first electrode, which is in contact with the plasma, is edge cooled with water. The emittance measurements are taken at 24 cm distance from the extraction system.

4. Experimental Results

4.1. Beam emittance for rf-driven source

In the case of an rf-driven ion source one major concern is the possibility of a distortion of the emittance due to the coupling of the rf voltage to the dc extraction voltage. Fig. 4 shows an emittance measurement (intensity plot above, contour plot below) of a 2 keV He^+ beam generated in the rf-driven multicusp ion source. As can be seen in the contour plot (below), the emittance is very large and the distribution highly distorted. Two separate regions with higher intensity values can be made out. It becomes even more obvious in the intensity plot (above), where the two peaks in the angular distribution at any position x can be clearly seen. This observation can be explained by the assumption that the extraction electrodes are picking up the rf-signal, and consequently the extraction voltage is modulated by the rf voltage. Such a modulation changes the ion optics for the formation of the beam, resulting in a variation of the beam envelope.

Fig. 5 shows another emittance measurement for a beam generated with similar source conditions. For this measurement, capacitors were installed between the first and second electrode of the extraction system and ground potential. The emittance, i.e. the area inside the phase space envelope, is much smaller than before, and the two peaks of the previous measurement are eliminated by a successful filtering of the rf component of the extraction voltage. This could be further shown by the fact that the beam emittance of this case also corresponds to a comparable one taken with a filament driven ion source

4.2. Beam emittance with and without magnetic filter

The magnetic field inside the plasma chamber may have an influence on the transverse energy distribution of the ions. Also, a deflection of the total beam due to the magnetic field seems to be possible. Any such deflection of the beam should occur in the direction perpendicular to the magnetic field vector. For this reason, the orientation of the scanner was chosen to be vertical, with the slit itself extending perpendicular to the filter rods.

Fig. 6 shows two xx'-emittance diagrams (contour plot) for a 150 μA, 2 keV He^+ beam. Both emittances were taken for the case of a filament driven plasma. The figure above shows the case without any magnetic filter field present in the source. The measurements were then repeated with the filter magnets (below). No difference in the shape of the emittance contours or in the width of the distribution could be detected. In addition, no deflection of the beam in either x- or y-direction can be observed.

The above results were also compared to similar measurements with an rf-generated plasma. Again, no difference in emittance could be detected.

5. Conclusions

For the operation of the ion source with an rf-induction generated plasma, the installation of capacitors between the extraction electrodes proves to be essential. Leaving them out results in a severe distortion of the beam emittance. When the rf-pickup is successfully filtered out, no difference in beam emittance could be observed in comparison to the filament-driven plasma. As the measurements show, the use of the magnetic filter field inside the plasma generator of the source does not result in any deflection of the beam or deterioration of beam quality, since neither a change of the x- or y-position of the beam, nor an increase in the transverse ion energy distribution could be observed in the emittance diagrams.

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Figure Captions

Fig. 1: Schematic drawing of a multicusp ion source with an rf-antenna and with the filter magnets installed.

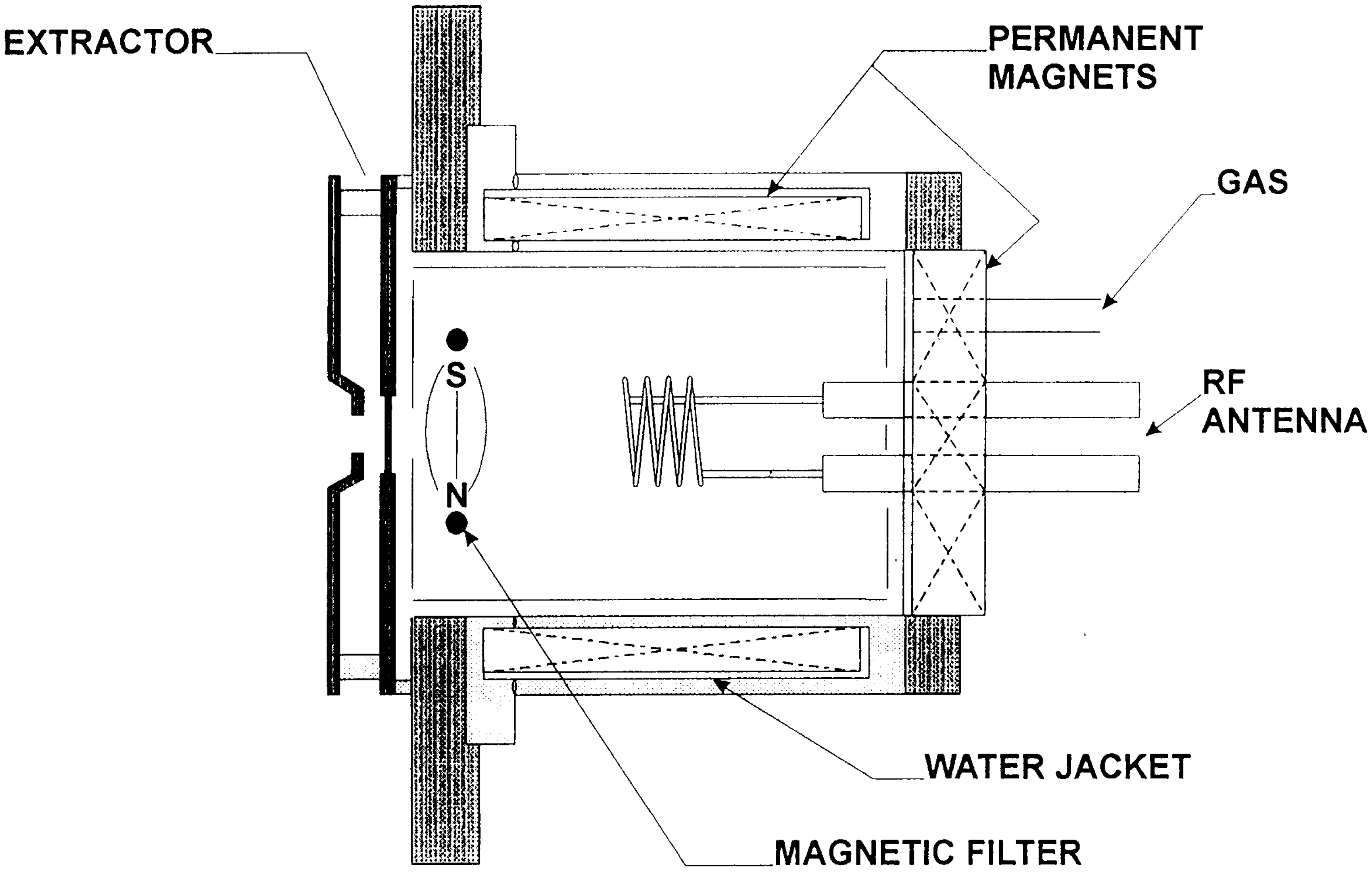
Fig. 2: Numerical simulation of the extraction area, performed with the computer code IGUNE. A 2 keV helium beam is formed in a triode extraction system. The gap widths are 6.5 mm and 1 mm, the aperture diameters 3 mm, 3.4 mm and 3.4 mm, respectively.

Fig. 3: Schematic of the experimental set-up. The ion source (IS) with the triode extraction system (Ex) is mounted onto a vacuum chamber (VC). Inside the chamber the emittance scanner (ES) is placed. Together with the profile monitor (PM) it is moved across the beam on a spindle (Sp). At the end of the vacuum chamber, a Faraday cup (FC) of 10 cm diameter is placed.

Fig. 4: Emittance diagram in the xx'-plane (intensity and contour plot) for the case of an rf-generated plasma. The beam is a 400 μA, 2 keV He+ beam formed in a triode extraction system (see Fig. 2). The extraction electrodes are picking up the rf-signal, and the resulting two peaks in the angular distribution at one position x can be clearly seen in the intensity plot above.

Fig. 5: Emittance of a beam for similar source conditions as in Fig. 4, but with capacitors installed between the electrodes of the extraction system and ground. The emittance in this case is much better than in the case without the capacitors.

Fig. 6: Emittance diagram for a 150 μA, 2 keV He^+ beam in the case of a filament driven plasma without (above) and with filter magnets installed (below). The same results were also obtained in the case of an rf-discharge.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GAS
RF ANTENNA
S
N
WATER JACKET
MAGNETIC FILTER

Fig. 1

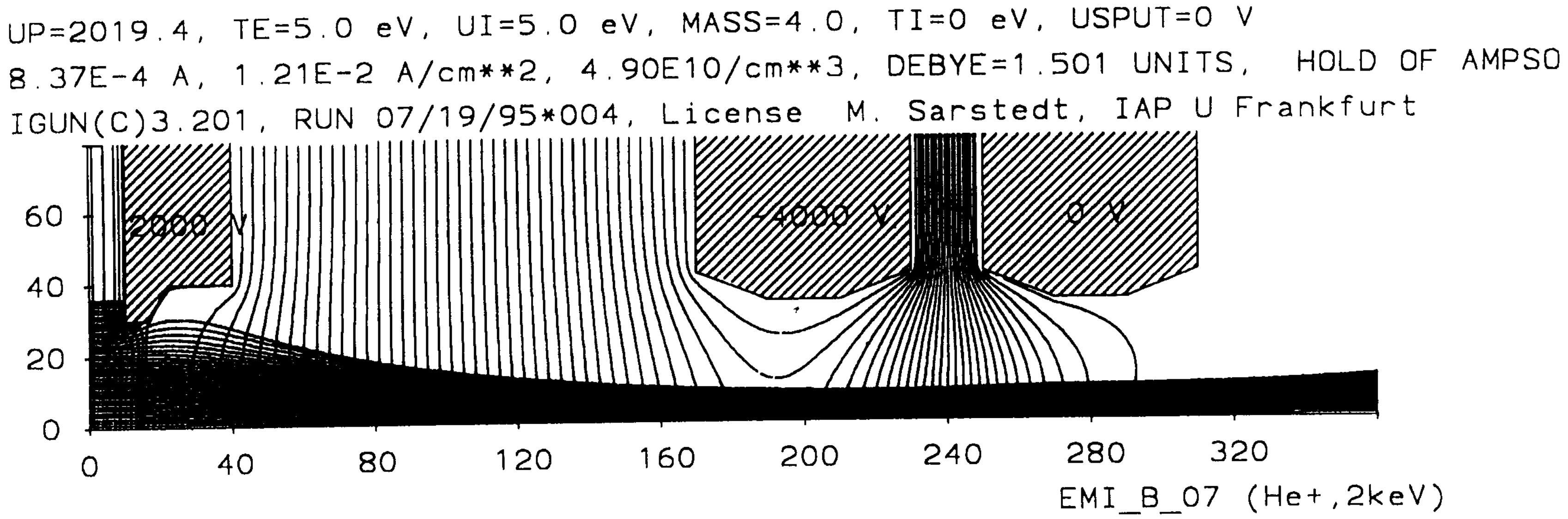
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Fig. 2

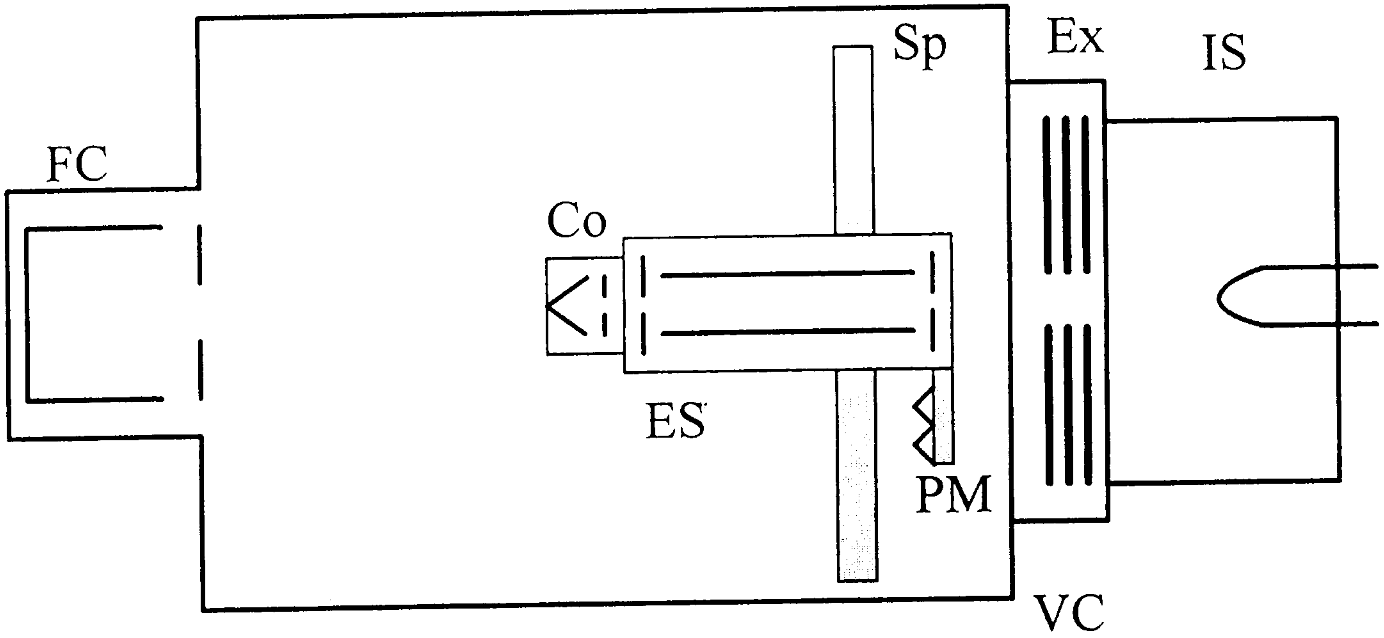

Fig. 3

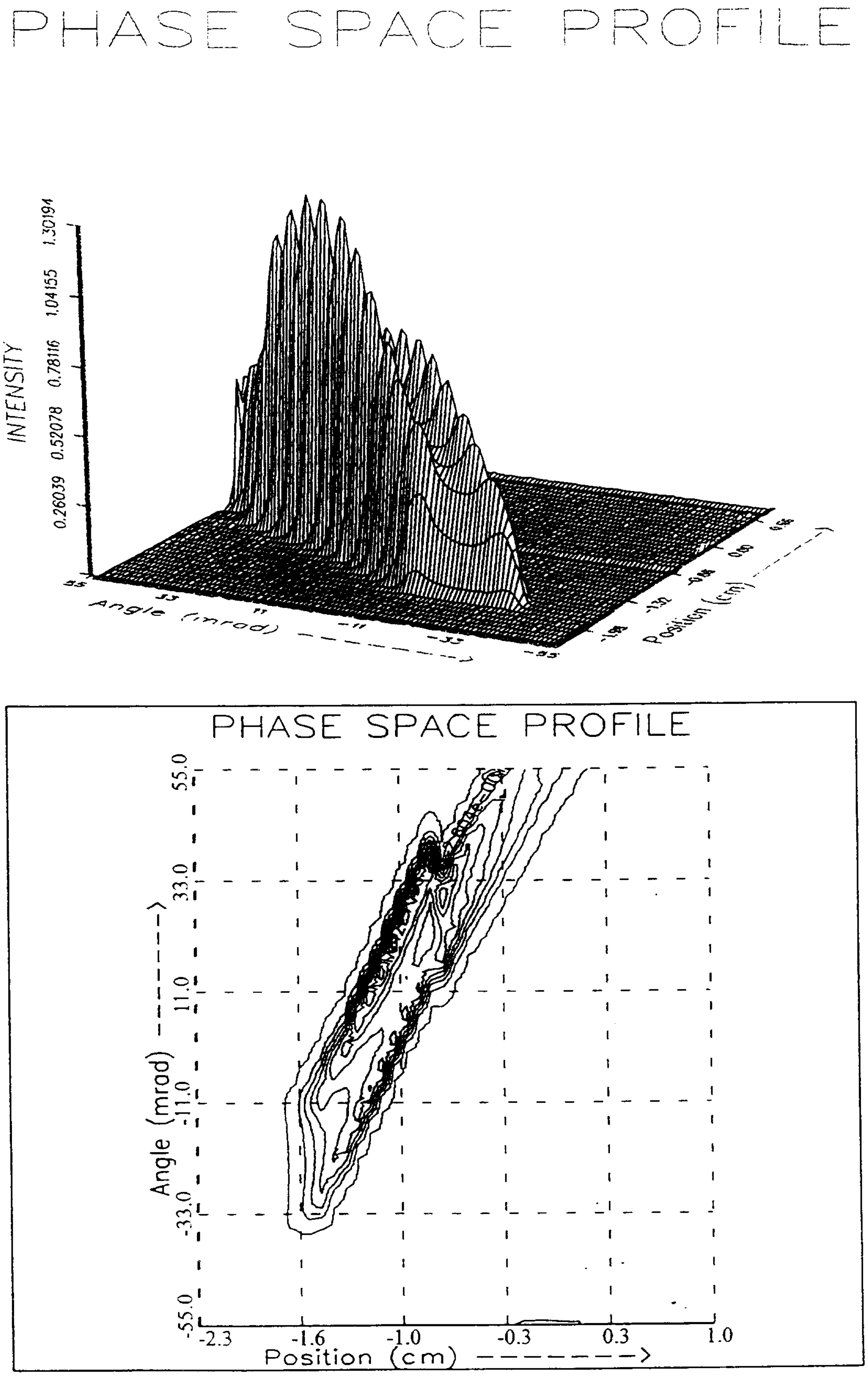

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Fig. 4

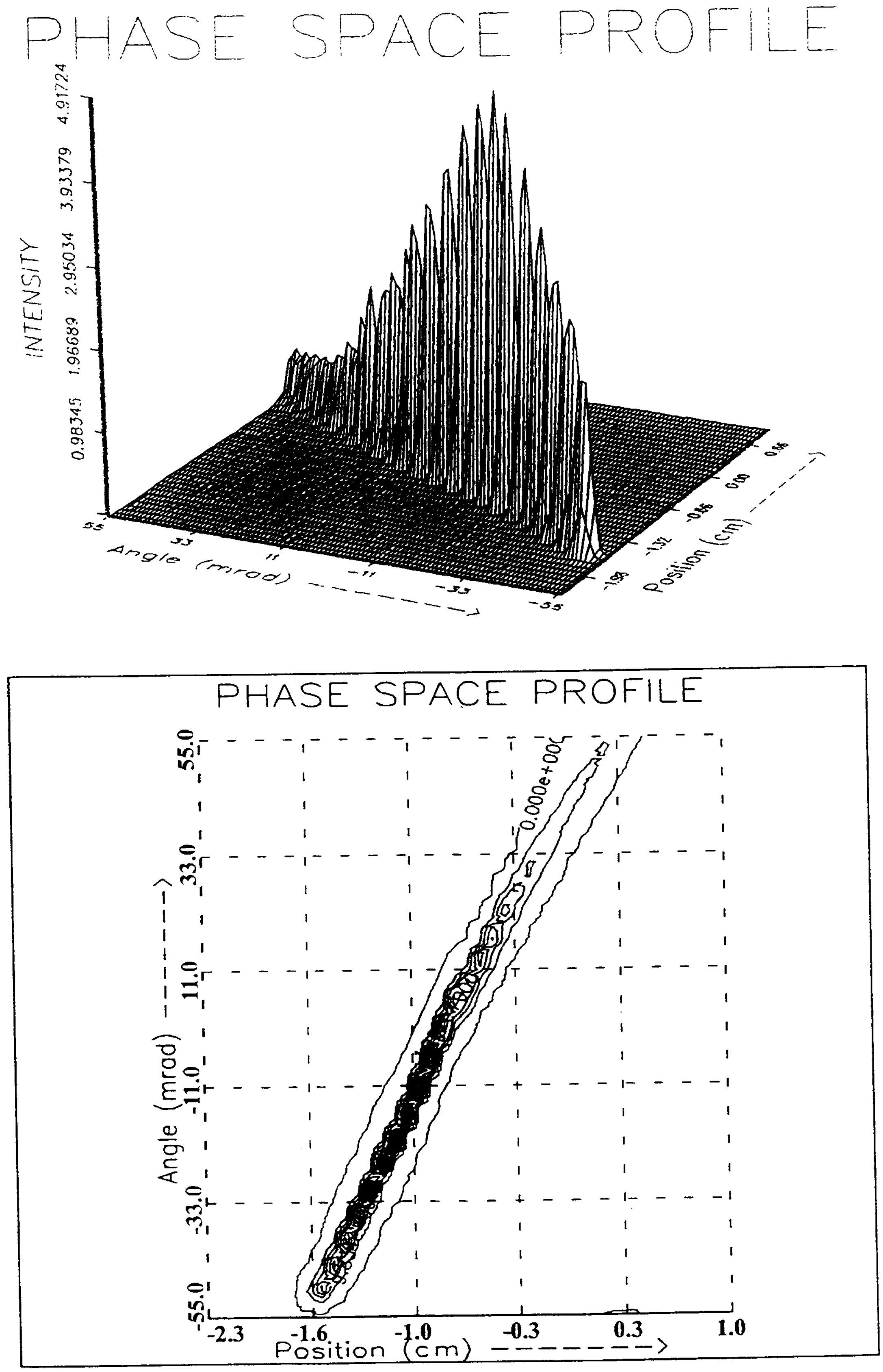
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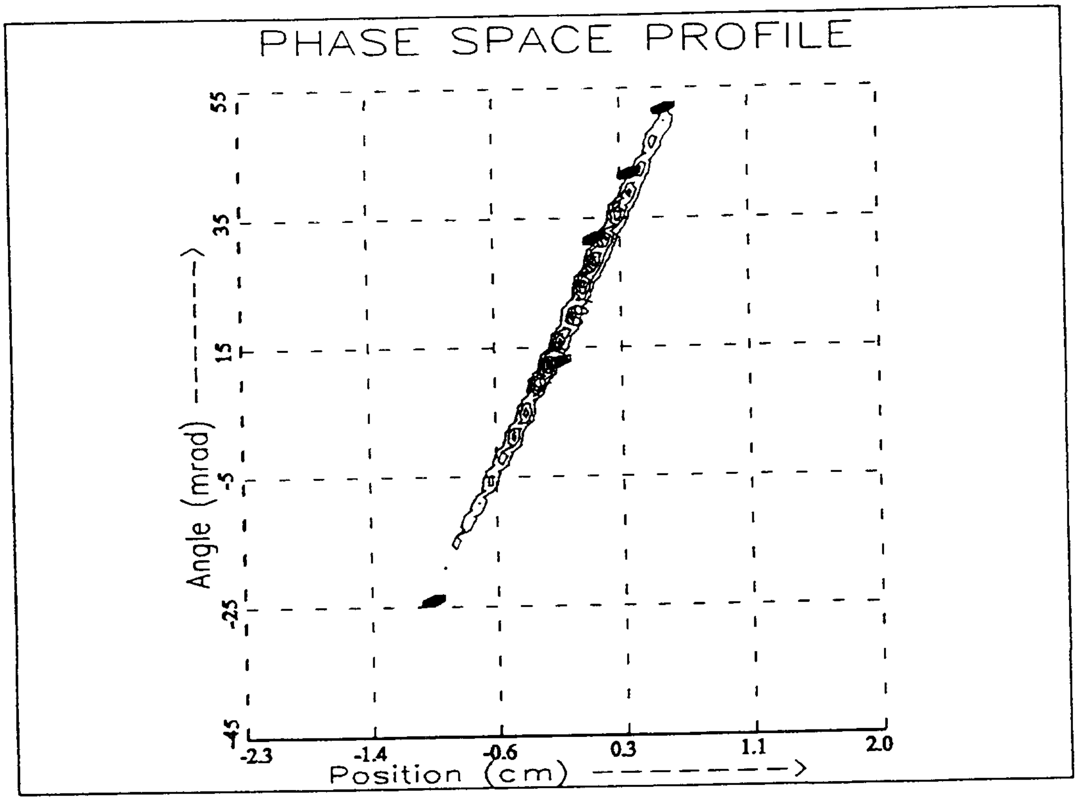
Fig. 5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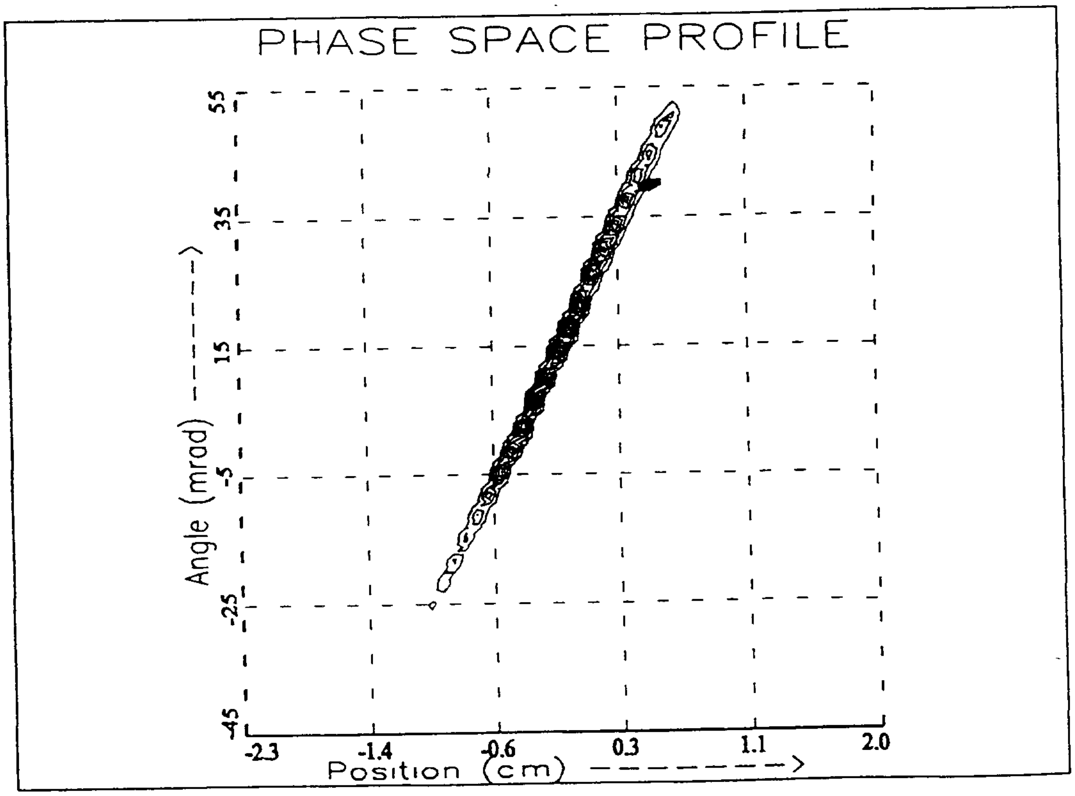
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Position (cm) ------->

Fig. 6