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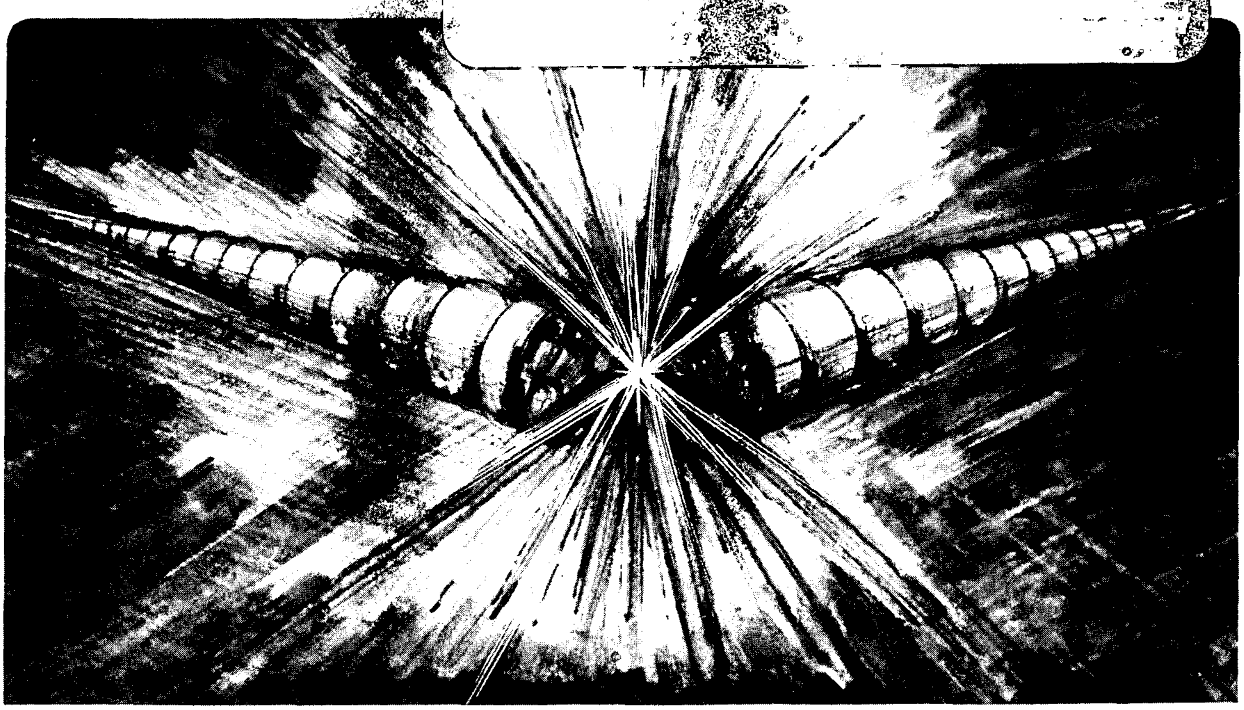

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Directly Heated Lanthanum Hexaboride Cathode*

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Abstract

A directly heated, cylindrical LaB_6 cathode has been tested in a multicusp plasma generator. Magnetic fields generated by the heater and the discharge current are minimized by the special coaxial construction, thus enabling electron emission at very low discharge voltages. At higher discharge voltage, a discharge current greater than 100 A has been obtained from a single cathode unit in a steady state plasma source operation. When the discharge current exceeds 25 A, the cathode can be operated without any heater current. The emission temperature is maintained just by ion bombardment from the discharge plasma.

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I. Introduction

Previous testings have demonstrated that directly heated LaB_6 "filaments" perform satisfactorily in different types of ion sources where tungsten or tantalum filaments are normally employed.[1] In a high-density plasma discharge where the filaments emit a significant electron current density, the temperature distribution along the filament is nonuniform. To further increase filament lifetime, the LaB_6 filament is properly shaped so that uniform electron emisssion can be obtained from the entire filament surface.[2]

In some experiments, very low discharge voltages are required.[3] The magnetic field generated around the filament by the high heater current is always strong enough to prevent low energy electrons from leaving the filament. Thus, electron emission from a filament is difficult to obtain when the discharge voltage is low. This problem can be solved either by employing an indirectly heated cathode[4] or by using a coaxial cathode structure to cancel the magnetic field produced by the heater current.

In this paper, the design of a simple, directly heated, coaxial LaB_6 cathode is described. Since the magnetic field generated by the heater current is minimized, this cathode is able to emit electrons at low discharge voltages. At higher discharge voltage (~ 70 V), the cathode is capable of producing discharge current over 100 A in a steady state plasma source operation. When the discharge current exceeds 25 A, the cathode heater current can be switched off and the emission temperature is sustained only be ion bombardment from the plasma. As a result, the source operation is maintained just by a single discharge power supply.

II. Cathode design

Some characteristics of LaB_6 when operated as directly heated "filaments" in an ion source have been discussed in two previous papers.[1,2] In summary, LaB_6 has the unusual physical properties, such as a high melting point, chemical inertness, low work function and resists erosion under ion bombardment. When heated to a temperature of $1600^{\circ}K$ or higher, LaB_6 is a copious emitter of electrons.

Figure 1 shows a plot of the calculated emission current density as a function of the LaB_6 temperature. For comparison, the emission current densities for tantalum and tungsten are also presented in the same diagram. It can be seen that a current density of 10 A/cm^2 can be easily obtained from LaB_6 with a cathode temperature of $1900^{\circ}K$. At a given cathode temperature, the emission current density for LaB_6 is more than three orders of magnitude higher than that of tantalum and tungsten.

Figure 2 shows a schematic diagram of the new LaB_6 cathode and the mounting structure. The cathode is a thin hollow cylinder (0.8 mm thick, 11 mm diam and 35 mm long) of LaB_6 with caps of the same material on both ends. A center rod of tantalum runs the entire length of the coaxial structure and carries both the discharge current and the heater current. The tantalum rod passes through a hole in both cathode caps and is terminated by a molybdenum nut. The LaB_6 end caps are separated from both the molybdenum nut and the tantalum base mounting by rhenium foils as illustrated by the upper diagram in Fig. 2. Lanthanum hexaboride is very reactive with refractory metals, and must be separated from them by rhenium, graphite or carburized tantalum.

The molybdenum nut and the LaB_6 cylinder and caps are held in place against the pull of the vacuum by the spring coil and bellows system at the other end of the assembly. The copper bellows is used as the vacuum seal between the center conductor and the external housing and it allows free movement of the parts due to thermal expansion. An adjustable spring coil is installed in parallel with the bellows to compensate for the vacuum load. This spring coil also provides the proper tension on the cathode components, so as to insure good electrical contact. The center tantalum rod and the outer tantalum base mounting are in turn attached to water-cooled copper tubings. An "O" ring between the ceramic discs seals the greater part of the structure from the vacuum system. Figure 3 is a photograph of the entire cathode assembly.

III. Cathode discharge testing

The LaB_6 cathode assembly has been tested in a 20 cm diam by 24 cm long multicusp plasma generator[5] operated with hydrogen gas at a pressure of about 1×10^{-3} Torr. The cathode was installed inside the field free region of the source chamber. The negative terminals of the heater and the discharge power supplies were both connected to the center conductor of the cathode. Only the positive terminal of the heater power supply was connected to the outer conductor.

In order to raise the cathode temperature to 1600° K, a heater current of approximately 130 A was needed. Because of the coaxial construction, the magnetic field associated with the heater current flowing up the tantalum rod tends to cancel the field generated by the same heater current flowing down the cathode cylinder. On the other hand, the magnetic field produced by the discharge current flowing up the tantalum rod is not completely canceled, because the discharge current gradually decreases as it flows down the outer cylinder. However, this magnetic field is much smaller compared to that generated on a filament surface due to the much larger cathode radius. With this cathode, it was possible to emit electrons with energies as low as 1 or 2 eV continuously into a background hydrogen plasma.

In order to initiate a discharge in an ion source, electrons with energies in the order of 70 eV are needed to ionize the background gas. In this case, a dc power supply equipped with a current limiting mode is required for the discharge operation. The discharge voltage is first set at a value of about 100 V. A heating power of about 3 V, 130 A is then used to bring the LaB_6 to the emission temperature. Once the discharge is established, the heater current can be reduced gradually with the increase of the discharge current. When the discharge current exceeds 25 A, the heater power supply can be switched off altogether. The ion source is now operated stably with only one power supply.

A plot of the discharge current versus the discharge voltage in the absence of a heater current is shown in Fig. 4. As the discharge current I_d is increased from 25 to 80 A, the discharge voltage V_d is reduced automatically from 105 to 60 V. Figure 5 is a view of the LaB_6 cathode when it is operating at a discharge current of about 80 A. It can be seen that the cathode temperature is quite uniform. Optical pyrometer measurement indicated that the average temperature on the cathode surface was about 1830^{o} K. With this temperature, Fig. 1 shows that the LaB_6 cathode should be able to provide an emission current density of 6 A/cm^2 or a total emission current of 78 A for a cathode area of 13 cm^2. This result is in good agreement with the observed discharge current of 80 A after the positive ion current (~ 2.6 A) collected by the cathode is subtracted off. A discharge current as high as 100 A (limited by the power supply) has been obtained from this cathode. By operating the LaB_6 at a temperature of 2000^{o} K, the cathode should be able to provide an emission current exceeding 200 A.

A similar LaB_6 cathode with the same diameter and thickness, but with a shorter length (L=2 cm) has been investigated in the same discharge chamber. This shorter cathode can also be operated without a heater current. The I-V characteristic curve for a hydrogen discharge is very similar to that of the 3.5 cm long cathode (Fig. 4). Since the new curve is displaced to the right, the discharge voltage and the LaB_6 temperature are therefore higher for the 2 cm long cathode for a given discharge current. For the range of discharge current considered, the average increase in V_d is approximately 10 V. This result suggests that one can achieve a specified operating discharge voltage and current if the length of the LaB_6 cathode is properly chosen.

For high discharge current operation, no heater current is needed to maintain the emission temperature of the LaB_6 cathode. For start-up purposes, one can simply use an ac current to pre-heat the cathode. In this case, a transformer together with a variac can replace the high current dc heater power supply.

IV. Discussion

The directly heated LaB_6 cathode has been operated for several hours in the multicusp ion source. When the cathode was examined after the test, no significant defect could be found except that the characteristic purple color of LaB_6 had changed to a gray color characteristic of LaB_4 + LaB_6, indicating a decrease in the B/La ratio.[4] Since the work function of LaB_4 + LaB_6 is lower than that of LaB_6,[6] electron emission from the cathode should be further enhanced.

We have not conducted any lifetime test for the coaxial LaB_6 cathode. However, it is expected that the lifetime of the cathode should be comparable to that of the LaB_6 filaments, which in some experiments has been observed to last more than 1,000 hours of continuous operation.[7] The emission properties of the cathode remain the same even though it has been disassembled and exposed to air several times.

Acknowledgments

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Figure Captions

Fig. 1 The calculated emission current density as a function of the LaB_6, tantalum and tungsten temperature.

Fig. 2 Schematic diagram of the directly heated LaB_6 cathode.

Fig. 3 A photograph of the entire LaB_6 cathode assembly.

Fig. 4 Discharge current versus voltage in the absence of heater current for two different LaB_6 cathodes.

Fig. 5 A view of the LaB_6 cathode when it is operating at a discharge current of 80 A.

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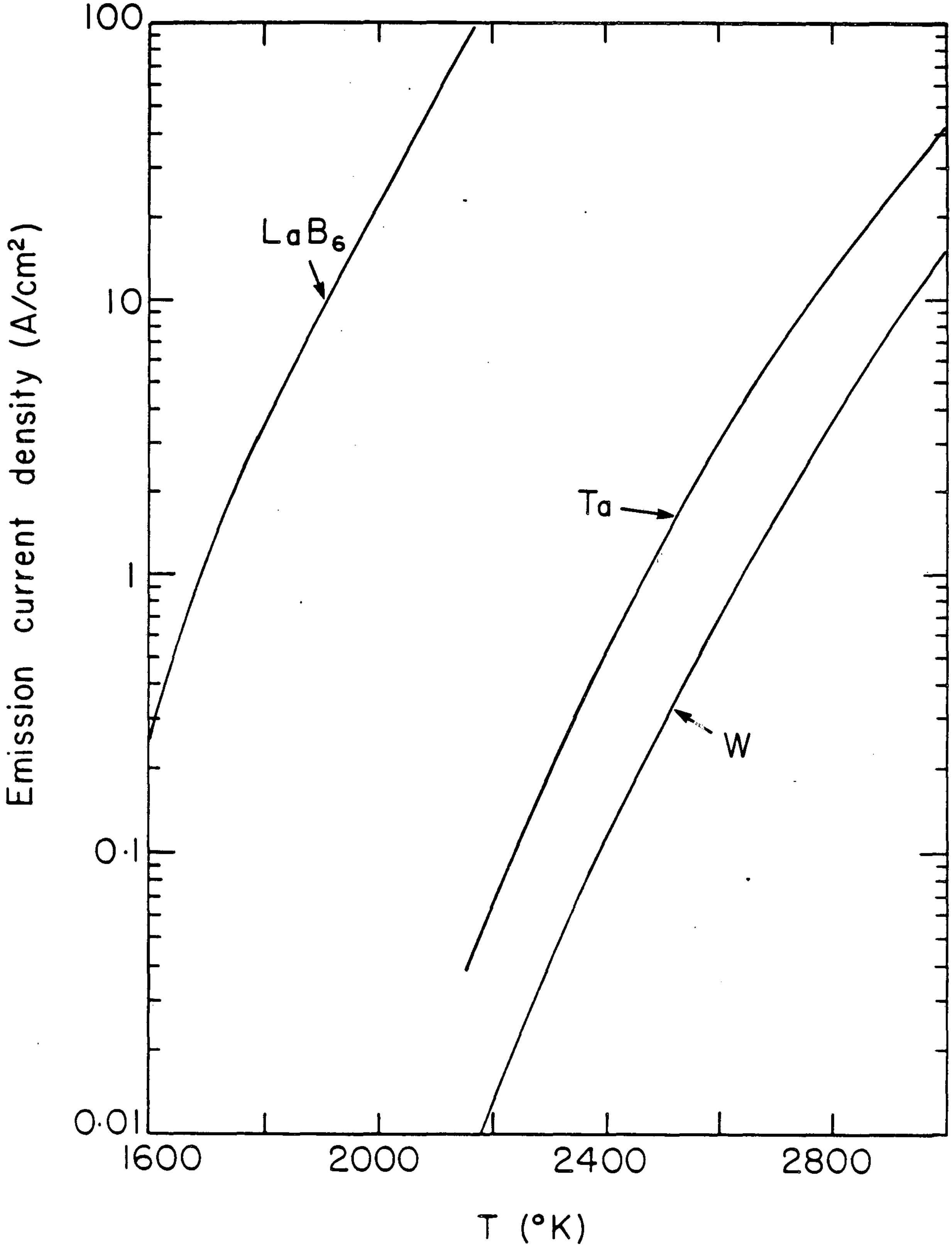

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Fig. 1

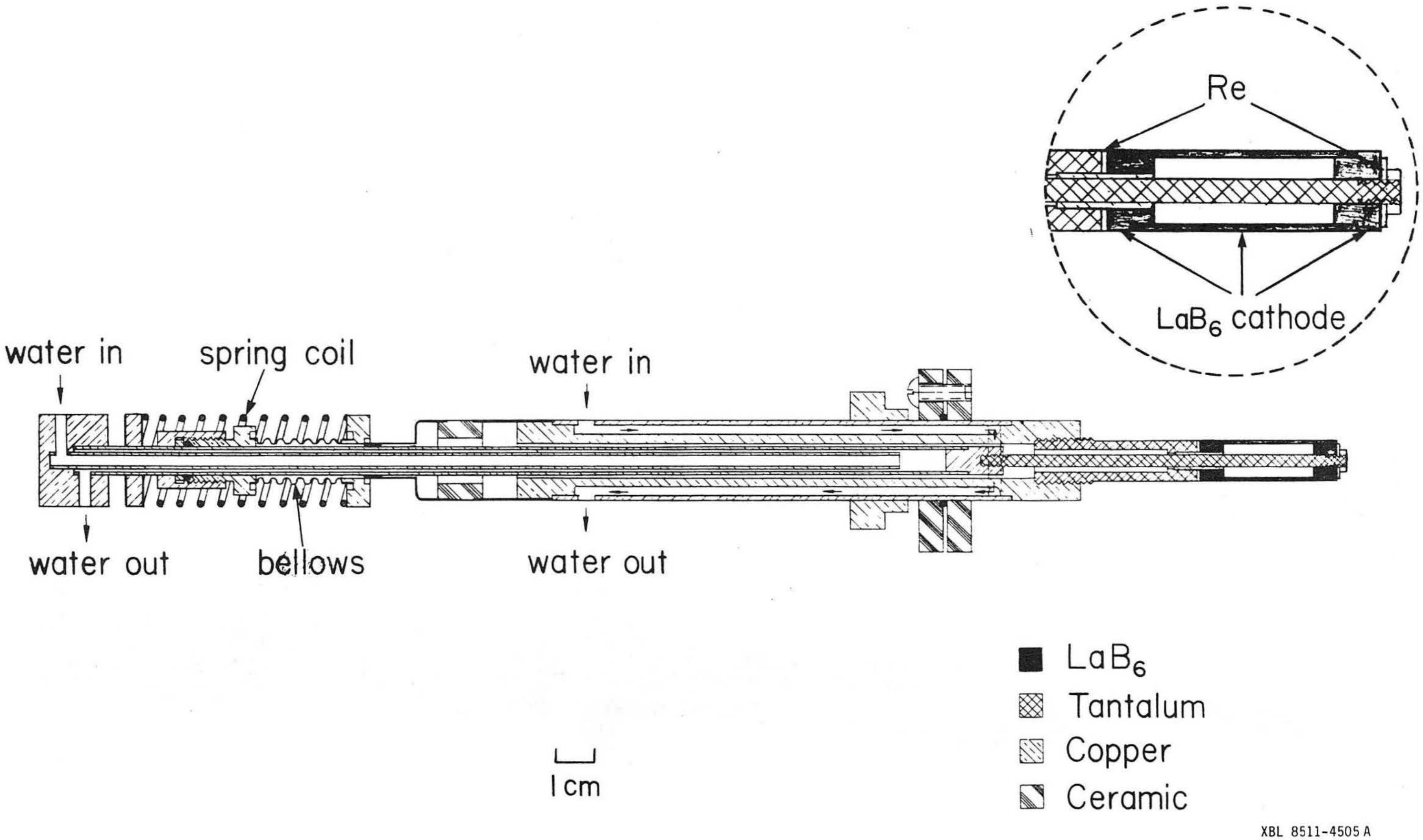
Re
LaB$_6$ cathode
water in
spring coil
water in
water out
bellows
water out
LaB$_6$
Tantalum
Copper
Ceramic
1 cm
XBL 8511-4505 A

Fig. 2

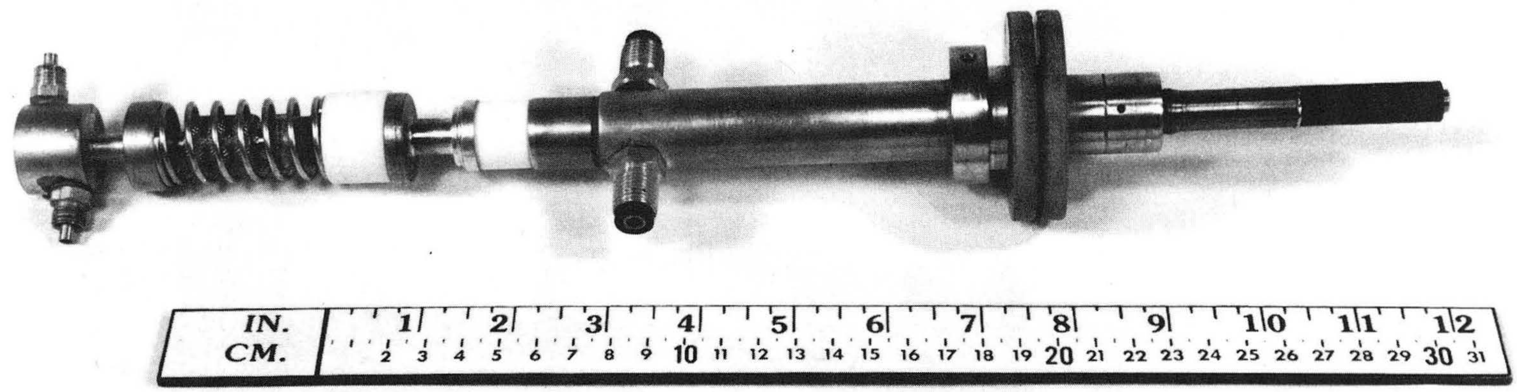

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Fig. 3

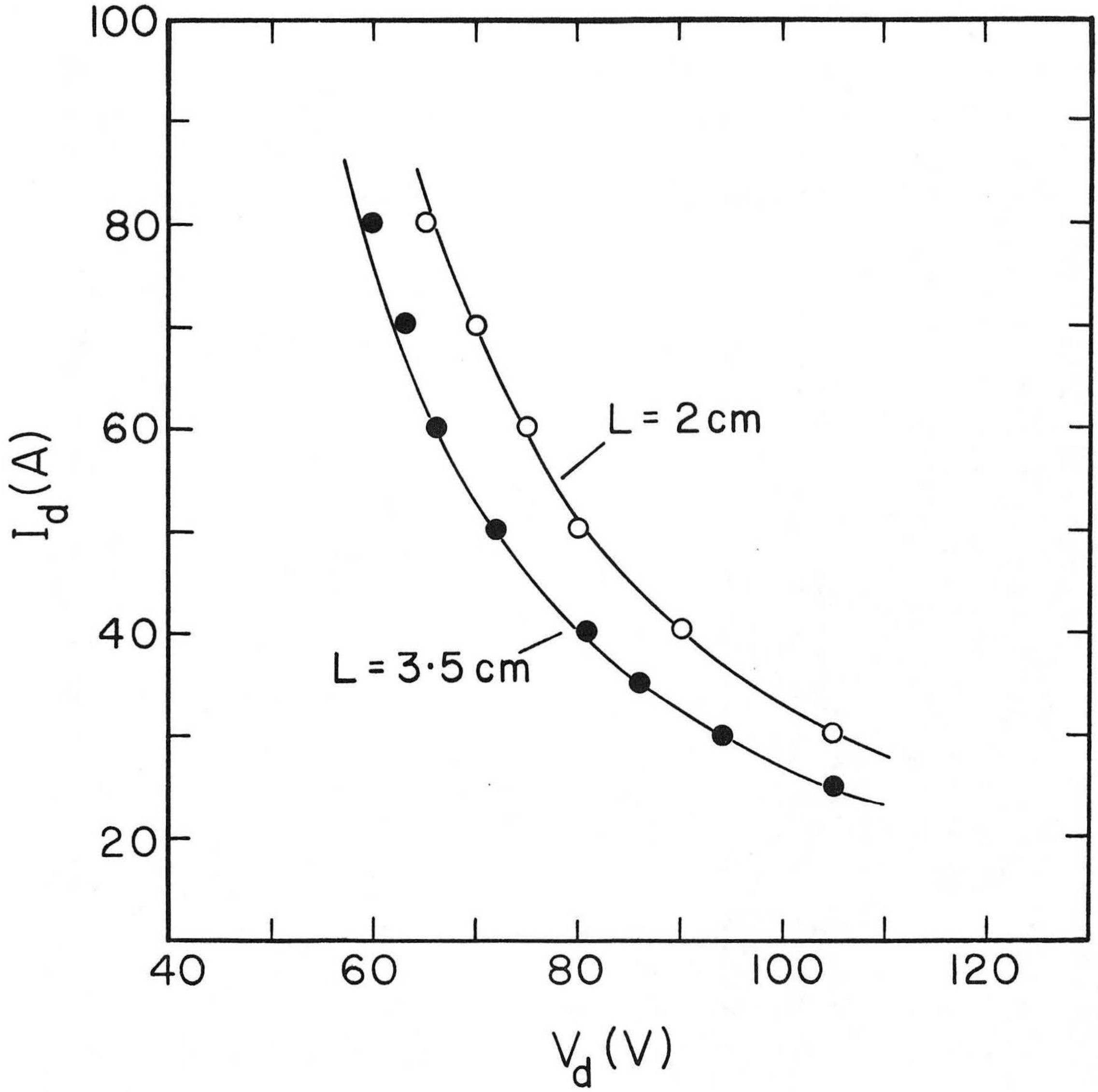

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Fig. 4

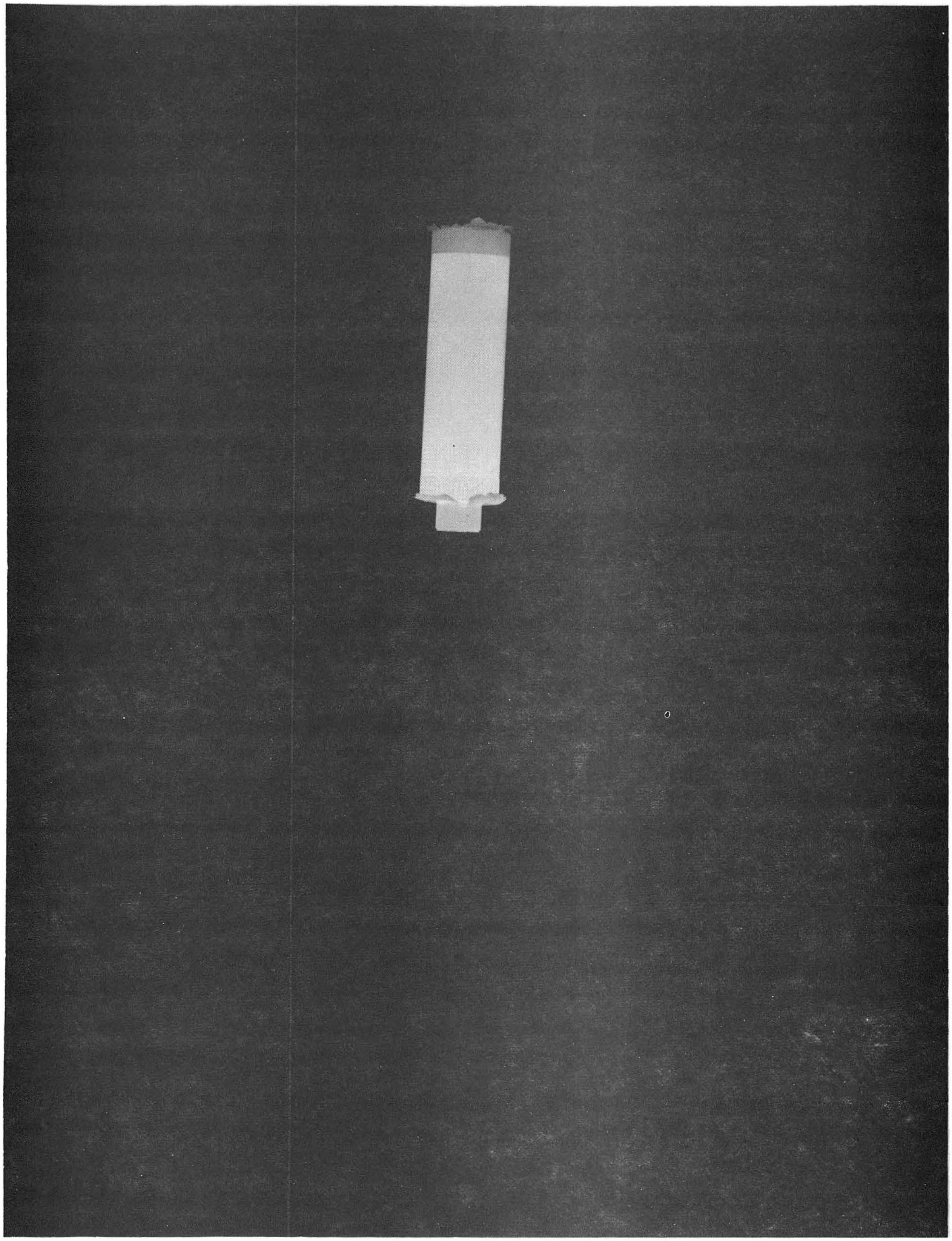

Fig. 5

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