Title
DIRECTLY HEATED LaB, CATHODES FOR ION SOURCE OPERATION

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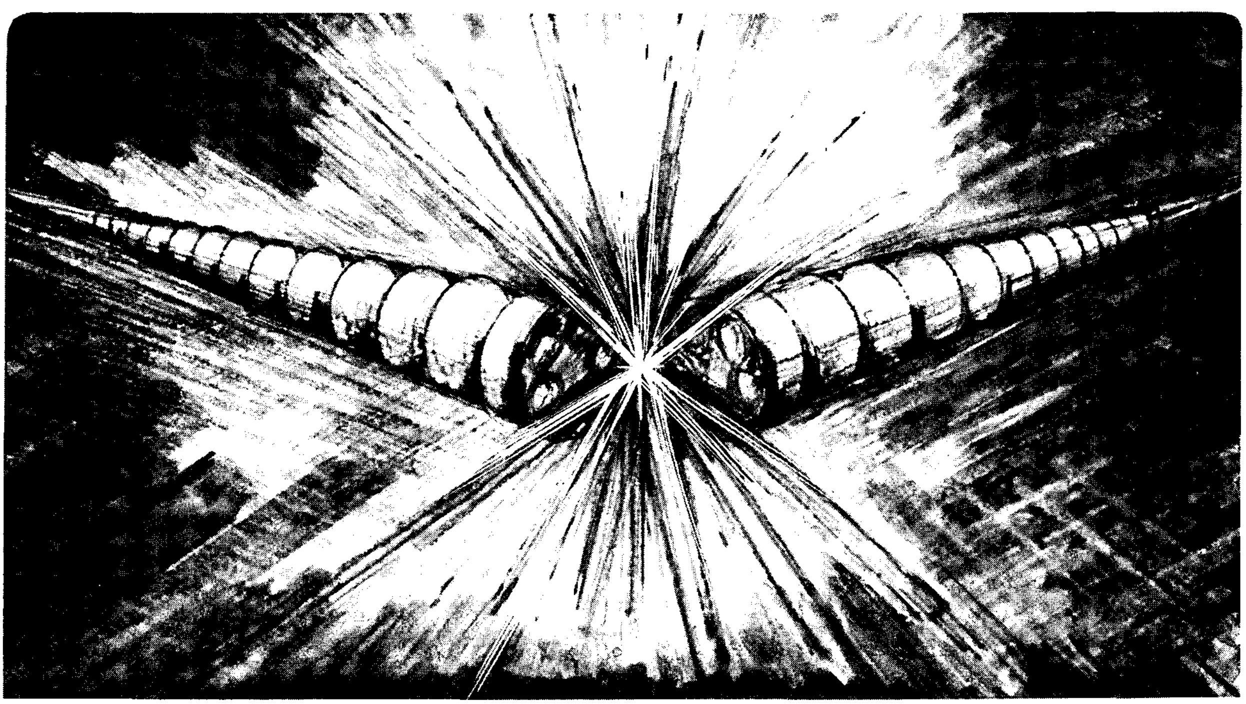

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Directly Heated LaB_6 Cathodes for Ion Source Operation

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Abstract

Some physical properties of lanthanum hexaboride "filaments", when operated as cathodes in a gas discharge, are presented. These directly heated hairpin shaped filaments have been tested in different types of ion sources and are shown to be capable of long pulse or cw discharge operations. The characteristics of a shaped lanthanum hexaboride filament for the purpose of further extension of lifetime is discribed. The design and operation of a magnetic-field-free, directly-heated, coaxial LaB_6 cathode is also discussed.

Introduction

It has been known for some time that lanthanum hexaboride (LaB_6) is a good material for use as an electron emitter. It has unusual physical properties such as a high melting point, chemical inertness, low work function, high brightness of emission current, and resist erosion under ion bombardment. For this reason, LaB_6 cathodes are now widely used in many branches of modern technology such as electron microscopes, mass spectroscopes, plasma sources, and thermionic converters. In most applications, LaB_6 is operated as an indirectly heated cathode, either in the form of a small crystal structure or in some geometric form with a heater behind it.

In this paper, the characteristics of LaB_6 when operated as a directly heated "filament" cathode[1] is presented. These LaB_6 filaments perform satisfactorily in different types of ion sources where tungsten filaments are normally employed. 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 emission can be obtained from the entire filament surface.[2]

In some experiments, very low discharge voltages are required. The design of a 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 voltages, the cathode is capable of producing discharge current over 100 A in a steady state plasma source operation.

1. LaB_6 filament operation

The properties of LaB_6 have been investigated by many authors.[3-5] When heated to a temperature of $1600^{o}K$ 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. 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.

LaB_6 is a very hard material and is best cut with diamond tools. Figure 2 shows a picture of different shapes of LaB_6 hairpin filaments which have been fabricated. In these hairpin configurations, the filament can expand and contract freely in a manner similar to regular tungsten hairpin filaments. Since LaB_6 attacks metals like copper and molybdenum, the hairpin filaments are mounted either on graphite holders or on molybdenum chucks but with the filament feet wrapped with rhenium foil.

The discharge characteristics of a single LaB_6 filament (cross-sectional area = 1.6 x 3 mm^2) have been studied in a cylindrical multicusp ion source[6] operated with hydrogen or argon gas. The filament was biased at -80 V with respect to the source chamber wall. With a filament heater current of about 125 V and a temperature of $1650^{o}K$, the LaB_6 filament should be able to provide 2 A of emission current. However, a steady state discharge current of more than 40 A was obtained from a single rectangular-shaped LaB_6 hairpin filament due to the additional heating from ion bombardment. The filament was operated with this discharge current for several hours. When the source was opened, no significant change in the color of the filament was observed.

During the discharge operation, the emission current could be easily regulated by adjusting the filament heater current in a manner similar to the operation of an ordinary tungsten filament. The power consumed in heating the LaB_6 filament was about 150 W. In comparison, a 10-cm-long, 0.15-cm-diam tungsten filament requires about 1.1 kW of heating power to produce 40 A of discharge current with a discharge voltage of 75 V. Thus, the tungsten requires about 9 times more heating power than the LaB_6 hairpin filament.

In some applications, such as the neutral beam injection systems in fusion research, hundreds of amperes of electron emission current are required for the operation of the ion source with pulse length in tens of seconds. If tungsten filaments are used as the cathode, a large number of filaments are required and their lifetime is always limited to evaporation and arc spotting. In order to test multiple filament operation, eight circular-shaped LaB_6 hairpin filaments were installed in a multicusp source. The source operation was similar to arc discharges using 0.15-cm-diam tungsten filaments. A discharge voltage of 100 V and current of 430 A produced an extractable ion current density of 220 mA/cm^2 during 7 seconds of discharge time.[1]

In this multiple filament operation, the pulse length was limited to 10 seconds or less due to inadequate cooling of the ion source chamber. However, the set of LaB_6 filaments can be operated with longer pulse or even cw if the discharge chamber is properly designed for high-power loading and the vacuum system is adequately pumped. When the filaments were examined after the test, no significant erosion marking due to sputtering could be observed on the surface.

2. Tapered LaB_6 filament

In a high-density discharge plasma where the filaments emit a significant electron current density, the temperature distribution along the filament is nonuniform. The result is that only a small part of the filament provides the bulk of the emission current and, hence, the lifetime of the filament is reduced. One method of solving this localized emission problem is the use of a filament with a variable cross-sectional area.[2] For this application, the LaB_6 can be cut in different geometrical shapes much easier than regular tungsten material.

Consider a rectangular LaB_6 filament with uniform thickness but with a variable width. When this filament is operated as a cathode in a discharge, it will be heated by Ohmic dissipation and by plasma ion bombardment of the surface and cooled by electron emission and by radiation. If heat conduction to the filament chucks is neglected, then a power balance equation can be obtained as shown in Refs. (1) and (2) and from this the proper tapering of the filament can be estimated.

A tapered LaB_6 filament (Fig. 3) has been designed and tested in a multicusp plasma generator. A heater current was first applied until the filament reached steady-state temperatures. Figure 3a shows that the filament was hot only at the positive (narrow) end. Once the discharge was initiated, the temperature of the negative (wide) end (to which the negative terminal of the discharge supply is connected) gradually increased with the discharge current. In this particular design, the temperature of the whole filament became fairly uniform (Fig. 3b) when the discharge current reached ~ 80 A. Although the filament was not tested to burn out, it was estimated that the lifetime of this tapered filament should be improved by a factor of three to four.

3. Directly-heated coaxial LaB_6 cathode

In some experiments, very low energy electrons are required. 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[7] or by using a coaxial cathode structure to cancel the magnetic field produced by the heater current.

Figure 4 shows a simple, directly heated, coaxial LaB_6 cathode. This cathode assembly has been tested in a multicusp plasma generator operated with hydrogen gas at a pressure of 1 mTorr. 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. Because of the coaxial structure, the magnetic field generated by the heater current was 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 by ion bombardment from the plasma. As a result, the source operation is maintained just by a single discharge power supply.

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 had been observed to last more than 1,000 hours of continuous operation.[8] 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. Directly-heated hairpin LaB_6 filaments.

Fig. 3 Tapered LaB_6 filament operated (a) with 90 A of heater current only, and (b) with a discharge current of ~ 80 A.

Fig. 4 A photograph of the coaxial LaB_6 cathode assembly.

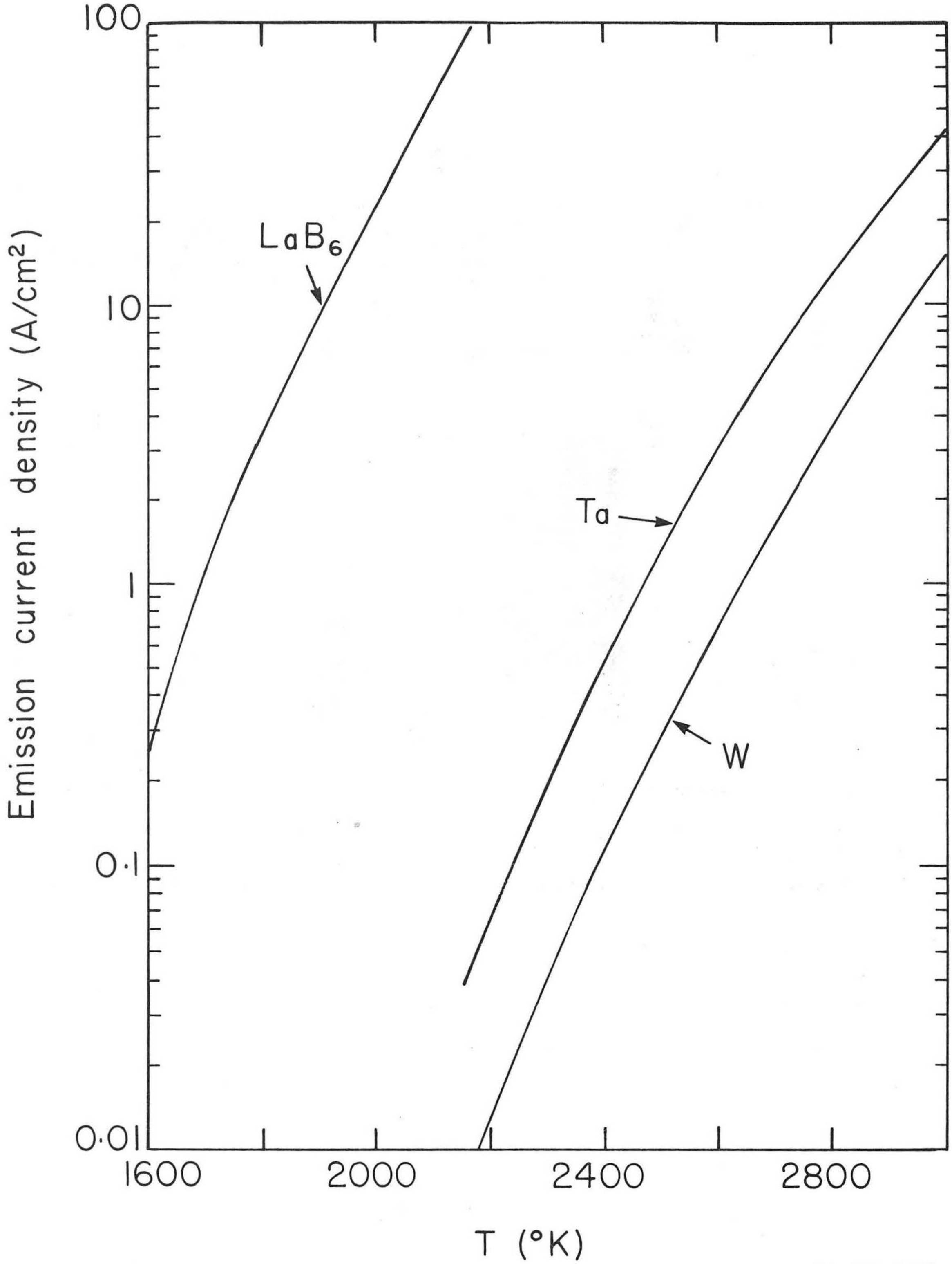

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Fig. 1

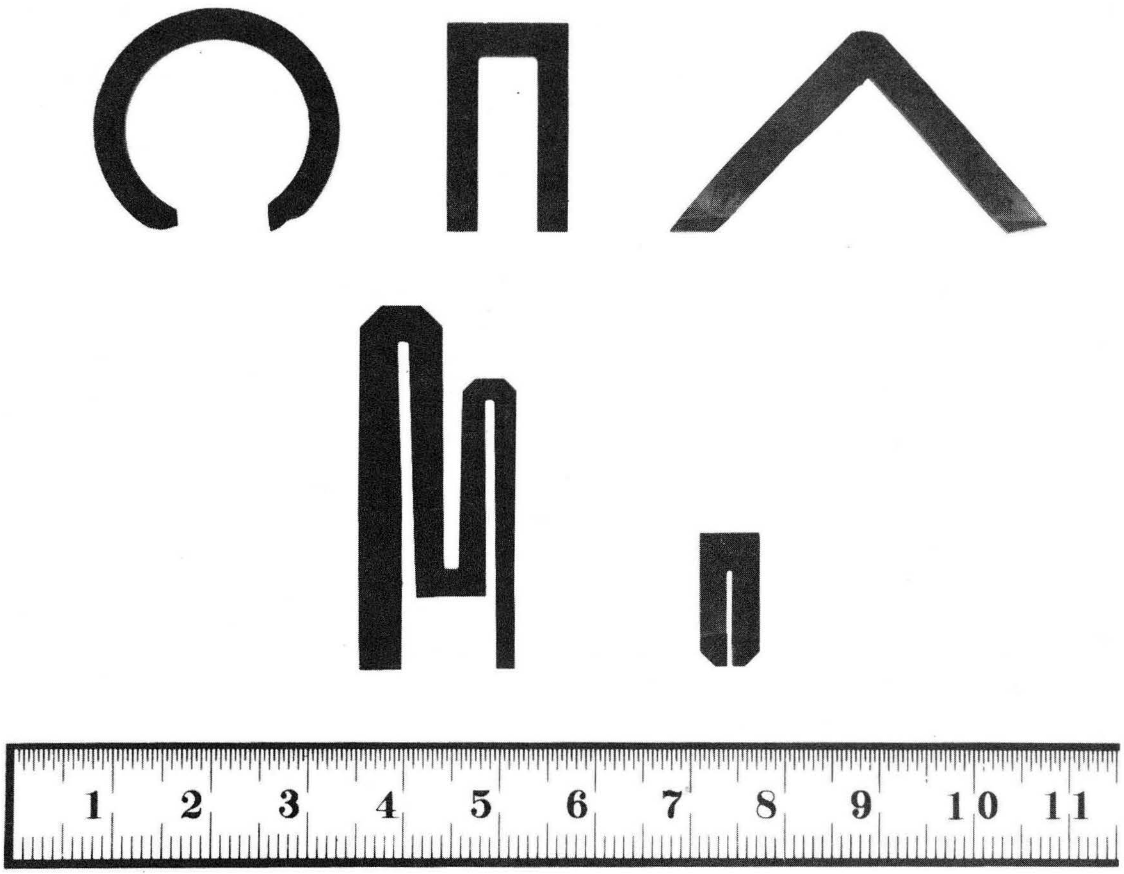

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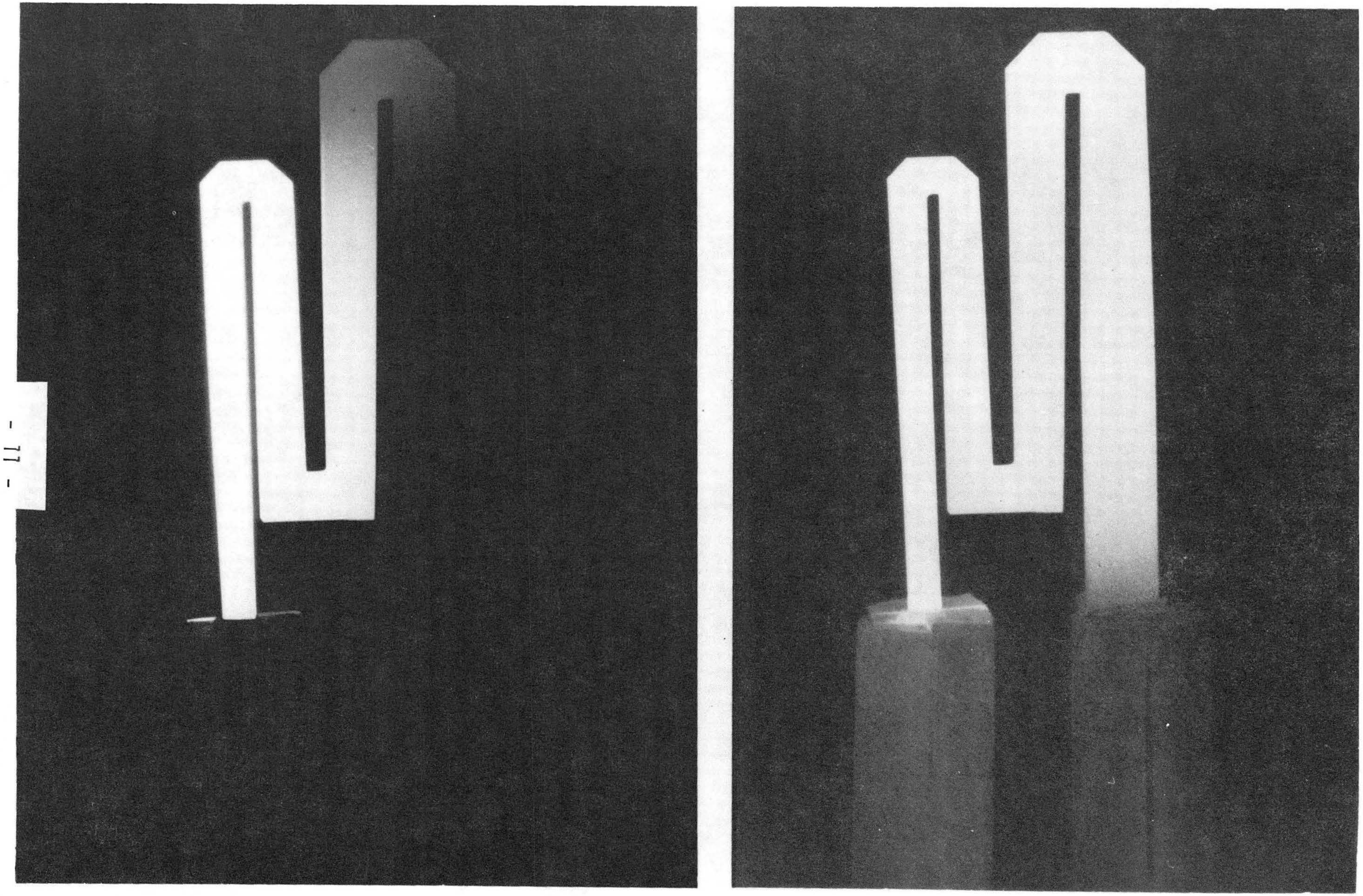
Fig. 2



(a) Fig. 3 (b) CBB 847-6284A

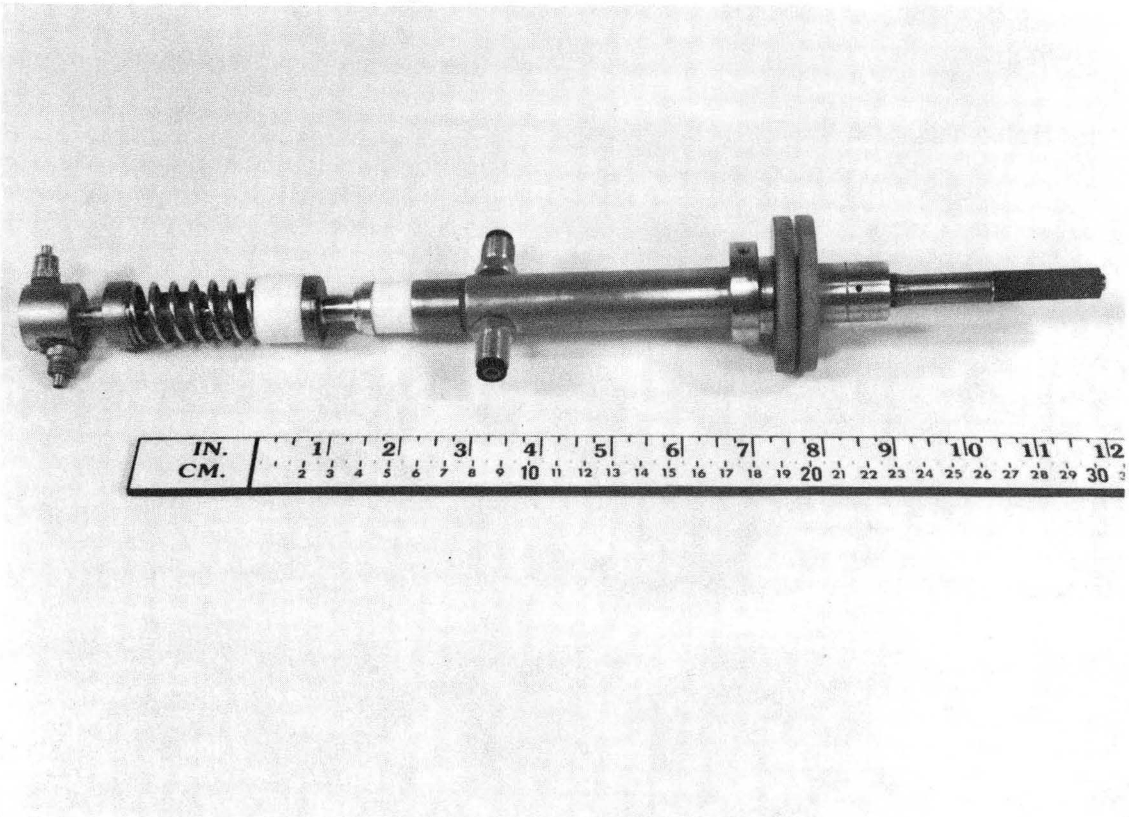


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Fig. 4

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