CONF-791102--152(Draft)

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HOLLOW CATHODE FOR POSITIVE ION SOURCES*

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Summary

Development to incorporate hollow cathodes into high power ion sources for neutral beam injection systems is being pursued. Hollow tube LaB_6-type cathodes, similar to a UCLA design, have been constructed and tested in several ORNL ion source configurations. Results of testing include arc discharge parameters of >1000 and 500 Amps for 0.5 and 10 second pulse lengths, respectively. Details of cathode construction and additional performance results are discussed.

Introduction

Next generation fusion experiments will require neutral beam heating for several (5-10) seconds duration. In the development of the positive hydrogen (deuterium) ion sources for these neutral beam injectors, one component that will require improvement is the electron emitter(s) (filaments or cathodes). The electron emitter(s) in one ion source should be able to sustain a hydrogen discharge of 1000 to 2000-A for ≥10 second pulses. It would also be desirable if the emitter had a long lifetime, was indirectly heated, required low input power, was able to withstand ion bombardment and would not be poisoned by exposure to air.

Multiple filaments, either tungsten or of the barium oxide coated type, lack most of these properties and will become very cumbersome to employ. A lanthanum hexaboride (LaB_6) hollow tube cathode design by UCLA appears to have these properties and therefore would seem to be a likely candidate.

One of these cathode assemblies shown in Fig. 1 was brought from UCLA and tired in an ORNL 22-cm PLT-type ion source. The results that were reported,[2] included discharge parameters of 800-A and 90 V. Although some problems were encountered such as sagging and shorting of the heater to the molybdenum housing and arc spotting of holes in the molybdenum, the basic operation was satisfactory and encouraging. We therefore decided to improve the mechanical design of this LaB_6 hollow tube cathode and do further testing in other ORNL ion source configurations.

Cathode Assemblies

Mod I Version

One version (Mod I) of the ORNL design is shown in Fig. 2. The heater consists of a 1.27 cm inside diam by 0.03 cm thick wall by 3.8 cm long, chemical vapor deposited tungsten cylinder that was slotted by EDM to create a resistive path as shown in Fig. 3. This was then T.I.G. welded to two tungsten support rods of 0.24 cm diam. We tried making heaters using thicker walled cylinders with more slots to produce the desired resistance but they tended to warp during use and short to the LaB_6. The cathode housing is made of tungsten. It was formed by plasma spraying powdered tungsten onto a mandrel 3.8 cm diam to desired thickness. It was then removed and sintered in hydrogen at ~1700°C. Several housings were made with different sized apertures.

The LaB_6 cylinder, with dimensions of 1.9 cm I.D. by 2.5 cm by 4 cm long was machined from a solid hot pressed billet using diamond tooling. The LaB_6 was supported at one end by a tantalum tube with a split graphite ring in between. The tantalum tube had multiple slits at one end forming "fingers," the ends of which were secured around the graphite ring with tantalum wire. All of the above mounted to a stainless steel block which in turn mounted to a water cooled copper flange.

Mod II Version

Figure 4 shows an alternate hollow cathode design with which we have some preliminary results. The main difference in this design is the location of the heater. It has been put around the outside of the LaB_6 cylinder. This was done to eliminate the evaporation and sputtering of tungsten from the heater onto the inside emitting surface of the LaB_6 cylinder as was observed with the Mod I version. This heater is of the same slotted cylinder design as in the Mod I version but with dimensions of 3.18 cm diam by 5.08 cm long. Initially, heaters of plasma sprayed tungsten were prepared, but they proved too brittle to handle. We therefore made one of tantalum. A cylinder was rolled from 0.03 cm thick sheet and the seam T.I.G. welded. So far this has performed satisfactorily. Another difference is that the tungsten aperture is mounted in a water cooled copper housing. The LaB_6 cylinder, heater and heat shielding are mounted inside a tantalum tube. This tube is mounted to a water cooled copper flange which is insulated from the outer housing. This provided the possibility of applying a striking potential between the LaB_6 cylinder and the outer housing and aperture. When first operated, we found that the arc would not strike with the LaB_6 cathode section and the outer housing connected together. The outer housing was therefore connected to the positive side of the arc supply through a 1000 Ω resistor and the arc would then strike.

Operation and Results

Mod I Version

The Mod I cathode required ~1.2 kW heater power (~8 V, ~150 A) to maintain the LaB_6 at ~1600°C for operation. Using a tungsten housing with a 0.3 cm aperture, the cathode was operated in a 15 cm magnetic cusp type ion source with anode chamber measuring 25.4 cm in diameter by ~37 cm long. See Fig. 5. Discharges up to ~100 V and 500 A for pulse durations to 10 sec were maintained. The plasma uniformity was scanned with a Langmuir probe near the plasma electrode and found to be ~±10% over a 15 cm diam. The probe current also followed the arc current fairly well. See Fig. 6.

Another ion source configuration in which the Mod I cathode was operated is shown in Fig. 6. The anode chamber measured 31 cm diam by 60 cm long. No intermediate electrode was used. Arc discharges >1000 A for 0.5 sec duration were maintained while extracting a beam current of 30 A at 35 keV. Plasma uniformity was ~±5% over a 25 cm diam. A species ratio of ~80%:10%:10% for H_1^+, H_2^+, and H_3^+, respectively was also measured. See Fig. 8

*Research sponsored by the Office of Fusion Energy, U. S. Department of Energy, under contract no. W-7405-eng-26 with Union Carbide Corporation.

The Mod I cathode was also operated in a 30 cm duoPIGatron PDX type ion source as a direct replacement for the usual 12 oxide coated filament array. Using a tungsten housing with a 0.6 cm diam aperture, discharges of ~1000 A for 0.15 sec duration were achieved.

Mod II Version

The Mod II cathode required ~1.3 kW (~8 V, ~ 160 A) heater power. It was first tried with a 0.3 cm diam tungsten aperture but the arc would not stike. The aperture was therefore increased to 0.48 cm and the cathode operated in the 15 cm ion source in two different configurations.

The first was as shown in Fig. 5. It was operated with discharges to 550 A, 85 V and 1 sec. The arc current started at ~300 A and increased to 550 A in ~0.8 sec. Increased heater power didn't improve this. Also, small changes in gas feed caused mode switching (sudden change in arc current) during the pulse. Another observation was that the Langmuir probe current near the edge of the plasma decreased with increasing arc current.

The other configuration tried, using the Mod II cathode was as shown in Fig. 7. The cathode replaced the oxide filament array of a duoPIGatron type electron feed assembly on the 15 cm ion source. Discharges of 500 A, 100 V and 0.9 sec were achieved. The arc current started at ~350 A and increased to 500 A in ~0.3 sec while the Langmuir probe current was level for the first 0.3 sec and then started decreasing slowly.

Discussion

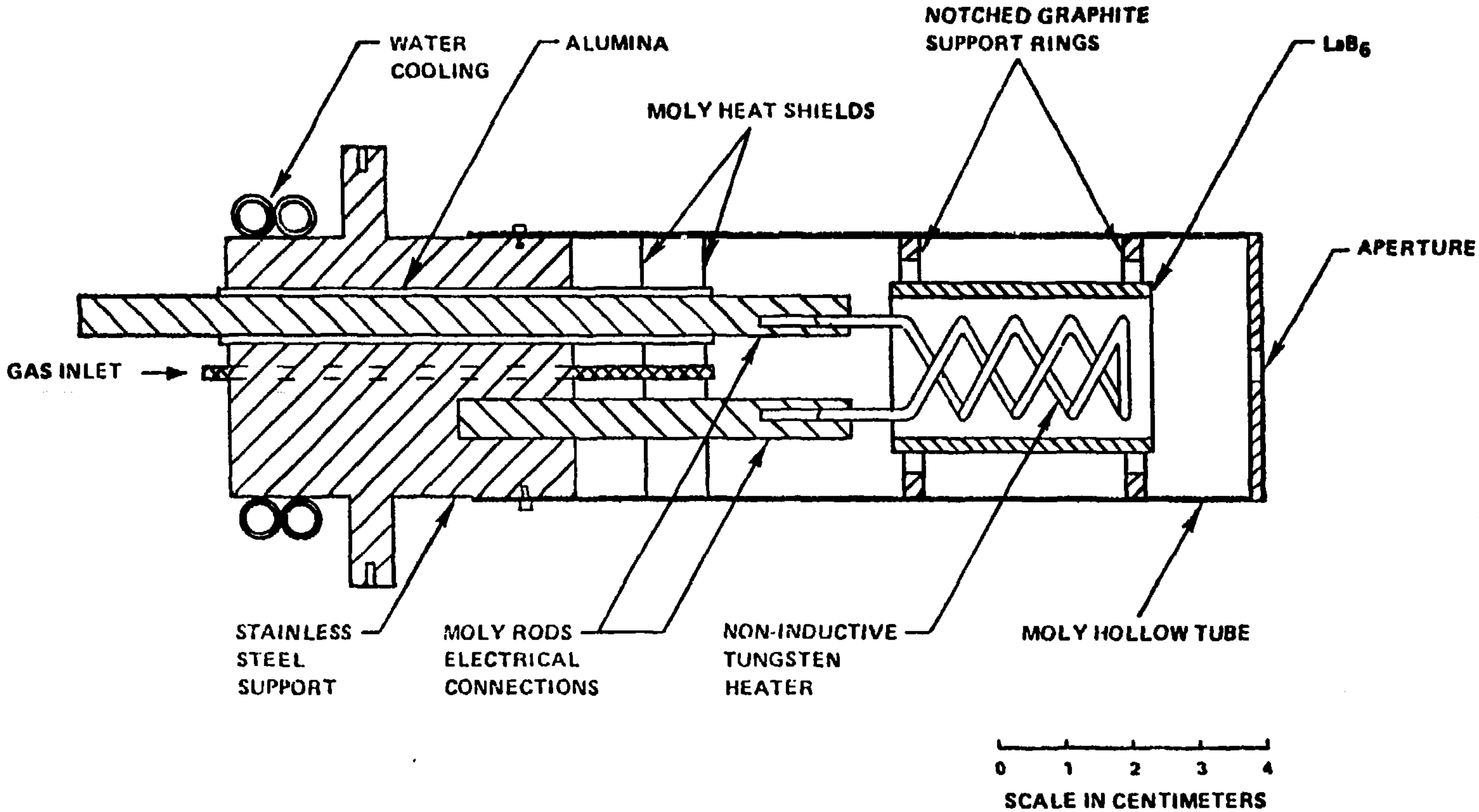
Results so far, indicate that LaB_6 hollow cathodes of the type tested should be capable of 1000 A/10 sec type discharges. The gas feed, however, was ~50% greater than required for our standard duoPIGatron electron feed, making efficiency poorer.

More testing needs to be done to improve the efficiency and determine lifetimes and reliability. Also, plasma purity needs to be examined.

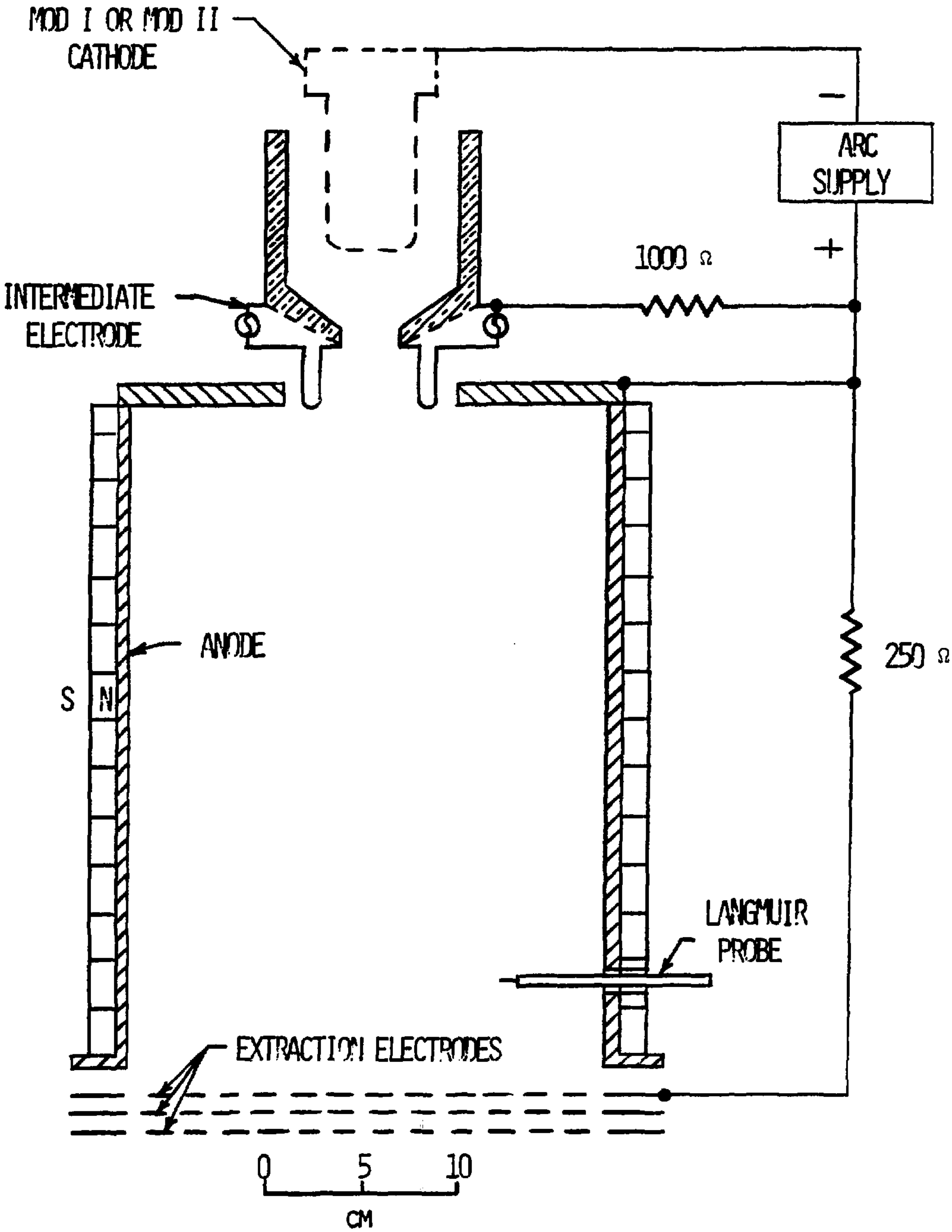
References

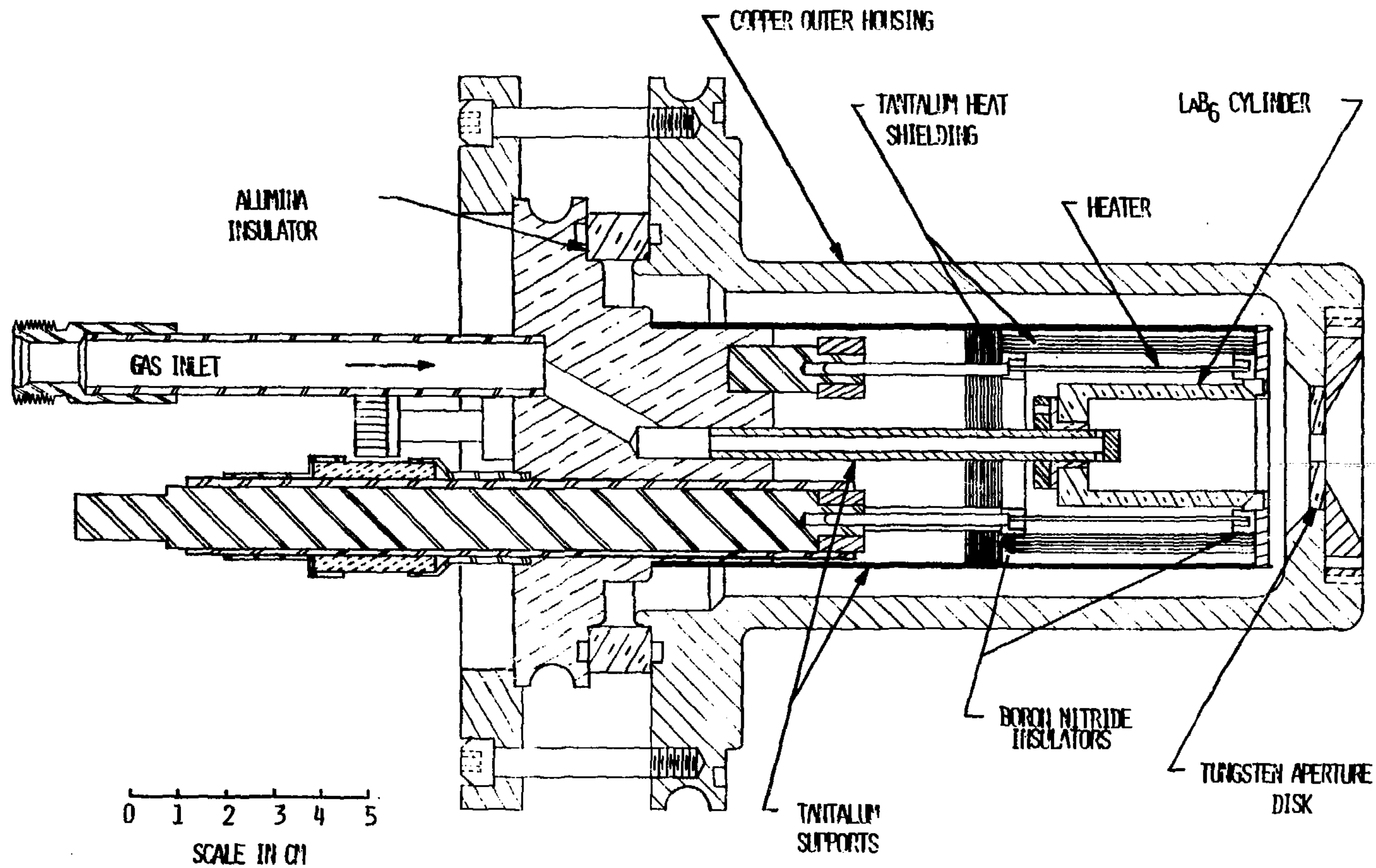
1. D. M. Goebel, J. T. Crow, and A. T. Forrester, Rev. Sci. Instrum. 49, 469 (1978).

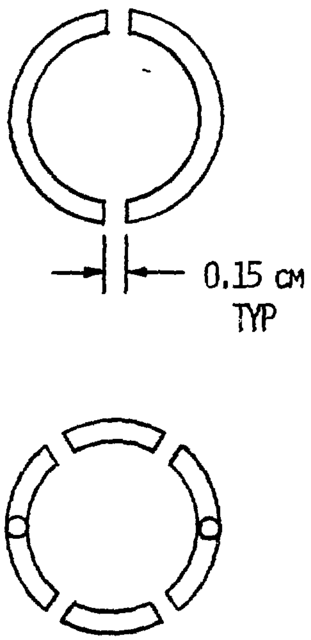
2. J. Kim et al., Plasma Technology Section TM 163, Oak Ridge National Laboratory, 1979.

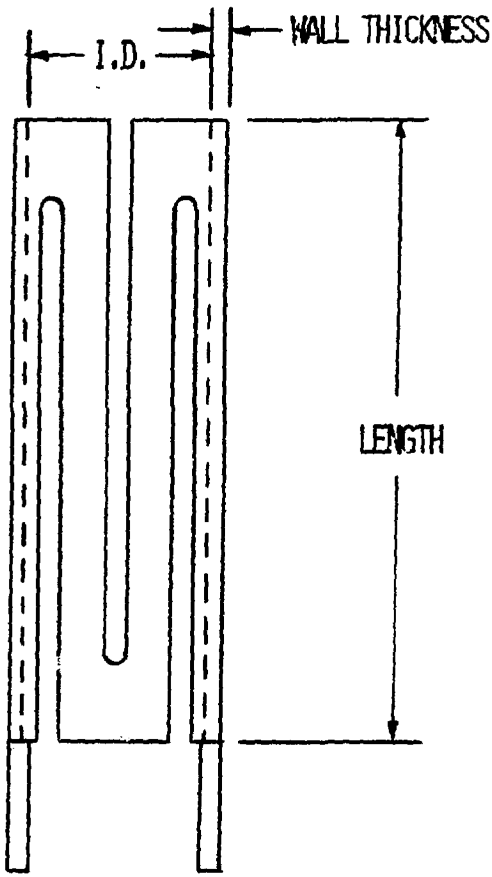


WATER COOLING
ALUMINA
NOTCHED GRAPHITE SUPPORT RINGS
LaB_6
MOLY HEAT SHIELDS
APERTURE
GAS INLET
STAINLESS STEEL SUPPORT
MOLY RODS ELECTRICAL CONNECTIONS
NON-INDUCTIVE TUNGSTEN HEATER
MOLY HOLLOW TUBE
0 1 2 3 4
SCALE IN CENTIMETERS

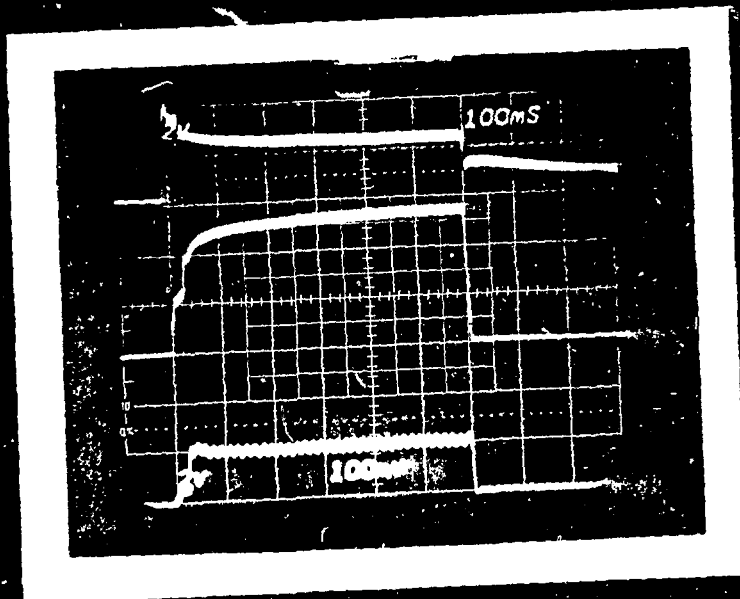

MOD I OR MOD II
CATHODE
ARC
SUPPLY
−
+
1000 Ω
INTERMEDIATE
ELECTRODE
ANODE
S
N
250 Ω
LANGMUIR
PROBE
EXTRACTION ELECTRODES
0
5
10
CM


COPPER OUTER HOUSING
TANTALUM HEAT SHIELDING
LaB6 CYLINDER
HEATER
ALUMINA INSULATOR
GAS INLET
BORON NITRIDE INSULATORS
TUNGSTEN APERTURE DISK
TANTALUM SUPPORTS
0 1 2 3 4 5
SCALE IN CM





	MOD I	MOD II
I.D. (CM)	1.27	3.18
WALL THICKNESS (CM)	0.03	0.03
LENGTH (CM)	3.8	5.08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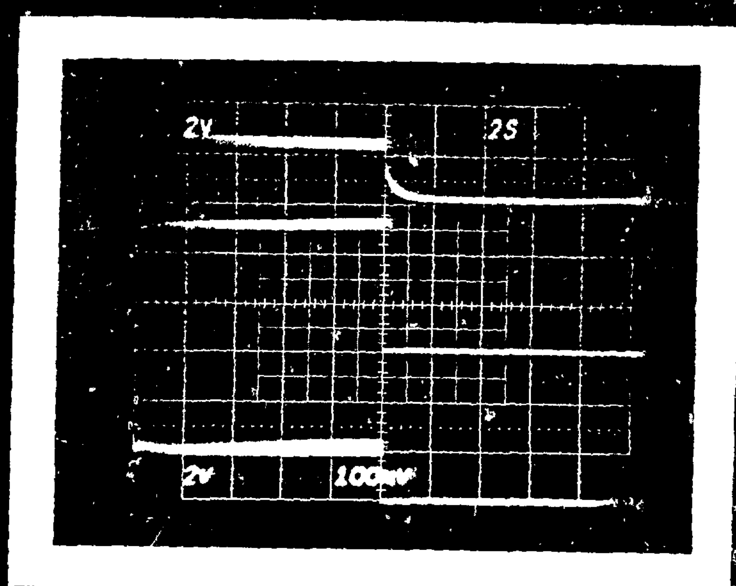
100mS
2V
100mV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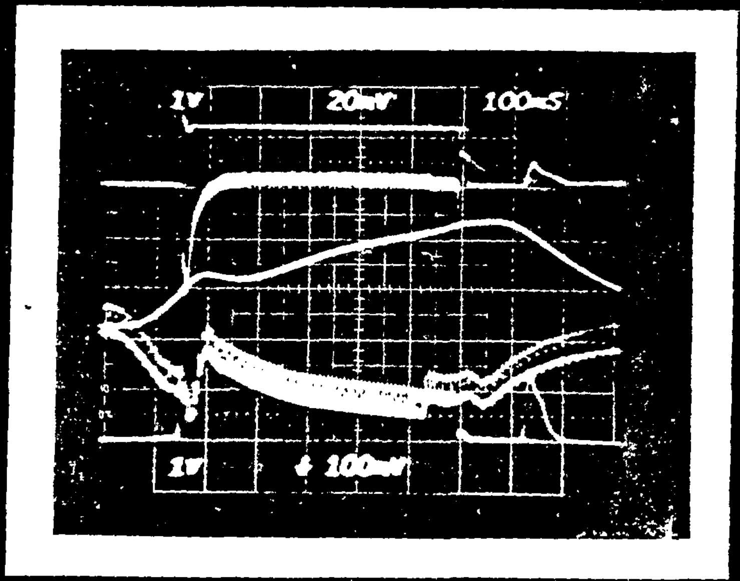
2S
2V
100mV



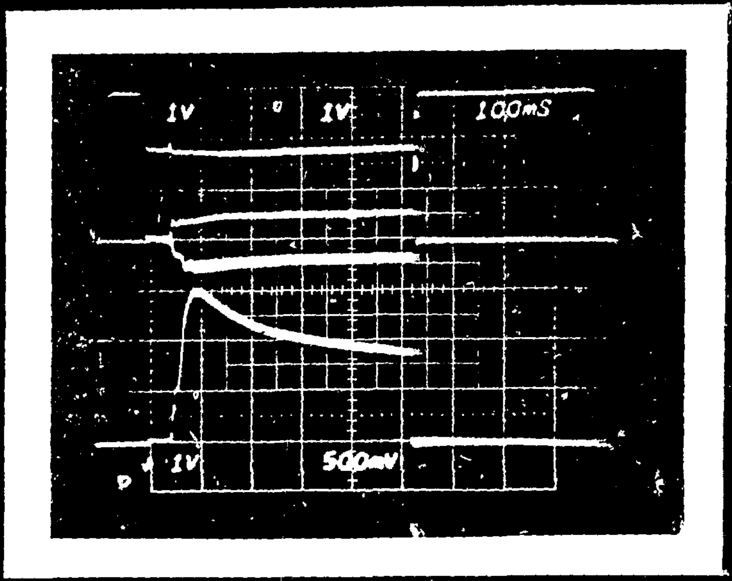
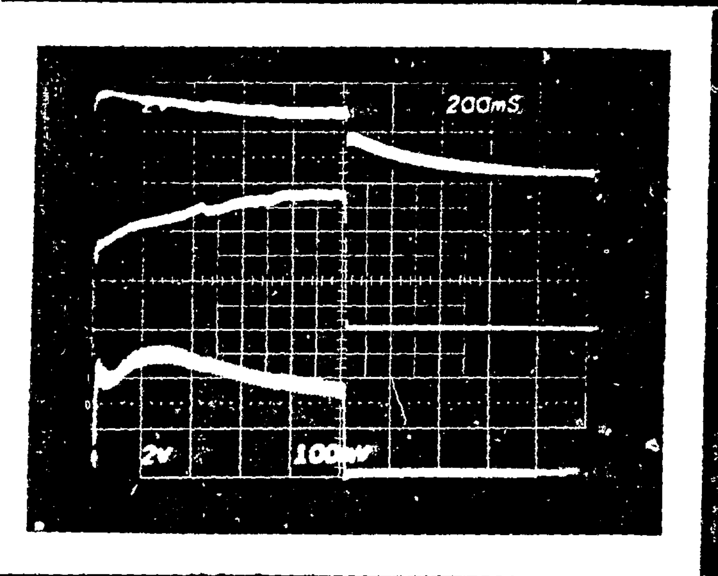


Fig. 8



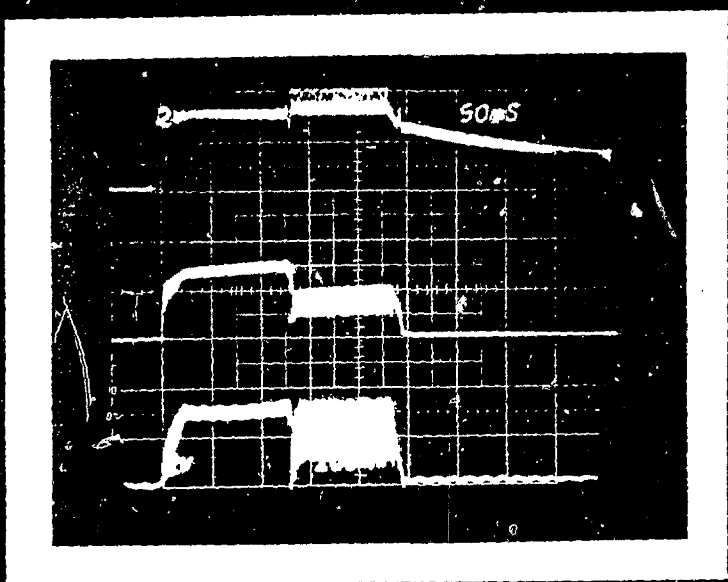
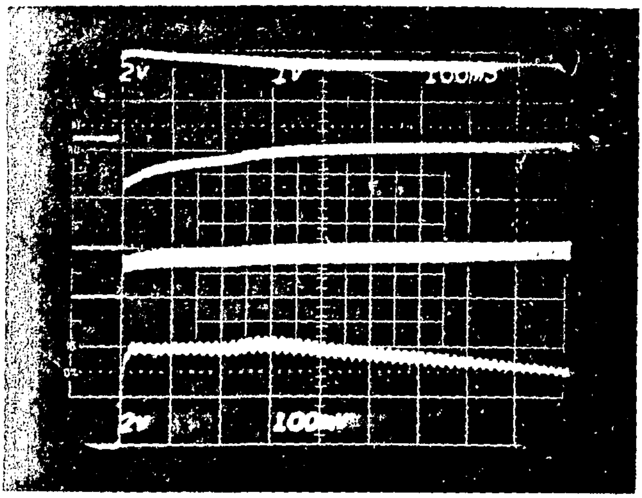


Fig. 9


2V
1V
100mS
2V