Simple, high current LaB_6 cathode

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A cathode constructed of a thin, directly heated strip of LaB_6 is described. The cathode is simple to construct, requires modest heating power, has high current emission capability and is quite rugged. Construction details will be given and cathode performance data presented. The cathode has been used in tokamak dc current injection experiments.

Recently, there has been much interest in the development of LaB_6 cathodes due to their high current emission capability. LaB_6, however, is fragile and highly susceptible to fracture under the stress of thermal cycling. Previous cathode designs[1-3] have circumvented this problem by indirectly heating the cathode, which requires high input power and a complex configuration, or by directly heating specially designed LaB_6 filaments. Neither method has achieved the high cathode temperatures necessary for efficient, high current density emission. This paper describes a simple, inexpensive, extremely high current density LaB_6 cathode which requires comparatively low power and is impervious to thermal cycling. The maximum current emitted by the cathode was 175 A, for an average current density of 140 A/cm^2, with input power of only 250 W. The essential design elements which enabled high current output with low power input were the use of very thin directly heated filaments with filament holders also made of LaB_6 which eliminated fracture during thermal cycling.

The cathode, shown schematically in Fig. 1, was built directly on a vacuum flange with high current feedthroughs (Ceramaseal 804B2779-01-W, 150 A, 12 kV). Boron nitride was painted on the feedthrough base to prevent arcing, while the use of graphite rods prevented surface contamination of the filament. Parallel slots were filed in the rods to accommodate LaB_6 filament holders which were secured with shims of 0.1-mm graphite sheet.

Both holders and filaments were cut and ground to size by a local petrographics firm from LaB_6 disks. Holders with less than a 3-mm-square contact area did not provide enough surface area for good electrical contact. Filaments were about 25 mm long, 3 mm wide and 0.4–0.5 mm thick. Some were ground to be 0.02–0.07 mm thinner at the ends to give more uniform heating across the filament. Shims made from thin slices of LaB_6 etched in a nitric acid solution secured the filament in the holder. When the electrical contact was sufficient for high-temperature operation, the filament was observed to heat from the middle rather than from the contact points. Poor electrical contact resulted in overheating and melting at the point of contact.

The filaments were heated directly with ac power by means of a 5–V 115-A transformer controlled with a variac. The feedthrough temperature was never more than 100 °C indicating localized heating at the filament. The filament was typically operated in argon with the chamber functioning as the anode. Due to power supply limitations, the discharge voltage was pulsed and we were unable to run dc discharges.

A number of experimental tests of the cathode have been performed in a large (25 ℓ) vacuum vessel. The cathode has been operated continuously in 150 mTorr of argon for over 60 h at 1800 °C (measured with an optical pyrometer) with pulsed emission current of 125 A (1% duty cycle), corresponding to 100 A/cm^2. The discharge current was measured with a transformer-type current monitor. The input heating power was 240 W and discharge voltage 140 V for this experiment. The higher sublimation rate at the central (hottest) part of the filament and attendant local increase in heating ultimately caused the filament to melt there. Thus, filament lifetime has been determined to be a strong function of operating temperature but we were unable to ascertain the effects of dc ion bombardment on filament lifetime.

In Fig. 2, (a) typical current and (b) discharge voltage pulses are shown. The current pulse was flat and noise-free up to the highest emission obtained. A 100-A discharge from the cathode in 150 mTorr of argon produced a plasma with a space potential of $\simeq 30$ V, density $\simeq 10^{10}$ cm^{-3}, and $T_e \simeq 3$ eV, as measured by a Langmuir probe 20 cm from the cathode in the afterglow plasma. We can estimate the plasma density at the cathode sheath from the relations[4] $J_e \cong (M_i/$

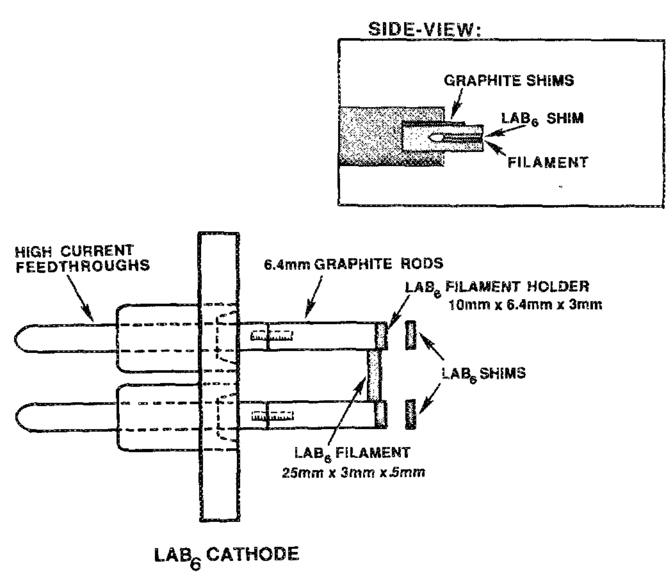

FIG. 1. Schematic drawing of LaB_6 cathode. The LaB_6 filament holder serves as a thermal anchor eliminating fracture during thermal cycling.

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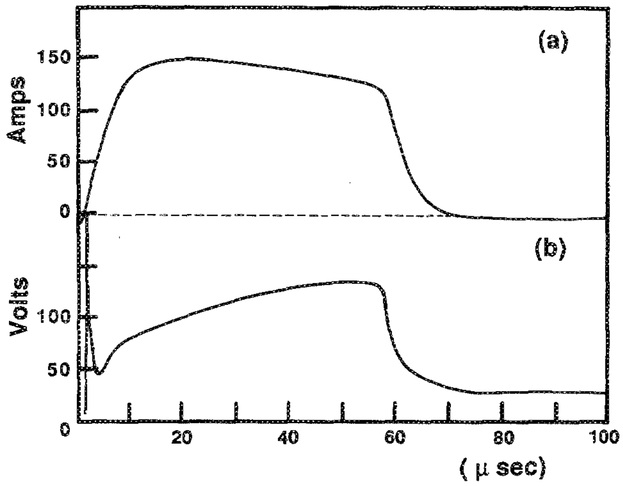

FIG. 2. Typical traces of (a) emitted current and (b) applied bias voltage for a 60-μs shot.

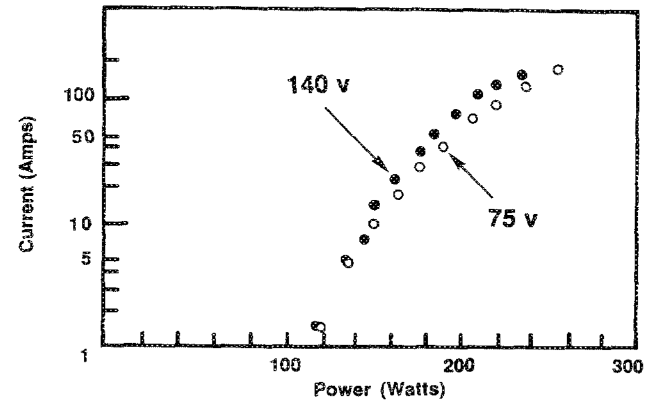

FIG. 3. Plot of emitted current as a function of heating power for two bias voltages (75 and 140 V). Note that the cathode is thermally limited over most of the operational range. Current limited operation is only evident at relatively high powers.

$m_e)^{1/2} J_i$ and $J_i \cong nec_s$, where J_i is the ion current to the cathode and c_s is the ion sound speed. For a discharge current of $J_e = 100$ A/cm^2 we find $n \simeq 10^{13}$ cm^{-3}. Evidently, dense plasma produced at the cathode expands to fill the large vacuum vessel.

A plot of emitted current versus heating power is shown in Fig. 3 for discharge voltages of 75–140 V. Note that we are evidently operating in a thermally limited (as opposed to current limited) regime. Experiments performed at fixed voltage showed that saturated emission current (i.e., the emission level at which current no longer increases with either discharge voltage or pressure) followed the Richardson equation for temperature limited current emission, $J = AT^2 e^{-e\phi/kT}$, where $A = 120$ A/cm^2 T^2 for LaB_6. The effective work function, ϕ (determined from a best fit to our data), was 2.86 eV which is consistent with Lafferty's[5] accepted value of 2.67 eV.

The LaB_6 cathode has been used to inject a small toroidal current into Caltech's Encore tokamak [similar to experiments performed on CDX (Ref. 6)]. When the cathode was operated at a fill pressure such that the emitted current was maximized (about 100 mTorr), then the current channel was dissipated by collisions with neutrals before it made a single toroidal transit. At lower fill pressures ($\sim 10^{-4}$ Torr), the cathode current was about 20 A and the current channel made five toroidal passes for a total plasma current of 100 A. If high levels of emission at low tokamak fill pressures ($\sim 10^{-4}$ Torr) are to be obtained, then a hollow tube cathode configuration will be necessary. For that experiment, the cathode is encased in a housing with a gas inlet and small aperture to the main chamber. Goebel, Crow, and Forrester[1] have found that a large pressure differential can be maintained between a small aperture hollow tube cathode and the exterior chamber. This should allow the cathode to be maintained at the high-pressure necessary for high-current emission, while the chamber remains at the desired lower pressure. In this way, the cathode might be efficiently used to inject large toroidal currents.

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