Low-Emittance Uniform-Density Cs+ Sources for Heavy Ion Fusion Accelerator Studies*

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ABSTRACT

Low-emittance (high-brightness) Cs^+ thermionic sources were developed for the heavy ion induction linac experiment MBE-4 at LBL. The MBE-4 linac accelerates four 10 mA beams from 200 keV to 900 keV while amplifying the current up to a factor of nine. Recent studies of the transverse beam dynamics suggested that characteristics of the injector geometry were contributing to the normalized transverse emittance growth. Phase-space and current density distribution measurements of the beam extracted from the injector revealed overfocusing of the outermost rays causing a hollow density profile. We shall report on the performance of a 5 mA scraped beam source (which eliminates the outermost beam rays in the diode) and on the design of an improved 10 mA source. The new source is based on EGUN calculations which indicated that a beam with good emittance and uniform current density could be obtained by modifying the cathode Pierce electrodes and using a spherical emitting surface. The measurements of the beam current density profile on a test stand were found to be in agreement with the numerical simulations.

I. INJECTOR DESCRIPTION AND CHARACTERISTICS

Four 10 mA C_s^+ ion beams are emitted thermionically into the diode gap from alumino-silicate layers coated on molybdenum cups[1]. The cups are mounted on a Pierce shaped graphite plate anode connected to a -200 kV Marx pulse generator. The beams, focused along the diode, pass through four holes in the cathode ground plate into the MBE-4 matching section. The ion source phase-space and current density distributions were determined experimentally using a pinhole and slit combination coupled to a Faraday cup. The pinhole was placed as close as possible to the ion source exit at a position where the beam is still cylindrically symmetric. Figure 1 (lower) shows the agreement between the measured beam phase-space distribution and the result of an EGUN[2] simulation for a zero emittance beam. One can see that the outermost rays of the beam are turned toward the diode axis due to overfocusing as a result of the diode field aberrations. This leads to current accumulation at the beam edges resulting in a hollow beam (figure 2, lower). Recent studies[3] have suggested that the source properties may contribute to the measured emittance growth for the 10 mA accelerated beam. A quick solution to improve the source beam dynamics by scraping the beam current to 5mA was temporarily adopted. Along with this solution we have developed a new improved 10 mA source.

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II. THE 5 mA SOURCE

A simple way of eliminating the outermost beam rays is to use a circular aperture ring (scraper) placed at the cathode plate, thus stopping down some of the beam current. Faraday cup measurements of the current taken at the entrance to the MBE-4 matching section initially showed a deteriorated current waveform. This appeared as an increase in the current rise-time and the total beam current. This current increase may be due to additional secondary electrons emitted from the scraper and accelerated towards the anode. To re-capture these secondary electrons the scraper was biased with a positive 4.5 kV d.c. voltage. Beam current waveforms at various bias voltages are shown in Fig. 3. The scraper is recessed 0.8" from the diode exit to eliminate electric field effects due to the bias voltage. The beam phase-space and current density distributions for various scraper diameters (0.4", 0.45", and 0.5") were measured and found to be in agreement with EGUN simulations. An optimum scraper diameter of 0.45" was chosen leading to a current of 4.5 mA and a higher quality beam as shown in Fig. 4. Transverse emittance measurments along MBE-4 using the high quality 4.5 mA beam revealed a normalized transverse r.m.s. emittance of 0.03 mm-mrad, reasonably consistent with the 0.1 eV temperature of the source emitter. Furthermore, the 4.5 mA beam showed a significant reduction in the variations of the measured r.m.s. transverse emittance in the MBE-4 matching section as compared to the 10 mA beam (figure 5).

III. THE 10 mA IMPROVED SOURCE

The new 10mA source consists of a curved ion emitter, a modified Pierce electrode (graphite plate) and a new mechanical assembly. EGUN simulations of the new improved source show a uniform current density and a lower emittance for a beam emerging from the new diode and scraped with a 20 mm aperture to 10mA at the input to the MBE-4 matching section. Improved fabrication techniques were developed and used to produce the new curved emitters. The performance of the new emitters was evaluated in a test stand using a diode configuration with an anode-cathode spacing of 0.5" and voltages up to 20kV. Figure 6 shows a temperature profile taken on the emitter surface along the diameter and Faraday cup current density through crossed slits positioned 0.9" from the cathode grid. The current density measurements were found to be in agreement with EGUN simulations for the

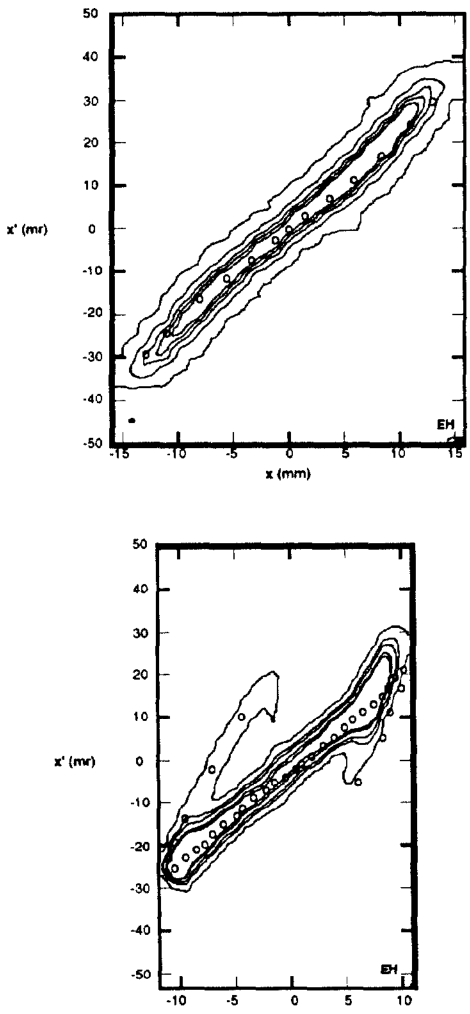

Fig. 1 Measured beam distribution in (x,x') phase space at diode exit. Comparison between experiment (-) and EGUN (o). Upper (lower) figure refers to the new (old) source.

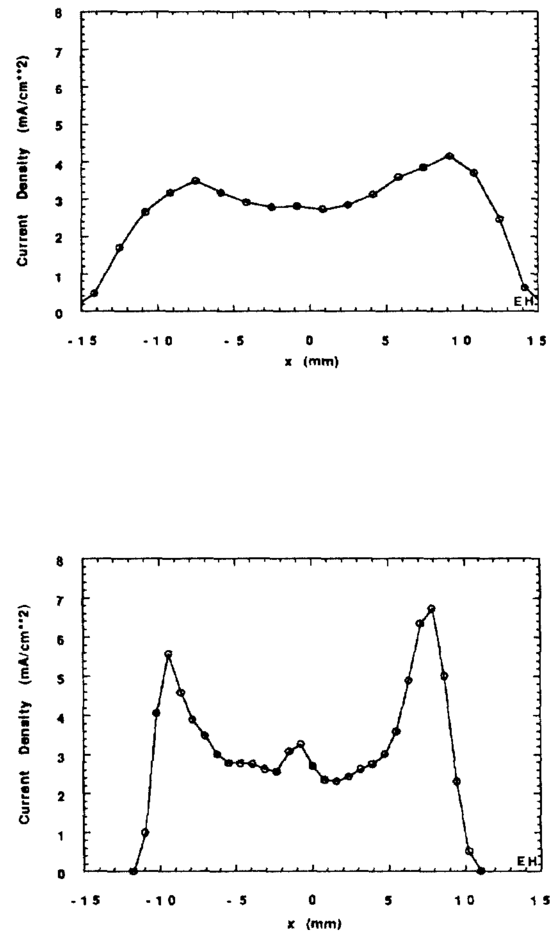

Fig. 2 Measured beam current density distribution vs. radial position. Upper (lower) figure refers to the new (old) source.

same geometry , thus approving the emitter for further tests in the MBE-4 ion source. The new mechanical assembly, which stabilizes the diode geometry (especially when going from air to vacuum) and improves the emitter alignment, was installed in the MBE-4 ion source section. The new mechanical assembly uses four insulating posts connecting the graphite plate (anode) to the output aperture plate (cathode). The mechanical stabilty of the diode was surveyed using optical telescopes placed at the far end of MBE-4 and set to have a line of sight coinciding with the MBE-4 axis. To perform the survey we have replaced the left and right-hand sources with "targets" containing a point source of light. A displacement of less than 0.007" was measured when the system went from air to vacuum. The assembly was tested for high voltage breakdown and found to withstand high voltage pulses in excess of 220 kV and 10 micro-second duration applied between the cathode and anode.

The new curved source was placed at the right-hand beam position and operated to evaluate the diode performance. Close agreement between the measured and the designed diode parameters, as predicted by previous EGUN simulations, was obtained when the source emitting surface was heated up to 1010 ^{o}C. The temperature was measured remotely through a window using a hot wire pyrometer. This temperature was found to be well above the diode current saturation temperature with the diode current determined by Child-Langmuir space-charge limit. The diode current, I_d, was measured for diode voltages, V_d, between ~100kV and ~200kV. The measured diode current was found to follow the well known Child-Langmuir law, $I_d = k\, V_d^{3/2}$, where k is the diode perveance, measured to be 2.3 x 10^{-4} µPervs.

The diode beam dynamics were measured using the aperture-slit technique described earlier. Figure 1 (upper) shows the beam phase-space profile. One can see that the optical

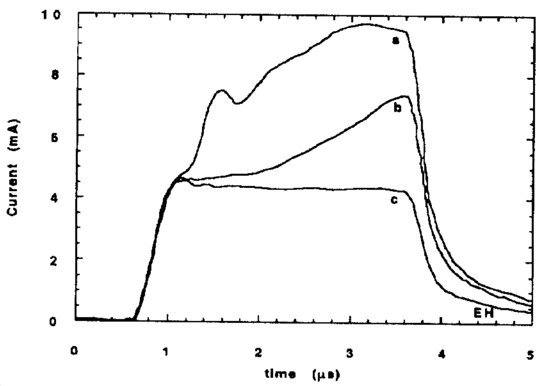

Fig. 3 Scraped beam current vs. time with a scraper bias of (a) 0.75kV, (b) 2.75 kV and (c) 4.75 kV.

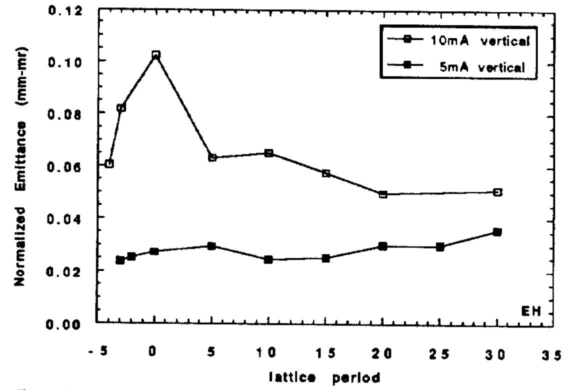

Fig. 5 5 mA and old 10 mA beam r.m.s. normalized transverse emittance vs. lattice period along MBE-4 . The matching section corresponds to lattice periods -4 through 0.

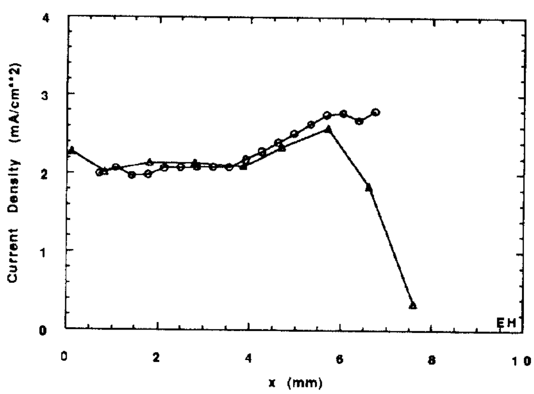

Fig. 4 5 mA beam current density at point of injection into first quadrupole of matching section. Comparison between experiment (Δ) and EGUN code (•).

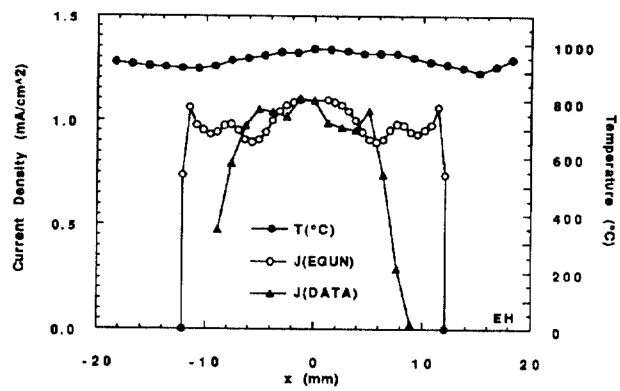

Fig. 6 Test stand measurements of the current density profile J(DATA) compared with EGUN simulation J(EGUN), and the temperature profile taken at the emitter surface.

aberrations in the diode are significantly reduced and that the previous filamentation in the profile is eliminated, thus leading to a more uniform current density profile as shown in Fig. 2 (upper). The full beam current of 16 mA measured using a Faraday cup at the exit of the MBE-4 matching section 1st quadrupole doublet and the beam divergence angle of 30 mrad. taken from the measured phase space profile shown in Fig. 1 (upper) were found to be in good agreement with the parameters predicted by the EGUN simulations. For applications in MBE-4 the beam is apertured to a diameter of 20 mm leading to a beam current of 10.6 mA consistent with the original nominal MBE-4 beam current. The normalized r.m.s. transverse emittance, ε_n, was measured using the double slit technique at the exit of the 1st MBE-4 quadrupole doublet and found to be 0.067 mm-mrad. As the intrinsic emittance of the beam is given by $\varepsilon_n = 2a\,(kT/m_i c^2)^{1/2}$, where m_i is the ion mass, a is the beam radius and T is the beam temperature, we obtain a temperature estimate of 1.4 eV. This is consistent with the source temperature and the adiabatic transverse compression of the beam by the focusing elements. From the measurements of current and emittance we calculate the beam brightness, $I_b/\pi^2\varepsilon_n^2 = 2.4 \times 10^{11}\,A/(m\text{-}rad)^2$.

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