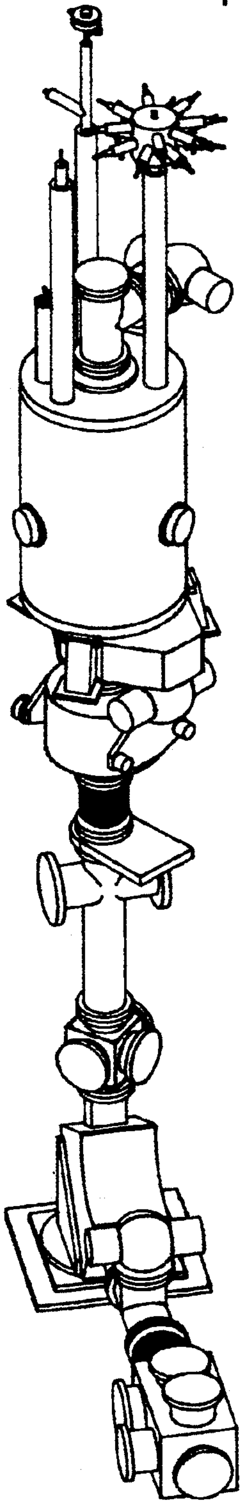
Michigan State University

National Superconducting Cyclotron Laboratory



Initial Results of the 2.45 GHz Excitation of the Superconducting ECR Ion Source in its High B Mode

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Abstract

The "frequency squared scaling" law, relied upon to enhance the production of high charge state ions from electron cyclotron resonance ion sources indicates that low frequencies of operation may not be viable for production of high ion densities, and hence for the production of high charge state ions. The superconducting ECR ion source at the National Superconducting Cyclotron Laboratory is a fully superconducting, hexapole stabilized tandem mirror ECR ion source with a multimode microwave cavity. When operated at its optimized high magnetic field (High-B) mode at 6.4 GHz, the high charge state current output of the SCECR approaches all existing ECR ion sources, including higher frequency ECRIS. In this study, the SCECR is operated at 2.45 GHz in its High-B mode that is scaled down for that frequency of operation. Initial results with oxygen and argon ion production at 2.45 GHz are presented. It is demonstrated that the SCECR can produce a plasma from which multiply charged ions of up to O^{7+} and Ar^{13+} can be extracted with ion current intensities comparable to several higher frequency ECRIS. This study concludes that 2.45 GHz is indeed a viable frequency for production of moderate intensities of multiply charged ions. This may lead to simpler, and more cost effective microwave apparatus, with a less demanding magnetic field configurations.

from the Wavemat Inc./Michigan State University design group [10] operating at 2.45 GHz. The MPDR class of sources in particular routinely generate plasma discharges with ion densities that are higher than the "critical density" as dictated by the frequency squared scaling law [3].

Figure 1 is a schematic of the Superconducting ECR ion source (SCECR) at the NSCL. It is a fully superconducting, variable frequency hexapole stabilized tandem mirror ion source with a multimode microwave cavity. Axial confinement of the charged particles is provided by the five superconducting coils stacked three (at the injection end) and two (at the extraction end) that allow fine adjustments in the magnetic mirror geometry. The hexapole, also superconducting, provides radial confinement. Together with the solenoids, it creates the "minimum-B" magnetic field configuration in the SCECR that helps prevent magnetohydrodynamic instabilities within the plasma. Working gas is fed through the first stage where a cold, collisional and low charge state plasma is generated, before being injected into the main stage. Microwaves are fed through a waveguide into the second stage. The SCECR presently represents the state-of-the-art for multiply charged ion production in an ECRIS. This performance is based on a number of unique features, namely a very strong magnetic field capability, a simplified axial plasma configuration and an off axis rectangular waveguide launch with a reduced coaxial ion injection stage.

The minimum-B confinement structure of most ECRIS utilizes mirror ratios of about 2 at the extraction stage, about 3 to 4 at the injection stage, and a wall to center ratio of about 2 for the radial field. First stated by Gammino and Ciavola as a theoretical configuration [11], the "High-B" magnetic field mode raises these ratios significantly. The High B mirror ratios are as follows: $B_{ext}/B_{min} \geq 4$, $B_{inj}/B_{min} \geq 7$, and $B_r/B_{min} \geq 2.5$. Trials on the SCECR by Gammino and Antaya proved that the 6.4 Ghz performance of the SCECR in its High-B mode was comparable to the performance of other ECRIS in the world, even those operating at higher frequencies [12].

stage as similar to the original as possible allows a definitive comparative study.

Microwave power was supplied by a HOLLADAY^{TM} 0-200W 2.45 GHz microwave power supply. The magnetron was protected from excessive reflected power by a circulator and dummy load configuration. A cross-guide coupler was used to sample the incident and reflected powers for accurate measurements of the same. Also, at the ion source end of the cross-guide coupler a 0.125" (0.3175 cm) thick Teflon plate and G-10 clamps were placed for electrically isolating the SCECR which has to be biased at up to 10 kV, from the microwave apparatus, which remains at ground.

The magnetic field topology was linearly scaled from that used for 6.4 GHz to 2.45 GHz, i.e. the 6.4 GHz High-B coil currents were multiplied by the ratio of 2.45 to 6.4. This provided a good starting point, from which minor tuning of the fields was necessary for optimizing the performance of the SCECR. The standard magnetic field at 2.45 GHz (scaled from the normal field topology of the SCECR and the RTECR) is compared to the High-B field configuration in Figure3. Note the high mirror ratios for the High-B mode.

III. Results and Discussion

Figure 4 compares the oxygen performance of the SCECR at 2.45 GHz with several other ECRIS (with helium as a support gas); Figure 5 compares the SCECR 2.45 GHz argon performance (with oxygen as the support gas) with the other ECRIS. Both sets of data on the SCECR are taken with about 150 W, 2.45 GHz input power, with the discharge pressure at or about 10^{-7} Torr. Comparisons are made with the following sources: the 10 GHz Minimafios [13], the 6.4 GHz LBNL ECR ion source [14], the Oak Ridge National Laboratory 10.6 GHz ECRIS [15] and the 6.4 GHz NSCL room temperature source RTECR [16]. Note that it is not the purpose of presenting the SCECR 2.45 GHz data in competition with data from these other sources, some higher power coils are then needed to obtain the desired field strength. At 2.45 GHz, the magnetic fields may be created with room temperature coils, or even with permanent magnets. Hence significant savings in terms of capital costs and complexity may be achieved in the design and construction of ECRIS generating moderately high intensity multiply charge state ions.

Further research for these tests focus on several fronts. More time is needed to optimize the results obtained in this study - the original tests were conducted in about three days. A better microwave injection technique may be studied, using a coaxial antenna, tunable cavity structure or side entrant probes (similar to the MPDR class of ion sources). Effects of techniques like silane conditioning, aluminum liners or coatings, and more effective gas mixing need to be studied. Emittance measurements of the extracted beams needs to be done, while other gases like krypton, or xenon that are typically used in the SCECR need to be tested. Multi-frequency operation of the SCECR - like the two frequency excitation of the AECR at LBL [19], with the SCECR operating at 2.45 GHz and 6.4 GHz should also produce interesting results.

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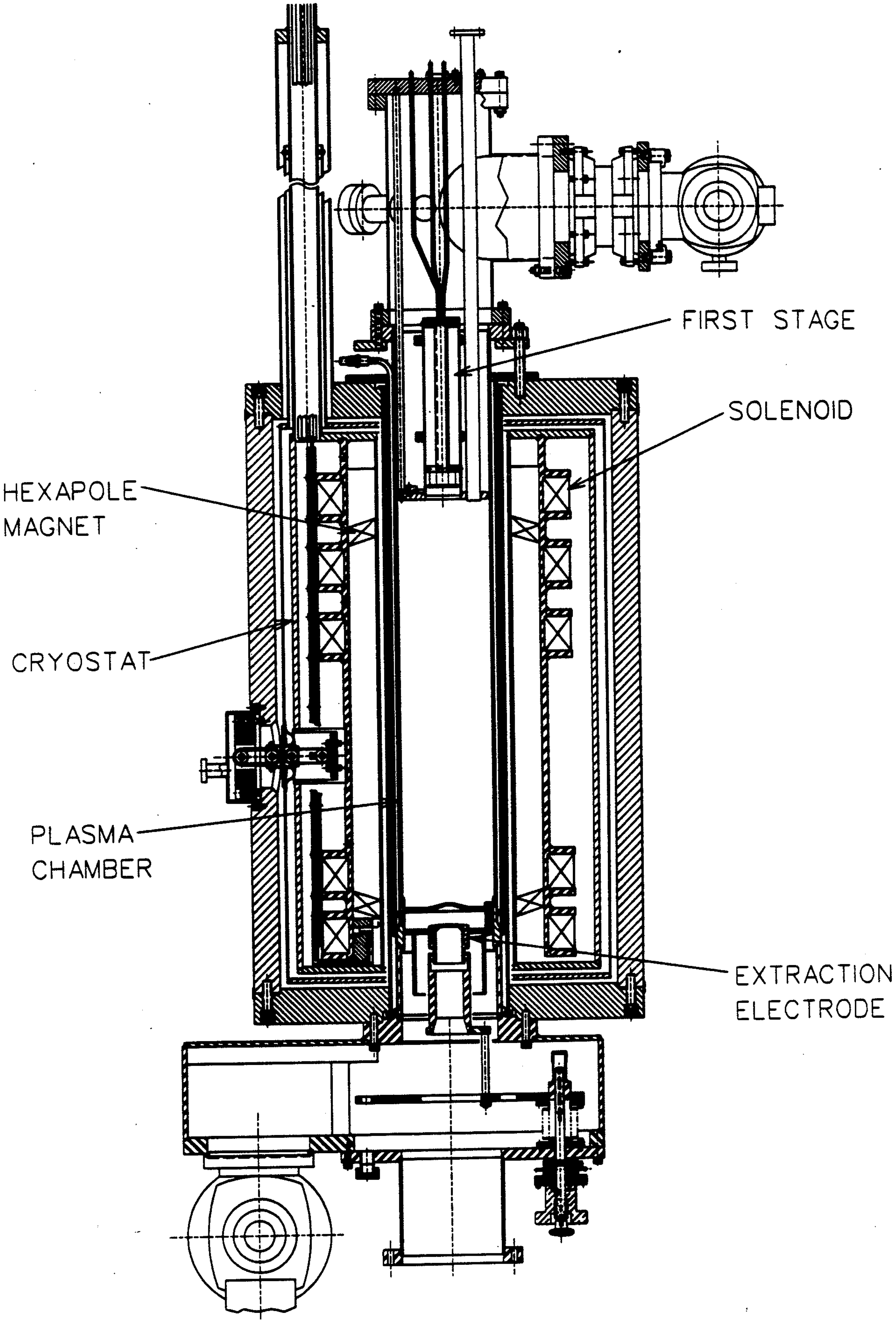
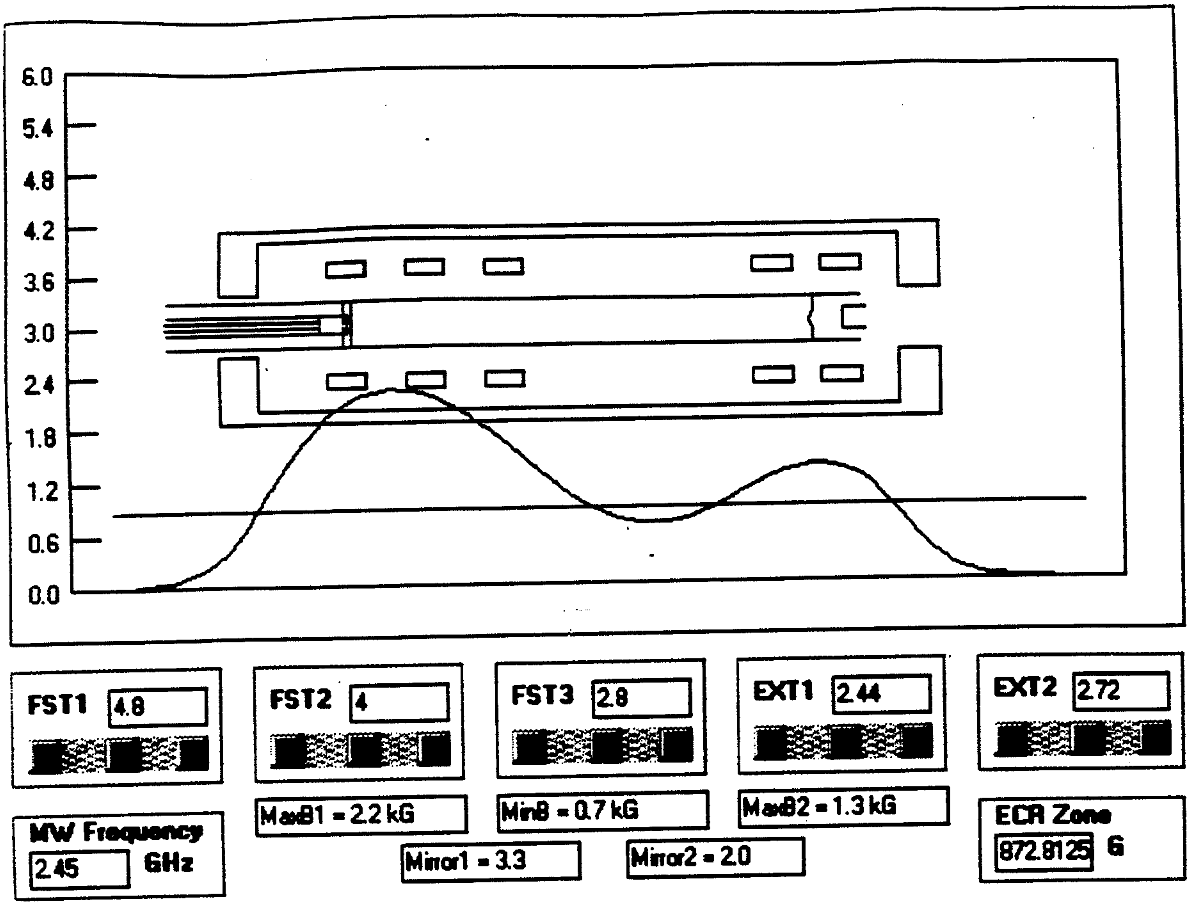

FIRST STAGE
SOLENOID
HEXAPOLE MAGNET
CRYOSTAT
PLASMA CHAMBER
EXTRACTION ELECTRODE



FST1 4.8

FST2 4

FST3 2.8

EXT1 2.44

EXT2 2.72

MW Frequency 2.45 GHz

MaxB1 = 2.2 kG

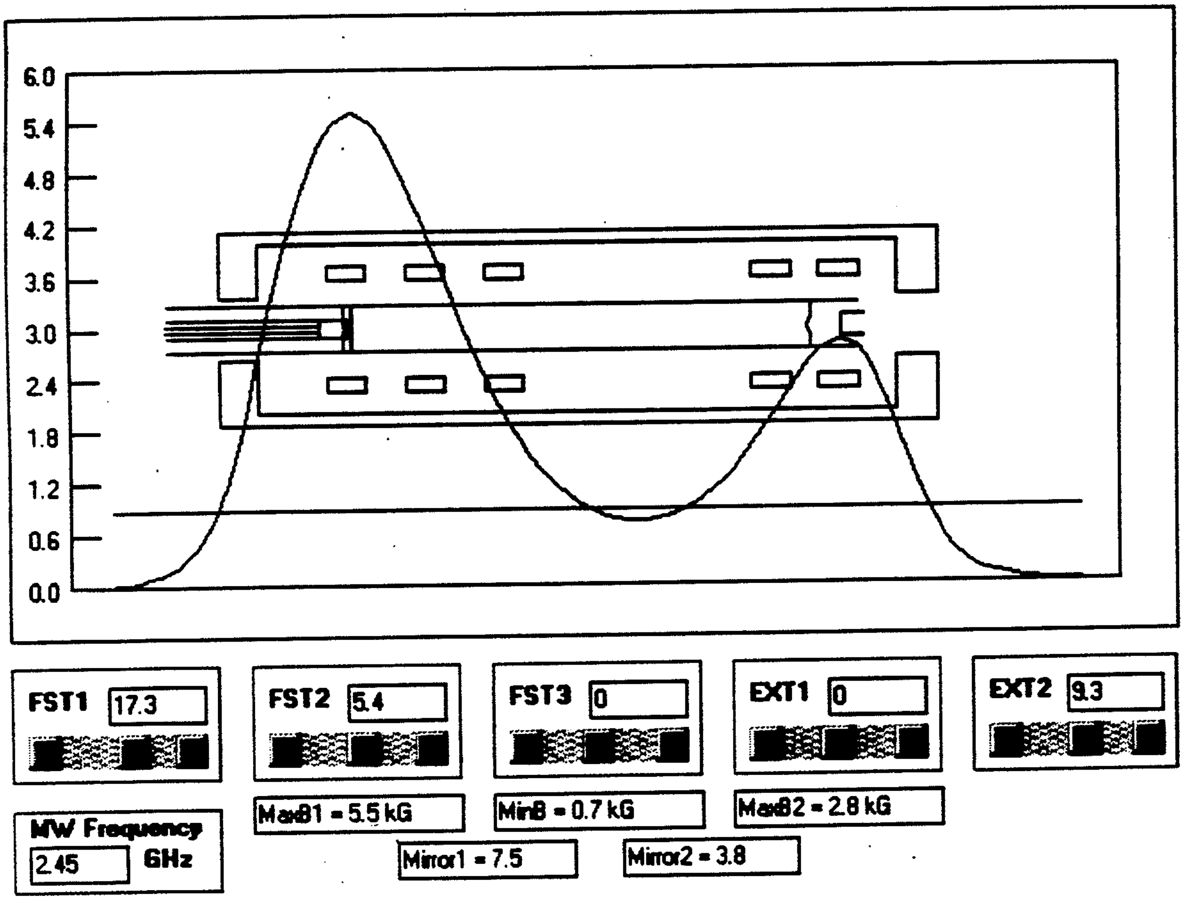
MinB = 0.7 kG

MaxB2 = 1.3 kG

ECR Zone 872.8125 G

Mirror1 = 3.3

Mirror2 = 2.0



FST1 17.3

FST2 5.4

FST3 0

EXT1 0

EXT2 9.3

MW Frequency 2.45 GHz

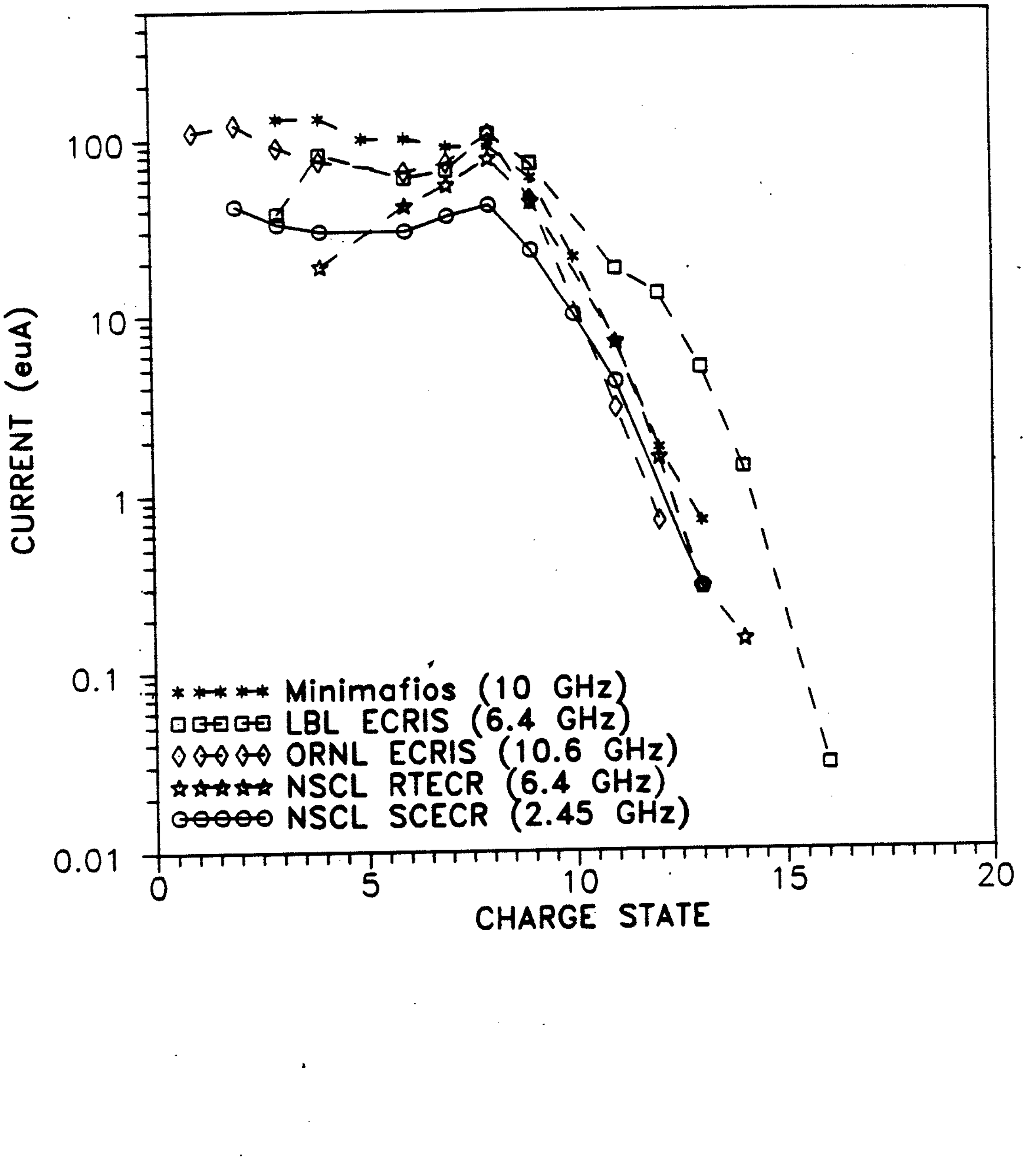
MaxB1 = 5.5 kG

MinB = 0.7 kG

MaxB2 = 2.8 kG

Mirror1 = 7.5

Mirror2 = 3.8


CURRENT (euA)
100
10
1
0.1
0.01
0
5
10
15
20
CHARGE STATE
Minimafios (10 GHz)
LBL ECRIS (6.4 GHz)
ORNL ECRIS (10.6 GHz)
NSCL RTECR (6.4 GHz)
NSCL SCECR (2.45 GHz)

6