Laboratory investigation of cyclotron radiation inhibition by background plasma relevant to the polar magnetosphere

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Introduction

Auroral Kilometric Radiation (AKR) is emitted at polar regions of magnetised planets such as Saturn, Jupiter and the Earth. Studies also suggest that similar cyclotron maser dynamics may be responsible for microwave emission (~GHz frequencies) from stellar objects such as UV Ceti, [1] and CU Virginis [2]. AKR arises as particles descend and accelerate through an auroral density cavity (region of partial plasma depletion where f_{pe}~9kHz and n_p~10^6m^{-3}) into the increasing magnetic field at the Earth's poles. The adiabatic conservation of the magnetic moment comes into effect, increasing the pitch angle of each electron causing a decrease in parallel velocity for perpendicular velocity, resulting in a horseshoe shaped distribution function in velocity space [3]. This distribution has been shown to be unstable to a cyclotron resonance maser type interaction [4] and produces radiation with spectral peaks at ~300kHz, GW's of power and with wave propagation in the X-mode [5].

Experimental Apparatus

A scaled laboratory experiment was constructed allowing magnetic compression of an electron beam to represent the action of the Earth's magnetic field on the particles [6]. A Penning trap [7] was inserted into the main cavity coil where the magnetic field is at a maximum, Figure 1(a), to allow generation and characterisation of background plasma. The trap is ~20cm in length and consists of a copper cathode plate, a cylindrical copper anode and has a brass cathode mesh, Figure 1(b) and (c).

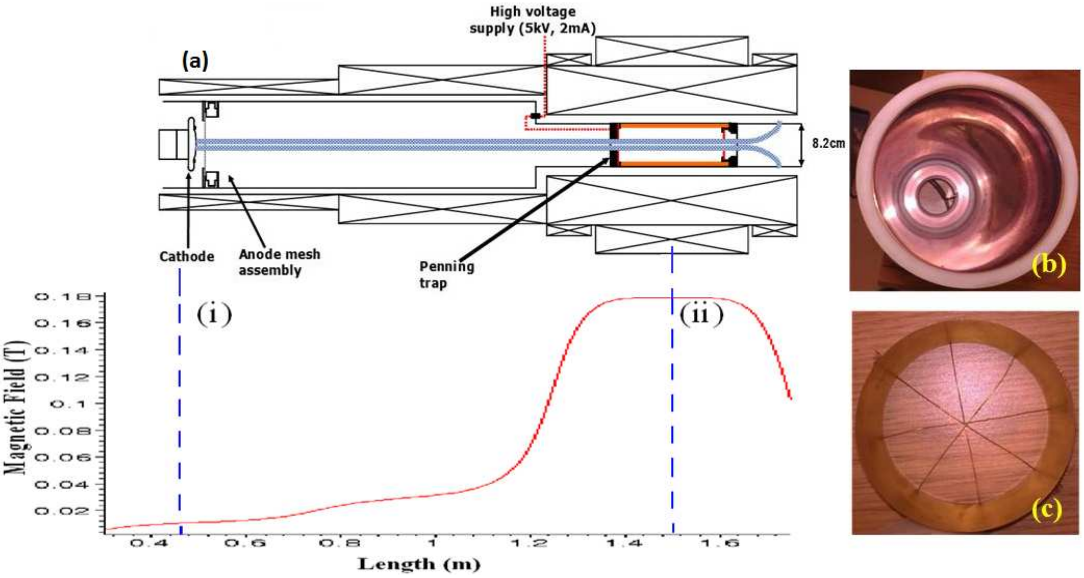

Figure 1: (a) Magnetic field profile through solenoids showing cathode placement at (i) and Penning trap placement at (ii). (b) View towards cathode end of Penning trap. (c) Cathode mesh of Penning trap.

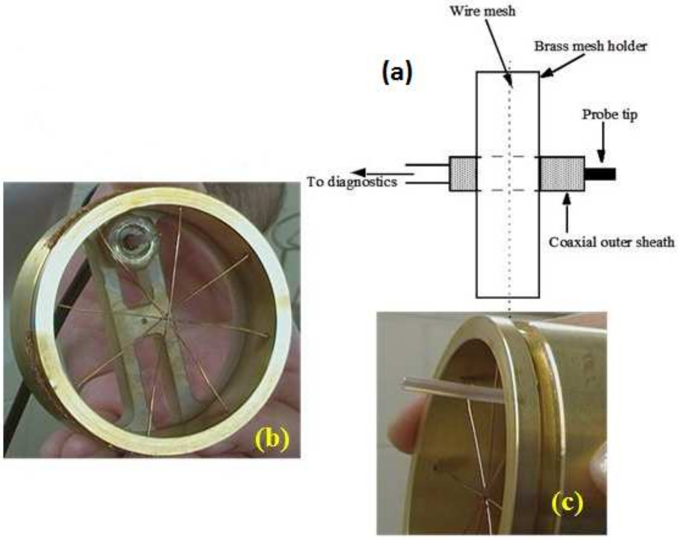

Figure 2: (a) Probe holder design showing barrel probe tip. (b) Brass mesh cathode with probe holder and probe in place. (c) Planar probe geometry.

Characterisation of the plasma was achieved using a plasma probe (planar and barrel geometries) constructed using a length of coaxial cable. The helical orbits of magnetized-plasma particles complicate the interpretation of their collection onto the probe tip. Test measurements showed that the cylindrical surface of the barrel probe dominated the current collection but not by the factor of 30 implied by the increased collection area. Therefore the probe face was made flush with the nylon outer of the cable, making it more suitable for primarily longitudinal current collection.

Experimental Results

The I-V characteristics of the Penning trap were tested both with and without probe insertion to ensure that the probe was not causing any adverse electrostatic effects on the discharge ignition. Figure 3 shows some examples of the traces measured with Helium at 10^{-5}mBar, the results of which were reproducible with and without the probe inserted.

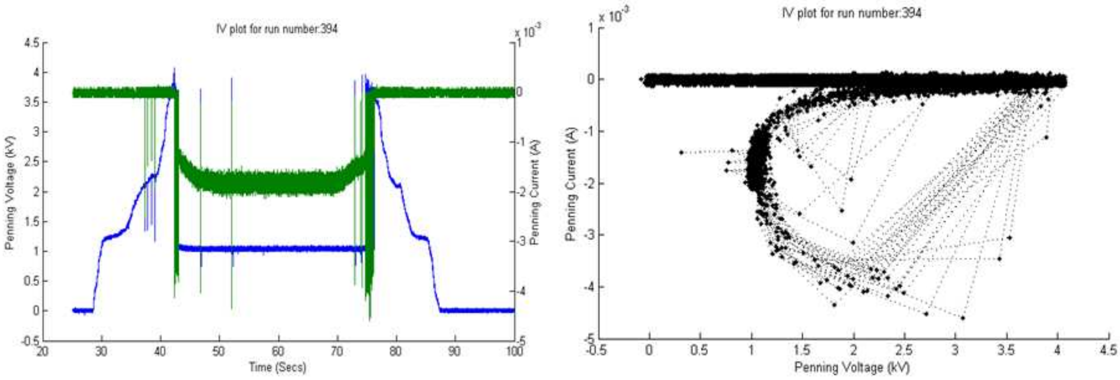

Figure 3: (a) I-V characteristics of the Penning trap against time. (b) Straight comparison of current and voltage on the Penning trap.

The plasma characteristics were measured using probe theory [8] and direct connection of probe to spectrum analyser for use as an antenna pickup. Measurements of current density and probe bias voltage, i.e., the difference between the applied probe voltage and the plasma's space potential, were obtained allowing a plot of LnJ vs V to be formed as shown in Figure 4. The gradient of the curve in Figure 4 gives a value for the electron temperature of the plasma which in turn allows values of plasma frequency, f_{pe}, and density n_e, to be obtained.

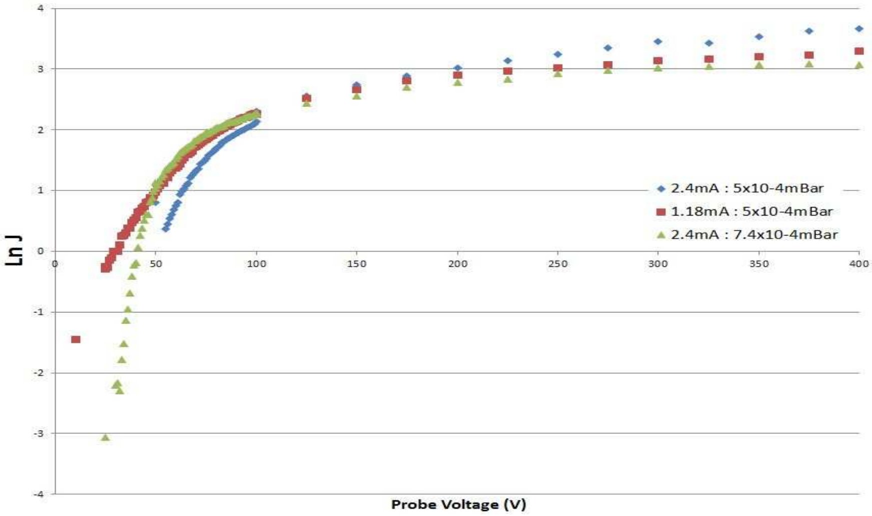

Figure 4: Logarithmic plot of the current density at the probe tip, allowed T_e to be estimated and therefore f_{pe} of the background plasma.

Figure 5 shows the spectrum of plasma oscillations measured by the analyser (using the probe as a direct antenna pick-up) within the vicinity of the probe, from zero frequency to some well-defined maximum frequency that varied approximately as $\sqrt{I_A}$. Implied here is that the f_{pe} increases as the distance away from the probe increases. Upon reaching the probe sheath boundary, the maximum f_{pe} of the bulk plasma is observed. Higher frequencies at this point are uncoupled to the plasma and cannot be sustained in the properties of the trap waveguide.

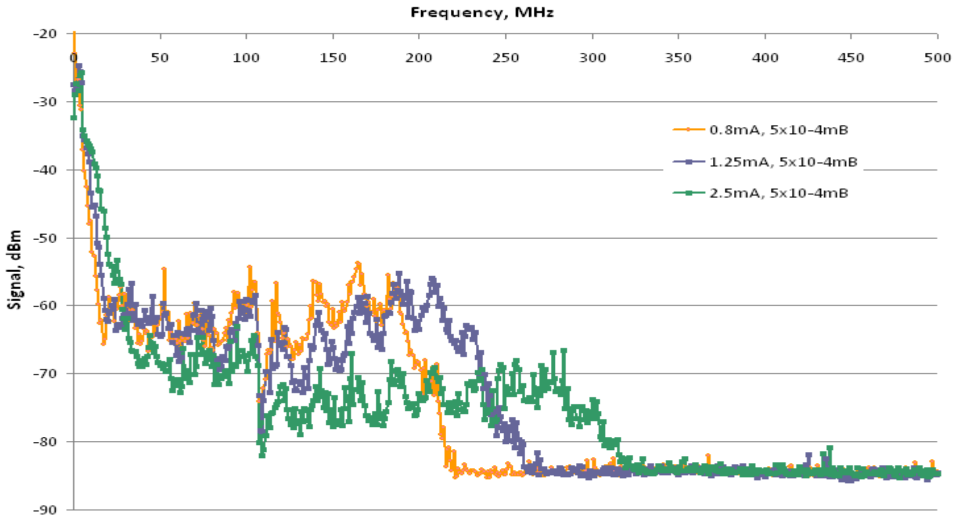

Figure 5: Direct plasma frequency measurements using the probe as an antenna pickup.

Characterisation of the plasma achieved values of $n_e \sim 7.5 \times 10^{14} - 2.17 \times 10^{15} m^{-3}$, $T_e \sim 5.51 \times 10^4 - 2.48 \times 10^5 K$, and $f_p \sim 128$-418MHz. Results showed that the background plasma affected the EM wave generation, characterised by reduced intensity, intermittent radio emission compared to the stable emission observed in the absence of plasma.

Summary

The results presented in this paper show characterisation of a background plasma within the interaction waveguide of the apparatus at Strathclyde which has previously been used to investigate Auroral Kilometric Radiation (AKR). A ratio of $f_{ce}/f_{pe} \sim 19$-40 was obtained which is comparable to the value in the magnetosphere ~30. It was seen that the presence of the background plasma had a large impact on the generated radiation.

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