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Pair Plasma Trapping by Higher Order RF Multipole Structures[1]

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Charged particle traps such as Penning and Paul traps may be used to confine non-neutral plasma, but space charge repulsion limits stable trapping to low plasma density. This paper demonstrates reducing space charge effects by loading the trap with neutral plasma. 2D and 3D particle-in-cell simulations [1] of RF Multipole Plasma Trap (MPT) structures are conducted [2], showing attainment of neutral plasma trapping up to the critical density set by the trapped species' plasma frequency—several orders of magnitude higher than the space charge-limited non-neutral plasma density. Positive and negative particles of the same charge-to-mass ratio are trapped symmetrically by the multipole field, and studies of pair plasma trapping are presented (100 MHz drive, 10^{17} m^{-3} pair ion plasma density; 250 MHz drive, 10^{14} m^{-3} electron-positron plasma density). The plasma quasi-neutrality and reduced space charge allows large trapped volumes (greater than 10 cm trap radius) and high total particle content, and higher order multipoles (e.g. n = 8 or 16, compared to n = 2 for the quadrupole Paul trap) become advantageous due to their nearly field-free interior and possibility of design with driving frequency above the plasma frequency. Effective trapping potentials in the MPT on the order of 100 V are achieved while still maintaining the essential adiabatic condition at the trap boundary [3], such that particle trajectories remain stable. This capability makes a compelling platform for experimental pair plasma studies, since the achievable parameters compare favorably with other current approaches [4]. Trapping of ion-electron plasma is also demonstrated, in which the electrons are responsive to the RF and in turn trap the positive ion species electrostatically. PIC simulations and experimental design considerations for loading and diagnostics are presented, as well as studies with magnetic fields at and around ponderomotive gyroresonance.

[1] C. Nieter and J. R. Cary, J. Comput. Phys. **196**, 448 (2004) [2] N. K. Hicks, (submitted to *Phys. Rev. Lett.*) (2019) [3] D. Gerlich, in *Adv. Chem. Phys. State_Selected State_To_State Ion_Molecule React. Dyn. Part 1. Exp. Vol. 82*, edited by C.-Y. Ng and M. Baer (John Wiley & Sons, Inc, 1992), pp. 1–176. [4] E. V. Stenson et al., *Phys Rev. Lett.* **121**, 235005 (2018)

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