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Ferromagnetic Enhanced Inductive Plasma Sources

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Inductively Coupled Plasma, ICP sources, or inductive discharges have been known for over a century. They have been used and studied in past decades mostly in two quite different regimes. At nearly atmospheric pressure, ICPs produce near equilibrium plasmas, while at low gas pressure, in the range of fraction and hundreds of mTorr, ICPs produce highly nonequilibrium plasmas. Low pressure ICPs have been used as ion sources for particle accelerators and thrusters for space propulsion. Recently, interest in low pressure ICPs has been revitalized due to their great advantages in plasma processing and lighting technology. The absence of electrodes, and the capability to provide large plasma densities, and high power transfer efficiency have made these discharges attractive for development of new technologies in various fields. The subject of this presentation is a review of ICP sources enhanced with a ferromagnetic core, FMICP, which found applications in plasma fusion, space propulsion, light sources, plasma chemistry and plasma processing of materials. Introduction of a ferromagnetic core to a magnetic rf circuit of ICP makes its operation close to that of an ideal transformer, thus enhancing its efficiency and power factor. The latter considerably simplifies ICP matching to a rf source. Application of a ferromagnetic core allows for considerable reduction of ICP driving frequency (up to 2-3 orders of magnitude) comparing to the standard in industry of 13.56 MHz. Reduction of the driving frequency allows for practical elimination of capacitive coupling and transmission line effects, inherent to ICP operating at 13.56 MHz. Utilization of lower frequencies also results in more efficient and less expensive rf power sources. However, the most valuable feature of FMICP for plasma processing is its ability for local rf power injection, which promises new possibilities in uniform processing over large substrate areas. The electrical and plasma characteristics of FMICPs, their matching to rf power sources, and their comparison with corresponding characteristics of conventional ICPs without a ferromagnetic core will be discussed in this review for various applications.