

# STUDIES OF ECR PLASMAS AND MATERIALS MODIFICATION USING LOW ENERGY ION BEAM FACILITY AT IUAC

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## Abstract

The ECR ion sources are widely used to produce high intensity of highly charged positive ions. To increase their performance further, several techniques are employed. The addition of a lighter gas into the main plasma (so called gas mixing) shows a substantial effect on the charge state distribution of highly charged ions. Although many theoretical models were used to explain this gas mixing effect, yet it is not fully understood. The low energy ion beam facility (LEIBF) at Inter-University Accelerator Centre (IUAC), New Delhi, India, which comprises of a 10 GHz all-permanent magnet NANO-GAN ECR ion source placed on a high voltage platform (400kV) has been used to develop several plasmas for the physical understanding of ions production and their confinement in a strong magnetic field. Further, the LEIBF allows us to extract ion beams from the plasma in the energy range of a few keV to tens of MeV for novel ion-matter interaction experiments. In this paper, the charge state distribution studies (relevant to gas mixing effect) of various atomic species at optimized ion source tuning parameters along with some interesting results on materials modification using ion beams is presented.

## INTRODUCTION

The Electron Cyclotron Resonance ion sources (ECRIS) [1] are most suitable for producing high intensity of multiply charged ions and therefore, preferred as an injector in high energy particle accelerators. In fact there exists some ECRIS based implanter/low energy facilities for conducting research in materials science, atomic and molecular physics [2–4]. A cylindrical vacuum chamber consisting of multi-pole magnets around it and two solenoids at its ends, RF power injector and gas feed systems are essential components of ECRIS. The electrons gyrating in a magnetic field gain energy from the input RF wave via ECR and the plasma is formed by the step-by-step electron impact ionization. In the past few decades, a significant progress has been made to enhance the performance, mainly with the better understanding of of plasma and advancement in the magnetic field technology for its confinement. With the frozen design of the source, some additional techniques are also employed to further increase the intensity of highly charged ions. [5].

The gas mixing technique has been found to be very effective to boost the intensity of the highly charged ions in many folds (3–4 times) [6]. In most studies of gas mixing effect, He gas is chosen for lighter masses (such as O, N, Ne etc.), whereas O and N are used for heavier masses (Xe, Ar,

Kr) [3, 7–12]. However, till now, there is no empirical rule for selecting a suitable gas for mixing purposes in a specific system. The gas mixing effect is mainly explained by the ion cooling model [13] and lowering a plasma potential [14]. These two processes decrease the ion temperature resulting a longer confinement time. However, a numerical simulation performed by Mironov et al. [15] showed that the ion temperature ( $T_i$ ) actually increases in parallel with the potential dip ( $\Delta\phi$ ), however  $\Delta\phi/T_i$  is always higher, following the overall ion confinement. Further, low frequency noise observed in the plasma due to instabilities and parametric decay of high frequency wave affect the ion dynamics by the process of selective ion heating [10, 16]. Due to the limited database of gas mixing experiments; it is very difficult to understand the ion behavior in the plasma and a consistent generalised model still needs to be established.

In present studies, we have recorded the charge state distributions (CSD) of Carbon (C) and Oxygen (O) in pure and Helium (He) mixed (at different %)  $\text{CO}_2$  ECR plasma and touched upon various aspects of ion behaviour. Further, the extracted and analysed ion beams from ECR plasma are used for ion-matter interactions studies.

## FACILITY DESCRIPTION

The Low Energy Ion Beam Facility (LEIBF) at IUAC, New Delhi, India [17] is a compact accelerator that has been functioning continuously for more than two decades, providing ion beams of energy ranging from tens of keV to a few MeV for diverse materials science and atomic molecular physics experiments. The schematic of the facility is shown in Fig. 1. The LEIBF consists of mainly a 10 GHz all-permanent-magnet ECR ion source, RF power and gas feed systems, efficient ion extraction system and an Einzel lens. All these components along with electronics and vacuum pumps are placed on a high voltage platform ( $V_{\text{max}} = 400$  kV). These are powered by using an isolation transformer (10KVA) and controlled by the fibre-optic communication. The ions extracted from the plasma are further accelerated using a general purpose tube (GPT) having electrostatic field gradient. The pre-analysis section of LEIBF consists of electromagnetic lenses, a Faraday cup, a beam profile monitor and a double slit. For the analysis of ion beam in energy and momentum, a large analyser-cum-switching dipole magnet ( $B_{\text{max}} = 1.4$  T) is used. For experiments, three beam lines at  $75^\circ$ ,  $90^\circ$  and  $105^\circ$  equipped with proper beam line components, are available. The ions extracted from the plasma are transported to experimental chamber at the end of each beam line by focusing and steering those using electromagnetic lenses. All ion source and beam line

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