Chapter 7

Overall summary and future scopes

7.1 Summary

In this thesis, the different controlling parameters for dust charging and their effects in low pressure laboratory complex plasma are investigated experimentally. During the experimental studies, a steady state, low pressure, direct current plasma is produced by hot cathode filament discharge technique in a multi-cusp dusty plasma device. A full line cusped magnetic field confinement system is used to improve the plasma confinement. The plasma is produced by striking a discharge between incandescent tungsten filaments and magnetic cage. The setup is equipped with plasma parameter measurement system, dust current measurement unit and spectrometer for plasma emission studies. The experimental campaigns which were undertaken to investigate the different controlling parameters for dust charging are reported in chapter 3, 4, 5 and 6 of the thesis.

The basic introduction to dusty plasma, its characteristics, occurrences, importance of the study of dusty plasma, dust charging mechanism, review of earlier
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work, objectives of the work under the thesis etc are described in chapter 1. The detailed description of the experimental set up, related experimental arrangements and different diagnostic tools are described in chapter 2.

In the first experimental campaign (chapter 3), the effect of working pressure on different plasma parameters like electron density, electron temperature, electron energy probability function (EEPf) and on the dust charging are investigated in filamentary hydrogen plasma. The effect on EEPF in presence of dust particles is also examined for different working pressure. From the observations, it is found that as the working pressure increases, the plasma density increases gradually up to $4 \times 10^{-4}$ mbar and correspondingly electron temperature decreases. Beyond $4 \times 10^{-4}$ mbar (up to $2 \times 10^{-3}$ mbar), the electron density and electron temperature gets saturated. The EEPF of hydrogen plasma is presented in a semi-logarithmic scale. It is seen that at very low pressure (below $4 \times 10^{-4}$ mbar), a bi-Maxwellian EEPF is observed in the lower energy range (below 10 eV) with a larger high energy tail and some dip/peak structures appear at the high energy range ($e > 10$ eV). When the working pressure increases, the bulk temperature and the tail temperature seem to approach each other and at $2 \times 10^{-3}$ mbar, a single Maxwellian distribution is observed in the lower energy range (below 10 eV). The dip structures between 10 - 15 eV and between 20 - 25 eV are due to the different inelastic collisions of electrons with hydrogen molecules and different hydrogen ion species.

From the EEPF observations, it is found that the number of high-energy electrons increases with respect to the number of the mid-energy range electrons in presence of dust grains. It indicates that the addition of dust grains to a plasma can efficiently thermalize the plasma.
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The dust charging profile is demonstrated for different working pressure. It is observed that the charge accumulated on dust grains is higher at low working pressure compared to higher working pressure. But beyond $4 \times 10^{-4}$ mbar (up to $2 \times 10^{-3}$ mbar), the charge accumulated on dust grains gets saturated. It proves that the dust charge strongly depends on the electron temperature. The effect of plasma density on dust charging is not significant in low pressure plasma. For dust accelerator which is generally used to investigate the hypervelocity dust impacts onto various materials, higher dust charging is preferable. It is observed that low working pressure is preferable for higher dust charging.

In the second experimental campaign (chapter 4), the effect of secondary electron emission (SEE) on dust charging is studied. The results show that secondary electron emission plays a significant role in dust charging mechanism. Due to the presence of high energetic primary electrons in hot cathode filament discharge plasma, secondary electron emission may take place from micron size dust grains depending upon the SEE yield of the material. It is seen that the secondary emission effect is not observed in tungsten dust because the SEE yield of tungsten is very low compared to Al$_2$O$_3$ dust. The charging of dust having low SEE yield value is more compared to that of having higher SEE yield. For application like dust accelerator where higher dust charging state is required, dust with low SEE yield is preferable.

From the dust charging profile of uncoated and Cs coated W dust, it is found that due to formation of Cs monolayer, the charge accumulated on W dust decreases. The reduction of the charge accumulation on Cs coated W dust is due to the production of negative hydrogen ion as well as SEE. From the experiment, it is concluded that the
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presence of negative ion as well as the SEE from dust grains both reduce the dust charging.

In the third experimental campaign (chapter 5), the effects of electrostatic confinement potential on plasma parameters and charging of the dust grains are described in an electrostatically plugged multi-cusp magnetic cage arrangement. From the experiment, it is observed that positive magnetic cage biasing helps for higher dust charging whereas negative cage biasing increases the plasma density by improving the plasma confinement. In multi-cusp device, the electrons and ions are mainly lost at the cusp region of the magnetic channel. When the cage is biased negatively, the electrons experience a repulsive force which reduces the loss of electrons. As a result, the degree of ionization of the plasma increases which in turn increases the plasma density. In the opposite case, i.e. for positive cage biasing voltage, the loss of the electrons increases due to the electrostatic force of attraction. The positive cage biasing voltage increases the effective discharge voltage. Therefore, for positive cage biasing voltage, the electron temperature increases.

From the dust charging results, it is seen that positive cage biasing voltage is preferable for higher dust charging. To control the dust charging, magnetic cage biasing potential can be used as an external controlling parameter.

In the fourth experimental campaign (chapter 6), different percentage of argon is added into the hydrogen plasma and its effects on plasma parameters as well as on dust charging are studied. From the experiment, it is found that the electron density rises at most by a factor ~ 2 and the electron temperature is reduced by a factor 0.5 upto 30% addition of argon flow rate with hydrogen gas. Beyond 30% addition of argon with
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hydrogen flow rate, the electron density slightly goes on decreasing whereas the
electron temperature gets saturated for 40 – 60% addition of Argon flow rate.

From the dust charging profile, it is observed that the dust current and dust
charge decrease significantly up to 40% addition of argon flow rate in hydrogen plasma.
But beyond 40% of argon flow rate, the reduction of dust current and dust charge are
insignificant. It is because of the reason that the dust surface potential or floating
potential strongly depends on electron temperature rather than the effective positive ion
mass. The effects of plasma density, degree of dissociation and positive ion mass on the
dust charging are not observed. From this experiment it is found that addition of argon
into the hydrogen plasma can be used as a tool to control the dust charging in low-
pressure hydrogen plasma.

7.2 Future scopes

The experimental studies presented in the thesis can be extended to some
numerical and experimental studies to give deeper insight the dust charging dynamics in
low pressure plasma. Some of these are given below:

• The effect of secondary electron emission (SEE) on electron energy probability
  function can be studied to estimate the energy of the secondary electrons and its
effect on plasma parameters can be examined.

• The effect of electrostatic confinement and SEE on the ion acoustic wave in
dusty plasma can be studied. The electron energy probability function at
different confining wall potentials can be examined.
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- The in-situ produced dust beam can be used to design a dust accelerator to study the effect of high-velocity, micron-sized, single-particle impacts on spacecrafts to examine the potential dangers of cosmic dust on spacecrafts.

- The phase velocity of the ion acoustic wave in presence of two species positive ion (H⁺ and Ar⁺) could be studied and the concentration of H⁺ and Ar⁺ ions can be calculated from the phase velocity of the ion acoustic wave (IAW).

- From the dust charging experiment with Cs coated W dust, it is found that Cs coated W dust can be used to generate negative hydrogen ions through surface production route. By using Cs coated dust, the effective low work function surface area inside the plasma volume can be increased compared to conventional negative ion source which is very important for efficient production of negative hydrogen ion. The negative hydrogen ions produced by Cs coated dust can be extracted easily compared to the conventional ion source because of the isotropic nature of negative ion production from all the surface of the Cs coated W dust. Thus, a novel negative hydrogen ion source can be developed by spraying cesium coated tungsten dust into the hydrogen plasma background.