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A nanodusty plasma experiment to create extended dust clouds using reactive argon acetylene plasmas

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ABSTRACT

A large volume 3D dust cloud containing *in situ* grown nanometer-sized particles is produced in a newly developed versatile table-top experimental device. Carbonaceous nanoparticles having almost uniform size throughout the dust cloud are grown using capacitively coupled rf discharge in Ar–C_2H_2 gas mixture with a low precursor gas flow rate ($\sim$2 sccm) and minimal rf power ($\sim$1 W). The vertical and radial extensions of the dust cloud are 40 cm and 5 cm, respectively. The pure Ar plasma in the setup is characterized by measuring the discharge parameters as well as plasma parameters under different discharge conditions. The average particle size and its temporal growth profile are determined by analyzing the scanning electron microscope images of the particles. The dust density measured using the laser extinction method is found to be of the order of 10^{16}–$10^{12}\,m^{-3}$ for the discharge duration of 2–10 min. A spontaneous dust density wave is also observed in the dust cloud.

I. INTRODUCTION

Plasma embedded with nanometer- to micrometer-sized particles is commonly known as dusty plasma. It is one of the most exciting and popular research topics in plasma physics because of its significance in exploring space physics and its vast impact on technological applications. The growing interest in dusty plasma research was mainly triggered by two major discoveries in 80s, which are (a) observation of radial spokes in Saturn's ring and (b) particle formation and levitation in semiconductor manufacturing devices.[1–4] Since then, dusty plasma has been extensively studied in the context of understanding various natural phenomena and exploring its role in device fabrication and material processing.[1–6] In addition to this, observation of dusty plasma crystal in 1994 has greatly motivated dusty plasma experiments in various laboratories worldwide.[7,8] Dusty plasmas are easily produced in the laboratory either by injecting dust particles into the plasma or by growing particles inside the plasma in a controlled manner. In general, the former method is used for producing dusty plasma medium containing micrometer-sized particles, whereas the latter one is suitable for nanodusty plasma (plasma with particles in the nanometer range) experiments. In most of the laboratory plasmas, dust particles quickly acquire a net negative charge by collecting highly mobile electrons. The value of the dust charge strongly depends on the particle size and the electron temperature. For particles of size in nanometer to micrometer range, the typical values of average charge on a dust particle vary from tens to several thousand elementary charges. The presence of charged particles in plasma results in many unique and interesting phenomena such as particle confinement, levitation, strong coupling effects, dust crystallization, new wave modes, instabilities, dust voids, and many dynamical structures. Studies on these dust collective processes have been carried out extensively in a dusty plasma containing micrometer-sized particles and have made a significant contribution toward fundamental research applicable to various interdisciplinary areas.[1–4,9] On the other hand, the dynamics of nanometer to sub micrometer-sized particles in plasma and the effect of electron depletion at high dust density (Havnes effect) have not been explored much. Such experiments are possible using nanodusty plasmas.

The observation of solid particle formation in a gaseous plasma environment is quite common in semiconductor fabrication devices, sputtering devices, as well as in fusion plasmas.[2,10] They are unwanted in these environments as the particles can severely reduce the