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Suppression of a spontaneous dust density wave by modulation of ion streaming

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Abstract

Synchronization of a self-excited dust density wave has been experimentally investigated in a strongly coupled dusty plasma. A dust density wave of frequency ~78 Hz is spontaneously generated from the dust void boundary due to the ion streaming instability. The electric field in the dust void region is measured, and the electric field force and ion drag force on the dust particles at the void boundary are estimated to explain the mechanism of spontaneous dust density wave excitation. Synchronization occurring through the suppression mechanism is observed by modulating the ion streaming by applying an external sinusoidal signal to the dust void. At sufficiently high modulation amplitude, the onset of period-doubling bifurcation is observed. Fast Fourier transform spectral analysis is done using time-series data obtained from high-speed video imaging. The van der Pol equation with a force term is used to correlate the observed suppression phenomena.

Keywords: dust density wave, suppression phenomena, strongly coupled dusty plasma, forced van der Pol equation

(Some figures may appear in colour only in the online journal)

1. Introduction

Dusty plasma is a medium containing micrometer- or nanometer-size dust particles in a plasma background of electrons, ions, and neutrals. Interest in the field of dusty plasma has grown immensely in the last few decades, due to its natural abundance in space environments like interstellar clouds, comet tails, Saturn's rings, etc. Dust formations occur in many laboratory devices such as in material processing industries and thermonuclear fusion devices [1–7]. Dusty plasma is produced in the laboratory either by introducing the dust particles externally or by growing particles in the plasma using a mixture of noble gases with reactive gases such as SiH_4, C_2H_2, CH_4, etc [8–10]. In the laboratory discharge plasma, dust grain floats with negative potential to maintain equilibrium between ion and electron fluxes onto the dust so that the surface current is zero. When the dust particle density in plasma is sufficiently high, Coulomb interaction between the dust particles dominates and the dusty plasma can support a variety of linear and nonlinear phenomena such as strong coupling effects, dust crystallization, low-frequency wave modes, instabilities, voids, vortex, solitary structures, etc [6, 11–17].

Dust particles, being larger in size and heavier in mass, have a relatively low charge-to-mass ratio compared to ions and electrons. The spatial and time scales of their motion are suitable for direct observation of various kinds of waves and instabilities like dust acoustic waves (DAWs), dust acoustic (DA) shocks and solitons, and other nonlinear structures [18, 19]. In particular, the DAW is a longitudinal wave analogous to an ion-acoustic wave in which the heavy dust particles provide the inertia and the electrons and ions provide the restoring force to drive the wave. Rao *et al* [20] predicted the existence of this low-frequency wave mode in dusty plasma for the first time in 1990, which was experimentally verified by Barkan *et al* [21] in 1995. Since then, DAWs have been observed in many laboratory experiments [22–26] as well as in microgravity-based experiments [27, 28]. Most of the experiments are, however, carried out with micrometer-sized dust grains levitated in the plasma against the effect of gravity by the sheath electric field of the lower electrode. In experiments, dust acoustic perturbations are excited externally