Two-dimensional plasma crystals: waves and instabilities

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Wake-mediated interactions result in the coupling between wave modes in 2D complex plasma crystals, which can trigger the mode-coupling instability and cause melting. Spectra of phonons with out-of-plane polarization were studied experimentally in 2D plasma crystals during dedicated experiments on the mode-coupling instability. The kinematics of dust particles during the early stage of mode-coupling induced melting is explored. It is found that the formation of the hybrid mode causes the particle vibrations to partially synchronize at the hybrid frequency. The spatial orientation of the synchronization pattern correlates well with the directions of the maximal increment of the shear-free hybrid mode.

Complex plasmas consist of particles immersed in a weakly ionised plasmas. Due to the absorption of ambient electrons and ions, microparticles acquire negative charges and can form coupled systems. Microparticles injected in capacitively-coupled radio-frequency discharges levitate in the sheath region near the bottom electrode, where the electric field can balance gravity. Under certain conditions the particles can form a monolayer and arrange themselves into ordered structures: 2D plasma crystals. In such crystals, two in-plane wave modes with an acoustic dispersion can be sustained (longitudinal and transverse modes). Since the strength of the vertical confinement is finite, there is a third fundamental wave mode associated with the out-of- plane oscillations that has a negative optical dispersion [1]. Due to the strong electric field in the sheath region, every particle is influenced by a strong ion flow. The ions tend to focus downstream of the particles making the system highly polarized (plasma wake). In 2D plasma crystals, wake-mediated interactions result in the coupling of the crystal in-plane and out-of-plane modes into a shear-free hybrid mode of the lattice layer and trigger the mode-coupling instability (MCI) [1, 2, 3] which can melt the crystal [4]. Localised "hot spots" in the lattice phonon spectra are a typical signature of this mode [1, 3]. MCI induced melting can only be triggered if (i) the modes intersect, and (ii) the neutral gas damping is sufficiently low.

In this paper, spectra of phonons with out-of-plane polarisation were studied experimentally in 2D plasma crystals. The dispersion relation was directly measured using a method of particle imaging that allowed us to resolve the particle motion in the 3 dimensions. We observed experimentally the coupling between the out-of-plane mode and the in-plane longitudinal mode which under certain conditions can form hybridised modes and trigger the MCI[5, 6]. The kinematics of dust particles during the early stage of MCI revealed that the formation of the hybrid mode induces the partial synchronisation of the particle oscillations at the hybrid frequency [7, 8]. Phase- and frequency-locked hybrid particle motion in both vertical and horizontal directions was evidenced. The spatial orientation of the synchronisation pattern correlates well with the directions of the maximal increment of the shear-free hybrid mode. Asymmetries observed in the current fluctuation spectra come from inhomogeneities of the horizontal confinement [8]. A theory of MCI in shear-deformed crystals explains the asymmetry of hot spots[9].

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