Video Imaging of Dust Acoustic Waves

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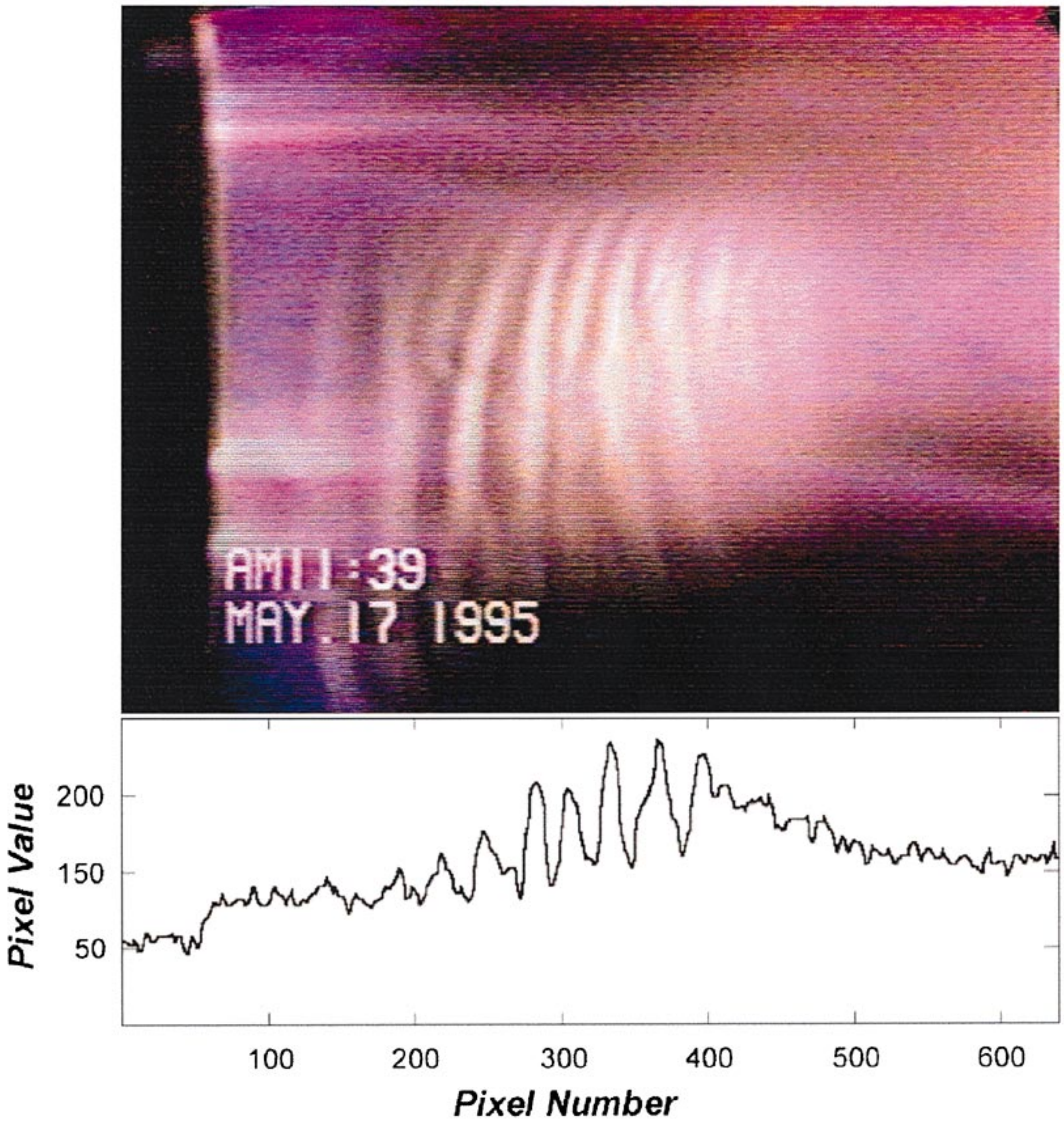

Fig. 1. Single video frame image of a dust acoustic wave. The bright vertical bands correspond to the wave crests (dust compressions). The bluish-red glow is the light emission from the plasma. The entire image covers 640 (vertical) pixels by 320 (horizontal) pixels. The bottom plot is the horizontal intensity map (pixel values) of pixel row 200.

***Abstract*—Imaging dust clouds is often the primary source of data acquisition, especially in situations where the dust grains participate directly in the dynamics, as in the case of very low frequency "dust waves." A sample image of a dust acoustic wave is presented.**

***Index Terms*—Image analysis, plasma oscillations.**

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THE addition of micron sized particles to a plasma can alter the fundamental electrostatic wave modes of the plasma, as well as create new wave modes that are associated with dust grain dynamics. The most prevalent example of such a "dust wave" mode is the dust acoustic wave (DAW), an acoustic wave that propagates through an ensemble of charged dust grains. Since the mass of the dust grains provides the inertia for this mode, it is typically of extremely low frequency (∼tens of Hz). This low frequency, along with the light scattering properties of small particles, allows the mode to be easily viewed with a simple video camera.

The dust acoustic mode was first considered theoretically using a fluid analysis, treating the dust particles as a separate fluid component of the plasma [1]. An experiment using an anode double layer to trap and confine dust particles in a Q machine yielded a visual observation of dust acoustic waves [2]. Measurements of the phase velocity and wavelength of the mode were made from the analysis of single frame video images. By driving the DAW's at a given frequency, the predicted dispersion relation was experimentally verified using similar video techniques [3]. Low frequency waves have also been observed in strongly coupled dusty plasmas [4]–[6] and in plasmas containing large negative ions [7].

The image presented in Fig. 1 was taken from a video of the initial dust acoustic wave observations made by our group [2]. The image was recorded on VCR tape using a standard (off the shelf) VHS video camcorder. In this experiment, a Q machine was operated in a discharge mode, in which a neutral gas was added to the background potassium plasma produced by a hot plate at one end of the device (Fig. 2). Nitrogen gas at a pressure of $\sim$70 mtorr was introduced into the device and a bias voltage ($\sim +200$ V) was applied to a small anode (diameter: 1.6 cm) disk located near the far end of the plasma column. This produced an anode double layer at the boundary of a glow discharge with dc electric fields of sufficient strength ($\sim$10 V/cm) to levitate the negatively charged dust particles. The aluminum silicate dust (kaolin) was dispersed into the double layer by means of a rotating dust dispenser.

Under these conditions, DAW's were spontaneously excited in the plasma and were visually observed as bright vertical bands propagating through the dust cloud in the direction away from the anode (from right to left in Fig. 1). The micron-sized dust scatters light, allowing easy imaging of the cloud with the use of a simple video camera. For this image, the light emitted by the Q-machine hot plate was sufficient to photograph the dust cloud, but for subsequent experiments it was found that backlighting the dust cloud with a high intensity light source provided better illumination for video imaging. The wavelength of the DAW ($\sim$0.6 cm) was measured directly from a single frame video image. The wave phase velocity ($\sim$9 cm/s) was determined from an analysis of successive frames of video images. The measured wave properties agreed with linear fluid theory predictions.

The video taken of the dust cloud can be converted into a series of digital images through the use of a digital video capture card. These still images can then be processed digitally with the use of standard mathematical software that utilizes matrix structured image processing. The image, now transformed into a matrix, can be separated into "slices" by matrix row operations, and plotted as an array of data points. Each slice across the image represents the scattered light intensity from the dust particles. Such a "slice" is shown below the image in Fig. 1. From the pixel intensity plot, the crests and troughs of the wave are clearly visible against the background of the plasma. Several wave crests and troughs of the DAW are clearly seen in the plot of the intensity (pixel value) versus position (pixel number).

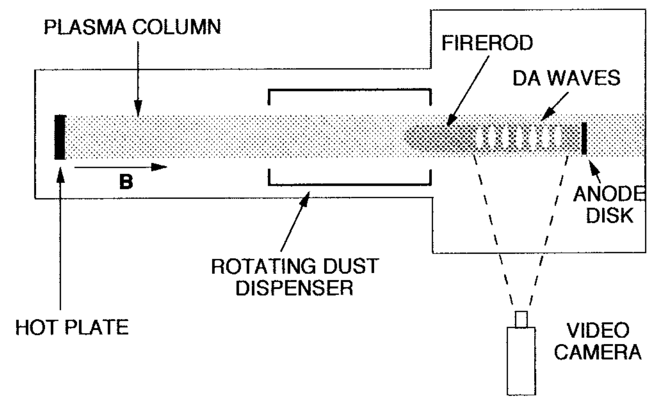

Fig. 2. Schematic of the experimental apparatus for producing a confined dusty plasma.

The use of video capture techniques is one of the few means available to study dust dynamics. Video imaging provides a way to obtain information about the dusty plasma without disturbing the dust grains. Future use of imaging will allow continued studies of dust dynamics, such as the formation and propagation of nonlinear waves and shocks and the interaction of dust clouds with moving objects.

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