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**Final Technical Report**

on

**Study of Dusty Plasmas**  
**Grant No. F49620-97-1-0007**

**For the period of**  
**November 1, 1996 to October 31, 1999**

**Submitted to**

**Dr. Robert Barker**  
**Directorate of Physics Electronics**  
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**Submitted on January 31, 2000**

**by**

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## ABSTRACT

This progress report describes research work performed at Texas Tech University under AFOSR Grant No. F49620-97-1-0007 during the period of November 1, 1996 to October 31, 1999. Theoretical and computational study of collective effects in dusty plasmas revealed (1) formation of oscillatory wake potential behind a highly charged dust grain placed in the ion flow in the sheath (2) stable polygon structures formed by a collection of trapped dust particulates in the wake potential minima (3) low frequency oscillations of order 10Hz associated with the polygon plasma crystal structure (4) interaction of dust particulates and plasma particles through Hamiltonian formulation (5) low frequency lattice oscillations ( $\sim 1$ Hz) described by Hamiltonian formulation (6) the attractive interaction between dust particulates through exchange of phonons (7) polarization of a dust grain in the order of a Debye length (8) the higher threshold of the dust ion-acoustic instability with the effect of dust-charging process, and (9) Buneman-type streaming instability in a dust plasma developed in a subsonic ion flow.

## **I. Objectives**

To study the collective effects in dusty plasmas, focusing on the theoretical and computational study of dusty plasmas when plasma crystal is formed.

## **II. Status of the Research**

The principal investigator, Professor Osamu Ishihara, in collaboration with Dr. Sergey Vladimirov of University of Sydney, conducted the research. Mr. Wu Zhang, a graduate student, completed his master degree in May 1999 on the topic of this research.

## **III. Accomplishments/New Findings**

Our theoretical and computational study of collective effects in dusty plasmas has revealed

- (1) formation of oscillatory wake potential behind a highly charged dust grain placed in the ion flow in the sheath, resulting in trapping of dust particulates in the potential minima provided by the wake potential
- (2) stable polygon structures formed by a collection of trapped dust particulates in the wake potential minima, as a result of the force balance between ion drags, gravitational fields, and the sheath electric fields
- (3) low frequency oscillations of order 10Hz associated with the polygon plasma crystal structure
- (4) interaction of dust particulates and plasma particles through Hamiltonian formulation
- (5) low frequency lattice oscillations ( $\sim 1$ Hz) described by Hamiltonian formulation
- (6) the attractive interaction between dust particulates through exchange of phonons
- (7) polarization of a dust grain whose size is in the order of a Debye length
- (8) the higher threshold of the dust ion-acoustic instability with the effect of dust-charging process
- (9) Buneman-type streaming instability in a dust plasma developed in a subsonic ion flow.

## **IV. Publications**

### **1. On Plasma Crystal Formation**

S.V. Vladimirov and O. Ishihara, *Physics of Plasmas* 3, 444-446 (1996)

Wake Potential of a Dust Grain in a Plasma with Ion Flow

O. Ishihara and S.V. Vladimirov, *Physics of Plasmas* 4, 69-74 (1997)

Polygon Structures of Plasma Crystals

O. Ishihara, *Physics of Plasmas* 5, 357-364 (1998).

Hamiltonian Dynamics of Dust-Plasma Interactions

O. Ishihara and S.V. Vladimirov, *Physical Review E* 57, 3392-3398 (1998).

Instability due to Dust Particulate-Phonon Interaction

O. Ishihara, *Physical Review E*, 58, 3733-3738 (1998).

Plasma Crystals - Structure and Stability

- O. Ishihara, *Physica Scripta*, T75, 79-83 (1998).  
 Wave Action in a Plasma with Coulomb Collisions  
 S. V. Vladimirov and O. Ishihara, *Physica Scripta* 57, 293-297 (1998).  
 Buneman-type Streaming Instability in a Plasma with Dust Particulates  
 S. V. Vladimirov and O. Ishihara, *Physica Scripta* 60, 370-372 (1999).  
 On the Realization of the Current-Driven Dust ion-Acoustic Instability  
 K. N. Ostrikov, M. Yu, S. V. Vladimirov, and O. Ishihara, *Physics of Plasmas* 6, 737-740 (1999).

## V. Presentations/Proceedings

1. On the Wake Potential of Dust Particles in a Plasma with Ion Flow, O. Ishihara and S.V. Vladimirov, IEEE Int. Conf. on Plasma Sci. (June 3-5, 1996, Boston, MA).
2. Effects of Plasma Fluctuations on the Evolution of Nonresonant Plasma Waves, S. V. Vladimirov and O. Ishihara, 1996 International Conference on Plasma Physics (September 9-13, 1996, Nagoya, Japan). *Plasma Physics*, ed. by H. Sugai and T. Hayashi, vol. 1, pp.806-809 (Japan Society of Plasma Science and Nuclear Fusion, 1997).
3. Wake Potential and Plasma Crystal, O. Ishihara and S. V. Vladimirov, 1996 International Conference on Plasma Physics (September 9-13, 1996, Nagoya, Japan). *Plasma Physics*, ed. by H. Sugai and T. Hayashi, vol. 2, pp.1962-1965 (Japan Society of Plasma Science and Nuclear Fusion, 1997)
4. On Coulomb Crystallization in a Dusty Plasma, S.V. Vladimirov, O. Ishihara and M. Nambu, Plasma '97, the 21st Australian Institute of Nuclear Science and Engineering, Plasma Science and Technology Conference (February 17-18, 1997, Sydney, Australia).
5. Wake Potential due to a Pair of Dust Particles, W. Zhang, O. Ishihara, and S.V. Vladimirov, IEEE International Conference on Plasma Science (May 19-22, 1997, San Diego, Ca).
6. Plasma Crystal Formation as a Result of Collective Effects in Dusty Plasmas, O. Ishihara, International Topical Conference on Plasma Physics: New Perspectives of Collective Effects (November 10-14, 1997, Trieste, Italy). Invited lecture.
7. Propagation of a Wave in a Plasma with Coulomb Collisions, S. V. Vladimirov and O. Ishihara, IEEE International Conference on Plasma Science (May 19-22, 1997, San Diego, Ca).
8. Dust Particulate Phonon Interaction, O. Ishihara, Seventh Workshop on the Physics of Dusty Plasmas (April 6-9, 1998, Boulder, Colorado).
9. Dust Particulate-Phonon Interaction and the Resulting Instability, O. Ishihara, IEEE International Conference on Plasma Science (June 1-4, 1998, Raleigh, North Carolina).
10. Interaction Between a Pair of Dust Particulates, O. Ishihara, APS Division of Plasma Physics Meeting (November 16-20, 1998, New Orleans).

## **VI. Student Thesis.**

Wu Zhang, MS May, 1999

Title: Plasma Simulation with a Dielectric Object in the Presence of an Ion Flow

### **Abstract:**

Recent dusty plasma experiments have investigated the crystallization of dust grains near the edge of a plasma sheath. Some theories were proposed to explain the crystallization mechanisms. The purpose of this simulation work is to study the electrostatics of a dielectric object immersed in a plasma sheath where the ion flow velocity is greater than the ion acoustic velocity, utilizing the object-oriented particle-in-cell code called XOOPIIC developed at UC-Berkeley. This simulation is designed to investigate the polarization in a charging process and the electrostatic traps downstream of an object caused by an ion flow in a plasma discharge. Both the polarization and electrostatic traps in the wake field are considered important factors in the formation of plasma crystals. In this thesis, the simulation model based on the XOOPIIC code is established, and the simulation results on wake potentials and polarization are obtained and analyzed. This simulation work was completed on the Sun workstation in the department of electrical engineering at TTU.

## **VII. New Discoveries, Inventions, or Patent Disclosures**

None

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