TWO DIMENSIONAL COMPUTER SIMULATION OF PLASMA IMMERSION ION IMPLANTATION

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As a line-of-size, accelerator based, implantation technique beamline ion implantation has some shortcomings:

- low implantation current
- small treatment area
- not adequate for treating complex shaped objects
- requires complex target manipulation
- high production cost
Plasma Immersion Ion Implantation

A novel implantation technique especially developed for fast and efficient treatment of complex-shaped 3D targets

- higher current density
- conformal implantation
- large treatment area
- low cost
- shorter implantation time

Disadvantages

- spatial dose uniformity is a priori not guaranteed
- secondary electron emission pose X-rays hazard and could significantly reduce the PIII efficiency
Objectives

- Development of realistic, particle-in-cell (PIC), computer simulation of plasma immersion ion implantation
- Detailed investigation of plasma sheath formation and dynamics
- Study of ion dose uniformity in case of complex shaped targets
- Examining the role of secondary electrons
- Possibility for magnetic confinement of the secondary electrons
Spatial variables are limited to two dimensions (r - z coordinates in cylindrical geometry). All three components of the fields and velocities are retained.

Nitrogen plasma is generated by ionization of neutral gas using primary electrons. Probabilistic Monte-Carlo collision algorithm is employed to simulate the ionization process.

Actual mass of $\text{N}_2^+$ ion is used.

High voltage pulse with finite rise time is applied to the target and the evolution of the plasma sheath is followed in the time.
Numerical parameters

KARAT is run in electrostatic mode
vacuum camera radius $R = 13$ cm and length $L = 38$ cm
neutral gas density $n_0 \sim 10^{14}$ cm$^{-3}$
bias voltage $V = -10$ kV
high voltage pulse starts at $t = 1.25 \mu$s and has rise time $t_r = 0.25 \mu$s
typical mesh size $\Delta r = 1.3-1.5$ mm, $\Delta z = 4-4.5$ mm
time step $\Delta t \sim 2.0$ ps
number of macro-particles $\sim 140000$
secondary electron yield $\gamma = 4$
external axial magnetic field $B = 0.04$ T
plasma density achieved in the simulation $\sim 10^9$ cm$^{-3}$
electron temperature $T_e \sim 3$ eV
Simulation geometry

10kV, plasma, gas, ioniz, electat, 1.5A

time = 0.00mcs
Initial electron density distribution
Balance of plasma particles (B=0 T and γ=0)
Ion trajectories
Axial distribution of implantation current

10kV, plasma, gas, ioniz, electat, 1.5A

time = 1.80mcs

A/cm

#2

0.12

0.10

0.08

0.06

0.04

0.02

z, cm

14.0

18.0

22.0
Energy distribution of incident ions
Ion implantation into convex sample
Current distribution for convex sample
Ion implantation into concave sample
Current distribution for concave sample

10kV, plasma, gas, ioniz, electrat, 1.5A, HOLE

Time = 1.60 mcs

Graph showing current distribution along the z-axis (cm) with two prominent peaks at 18.0 cm and 22.0 cm.
Role of secondary electrons in plasma net balance (B=0 T and $\gamma=4$)
Effect of energetic secondary electrons
Axial distribution of electron current
Effect of axial magnetic field ($B=0.04\,T$, $\gamma=4$)
Plasma sheath with external magnetic field

10kV, s.el., gasn=2.2x10^-14, ion, 3.0A, B=.04
time= 3.50mcs
Confinement of secondary electrons
Ion trajectories in magnetized plasma
Plasma sheath expansion

![Graph showing plasma sheath thickness and target potential over time. The graph includes data points labeled as Simulation and a line labeled 1D Theory.](image-url)
Conclusions and Future Work

• Realistic PIC computer simulation of PIII process has been developed
• Steady-state plasma was generated by ionization of neutral gas
• Implant conformality for complex shaped samples has been studied
• Time evolution of plasma sheath has been investigated
• Effect of secondary electron emission has been included
• Magnetic confinement of secondary electrons has been examined

• Further refinement of numerical algorithm
• Achievement of higher plasma density in order of $10^{10}$ cm$^{-3}$
• Use of electromagnetic mode for better simulation of transient processes
• Study of plasma sheath collapse
• Investigation of PIII in nonconductive materials