Plasma Cleaning of Carbon and Nanoparticles From EUV Materials

W. M. Lytle, M. J. Neumann, V. Surla, D. N. Ruzic
Center for Plasma-Material Interactions • Department of Nuclear, Plasma and Radiological Engineering University of Illinois at Urbana Champaign, Urbana, IL 61801 USA
*contact email: druzic@illinois.edu

Abstract
Carbon contamination on the collector optics as well as nanoparticle contamination on EUV masks can cause degradation of the lithography system as well as cause errors in the transfer of features from the mask to the wafer. Traditional cleaning techniques extended from optical lithography to EUV lithography are limited in their cleaning effectiveness at the smaller contamination dimensions for EUV lithography. Plasma Assisted Cleaning by Metastable Atomic Neutralization (PACMAN), a plasma-based non-contact cleaning technique being developed in the Center for Plasma Material Interactions (CPMI), has demonstrated 100% cleaning efficiencies of planar carbon contamination as well as carbon based nanoparticles (30 nm – 500 nm) from silicon wafers as well as EUV mask materials. This methodology uses a high-density plasma source producing highly energetic metastable species in order to provide a cleaning technique for several types of surfaces involved in integrated circuit manufacturing without damage to the underlying substrate (roughening or surface sputtering). Current results of the PACMAN cleaning technique are presented.

Apparatus

Plasma cleaning of a photo mask

Full 6 inch by 6 inch masks can be cleaned inside the processing chamber

Not Sputtering

- Classical sputtering yields calculated via SRIM/TRIM
- Some sputtering does occur
- Sputtering does not account for the measured removal rates for PSL and Carbon

Energy Transfer Mechanism
- Auger de-excitation of metastable at contamination surface
- Metastable “steals” bonding electron from surface to fill 1s state, emits high energy electron

Proposed Removal Mechanism

- Plasma creates electrons, helium ions, and helium metastables
- He ions directed to the surface by plasma sheath electric field
- Metastables (non ionized) diffuse to the surface/particle
- He ions and metastables impart energy to atoms of the particle
- Particle bonds break
- Volatilization of particle occurs
- Particle is removed similar to etching

Plasma Effects on He Metastable Density and Removal
- Relative density of helium metastables vs. sample bias shows an increase of metastable density at positive bias
- Removal rate increases slowly with more negative bias (increased classical sputtering)
- At positive bias, removal rate significantly increases

Separated Components of Plasma on Removal

- Density of helium metastables increases with increasing plasma power
- Removal rate increases as plasma power is increased

What are Helium Metastables?
- Excited, but not ionized, helium neutrals, that are long lived (up to 4.2x10^9 seconds)
- Quantum mechanically “stuck”, ΔE ≠ 0 (conservation of angular momentum, 2s to 1s transition “forbidden”)
- Relatively high energy (~20 eV), circled in red
- Only lose energy through three body collisions
- Interact, give energy, to particle (He*– particle/surface collision)
- Can not “observe” them via optical emission spectroscopy, but can see the transitions that populate the two metastable states

Conclusions

- PACMAN has shown 100% cleaning of PSL on silicon
- PACMAN has shown 100% cleaning of carbon on silicon
- Reflectivity and surface smoothness is maintained post cleaning
- Modeling and physical understanding of the removal mechanism is being determined in order to show extendability to inorganic material

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