

to produce deeper sub-surface damage that is characteristic of conventional ion beam processing.

[0005] Conventional cluster ion sources produce cluster ions having a wide size distribution scaling with the number of molecules in each cluster that may reach several thousand molecules. Clusters of atoms can be formed by the condensation of individual gas atoms (or molecules) during the adiabatic expansion of high-pressure gas from a nozzle into a vacuum. A skimmer with a small aperture strips divergent streams from the core of this expanding gas flow to produce a collimated beam of clusters. Neutral clusters of various sizes are produced and held together by weak inter-atomic forces known as Van der Waals forces. This method has been used to produce beams of clusters from a variety of gases, such as helium, neon, argon, krypton, xenon, nitrogen, oxygen, carbon dioxide, sulfur hexafluoride, nitric oxide, nitrous oxide, and mixtures of these gases. Thus, there exists a need to provide methods and apparatus for improving the beam stability in high current GCIB workpiece processing systems.

SUMMARY

[0006] Described herein is a nozzle/skimmer module and an improved gas cluster ion beam (GCIB) system for treating a substrate using a GCIB.

[0006a] According to a first aspect of the present invention, there is provided a nozzle assembly for use in a gas cluster beam (GCB) processing system, including: a gas supply manifold having at least one gas supply conduit; a first nozzle component through which a first portion of at least one conical nozzle is formed that extends from a nozzle throat at a first entry surface to an intermediate exit at a first exit surface; a second nozzle component through which a second portion of said at least one conical nozzle extends from an intermediate inlet at a second entry surface to a nozzle exit at a second exit surface, said second nozzle component further including a re-entrant cavity into which said first nozzle component inserts such that said first exit surface mates with said second entry surface, and said first nozzle portion aligns with said second nozzle portion to form said conical nozzle; and a sealing member disposed between said first nozzle component and said gas supply manifold such

that when said second nozzle component is attached to said gas supply manifold, said first entry surface of said first nozzle component presses against said sealing member and creates a seal with said gas supply manifold surrounding an outlet of said at least one gas supply conduit.

[0006b] According to a second aspect of the present invention, there is provided a nozzle assembly for use in a gas cluster beam (GCB) processing system, including: a nozzle component comprising: at least one conical nozzle; and a nozzle throat disposed proximate to one end of said at least one conical nozzle that can receive gas from a gas supply conduit; a re-entrant cavity component comprising: a cavity that houses said nozzle component; a first opening of said cavity that can receive said nozzle component or said gas; a second opening of said cavity that is opposite said first opening and that can receive said gas from said at least one conical nozzle; and a continuation nozzle comprising a conical cavity that is aligned with said at least one conical cavity and can receive said gas from said at least one conical nozzle via said second opening, the conical cavity comprising an entrance diameter that is larger than any diameter of said at least one conical nozzle.

[0007] The nozzle/skimmer module may include an internal nozzle element and internal skimmer cartridge assembly to control the formation of the GCIB. The nozzle/skimmer module can be pre-aligned to position the GCIB relative to the substrate. The nozzle/skimmer module may include a nozzle assembly and a skimmer assembly to control the formation of the gas clusters of the GCIB.

[0008] According to another embodiment, an improved GCIB processing system is provided that comprises a source subsystem that includes a nozzle/skimmer module, an ionization/acceleration subsystem, and a processing subsystem. The source subsystem can include a source chamber having an interior space in which the nozzle/skimmer module is configured, the ionization/acceleration subsystem can include an ionization/acceleration chamber, and the processing subsystem can include a processing chamber. The improved GCIB processing system comprises a first gas supply subsystem, a