Accelerated Neutral Atom Beam (ANAB) Technology for Nanoscale Surface Processing

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Abstract— **Many difficulties and limitations of surface processing by traditional ion beam techniques are associated with the electrical charges that are fundamental to ion acceleration. Flux neutralization approaches used to minimize space charge repulsion effects and neutralization methods employed to avoid surface charge accumulation and damage phenomena complicate the use of ion beams in many situations, particularly so as device dimensions approach nano-scale. It has long been recognized that simplified fabrication processes and superior nano-level processing capabilities would be possible if process beams comprised of only neutral atoms having adequate and controllable energies could be generated. The obstacle to creating such beams has always been the problem of how to remove all electrical charges from a beam of ionized atoms after acceleration. This paper describes a method known as Accelerated Neutral Atom Beam (ANAB) in which energetic neutral atoms are produced by causing large numbers of neutral atoms to be released from the individual gas clusters within a stream of high energy gas cluster ions and then using an electrostatic field to eliminate residual charged species from the beam.**

The ANAB technique provides high flux collimated beams of energetic neutral atoms that have average energies which are controllable from less than 10 eV per atom to more than 100 eV per atom, a range found to be ideal for many nano-scale surface modification actions. Available neutral beam species include virtually any element or molecule that exists as a gas at room temperature. ANAB processes are useful for precise sputtering, nano-level surface smoothing, extremely shallow doping, highly selective etching, ultra-thin film deposition, surface passivation, various surface specific molecular transformations, and for a range of other ultra-shallow surface actions. Due to its highly collimated nature, ANAB offers excellent performance for nano-scale patterning and for uniform depth processing of structural geometries with varied aspect ratios. ANAB is being employed in a number of areas, including medical implants, other medical and biological devices, optics, MEMS, semiconductors, and metrology.

The paper describes the ANAB technique, including methods of beam generation, beam characterization, and process control. Surface modification characteristics which are inherent to ANAB processing, and unique aspects of ANAB actions, are discussed. Applications of ANAB being introduced in various fields are reviewed.

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I. INTRODUCTION

A process for generating ANAB begins when gas is admitted into vacuum at controlled flow through a specially shaped small nozzle. As the pressurized gas expands at high velocity through the nozzle throat, the atoms cool and coalesce into weakly bound clusters held together by van der Waals forces. The average cluster size can be controlled by varying the pressure and flow of the gas entering the nozzle. Typical cluster sizes range from several hundred to several thousand atoms. The stream of formed clusters is directed through a small skimmer orifice into an adjoining vacuum vessel held at lower pressure, typically below 1E-4 torr so that high voltage fields can be maintained. The cluster stream passes through a field of bombarding electrons where one or more of the cluster atoms become ionized. Once ionized, the clusters are accelerated toward ground through a voltage of typically 10 kV to 50 kV. To produce a beam of accelerated neutral atoms, the ionization and acceleration regions are configured so that immediately after acceleration the cluster ions collide with non-ionized monomer gas atoms travelling at low velocity along the beam path. As a result of such collisions, energy is transferred into the cluster ions, causing them to become unstable and resulting in release of large numbers of neutral atoms which continue to travel in the same direction and with the same velocity as the parent cluster, but no longer bonded to it. Residual charged species, diminished cluster ions or monomer ions, are then removed by means of an electrostatic deflector [1].

Figure 1 is a schematic for ANAB generation. As an example of the neutral atom formation mechanism, the energy of each atom within a 1000 atom Ar gas cluster ion accelerated to 30 keV is 30 eV. Upon collision of the 1000 atom cluster with a non-accelerated neutral Ar atom, approximately 30 eV will be transferred into the internal energy of the cluster, forcing it to release bonded atoms in order to regain stability. At the binding energy of 0.086 eV per atom [2] within a 1000 argon atom van der Waals cluster, a total of (30 eV)/(0.086 eV/atom) = approximately 350 atoms will be released due to the single collision. Smaller clusters can become completely dissociated.