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Gas cluster ion beams for wafer processing

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Abstract

Gas cluster ion beams (GCIB) represent a powerful new tool for wafer processing. This paper will review the development status of GCIB equipment as pertains to semiconductor applications.

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Keywords: Cluster ion beams; GCIB; Equipment for GCIB

1. Introduction

Gas cluster ion beams (GCIB) have been demonstrated to be valuable for surface smoothing and etching [1]. Commercial GCIB equipment has been developed that allows corrective etching of wafer surfaces to obtain smooth surfaces with a consistent and uniform thickness profile [2]. This feature has resulted in the use of GCIB for SAW device production [3]. Most recently GCIB has been used to dope silicon with boron [3,4] and to form low defect germanium–silicon layers [3,5].

Commercial 300 mm GCIB processing equipment is available at the 500 μA level and currents up to 1 mA have been achieved in the laboratory [7]. While the currents are low compared to most ion implant equipment, the atomic flux levels of such beams are in the range of one to several amperes making them well suited for directed beam chemistry, deposition, etching and surface modifications. The design of the Epion GCIB equipment, the only such systems currently in production, has been described in the literature [7,8]. Beam lines are similar to those used in ion implanters but are modified to account for differences such as the high gas flow in the beam, itself, and the high magnetic rigidity of the clusters. In the past several years, the equipment has evolved largely to address production worthiness issues. It is the purpose of this paper to report on the significant progress that has occurred in these critical areas.

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2. Cluster formation

Clusters are formed by an adiabatic expansion of the cluster gas through a supersonic nozzle into a vacuum. With typical nozzle stagnation pressures of ~5000 Torr, exit temperatures of ~1 K would be expected. Actual cluster temperature is higher, since the atoms give up heat on nucleation. In many cases binary and tertiary mixes of gases are used for processing. For example, NF_3 and O_2 are often combined for etching while diborane, B_2H_6, is combined with argon for boron doping [4,6] or may be combined with germane and argon to produce a boron doped germanium infusion [6]. In all these mixtures the etchant or deposition gas is a minor fraction of the total gas flow. In such cases RGA studies have shown that the gases do not necessarily nucleate at the same flow rate. With germane and argon increasing the flow rate results in germane nucleating first with the argon nucleation following only at higher flow rates. Thus, by varying the flow rate the composition of the clusters formed can be varied.

3. Ionizer development for metals reduction

Clusters leaving the nozzle and entering the ionizer will travel with roughly the sound speed characteristic of the gas entering the nozzle. For typical cluster sizes (2000–15 000 atoms) this corresponds to a kinetic energy of 130–1000 eV. At these energies any departure from space charge neutrality within the ionizer will result in a rapid blow up of the jet with a significant loss of beam current. For this reason, one of the first ionizers developed at Epion was the so-called self-neutralizing ionizer (Fig. 1). As with all such ionizers clusters are ionized by electron impact [7]. In this design electrons extracted from thermionic filaments pass through the jet and then strike the opposite beam forming electrode to produce low energy secondary electrons. These electrons help ensure that the ionized jet remains space charge neutral. This design proved very effective and with modifications achieved over 1000 μA argon cluster beams.

A major limitation of the self-neutralizing ionizer is that gases evolved from clusters during the ionization processes [7] produce an elevated internal pressure. With corrosive gases, particularly NF_3 in O_2, this results in attack of the various ionizer parts particularly the filaments. Filament life is shortened and unacceptable metals contamination is produced on wafers being processed. To overcome these shortcomings the reflex ionizer was developed. In this ionizer the beam forming and repeller electrodes are replaced by graphite rods. Fig. 2 illustrates the reflex ionizer and shows a simulation of electron trajectories from one of the three filaments. In the figure the inner row of rods is at ionizer potential, the filament is biased at −165 V and the second ring at −325 V, both with respect to ionizer potential. The reflex design causes recir-

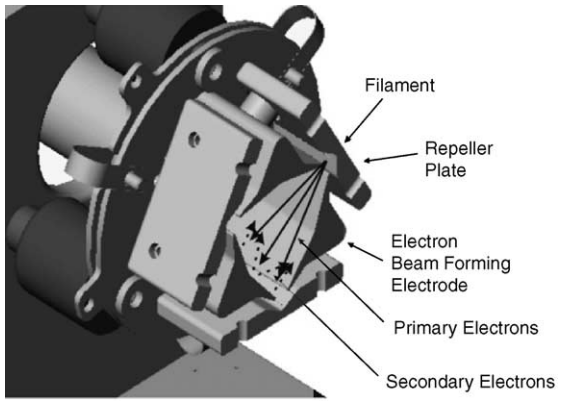

Fig. 1. Cutaway of the self-neutralizing ionizer.

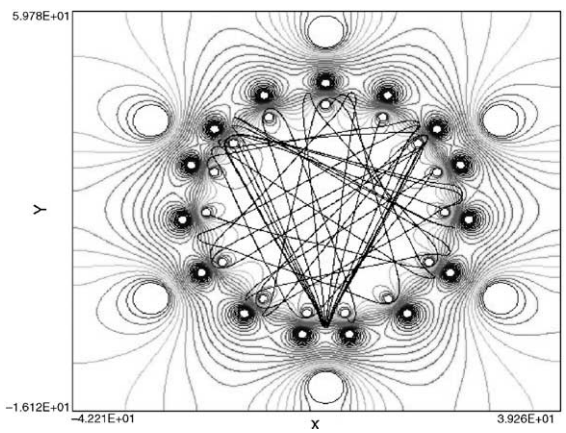

Fig. 2. Cross section of reflex ionizer showing electron trajectories.