Cluster Ion Beam Processing: Review of Current and Prospective Applications

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ABSTRACT

Cluster ion beam processes which employ ions comprised of a few hundred to several thousand atoms are being developed into a new field of ion beam technology. The processes are characterized by low energy surface interaction effects, lateral sputtering phenomena and high-rate chemical reaction effects. This paper reviews the current status of studies of the fundamental cluster ion beam characteristics as they apply to nanoscale processing and present industrial applications. As new prospective applications, techniques are now being developed to employ cluster ions in surface analysis tools such as XPS and SIMS and to modify surfaces of bio-materials. Results related to these new projects will also be reviewed.

INTRODUCTION

In cluster ion beam bombardment of solid surfaces, the concurrent energetic interactions between many atoms comprising a cluster and many atoms at a target surface result in highly non-linear sputtering and implantation effects. Following successful accomplishment in 1988 of intense beams of gas clusters from small nozzles at room temperature, an extended series of investigations was conducted at Kyoto University and at the University of Hyogo to develop gas cluster ion beam (GCIB) fundamentals and applications [1].

By 1995, it was recognized that it would not be practical to use substantially greater gas flows in order to increase cluster ion beam currents to the levels to be required for production processors. No other groups or institutes in the world had yet paid attention to the concept of cluster ion beam equipment and to possible uses of gas cluster ions for surface processing. In collaboration with the author's group (IY) at Kyoto University, in support of work sponsored by the Japan Science and Technology Agency (JST), Epion Corporation in the US began development of commercial GCIB equipment in 1995 [2]. Efforts to increase cluster generation, to improve efficiency of cluster ionization, and to optimize beam transport without increasing gas consumption or pumping requirements, were successful. Cluster ion beam currents of several hundred microamperes on target became possible with source gas flows that could be handled by standard vacuum pumps. Commercial GCIB equipment by Epion was introduced in 2000.

Historically, cluster ion beam processing efforts expanded into two different but closely related major categories: gas cluster ion beam (GCIB) processing and polyatomic ion beam processing. GCIB has become useful in a number of nanotechnology areas by employing its unique characteristics of very low effective energies, its lateral sputtering effects and its high chemical reactivity effects. Polyatomic ion beam technology investigations were initially started during the early GCIB research in order to experimentally demonstrate the low energy interaction effects which are associated with bombardment by multiple atom particles. Because a GCIB beam contains a wide range of cluster sizes, typically from a few hundred atoms to many thousands of atoms, it had during early investigations been difficult to quantitatively describe the dependence of low energy interaction effects upon cluster size. In order to obtain clear experimental evidence, it was desirable to use cluster ions of a single specific number of atoms per cluster. The idea then emerged to use a molecular ion consisting of a relatively large number