Cluster Ion Beam Process Technology

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Characteristics of the technology: Cluster Ion Beam processing of materials is based on the use of electrically charged cluster ions consisting of a few hundreds to a few thousands of atoms or molecules of gaseous materials. Individual gas atoms are first condensed into neutral clusters, which are subsequently ionized and accelerated. When an energetic cluster ion impacts upon a surface, it interacts nearly simultaneously with many target atoms and deposits high energy density into a very small volume of the target material. The concurrent energetic interactions between many atoms comprising the cluster and many atoms of the target result in highly non-linear sputtering and implantation effects, which are fundamentally different from those, associated with the more simple binary collisions, which take place during monomer ion impacts. Cluster ion beam technology introduces new interaction processes which are expected to become fundamental tools in the emerging field of nano-scale processing and to also become facilitating processes for existing industrial applications.

The study of cluster beam formation was initially a most important topic. The supersonic expansion approach had been very successful for producing cryogenic beams containing large numbers of clusters. Our investigations showed that supersonic expansion nozzles with convergence-divergence shapes could produce strong cluster beams. Our new type of cluster ion source, which employed these supersonic nozzles operated at room temperature, has successfully produced adequately intense cluster ion beams. With this, we were able to start investigations of new ion-solid interactions produced by cluster ion impacts. These studies have shown that gas cluster ion beams, offering unique ion/solid interaction processes, can open a new field in atomic and molecular ion beam process technology.

Gas cluster ion beams (GCIB) are now being used for producing novel materials with superior properties, for developing new chemical compounds and for altering, refining and machining of materials and surfaces. Examples include: low-damage atomic-scale surface smoothing for metals, for superconductors, for diamond films, for non-spherical plastic lens molds, and for SiC surfaces of synchrotron radiation (SR) mirrors; shallow implantation for LSI junction formation; high-rate and low-damage anisotropic surface etching for MR sensors; assisted-formation of thin multi-layer film coatings to be used in reliable and durable optical filters. Some of the unique processes and recent results will be shown at the symposium.

Equipment Development: Cluster ion beam currents of several hundred microamperes have already been demonstrated. At these levels, many production applications of GCIB are economically viable. Other applications will require beam currents as high as 1000 mA or more. Development programs now being conducted are expected to result in availability of commercial 1000 mA cluster ion beam processors within about two years.

Shallow implantation: Low energy bombarding effect due to cluster ion beam has been successful applied to fabricate p-MOSFETs by using B10H14 implantation for shallow source/drain formation. B10H14 ion implantation for p-type source/drain (S/D) junctions was performed at an acceleration energy of 30 keV to a dose of 1x10 13 ions/cm2 and was followed by an anneal at 1000oC for 10 sec. A junction depth of 20 nm was achieved. For S/D extensions, B10H14 ion implantation at 2 keV was carried out to a dose of 1x1012 ions/cm2 followed by annealing at 900oC for 10 sec. A 7nm ultra-shallow junction without TED or TD was achieved.

Lateral sputtering: A characteristic of bombardment by large size gas cluster ions is the lateral sputtering. The angular distribution of sputtered atoms by Ar cluster ion shows laterally ejected distributions. This was the first experimental evidence of the “lateral sputtering”. Very high sputtering yields on metal, semiconductor and insulator surfaces due to bombardment with cluster ions have been observed experimentally, and they have also been studied by computer simulation. Gas cluster ion beam irradiation on thin film surfaces results in extraordinary smoothing effects which are distinct from any other processing techniques. Many examples were already shown. For examples, superconductor film was smoothed to from 7nm to below 0.8nm using 20 keV Ar GCIB at a 2x1016 ions/cm2 dose. Smoothness of a CVD diamond film before and after irradiation with an Ar cluster ion beam at an energy of 20 keV and a dose of 1x1017 ions/cm2 was reduced from 33nm to 4nm. Thin Film Formation: Cluster ion beams can be utilized for reactive growth of thin films at low temperatures. The high density of transient energy produced by individual cluster impacts on a surface can significantly enhance the rates of chemical reactions on the surface even at low substrate temperatures. High chemical reactivity of gas cluster ions and control over film microstructure have been demonstrated using O2 cluster ion assisted deposition of Ti2O5, SiO2, Nb2O5, etc. By using GCIB assisted deposition, very uniform and dense films without porosity or columnar structure were obtained. In formation of multilayer film, the interface is extremely flat and uniform due to the lateral sputtering.