ATOmic SCALE PROCESSING using PLASMA NANOTECHNOLOGIES

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Low-temperature chemically active plasmas for about 50 years are one of the main tools for fabricating the device structures of integrated circuits (ICs). In a process flow in concept of planar technology the thin films of semiconductors, dielectrics, and metals are sequentially formed, and then through the area selective interaction of plasma with the surface of these films the topology of the pattern of lithographic masks is transferred to functional layers. As a result it creates the design of integrated devices and the electrical circuit of their connection. These plasma technologies are based on heterogeneous plasma-stimulated reactions on the surface of structures on silicon substrates. In modern microelectronics which have been transformed in the XXI century into electronics of nanoscale devices (nanoelectronics) the minimum topological size is reached to 7–10 nm, and the thickness of functional layers consisting the device is even smaller - up to 2–3 nm. Thus, the linear size of the areas of semiconductor devices is going to 15–50 lattice parameters of materials. Therefore, the technologies that provide both the deposition and structuring of layers with an accuracy of *single atomic layer* are very much in demand. Such accuracy is possible under the condition when saturable (self-limiting) heterogeneous plasma stimulated reactions on the surface of nanostructures take place. Monolayer resolution is implied for both deposition processes and selective anisotropic etching (or structuring) of thin films in cyclic regimes.

Precise atomic layer deposition (ALD) of functional films is provided by red-ox reactions of single monolayer of first precursor which is at chemisorption status on surface. As a result of the reaction with the second precursor component strictly one monolayer of the target material (dielectric, metal, semiconductor) is formed. The mechanism of saturation of the reaction comes from the limited density of chemisorption centers on the surface and a significant difference in the energy of chemisorbed and physically adsorbed excess molecules. This fact allows selective removal of the latter. The stimulation of a heterogeneous red-ox reaction by the low-temperature plasmas of second (gaseous) precursor provides a number of advantages discussed in the report. The specific requirements for plasmas used in PEALD processes are discussed. Examples of the implementation of PEALD technologies in the fabrication of nanoelectronic device structures are given.

Atomic layer etching (ALEt) was proposed later than the ALD processing due to the long search for mechanisms ensuring self-limiting heterogeneous plasma-stimulated etching reactions. It is shown that simple pulsed modes with pulsed plasma sources do not provide reproducibility from cycle to cycle and over the area of substrate at monolayer level. Real ALEt cyclic process is designed as a “reverse” of the ALD when chemisorbed monolayer of an active precursor is subjected the heterogeneous reaction with upper monolayer of material and then completion of reaction and the desorption of by-products is stimulated by bombardment with chemically inert plasma ions in a narrow energy window. In that case the atomic-layer regime is ensured by the absence of a spontaneous chemical reaction of adsorbed molecules and plasma components with the surface. The possible applications of ALEt processes that can significantly improve the characteristics of nanoelectronic devices as well as fabricate promising devices on 2D materials are demonstrated.