Atomically Controlled Epitaxial Growth for Future Si-Based Devices

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One of the main requirements for nanoscaling and nanotechnology is atomic-order control of process technology for device fabrication. Here we show the concept of atomic-level processing based on atomic-order surface reaction control. This concept is demonstrated for Si-based group IV heterodevices, which are becoming increasingly attractive for high-speed applications. The main idea of the atomic layer approach is the separation of the surface adsorption of reactant gases from the reaction process.

Langmuir-type self-limiting formation of atomic-layer-order thermal adsorption and reaction of reactant gases (SiH_4, GeH_4, CH_4, SiH_3CH_3, PH_3, B_2H_6, NH_3 and WF_6) on Si(100) or Ge(100) have been generalized in connection with the H desorption on the surface. Most representative one is low-temperature atomic-order surface nitridation of Si using NH_3. The experimental results are well expressed by Langmuir-type rate equation, assuming that NH_3 is adsorbed physically at a single adsorption site, and that the NH_3 surface reaction proceeds on H-terminated Si(100) surface with H desorption. Next, Si epitaxial growth over the material already-existed on Si(100) or Ge(100) has been investigated. The heteroepitaxial growth of Si/half atomic layer of P/Si(100), Si/half atomic layer of B/Si(100), Si/half atomic layer of N/Si(100), Si/one tenth atomic layer of W/Si(100) and Si/one tenth atomic layer of C/Ge(100) have been achieved at growth temperatures below $500^{o}C$. In their structures, although a part of P and W atoms apparently segregate on the top surface during the capping Si growth, the surface segregation of B, N and C atoms are suppressed and confined within about 1nm thickness, which is nearly the same as the measurement accuracy. Higher level of electrically active P and B atoms exist in such film, compared with doping using thermal equilibrium conditions. By introducing C at interface between Si and Ge, intermixing is efficiently suppressed.

The final goal of the atomic layer approach is the generalization of the atomic-order surface reaction processes and the creation of new properties in Si-based ultimate small structures which will lead to nanometer scale Si devices as well as Si-based quantum devices.