Atomically Controlled Processing for Future Si-Based Devices

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Atomically controlled processing has become indispensable for the fabrication of Si-based ultrasmall devices and Si-based heterodevices, because high performance Si-based devices require atomic-order abrupt heterointerfaces and doping profiles. Our concept of atomically controlled processing is based on atomic-order surface reaction control. The final goal 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.

Self-limiting formation of 1-3 atomic layers of group IV or related atoms in the thermal adsorption and reaction of hydride gases on Si(100) and Ge(100) have been generalized based on the Langmuir-type model. By the epitaxial growth of Si and SiGe over the material already-formed on (100) surfaces, atomic layer doping of a half atomic layer of N and P and a single atomic layer of B have been achieved. Atomic layer doping results indicate that new group IV semiconductor of very high carrier concentration and higher mobility is prepared compared with doping under equilibrium conditions. The atomically controlled processing for the base doping of SiGe:C HBTs has been demonstrated. These results propose that atomic layer-by-layer epitaxy of group IV materials as well as atomic layer doping are possible with well-controlled initiation of the reaction governed by Langmuir-type self-limited kinetics in many cases, and open the way to atomically controlled CVD technology for ultra-large-scale integrations.

Plasma assisted processing is one of the candidate techniques for very-low-temperature growth of heterostructures with an abrupt heterointerface. By the electron-cyclotron resonance Ar plasma enhanced chemical vapor deposition, Si and Ge epitaxial growth on Si(100) were achieved without substrate heating using SiH_4 and GeH_4, respectively. In the nitrogen plasma irradiation of Si(100), we fine that the nitridation of the deeper Si atoms below the surface is enhanced with increasing ion energy as well as the Si surface temperature. Silicon epitaxial growth on atomic-order nitrided Si(100) was also achieved without substrate heating, and it is confirmed that N atoms of about 0.8 atomic layer are confined within about 3nm-thick region under the present accuracy. These results open the way to atomically controlled processing at around room temperature.