

Atomic Level Control of SiGe Epitaxy and Doping

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There is an ongoing progress in silicon based integrated circuits technology based on reduced transistor dimensions, increased transistor counts and increased operating frequencies [1] predicted by Gordon Moore ("Moore's Law") in 1965 already. By aggressive scaling and exploring new device architectures the nanometer scale region is entered pushing the metal-oxide-semiconductor field-effect transistor (MOSFET) to its limits. Moreover, alternative, revolutionary concepts for nanotechnology devices as for example carbon nanotubes [2], single electron transistors [3,4], scaling the transistor to the size of a molecule using single molecular layers [5], and quantum dots [6] are under investigation.

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 as high-speed devices for telecommunication. The main idea of the atomic layer approach is the separation of the surface adsorption of reactant gases from the reaction process. By this way the process is controlled by the surface adsorption equilibrium only. Self-limiting processes at atomic level and very low process temperature (even room temperature) are reached. Atomic level control is shown for epitaxy (Si, Ge) and doping (P, B, C) [7,8]. Atomic level control of P, B, and C doping of SiGe films were obtained using Low Pressure and Reduced Pressure CVD in a single wafer reactor. We used PH₃ in H₂ for P doping, B₂H₆ in H₂ for B doping and methylsilane in H₂ for C incorporation. The incorporation of dopants or C was performed without SiGe growth. Epitaxy was interrupted by switching off the source gases (SiH₄, GeH₄). After an H₂ purge of the reactor, the surface was exposed to PH₃/H₂, B₂H₆/H₂ and methylsilane, respectively. The temperature for the exposure was varied between room temperature and 650°C. The coverage (P, B, C) was investigated as function of the partial pressure of the source gas for different H₂ partial pressures. After surface exposure and a further H₂ purge, the SiGe growth parameters were readjusted, and the epitaxial process continued.

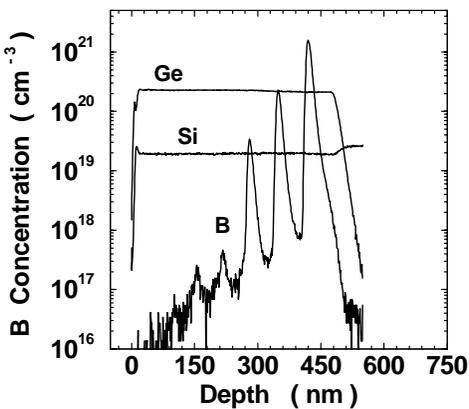


Fig. 1: SIMS profile of B ALD peaks fabricated at different B₂H₆ partial pressures during exposure at 400°C.

Atomic layer control was demonstrated for doping of heterojunction bipolar transistors [9].

For illustration in fig.1-3 results of atomic layer doping of B and C are shown.

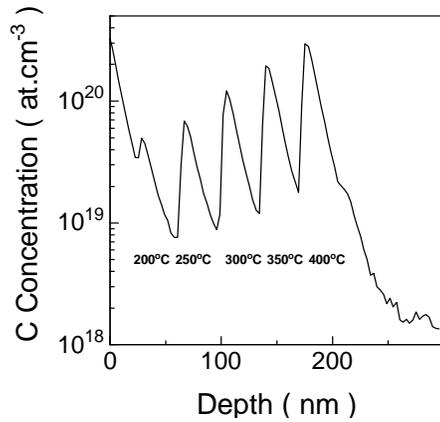


Fig. 2: SIMS profile of C ALD peaks fabricated at different exposure temperatures.

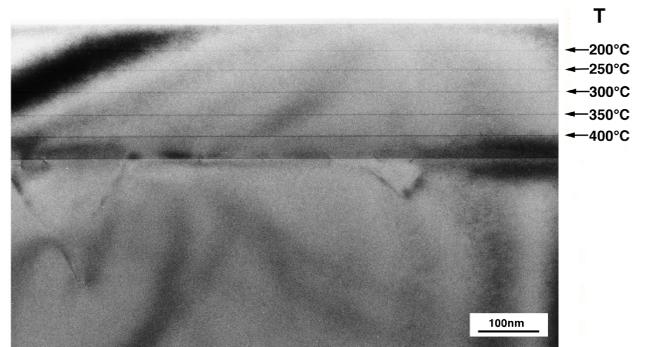


Fig. 3 TEM cross section of C ALD peaks fabricated at different exposure temperatures (corresponding to fig. 2)

We found the doping process of P and C to be self-limiting by the surface adsorption of PH₃ and methylsilane, respectively. There was no self-limitation found for the atomic layer doping by B₂H₆.

The results shown here offer the opportunity for atomic level control of dopant dose and location during Si and SiGe epitaxy.

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