Abs. 1396, 206th Meeting, © 2004 The Electrochemical Society, Inc.

Maximization of Active As doping in (selective) epitaxial Si and SiGe layers

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The continuous development of new advanced semiconductor device concepts leads to impressive challenges, i.e. contact layers with n-type doped epitaxial layers. Because of the lower diffusion constant, As doping is preferred above P doping. We studied the As incorporation for epitaxial growth conditions which are either optimized for maximal throughput at low temperatures (low thermal budget) or for loading effect-free Selective Epitaxial Growth (SEG) conditions.

The Reduced Pressure Chemical Vapor Deposition (RP-CVD) System used in this work is a standard ASM Epsilon 2000 epi reactor, which is designed for production applications. To avoid loading effects, SEG of Si and SiGe is done at low pressure [1]. Suitable growth conditions allow facet free SEG [1]. However, throughput of SEG Si growth might be limited by the restricted allowable thermal budget. This is even more a concern in case of n-type doped epitaxial layers, because addition of high AsH_3 or PH_3 flows generally reduces growth rate. The growth rate (throughput) can be improved by adding GeH_4 during epitaxial growth (Fig. 1). It turned out that for in-situ doped epi layers the resistivity is reduced by the addition of GeH_4. It means that As incorporation is more efficient in case of SiGe growth. For optimal SEG SiGe conditions we obtained resistivities down to 3 mΩcm. However, As diffuses faster in SiGe than in Si. This is a concern during further device processing steps. The replacement of Si by SiGe is not permitted, if sharp doping transitions are required.

Si and SiGe growth rates can be strongly enhanced if deposition is done at higher pressures (Fig. 2). An increase of growth pressure has no negative influence on the total active n-dopant concentration (Fig. 2). By optimizing our growth conditions, we were able to reduce the resistivity of as grown epitaxial Si layers down to 1 mΩcm. This corresponds to an active As concentration of ~7×10^{19}cm^{-3}, which is higher than generally reported. The low resistivity was obtained together with a high Si growth rate (~20nm/min) and a low growth temperature of 700 °C. The growth rate was measured for epitaxial growth on blanket wafers. Because of the reduced active area, the growth rate on patterned wafers might even be higher [1]. The total As concentration as measured by SIMS was ~1×10^{20}cm^{-3}. The As concentration increases with AsH_3 flow, while the active concentration saturates at 7×10^{19} cm^{-3}. No degradation of epitaxial layer quality was seen for As concentration up to 1.3×10^{20} cm^{-3}.

It can be concluded that high active As concentrations can be obtained using conventional epitaxial Si growth conditions. The optimized growth conditions enable high throughput at low growth temperature but in case of SEG loading effects should be taken into account.

[1] R. Loo, et al. Journal of Electrochemical Society. **150**, 638 (2003)

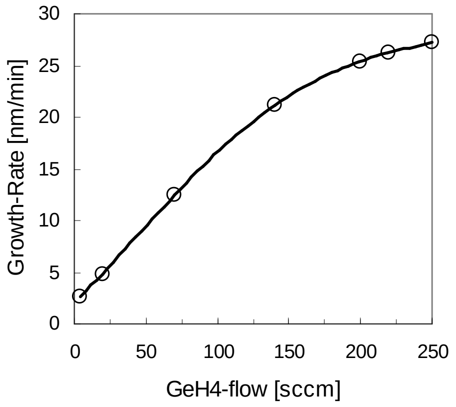

Fig. 1 Growth-rate as function of GeH_4 gas flow for SEG growth at 750 °C

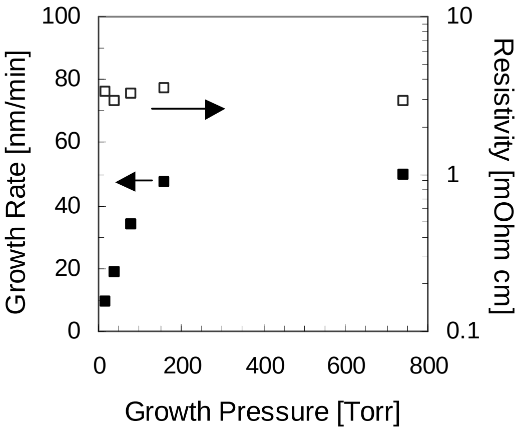

Fig. 2 Growth rate and resistivity of As doped SiGe layers as function of total pressure during growth. (Growth temperature: 730 °C)