ULTRA-SHALLOW JUNCTIONS IN $Si_{1-X}Ge_X$ FORMED BY MOLECULAR-BEAM EPITAXY

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Ultra-shallow junction layers in Si are required for deep submicron CMOS and quantum devices. We have investigated the use of low-temperature (320 °C) molecular-beam epitaxy (MBE) to form highly conductive, p^+, ultra-shallow layers in $Si_{1-x}Ge_x$ (x = 0, 0.2, and 0.4) using boron doping. The purpose of the investigation was twofold: the first was to determine the composition which produced the minimum as-grown sheet resistance and the second was to establish the thermal stability of the layers. The nominal thickness of the doped layers was 10 nm. The sheet resistance, R_{sh}, measured in units of ohm/square, was determined with 4-point probe, calibrated with an implantation standard. Thirteen regions were measured in a cross pattern on the three inch wafers. The B atomic distribution profiles were obtained using a quadrapole secondary ion mass spectrometry (SIMS) instrument.

The sheet resistance of the as-grown 10 nm, uniformly doped Si layer is presented in Fig. 1. Using the junction depth, 17.5 nm, defined by the location in the SIMS profile where the B concentration has dropped to $10^{18}/cm^3$, the minimum resistivity, attained with a B concentration of $10^{21}/cm^3$, is 2.38 x 10^{-4} ohm-cm. When the B concentration was increased to 5 x $10^{21}/cm^3$, there was not a concomitant decrease in R_{sh}. This is the limit that can be reached with a uniformly B-doped 10 nm Si layer, and which will be used as a standard to judge other processes. The MBE grown layers represent a factor of ten reduction in the sheet resistance compared to the best B ion implanted layers, which can be approximated with a uniform B concentration of $10^{20}/cm^3$[1].

In Fig. 2, it is observed that the addition of Ge has minimal impact on the sheet resistance of the highest B doped layers, but, as will be demonstrated below, Ge improves the B thermal stability. We have previously reported [2] that little change was detected in either the B atomic profiles or the resistivity of 10 nm B-doped Si layers after a 10 s rapid thermal anneal (RTA) or a 10 min furnace anneal (FA) up to 700 °C. However substantial B diffusion was observed after a 800 °C 10 min FA. With the addition of Ge to the doped layer, the out-diffusion of B is inhibited, Fig. 3. Once the B moves beyond the alloy layer, the diffusion is similar to that in pure Si. This result implies that one strategy to obtain thermally stable, ultra-shallow junctions is to dope the top portion of a thicker SiGe layer.

It must be noted that the sheet resistance of the as-grown shallow junctions are all substantially less than equivalent layers obtained by ion implantation. Only after the 800 °C FA did the MBE-grown layers degrade to have as large a sheet resistance as the **best** ion implanted layers.

[1] P. E. Thompson and J. Bennett, APL **77** 2569 (2000).
[2] P. Thompson and J. Bennett, accepted for publication in Materials Science and Engineering B.

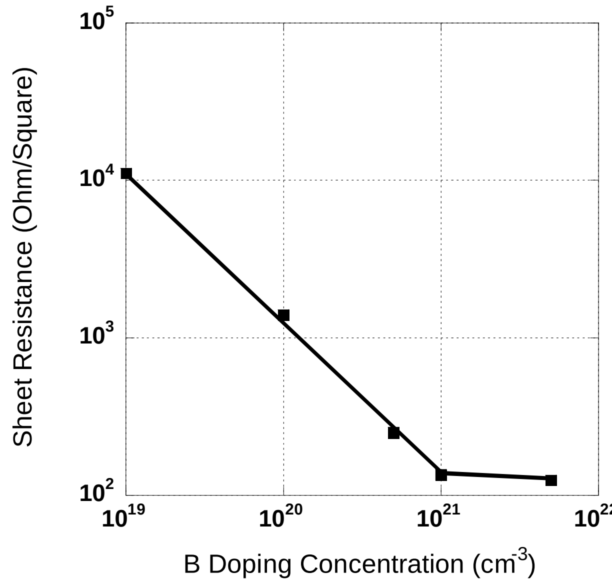

Fig. 1. Sheet Resistance of as-grown 10 nm B-doped Si

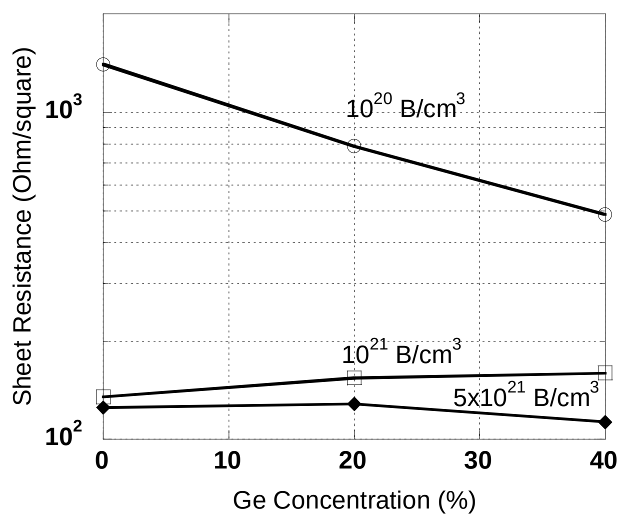

Fig. 2. Effect of Ge Concentration on the sheet resistance of 10 nm layers of $Si_{1-x}Ge_x$ (x = 0, 0.2, and 0.4).

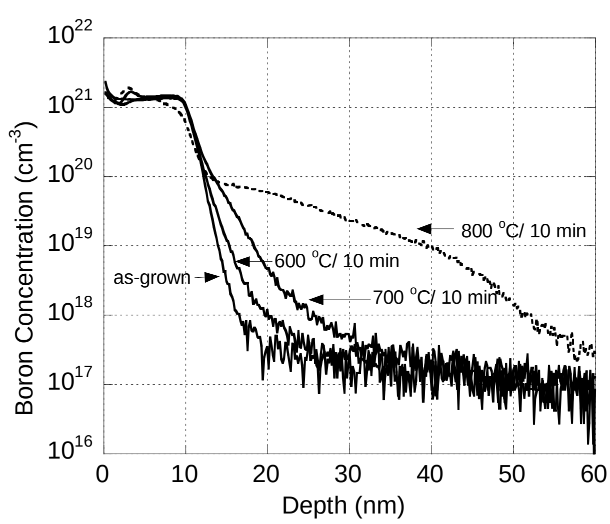

Fig. 3. Thermal stability of B-doped $Si_{0.6}Ge_{0.4}$ after a 10 minute furnace anneal.