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Low Temperature Chemical Vapor Deposition of Column-IV Heterostructures

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In the last several years there has been an increasing interest in Column-IV heterostructures for high performance electronic and opto-electronic devices. The main reason for this interest has been the possibility of integrating these devices with VLSI, and hence nearly all of the work has been performed on Si (100) substrates. Most of the research in the field has been performed using either Molecular Beam Epitaxy (MBE) or various forms of Chemical Vapor Deposition (CVD) to grow the heterostructures. In the CVD field, one can choose from growth pressures ranging from that in "UHV-CVD" (about 1 mtorr) [1] up to atmospheric pressure [2], nearly 6 orders of magnitude higher. Most of the materials work to date has been focused on the SiGe material system, but the limits of that material system by now have been fairly well explored.

In this paper, both the MBE and CVD growth techniques will be contrasted from a fundamental point of view, and it will be shown that CVD is inherently better suited towards the growth of high quality material. Second, hydrogen will be shown to be responsible for our ability to grow at high pressures. Finally, the role of carbon in extending the limits of the SiGe material system through SiGeC alloys will be shown.

Because MBE is a physical deposition process, growth rates are fairly independent of temperature, a substantial practical advantage compared to most low-temperature CVD. On the other hand, the energy of the incoming atoms or molecules can substantially alter the quality of the resulting material. While these energies are nominally only thermal energies, the electron beam evaporators typically used for the silicon (and often germanium sources) in MBE can lead to electrical charging of some fraction of the source atoms/molecules, which can then obtain high energies through potential differences in the growth system. For example, we have shown that the deep sub-bandgap luminescence often seen in MBE-grown SiGe samples (but not in CVD samples) is caused by radiation damage [3], and subsequent work has shown that this effect depends on the substrate voltages applied in MBE machines during the sample growth [4].

The original motivation for UHV-CVD (growth pressure of 1 mtorr) was to reduce the partial pressures of water vapor and oxygen from gas contamination or reactor background to levels low enough to prevent the pressures of contaminants were many orders of magnitude higher than those expected to limit epitaxial growth in the earlier work. The reason for the success of the experiments at higher pressure is the hydrogen used as a carrier gas. The high overpressures of hydrogen result in a hydrogen coverage of the surface even if the temperature is substantially above the hydrogen desorption temperature on silicon of 550 °C [6]. These high hydrogen coverages result in a decreased sticking coefficient for impurities compared to that on clean surfaces, so that high quality epitaxy can proceed in regimes not expected from earlier work. A second advantage of the hydrogen coverage is that it acts as a surfactant to supress segregation of boron and germanium to the surface, and effect which can lead to non-abrupt interfaces in MBE growth.

Finally, for strained SiGe layers on Si (100) substrates, the thickness of layers one can grow is limited by the onset of relaxation, leading to a trade-off between bandgap offset of the SiGe layer from that of the substrate and the allowable thickness of the layer. Adding C to create a SiGeC alloy reduced the strain in these layers [7] and increases the critical thickness [8] due to the small size of the C atom. As the strain is reduced through the addition of carbon, both photoluminescence [9] and device measurements show that the bandgap increases only slowly, so that for a given bandgap, SiGeC layers will have a lower strain and increased critical thickness compared to SiGe layers. Therefore SiGeC alloys substantially increase the "design window" available to Si-based heterojunction device engineers beyond that available with SiGe alloys.

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