Group-IV epitaxy at ultra-low temperatures for optoelectronic and quantum photonic applications

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For homo- and heteroepitaxy of group-IV materials like Si and Ge, ultra-low temperature (ULT) growth, (100°C and 350°C), is the key to extending the material properties beyond the state-of-the-art. We highlight that MBE is the suitable choice for ULT growth and stress that the chamber conditions during the growth need to be excellent to limit detrimental point defect formation during epitaxy [1-6].

First, we show that ULT growth can lead to unattainable layer structures for the strained (Si)Ge/Si(001) system. While Ge has successfully entered Si technology, due to the inherent lattice mismatch, high-crystalline and flat SiGe/Si epitaxial layers of a sufficient thickness could only be grown for relatively low Ge concentration (<40%). In turn, planar Ge-rich heterolayers on SOI can be essential for efficient integration and reliable addressing of novel devices [1]. ULT growth can lead to layer that are significantly thicker than their equilibrium thickness [2]. These can be used to demonstrate double heterostructure light-emitting diodes emitting at room temperature and above in the telecom band [3].

Second, we use ULT Si homoepitaxy to obtain Si-color centers within thin carbon-doped Si layers. Such Si telecom emitting color centers, normally generated through ion implantation, can be envisioned as scalable deterministic group-IV-based quantum light sources. However, the resulting ion implantation profiles are broad and lead to a decisive lack of control over the vertical emitter position. This drawback can significantly degrade the coupling efficiency to photonic structures such as resonators or waveguides, and no two SiCC emitters will be located vertically at the same position below the substrate surface. The here presented all-epitaxial approach for fabricating variable SiCCs departs entirely from ion implantation and enables us to restrict the formation of SiCCs to a specific epilayer and control their vertical position in a structure even with sub-nm precision [4,5]. Thereby, the emitter density can be conveniently controlled via the C doping concentration and the Si:C layer thickness [4]. Furthermore, we show the first results for electrically-pumped self-assembled SiCCs by integrating the Si:C nanolayers into ULT-grown p-i-n light-emitting diodes [5].

References

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