Study of GeSn/(Si)Ge(Sn) Quantum Structures for Light Emitters

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The ongoing growth of consumer electronics market, as well as the demand for even more complex data and telecommunication systems require energy-efficient integrated circuits and data links [1]. One possibility to tackle this challenge is to replace electrons with photons for low-power on-chip and/or chip-to-chip data transfer [2]. Here, monolithically integrated, Si-based photonic devices would be the most convenient solution due to the accessibility to low-cost Si CMOS fabrication. Concerning group IV based photonic integrated circuits (PIC), one major disadvantage is their indirect bandgap nature, causing them to be inefficient light emitters. Very recently, the demonstration of a direct bandgap group IV laser based on GeSn [3] represents a breakthrough in the field of group IV photonics and opened the path towards fully integrated electronic and photonic circuitry [4]. In this contribution, we present theoretical studies as well as the growth and thorough structural characterization of GeSn/(Si)Ge(Sn) quantum-well and quantum dot structures that are suitable for light emitting devices (i.e. LEDs). The heterostructures were grown using a 200 mm industrial compatible AIXTRON RPCVD reactor with showerhead technology employing growth temperatures between 350 °C and 425 °C. Material properties like the Sn concentration, crystalline quality and strain were analyzed by RBS, TEM, XRD and SIMS.

Partially strain relaxed GeSn/Ge multi quantum well (MQW) LEDs with 8 at. % Sn and a residual compressive strain of -0.71% exhibit electroluminescence at low current densities below 100 Acm^{-2}. Based on band structure calculations, the suitability of GeSn/(Si)Ge(Sn) MQWs and GeSn/(Si)Ge(Sn) double heterostructures for efficient light emitters will be discussed. We will particularly focus on the charge carrier confinement in GeSn wells embedded in different barrier materials, e.g. Ge or SiGeSn ternary alloys. While Ge is a natural choice for growing GeSn/Ge MQW, its use as barriers in type I heterostructures is restricted to regions where the GeSn is an indirect bandgap semiconductor. These calculations indicate a way out of this limitation to be the introduction of ternary group IV alloy SiGeSn. Band structure calculations for different amounts of Si and Sn in the barrier and well will provide evidence that efficient carrier confinement can be achieved by using GeSn/SiGeSn heterostructures. These structures not only exhibit type I alignment in Γ and L bands, but also allow larger barrier heights for both electrons and holes compared to GeSn/Ge heterostructures.

As a further step in modifying the density of states by reducing the dimensionality, we studied GeSn quantum dots - embedded in single and multi quantum wells - that were produced via rapid thermal annealing. Structural and compositional investigations by TEM and ChemiSTEM reveal crystalline GeSn-dots with an increased amount of Sn compared to the surrounding GeSn matrix.

The use of different quantum structures based on GeSn and SiGeSn towards electrically pumped lasers would be discussed.

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