Epitaxy of Si-Ge-Sn-based heterostructures for CMOS-compatible light emitters

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Silicon (Si)-based group IV materials underpin our modern digital world. Unfortunately, however, they lack the primary requirement for efficient light emission and detection, a direct bandgap. Photonic components, such as lasers or LEDs, therefore rely on III-V materials such as GaAs. A truly Si-compatible material would allow fabrication of photonic components with state-of-the-art CMOS electronics on the same chip. Such opto-electronic integrated circuits (OEICs) would enable radically reduced power consumption and increased data bandwidths, both of which have been shown to be bottlenecks in modern electronics [1].

Alloying of group IV elements germanium (Ge) and tin (Sn) has turned out to be a Si-compatible solution, since a direct bandgap, as well as optical pumped lasing has been evidenced for Sn incorporations above ~9 atomic % [2]. The value of the bandgap can further be controlled by adding Si into the mix, which can be exploited for the formation of heterostructures for carrier confinement [3].

In this contribution, we will present comprehensive characterization of direct bandgap heterostructures, formed from active GeSn layers and SiGeSn ternary claddings. Advanced structural characterization techniques, such as atom probe tomography, are performed to obtain precise elemental distributions within the heterostructures. Optically pumped lasing from different type of heterostructures will be shown, clearly evidencing the superiority of multiquantum well structures over bulk layers.

For future integrated light emitters, however, carriers need to be injected electrically. We will show first experiments on epitaxially grown *p-i-n* diodes. Strong electroluminescence of GeSn/SiGeSn heterostructure diodes proves their applicability for group IV-based light emitters. We will further discuss possible improvements that may pave the way towards future energy-efficient OEICs.

1. L. Vivien, "Computer technology: Silicon chips lighten up", *Nature* **528,** 483 (2015).
2. S. Wirths, R. Geiger, N. von den Driesch, *et al.*, "Lasing in direct-bandgap GeSn alloy grown on Si", *Nature Photonics* **9,** 88 (2015).
3. N. von den Driesch, D. Stange, S. Wirths, *et al.*, "SiGeSn ternaries for efficient group IV heterostructure light emitters", *Small* **13**, 1603321 (2017).