Theoretical analysis of optical gain in $Ge_{1-x}Sn_x$/Ge quantum well on Ge-on-Si substrates

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$Ge_{1-x}Sn_x$ alloys have emerged as a new active material for efficient Si-based lasers [1-3]. With a Sn composition of 6-10%, $Ge_{1-x}Sn_x$ alloys can become a direct bandgap material to enable efficient electron-hole recombination. Enhanced photoluminescence from GeSn has been recently observed [1], as well as first demonstration of GeSn lasers at low temperatures [2]. However, the high threshold of the GeSn laser hinders the device from practical applications. To reduce the threshold, research attention has been shifted to low-dimensional GeSn material systems for active materials due to modified density-of-states and better carrier confinements [3]. Here we present a theoretical investigation of optical gain of $Ge_{1-x}Sn_x$/Ge quantum wells pseudomorphically grown on Ge-on-Si substrates for Si-based lasers.

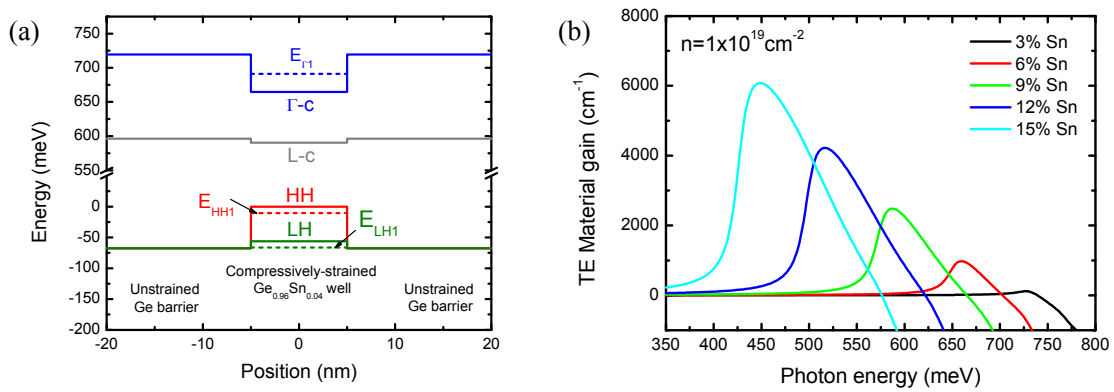

Fig. 1 (a) Calculated band structure for $Ge_{0.96}Sn/Ge_{0.04}$ QW on Ge-on-Si substrates with a thickness of 10/15 nm. (b) Calculated optical gain for $Ge_{1-x}Sn_x$/Ge QW under a carrier density of $n = 1 \times 10^{19}$ cm^{-3}.

Figure 1(a) shows the band structure for pseudomorphic $Ge_{0.96}Sn_{0.04}$/Ge QW on Ge-on-Si substrates calculated using the model described in Refs. [1, 3]. The results indicate a crucial type-I alignment in the $Ge_{0.96}Sn_{0.04}$/Ge QW for efficient electron-hole recombination. Due to the compressive strain in the $Ge_{0.96}Sn_{0.04}$ well, the valence band is HH-like, resulting in dominant Γ1-HH1 direct transition and large transverse-electric (TE) optical gain. Figure 1(b) shows the calculated optical gain for $Ge_{1-x}Sn_x$/Ge QW. As the Sn composition increases, high optical gain becomes achievable because of the reduced energy separation between the lowest L- and Γ-confined states. These results indicate that $Ge_{1-x}Sn_x$/Ge QW is promising for Si-based lasers that can operate at room temperature with a low threshold.

References

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