

Enhanced infrared photoluminescence from $\text{Ge}_{1-x}\text{Sn}_x$ alloys

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1. Introduction

$\text{Ge}_{1-x}\text{Sn}_x$ alloys have recently attracted great research attention for new optoelectronic devices, especially efficient Si-based light emitters [1]. While Ge is an indirect semiconductor, its direct conduction band lies just 136.5 meV above the lowest conduction band at L point in the Brillouin zone. This energy difference can be greatly reduced by alloying Ge with Sn, another group-IV element, leading to remarkably improved light-emitting efficiency. With a Sn composition of $\sim 7\%$, direct-bandgap $\text{Ge}_{1-x}\text{Sn}_x$ alloys can be created [2] for laser gain media. In this paper, we present a study of photoluminescence (PL) from strained $\text{Ge}_{1-x}\text{Sn}_x$ films on Ge virtual substrate (VS) on Si wafer. The transparent carrier densities are also predicted.

2. Sample structures and PL characterization

The $\text{Ge}_{1-x}\text{Sn}_x$ film was grown on a Ge-buffered Si (100) substrate by molecular beam epitaxy (MBE) at low temperature. The structure consists of (a) a 100 nm Ge layer grown at 350°C, (b) a 100 nm Ge layer grown at 500°C, (c) a 100 nm Ge layer grown at 350°C, and (d) a 250 nm $\text{Ge}_{1-x}\text{Sn}_x$ layer grown at 150°C. Post rapid thermal annealing (RTA) at 500°C was performed for 30 seconds for all samples to improve the crystal quality. x-ray measurements reveal that the Ge VS is fully strain-relaxed, and the $\text{Ge}_{1-x}\text{Sn}_x$ film is nearly fully strained to the Ge VS.

Figure 1 shows the PL spectra for the $\text{Ge}_{1-x}\text{Sn}_x$ samples measured at room temperature. For Ge, a peak at 1550 nm is attributed to the direct bandgap emission, while a shoulder at lower-energy is due to the indirect interband transitions. When the Sn composition increases to 0.5%, the direct emission peak shifts to 0.756 eV (1640 nm) due to the reduced direct bandgap. In addition, the direct PL peak intensity slightly increases due to the reduced Γ - L energy separation. When the Sn composition increases further to 2.5%, the direct PL peak moves to 0.712 eV (1740 nm) with a further enhancement in PL peak intensity. The insert in Fig. 1 shows the integrated PL intensities for the samples. The integrated PL intensity enhancement can be up to 1.45 times with a Sn composition of 2.5%.

Figure 2 shows the calculated transparent carrier density (n_{tr}) for the $\text{Ge}_{1-x}\text{Sn}_x$ -on-Ge structure as a function of Sn composition. The theoretical model and parameters can be found in Refs. [3] and [4]. For pure Ge, a large carrier density of $9.75 \times 10^{19} \text{cm}^{-3}$ is necessary to reach the transparent condition. As the Sn composition increases, n_{tr} is reduced

continuously. With a Sn composition of 2.5%, n_{tr} is significantly reduced to $8.41 \times 10^{19} \text{cm}^{-3}$. Above this density, important optical gain can be achieved.

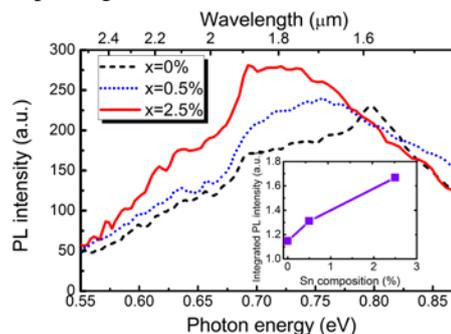


Figure 1. Measured room-temperature PL spectra of the $\text{Ge}_{1-x}\text{Sn}_x$ -on-Ge samples.

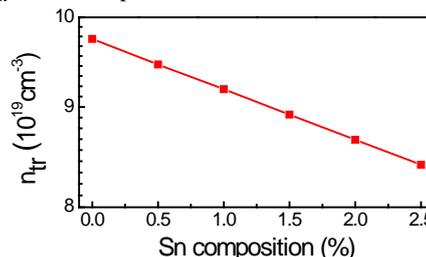


Figure 2. Calculated transparent carrier density for the $\text{Ge}_{1-x}\text{Sn}_x$ -on-Ge film as a function of Sn composition.

4. Conclusions

We have presented room-temperature PL from $\text{Ge}_{1-x}\text{Sn}_x$ -on-Ge films. The photoluminescence intensity is enhanced with increasing Sn composition due to the reduced Γ - L energy separation, leading to a significant reduction in transparent carrier density. Those results indicate that $\text{Ge}_{1-x}\text{Sn}_x$ alloys are promising for efficient infrared lasers for bio-medical and gas sensing applications.

Acknowledgements

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References

- [1] R. Soref, J. Kouvetakis, J. Tolle, J. Menendez and V. D'Costa, *J. Mater. Res.* **22**(12), 3281 (2007).
- [2] R. Chen, H. Lin, Y. Huo, C. Hitzman, T. Kamins and J. S. Harris, *Appl. Phys. Lett.* **99**, 181123 (2011).
- [3] G. E. Chang, S. W. Chang and S. L. Chuang, *IEEE J. Quant. Electron.* **46**, 1813 (2010).
- [4] G. E. Chang and H. H. Cheng, *J. Phys. D* **46**, 065103 (2013).