

Improvement of Light Emission and Wavelength Tunability of n-Ge(Si) Thin Films under High-Speed Continuous-Wave Laser Annealing

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Abstract

Germanium is a promising material for optoelectronic devices owing to its quasi-direct bandgap under tensile strain and heavy n-type doping. However, achieving electron concentrations above 10^{20} cm^{-3} has been challenging because of the low solid solubility of dopants in Ge. Nonequilibrium annealing techniques such as pulsed laser annealing have been explored to overcome this limitation, although the extremely rapid cooling rates restrict crystal growth. In this work, we demonstrate electron concentration exceeding $1.0 \times 10^{20} \text{ cm}^{-3}$ together with high mobility ($\sim 100 \text{ cm}^2/\text{Vs}$) in Ge films by employing high-speed continuous-wave laser annealing. Owing to the microsecond-scale thermal process, this method simultaneously enables large-grain crystallization and efficient dopant activation, as confirmed by Raman spectroscopy and EBSD analysis. Furthermore, the approach allows for high electron concentrations in n-Si_xGe_{1-x} ($0 \leq x \leq 0.25$). Photoluminescence measurements reveal tunable emission wavelengths through the combined effects of Si incorporation and laser annealing. These results indicate that the annealing method effectively introduces the in-plane tensile strain, activates dopants, and provides a versatile route for achieving highly doped Ge-based materials for infrared optoelectronic applications.

Keywords

nonequilibrium growth, germanium, laser anneal, solubility

Introduction

Results and discussion

Experimental methods

Sample preparation

Characterization

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Supporting information

The following files are available free of charge.

- support_info.pdf: Chemical composition of $n\text{-Si}_x\text{Ge}_{1-x}$ films measured by AES (Figure S1), Depth profile of Sb atomic concentration of $n\text{-Si}_x\text{Ge}_{1-x}$ ($x = 0.11$) film measured by SIMS (Figure S2), Ge-Ge vibrational phonon peak position of i-Ge and n-Ge without capping layer measured by Raman spectroscopy (Figure S3), and Raman spectra of $n\text{-Si}_x\text{Ge}_{1-x}$ films in a wider range of Raman shift (Figure S4).