Observation of Ge-Vibration Modes in the Luminescence of Si-Rich Si$_{1-x}$Ge$_x$
Layers Grown by Molecular Beam Epitaxy

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Low temperature photoluminescence spectroscopy has been used to study Si$_{1-x}$Ge$_x$ layers grown by molecular beam epitaxy. The layers investigated were deposited on top of relaxed SiGe-buffer layers grown at 700°C, which results in a drastically reduced dislocation density in the layer. Depth profiling by a variation of the excitation wavelength in the luminescence experiment clearly confirms that most of the dislocations are trapped in the interface and the buffer-layer. Consequently the luminescence spectra from the Si$_{1-x}$Ge$_x$-layers with the germanium composition varying between 12–23% are dominated by the near-band gap luminescence from the Si$_{1-x}$Ge$_x$-layers. In all the samples investigated we clearly observe in addition to the excitonic no-phonon luminescence several well resolved phonon replicas of Si$_{1-x}$Ge$_x$-near band gap bound exciton luminescence. Our results allow us to differentiate between different phonon modes. The transverse optical (TO) phonon replica of the near-band gap luminescence can be observed as the TO-like vibration modes in Ge (TO$^{\text{Ge-Ge}}$) and in Si (TO$^{\text{Si-Si}}$) as well as the vibration of a Ge atom in a Si lattice (TO$^{\text{Si-Ge}}$). In addition to the transverse optical phonons we also could detect the transverse acoustic (TA) phonon replica of the excitonic SiGe near-band gap luminescence, but with an energy between those observed for silicon and germanium. Although the longitudinal acoustic (LA) Ge-Ge phonon is favoured only in Ge-rich SiGe alloys we have been able to detect the LA Ge-Ge phonon replica of the SiGe bound excitons in all our samples out of the range of composition between 12–23% Ge. However as the LA(L2) and the LA(X1) phonons are not very well separated in energy it is not clear whether the observed LA-phonon is identical with the phonon at the L- or X-symmetry point of the Brillouin zone. The possible coupling of the different LA-phonons will be discussed in terms of a detailed luminescence study.
Figure 1: Photoluminescence spectrum of $Si_{1-z}Ge_z$-layer, measured at $T = 4.2 \, K$ showing the well resolved phonon replicas of the excitonic near-band gap photoluminescence of SiGe.

Figure 2: Near-band gap photoluminescence of a $Si_{1-z}Ge_z$-layer with the germanium LA phonon replica.