Self-Assembled Silicon-Germanium Nanostructures for CMOS Compatible Light Emitters

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With the microprocessor clock speed approaching 10 Gbps, optical interconnects are now being considered for on-chip interconnects as an alternative to conventional metal wires. Major avenues toward this goal include the hybrid approach with densely packaged III-V optoelectronic components and the all-group-IV approach (mainly Si, Ge, and SiGe), where all the major components, e.g., light emitters, modulators, waveguides and photodetectors, are monolithically integrated into the CMOS environment. The efforts on obtaining light emission from group-IV semiconductors have been mainly focused on porous silicon, silicon/silicon dioxide superlattices, silicon nanoprecipitates in silicon dioxide, erbium in silicon, silicon/germanium quantum wells, and iron disilicide. However, no approach has so far been applied commercially. There are several reasons, including the lack of a genuine or perceived compatibility with conventional CMOS technology, the long carrier radiative lifetime in Si-based nanostructures, and, especially in the case of near-infrared emitters, the significant thermal quenching of the luminescence quantum efficiency. In this invited talk, we review the basic light emitting properties of three-dimensional Si/SiGe nanostructures. These nanostructures emit light at the technologically important 1.3-1.6 μm wavelength region, and the highest photoluminescence (PL) and electroluminescent (EL) quantum efficiency is found in SiGe clusters with a ~50% Ge composition near the cluster core. The highest luminescence efficiency is observed at low excitation intensity, and the PL quantum efficiency decreases as the excitation intensity increases, due to competition with faster non-radiative Auger recombination. Using time resolved PL measurements, it is found that within the broad PL band, the part of the PL spectra at higher photon energies exhibits a ~100 times faster radiative transition, which is explained by radiative recombination occurring between holes occupying excited states within the SiGe clusters and electrons mostly localized at the Si/SiGe interfaces. This fast PL is less susceptible to Auger-induced intensity saturation as the excitation intensity increases. The EL in Si/SiGe nanostructures is very similar to the PL in its physical nature and, like the PL, it can also be extended up to room temperature. At higher excitation intensity Auger recombination is not only responsible for the quick saturation of the SiGe cluster PL intensity, but it also effectively injects holes into the Si barriers. This hole “Auger fountain”, presumably enhanced by the relaxation of the momentum conservation selection rules at the Si/SiGe hetero-interface, facilitates the efficient formation of electron-hole droplets (EHDs) and an exciton/EHD phase transition in the nanometer-thick Si layers. These experimental observations suggest that by controlling and modifying the composition of Ge-rich SiGe clusters (and possibly other types of two-dimensional and three-dimensional Si/SiGe nanostructures) it is possible to fabricate a more efficient SiGe light-emitting device. Despite the many challenges associated with integration into the traditional CMOS environment, the proven compatibility between planar Si/SiGe and conventional CMOS technology suggests that this task for three-dimensional nanostructures is not an impossible one.