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一軸歪み印加による Ge 量子ドット発光の巨大増強

Giant Light Emission Enhancement from Uniaxial-Strained Ge Quantum Dots

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Ge is a promising material for Si-based monolithic integrated light sources due to its unique band structure and complementary metal-oxide-semiconductor process compatibility. It can be engineered into quasi-direct band gap material through tensile strain and n-type doping. So far, most of the research focused on bulk Ge film grown on Si, in which tensile strain is easily introduced due to the thermal expansion mismatch between Si and Ge [1]. On the other hand, Ge self-assembled quantum dots (QDs) directly grown on Si are compressive-strained, which makes them less efficient as direct band gap light emitters. However, their features likes good crystal quality and three-dimensional carrier confinement are still attractive. In this paper, we present that Ge QDs, with appropriate strain engineering, can be also efficient light emitters.

We grew one layer of Ge QDs embedded in SiGe, instead of Si in usual case, on silicon-on-insulator (SOI) substrate by solid-source molecular beam epitaxiy. The SiGe layer is compressive-strained due to the lattice mismatch between SiGe and Si. The layer stack was then patterned into micro-bridge structure and the underlying buried oxide (BOX) layer was wet-etched, as shown in Fig. 1(b). Due to the release of the BOX layer, the wider pads tend to relax and squeeze the central narrow bridge, thus compressive strain is uniaxially enhanced and the enhancement factor is proportional to the ratio of the width of the wide pad and narrow bridge [2]. Fig. 1(c) shows the room-temperature micro-photoluminescence (μPL) spectra recorded at the unpatterned, pad and bridge regions. The light emission from the center of the bridge is enhanced by almost THREE ORDERS of magnitude. Fabry-Perot resonance also appears in the spectrum due to the reflection at the top SiGe/air and bottom Si/air interfaces. Due to the cut-off of the detector in the PL system, light emission above 1.6 μm could not be revealed. This giant enhancement is not likely due to the cavity effect or enhanced light extraction efficiency. The most possible reason is that direct band gap recombination is dominant in the Ge QDs. Since SiGe is with uniaxial compressive strain along the bridge ([100] direction), it is with biaxial tensile strain in the plane perpendicular to the bridge ((100) plane) due to the Poisson effect. This tensile strain is also transferred into the embedded Ge QDs, thus enhance the direct band gap light emission. These results shows that Ge QDs with large uniaxial compressive strain along <100> direction are very promising light emitting materials.

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References:
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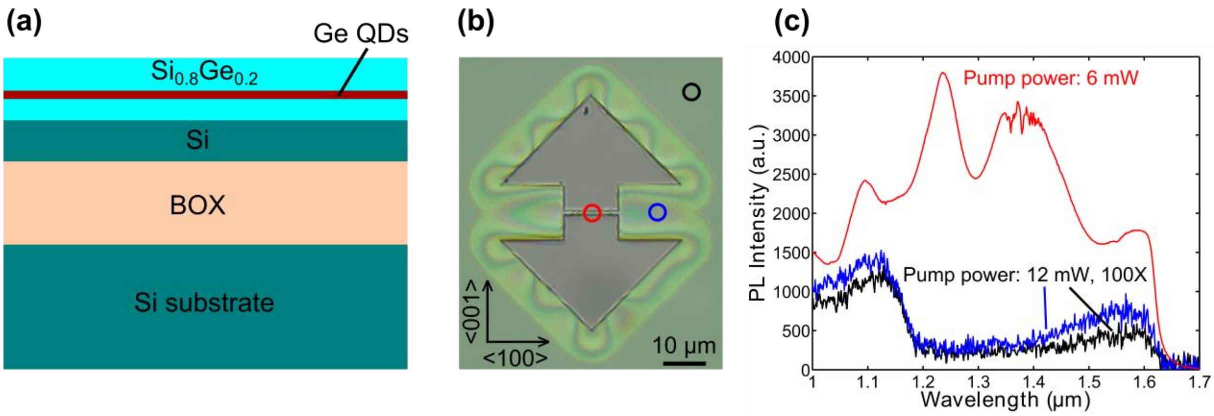

Fig. 1 (a) Layer structure of Ge QDs embedded in SiGe grown on SOI substrate; (b) Microscope image of micro-bridge structure for strain accumulation; (c) μPL spectra recorded at different positions marked as circles with different color in (b). Note that the intensity of black and blue ones is multiplied by 100 for clear view.