SiGe on Si material platform for THz applications

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Abstract: The advantages and challenges of the non-polar SiGe material system as a promising candidate for the development of a THz platform compatible with CMOS technology, as well as the progress achieved so far, will be discussed.

Intersubband (ISB) transitions in semiconductor quantum wells (QWs) enable a broad range of advanced THz electronic and photonic technologies, including high-performance detectors, modulators, and quantum cascade (QC) lasers—key elements for fully integrated photonic platforms.

SiGe presents a unique mix of advantages and challenges compared with III–V semiconductors for THz applications. It is fully CMOS-compatible, allowing monolithic integration with silicon electronics. Its non-polar lattice eliminates the Reststrahlen band, enabling THz emission and absorption in spectral regions inaccessible to III–V materials.

However, the full exploitation of SiGe is still limited by the difficulty of growing high-quality SiGe/Ge heterostructures on Si, due to the mismatch in lattice parameters and thermal expansion coefficients. The resulting epitaxial and thermal strain strongly affects material quality and electronic properties, thereby impacting device design [1,2].

This work reports advances in the growth of rectangular and parabolic QWs in n-type, high-Ge-content SiGe/Ge heterostructures using ultra-high-vacuum chemical vapor deposition (UHV-CVD). We demonstrate precise control over composition, band profile, strain compensation, interface sharpness, and doping—requirements that enable accurate engineering of electronic states in the QWs. The structures were grown on reverse-graded SiGe virtual substrates, with strain-compensation conditions optimized to prevent plastic relaxation of the active region. Composition and conduction-band profiles were tailored by continuously tuning the silane/germane ratio during growth. Structural characterization was carried out using STEM, SIMS, and XRD, while optical properties were evaluated via FTIR spectroscopy.

Rectangular QC structures with Ge wells and SiGe barriers as thin as 2 nm were successfully realized, exhibiting sharp interfaces, controlled dopant profiles at nm level. Recent demonstrations of THz electroluminescence (EL) in Ge/SiGe QWs highlight the potential of this material system for QC lasers [3]. Furthermore, the precise nanometer-scale control achieved during the growth process, together with the resulting high crystalline quality of the deposited QC structures, paves the way for the next future development of THz QC photodetectors.

Parabolic SiGe QWs with varying widths and doping levels were also grown. Their dichroic transmission spectra show an almost temperature-independent absorption signature, a distinctive fingerprint of parabolic QWs. Moreover, SiGe parabolic QWs embedded in a MIM-cavity architecture reached the ultra-strong coupling regime with the observation of upper and lower intersubband polaritons up to room temperature [4].

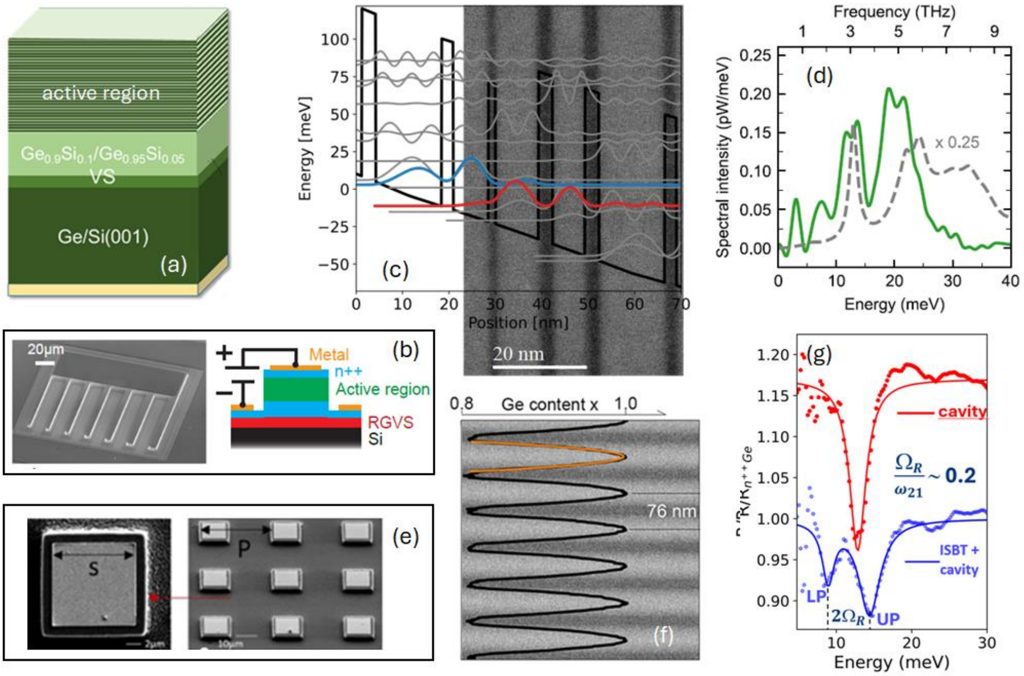

Fig.1 (a) schematics of the deposited samples; (b) SEM image and schematic diagram of the gratings used for EL measurements; (c) Calculated conduction band profile and electronic states (squared modulus) of the QC laser structure superimposed to the STEM image of the sample (d) EL spectrum (green curve) compared to the NEGF simulation (grey dashed curve). (e): SEM images of the arrays of MIM square patch cavities fabricated on PQW sample whose SIMS-calibrated STEM composition profile is shown in (f); (g) Reflection spectra of the bare cavity and of the cavity embedding doped PQWs showing the formation of upper and lower ISB polaritons.

In conclusion, this work demonstrates the capability to realize high-quality SiGe/Ge heterostructures with engineered band profiles using UHV-CVD, marking a significant step toward the integration of SiGe-based quantum photonic devices.

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