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Perspectives on electrically pumped Ge/SiGe QW emitters at THz frequencies

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***Abstract* — The realization of a Ge/SiGe THz emitter is of great interest since it can help to reach room-temperature operation due to the peculiar electron-phonon interaction in nonpolar crystals. Here we present Ge/SiGe quantum-well building blocks grown by epitaxy on silicon wafers in order to understand limitations of this material platform in the perspective of realizing a Si-based laser.**

I. Introduction

EMITTERS exploiting the intersubband transitions (ISBTs) in quantum wells (QWs) are still under the spotlight thanks to the easiness of selecting by design the emission photon energy in the entire spectral range from THz to IR. III-V Quantum Cascade Lasers (QCL), Quantum Fountain Lasers (QFL) and Parabolic Quantum Wells (PQW) are now commercially exploited in the mid-IR and widely employed also as THz sources [1]. Nevertheless, the polar nature of the crystal structure of III-V semiconductors prevents both room-T operation and emission throughout their Reststrahlen band (5-10 THz). Conversely, the nonpolar group-IV semiconductors (Ge, Si and alloys) in principle allow for the realization of room temperature QW devices emitting over the entire THz range. Moreover, SiGe emitters could be eventually integrated in photonics integrated circuits since they can be epitaxially grown on Si substrates.

Among different structures, *n*-type Ge/SiGe QCLs have been predicted to be the most promising structures for reaching such target [2]. Many heterostructure growth challenges must be addressed to realize an electrically pumped SiGe QCL, but the easier growth of QW building blocks can provide important information in the path towards Si-based QCLs. Optically pumped Ge/SiGe QFL have recently been investigated experimentally, but they suffer from low efficiencies [3]. Interesting results could be obtained instead from electrically pumped PQWs [4]. Indeed, PQWs feature ISBTs among equally spaced subbands providing a single absorption (and therefore emission) peak at both low and high temperatures. This property makes them suitable for several applications of light-matter strong-coupling at room-T in the THz [5]. Here we report the structural and optical characterization of Ge/$Si_{1-x}Ge_x$ PQWs grown by ultra-high vacuum CVD realizing continuously-graded interfaces [6, 7] and compare their optical properties with those of QW building blocks having a different geometry.

II. Results

Multiple-period Ge/$Si_{1-x}Ge_x$ PQW samples were epitaxially grown on a reverse-graded SiGe buffer. The period, sketched in Fig. 1a, is composed by a 13 nm $Si_{0.17}Ge_{0.83}$ barrier and a 45 nm-parabolic well with a Ge content continuously increased from 0.83 to 1. Secondary ion mass spectrometry (SIMS) measurement of the Ge concentration on a four period PQW sample is reported in Fig.1b, revealing a compositional profile that perfectly follows a parabola (blue curve). We remark that, from the growth standpoint, obtaining such perfect match is a nontrivial task that requires a fine control over the flux of precursors. The high structural and crystalline quality of the samples is also confirmed by high-resolution rocking curve obtained around the (004) Si Bragg peak by X-ray diffraction (XRD) where several-order sharp satellite fringes associated to the superlattice periodicity are visible (Fig. 1c).

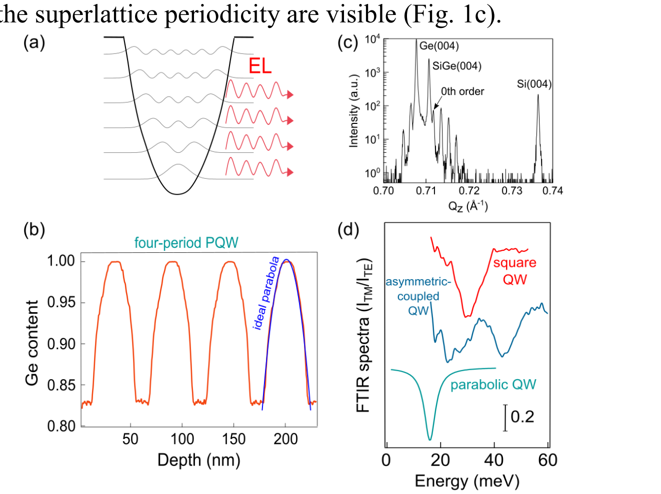

Fig. 1. a) Sketch of the electroluminescence (EL) experiment. PQW wavefunctions have been simulated by the nextnano software. b) SIMS measurement on a four-period PQW (orange curve) confirming the parabolic profile (blue curve). c) XRD rocking curve around the (004) reflection. d) Typical FTIR spectra of QW-based structures (red and blue lines) and theoretical spectrum of the four-period PQW (green curve).

Samples were *n*-doped in the well by phosphine co-deposition to a theoretical sheet carrier density of $1.5 \cdot 10^{11}$ cm^{-2}, which is high enough to guarantee strong absorption lines in optical experiments but not so high to degrade the absorption linewidth. Fourier Transform Infrared (FTIR) spectroscopy is being employed for the optical characterization of the PQW samples.

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