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Electron-doped SiGe Quantum Well Terahertz Emitters pumped by FEL pulses

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***Abstract* — We explore saturable absorption and terahertz photoluminescence in a set of n-doped Ge/SiGe asymmetric coupled quantum wells, designed as three-level systems (*i.e.* quantum fountain). We generate a non-equilibrium population by optical pumping using a free-electron laser as the optical pump and characterize the non-equilibrium population by observing saturable absorption.**

I. Introduction

Asymmetric-coupled quantum well systems based on group-IV materials are the best semiconductor candidates for the realization of light emitters over the entire THz range. Quantum well THz-emitters, such as the THz-quantum cascade lasers (QCLs), are presently made of group III-V compounds, whose polar crystal lattice prevents their operation between 5 and 10 THz due to radiation absorption by optical phonons. The non-polar lattice of Si and Ge could thus help fill this THz-frequency gap; in particular, it has been predicted theoretically [1] that *n*-type (electron-doped) Ge/SiGe multi-quantum well systems are the most promising structures for the realization of a room-temperature THz-QCL. Moreover, SiGe-based emitters could be grown epitaxially on silicon substrates and are thus potentially integrable with silicon microelectronic foundry processes.

The realization of an electrically pumped SiGe emitter (QCL or electroluminescent device) is, however, very challenging, especially due to the lattice constant mismatch between Ge and Si, which introduces strain. Therefore, here we start by characterizing, in simpler optically pumped three-level systems, the population dynamics and the electron scattering by interface roughness and phonons, all important parameters influencing the THz emission efficiency [2].

II. Results

N-type doped three-level Ge/SiGe asymmetric-coupled quantum well structures (ACQWs, also known as quantum fountain emitters) have been designed, grown and characterized by FTIR spectroscopy [3]. We used the free-electron laser (FEL) FELBE (Dresden, Germany) to pump electrons from the ground state to the second excited level (0→2 intersubband transition (ISBT)).

We searched for photoluminescence (PL) emission at the 2→1 ISBT. In order to observe any ISBT-PL signals, the second-excited level has to be heavily populated by the FEL pulse. Saturation of absorption (SA) was simulated and measured as a function of the FEL pump photon flux, providing the crucial information on the population of the second excited state (see Fig. 1b). Relative ISBT bleaching of up to 30% was obtained, corresponding to an excited-state peak population N_2 of almost 10% of the total ground state population N_0 (Fig. 1c). This experiment also demonstrates the potential of SiGe ACQWs as THz-SA devices in the 3-10 THz range, if appropriately band-structure engineering is carried out [4]. The intensity of the observed weak ISBT-PL signals is compatible with N_2 values determined from the SA data.

In order to discriminate the role of the different scattering channels, we also studied ISBT lifetimes in SiGe QWs. We compared THz time-resolved pump-probe spectroscopy data obtained at FELBE with a theoretical model based on Schrödinger-Poisson and energy-balance equations.

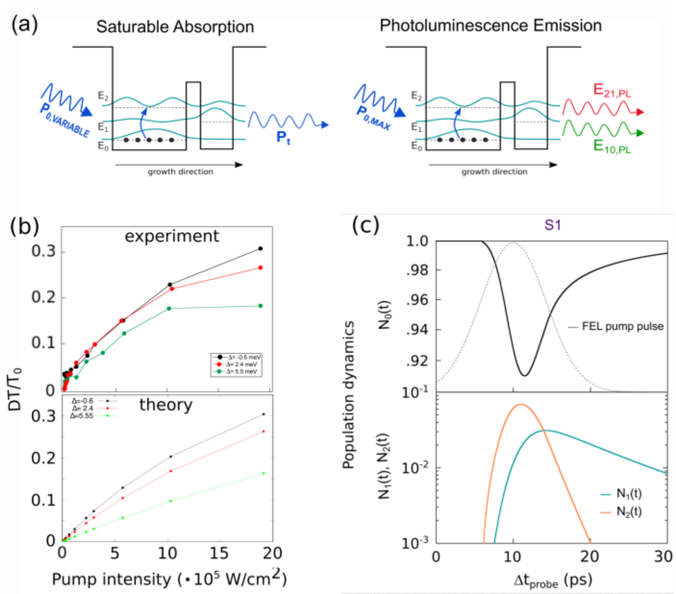

Fig. 1. a) A sketch of the SA and PL experiments performed on Ge/SiGe ACQWs doped in the conduction band. b) The SA data and simulations with the FEL pump at three different photon energies (Δ is the detuning with the ISBT resonance measured by FTIR spectroscopy [3]). c) The simulated population dynamics obtained with the energy-balanced rate equation model.

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