Mid-infrared second harmonic generation with Ge quantum wells grown on Si

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We present the theoretical investigation and the experimental demonstration of second harmonic generation in the mid-infrared by hole-doped Ge/SiGe asymmetric quantum wells. Possible applications in non-linear molecular sensing are discussed.

Keywords: germanium, non-linear optics

1. Introduction

Mid-infrared (MIR) photonics is receiving considerable attention due to the variety of envisaged applications in medical diagnostics, biochemistry studies, chemical analytics, and environmental monitoring for safety and security. Nowadays, commercially available MIR spectroscopic systems are based on bulky and expensive instruments and, as a consequence, there is an increasing demand for compact sensing solutions. In this framework, group IV photonics is emerging as a promising option to realize portable MIR spectroscopic systems. Since broadband MIR light sources integrated on silicon are still not available, wavelength conversion through nonlinear effects is strongly demanded. Second-order nonlinear effects are forbidden in bulk Si and Ge for their centrosymmetric crystalline structure, but this limitation can be overcome by creating asymmetric potential profiles through quantum confinement and by exploiting intersubband optical transitions (ISBT). In this work we present the theoretical investigation and the experimental verification of mid-infrared second harmonic generation in hole-doped Ge/SiGe asymmetric quantum wells (QW).

2. Theory

The Ge/SiGe quantum well used in this work has been designed by using a semi-empirical first-neighbor $sp^3d^5s^*$ tight-binding Hamiltonian which includes spin-orbit interaction in order to calculate the electronic band structure. The results have been then used to calculate the second-order nonlinear optical susceptibilities as a function of the temperature, doping, pump wavelength and polarization. The model predicts second-order non-linear susceptibilities as high as 38 nm/V at room temperature for TM polarization [1].

3. Material

The sample has been grown by LEPECVD and it consists of 20 Ge/SiGe asymmetric QW (the epitaxial scheme is reported in Fig 1(a)) grown on top of a $Si_{0.3}Ge_{0.7}$ virtual substrate deposited on silicon. The grown material has been characterized by STEM (see Fig 1(b)) and HR-XRD.

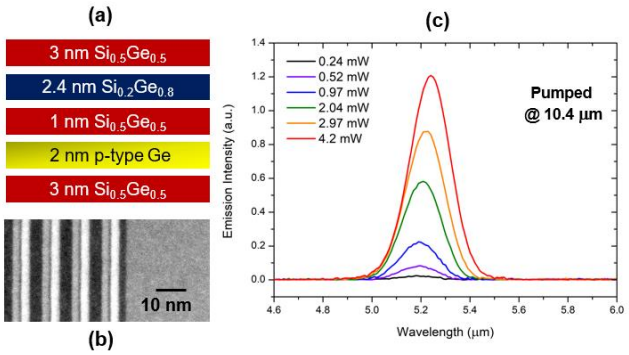

Fig. 1: Epitaxial scheme of the Ge/SiGe QW (a), STEM image showing the first four periods if the QW (b), Second harmonic emission as a function of the pump power (c).

4. Optical characterization

A clear second harmonic emission has been observed at λ=5.2 µm by pumping the sample with optical pulses (λ = 10.4 µm) delivered by an optical parametric amplifier.

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References

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