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Strong electro-refractive effect in Ge/SiGe coupled quantum wells

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Abstract – In this work we investigate the electro-refractive effect in Ge/SiGe coupled quantum wells. An effective index variation of 2.3×10^{-3} has been measured at 1.5 V bias in a planar waveguide, with an associated figure of merit $V_{\pi}L_{\pi}$ of 0.046 Vcm.

I. Introduction

Silicon photonics has generated strong advances in the last decade for on-chip optical communications. Silicon based optoelectronic devices have been widely studied and the recent advances proved the capability of silicon photonics to provide some promising solutions for many applications including optical telecommunications and optical interconnects. In this framework Ge/SiGe quantum wells (QW) have received an increasing interest since the first demonstration of the quantum-confined Stark effect (QCSE) in these structures in 2005 [1]. This result paved the way to a number of exciting works addressing the absorption mechanisms in Ge/SiGe QW structures[2-6]. In contrast much less efforts have been made in order to investigate the electro-refractive properties of this material system. Only recently an experimental value of effective refractive index variation of 1.3×10^{-3} under -8V, with a figure merit $V_{\pi}L_{\pi}$ of 0.46 Vcm was reported for Ge/Si_{0.15}Ge_{0.85} QW [7]. In this work we explore the possibility to tailor the electro optical properties of Ge QW by coupling them together. The electro-optical properties have been characterized by transmission measurements in a Fabry Perot cavity. The results have been used to evaluate the performance of a phase shifter based on this material system.

II. Sample growth and fabrication

The coupled quantum well (CQW) heterostructure was grown by low-energy

plasma-enhanced chemical vapour deposition (LEPECVD). The CQW is made by seven pairs of CQWs: 7 x [7 nm Ge QW + 1.5 nm Si_{0.15}Ge_{0.85} inner barrier + 7 nm Ge QW + 26 nm Si_{0.15}Ge_{0.85} outer barrier]. The outer barrier is thick enough to avoid coupling between adjacent periods. The good agreement between the experimental and the dynamically simulated X-ray diffraction spectra confirms the presence of the thin Si_{0.15}Ge_{0.85} inner barrier. The CQW are embedded in a PIN diode in order to apply an electrical field perpendicular to the CQW planes. 64 μm long, 100 μm wide planar waveguides were fabricated by UV lithography and dry etching.

III. Measurement of the refractive index

The refractive index change was experimentally characterized by the shift of the Fabry-Perot fringes in the absorption spectra of the waveguide with the applied bias (see fig. 1) with the same procedure described in [7]. The measurements were performed with a

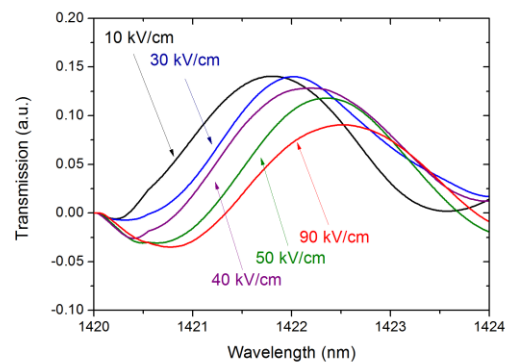


Figure 1: Shift of the Fabry Perot fringes as a function of the applied electric field.

tunable laser with a spectral resolution of 0.1 nm and a power of 1 mW. Light from the laser was butt coupled into the waveguide using a tapered-

lensed fiber. An objective was used to couple the output light into a photodetector.

IV. Discussion

The measured effective index variation as a function of the electric field is reported in Fig. 2 for different wavelengths above the absorption band-edge. Due to the built-in potential, an electric field of 10 kV/cm is present when the applied bias voltage is 0V. Interestingly, the effective index variation has a local maximum at an electric field of 40 kV/cm (1.5 V) for all the considered wavelengths. On the contrary, in a standard non-coupled QW the effective index increased quadratically with the electric field [7]. As a consequence, CQW structures can

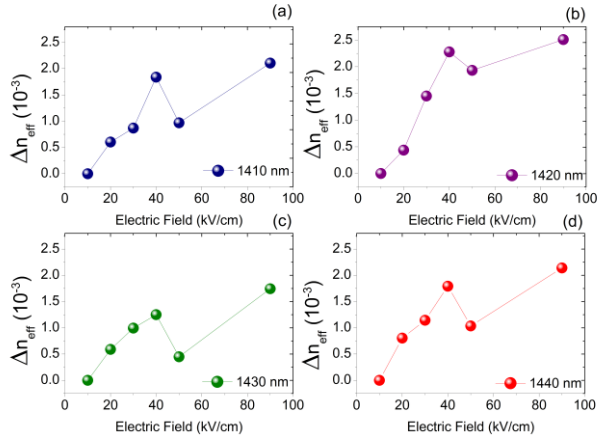


Figure 2: Effective index variation as a function of the applied electric field at 1410 nm (a), 1420 nm (b), 1430 nm (c) and 1440 nm (d).

be specially tailored for optimized operation at low-bias for different spectral regions. A $V_{\pi}L_{\pi}$ of 0.046 Vcm has been measured at a wavelength of 1420 nm with 1.5 V applied bias. This value is one order of magnitude higher with respect to uncoupled Ge/SiGe QWs [7] and very competitive with respect to Si-based phase shifters. The complex behavior of the effective index variation as a function of the electric field arises from the large number of excitonic transitions involved in the optical absorption. In a CQW the electric field breaks the symmetry of the structure, thus the optical transitions $\text{HH}_2\text{-c}\Gamma_1$ and $\text{HH}_1\text{-c}\Gamma_2$ are no longer forbidden by selection rules as in standard uncoupled QW. As a consequence, the absorption spectra, in the

considered energy range, consist of a combination of four optical transition: $\text{HH}_1\text{-c}\Gamma_1$ (T_{11}), $\text{HH}_2\text{-c}\Gamma_2$ (T_{22}), $\text{HH}_2\text{-c}\Gamma_1$ (T_{12}) and $\text{HH}_1\text{-c}\Gamma_2$ (T_{21}). The energy separation between all these transitions is very small, giving rise to four closely spaced excitonic peaks. The absorption spectra for different applied electric fields are reported in Fig. 3.

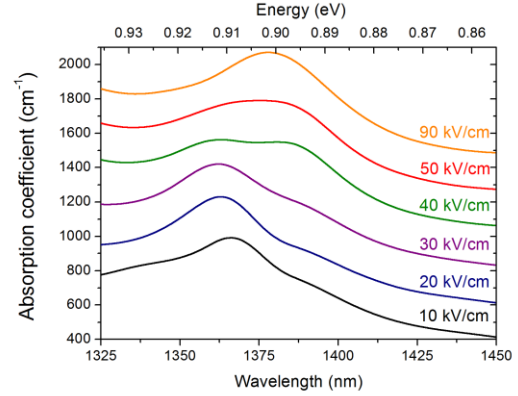


Fig. 3: Absorption coefficient as a function of the wavelength for different electric fields.

V. Conclusion

We have demonstrated a strong electro-refractive effect in Ge/SiGe CQW. Thanks to the strong effective index variation at low bias, a $V_{\pi}L_{\pi}$ figure of merit of 0.046 Vcm has been measured. The effect is promising for the realization of compact and low-power Mach-Zehnder modulators.

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