Optical Modulator on Si Employing Ge Quantum Wells

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Abstract: We demonstrate the first electroabsorption modulator using the quantum-confined Stark effect in Ge. For 10 V swing, the contrast ratio is 7.3 dB at 1457 nm, and exceeds 3 dB over 20 nm bandwidth.
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The recently demonstrated quantum confined Stark effect (QCSE) in germanium quantum wells is a likely candidate for creating optoelectronic modulators for monolithically integrated electrical and optical systems. The absorption modulation achievable is comparable to the QCSE in III-V semiconductors, and a change of absorption of 2800 cm^{-1} has been shown [1,2]. The use of silicon substrates will allow for simple integration with CMOS electronics compared to methods of modulation using hybrid-integrated materials. We have now demonstrated optoelectronic modulators with the QCSE in Ge in several device architectures. In one particularly interesting and novel side-entry architecture, the optical ports are on the polished edges of the silicon substrate, leaving the top and bottom free for electrical interconnects and heat removal, as is typical in electronic chips. The light is obliquely incident upon an asymmetric Fabry-Perot cavity containing quantum wells. The cavity enhances the interaction of the light with the quantum wells, and oblique incidence increases the interaction length per pass as compared with surface-normal configurations. Since the device does not use a waveguide, the alignment constraint is relaxed, allowing useful performance with the beam misaligned by tens of microns.

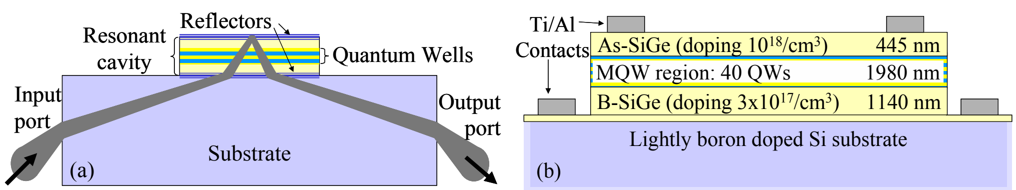

Fig. 1. (a) Side-entry optoelectronic modulator schematic, not to scale. (b) Diagram of the PIN diode mesa fabricated in a sample with 40 quantum wells for side-entry modulation, not to scale.

The side-entry modulator is illustrated in Fig. 1. The beam enters and exits the polished substrate edges at a 45º angle, leaving the top and bottom of the chip free for electrical interconnections and heat removal. A 450 x 450 µm PIN diode mesa is defined in a SiGe epitaxial growth in which the intrinsic region contains 40 Ge quantum wells each ~ 15 nm thick. An asymmetric Fabry-Perot cavity is formed between a reflection at the interface between the Si substrate and the SiGe epitaxy, and the total internal reflection at the interface between SiGe and air. The cavity resonance is tuned to the wavelength range where absorption modulation occurs due to the QCSE.

The contrast ratio (CR) was measured on transmission through the device for a 0-10 V swing in reverse bias. The peak CR was 7.3 dB at 1457 nm, and the CR exceeded 3 dB from 1441 to 1461 nm. Unlike waveguide modulators there is no mode matching constraint, and at 1457 nm, the CR exceeded 3 dB while the beam was misaligned by 460 µm in one dimension and 86 µm in the orthogonal dimension. The transmission through the device at the peak of the contrast ratio in the 'on' state is 10%. This could be improved by antireflection coating the edges of the Si substrate, as the maximum transmission attainable given those reflections is estimated at 37%.

References

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