

Misalignment-tolerant surface-normal low-voltage modulator for optical interconnects at 1.55 μm

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Abstract: We introduce an electroabsorption modulator architecture that combines desirable properties of conventional waveguide designs (e.g. low-voltage operation and optical bandwidth) and surface-normal designs (e.g. misalignment tolerance). Results for an InP/InGaAsP implementation are presented.

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Optical interconnect systems often use modulators to convert electrical signals into the optical domain. An ideal modulator would provide large contrast ratio with small drive voltage for compatibility with standard Si CMOS circuitry, and would allow operation over a wide wavelength range around 1.55 μm for compatibility with standard C-band optical networks.

Conventional optoelectronic modulators, typically in waveguide or surface-normal geometries, have significant drawbacks. Waveguide modulators are expensive and difficult to package because they operate in small, non-circular optical modes, requiring submicron alignment of the waveguide to input and output ports. In addition, waveguides can only be fabricated in 1D arrays, limiting the number of devices that can be integrated with control electronics. On the other hand, surface-normal devices can be made in 2D arrays and are less alignment-sensitive, but they typically fail to provide enough contrast at low voltages due to small optical interaction length, especially for 1.55 μm wavelength devices. Implementing a Fabry-Perot cavity around the active region can increase the contrast ratio, but sacrifices optical bandwidth [1].

We present a hybrid solution that offers desirable properties of both: a quasi-waveguide angled-facet electroabsorption modulator (QWAFEM) (Fig. 1). In this architecture angled mirrors are etched into a semiconductor substrate at an angle steeper than 45°. The optical beam reflects (by total internal reflection) three times and exits in the same direction as the input. At the location of the second reflection, an electrical signal across a *p-i-n* diode with multiple quantum wells (MQW) in the intrinsic layer modulates the absorption via the quantum-confined Stark effect.

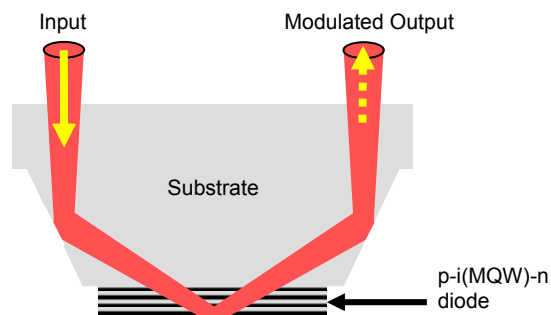


Fig. 1. Schematic diagram of QWAFEM device (not to scale)

Due to the three-bounce geometry, lateral movement of the input beam with respect to the modulator results in the same movement of the output beam. This guarantees relative lateral alignment of the input and output beams as well as same-side optical access, as in conventional surface-normal modulators. In addition, the geometry results in propagation of the optical beam through the active region at a shallow angle, yielding the large interaction length advantage of waveguide modulators. Effective interaction length can be further increased by the inclusion of a resonator around the *p-i-n* diode.

QWAFEM devices were fabricated with an InGaAsP/InP *p-i-n* diode structure. Angled facets at 54.7° were wet etched into the InP substrate using HBr (to selectively etch along the (111)A crystal plane) and 5HBr:1H₂O₂ (to smooth the surface) [2]. Initial results show a peak contrast ratio of 1.8:1 for 3 V drive voltage with wide optical bandwidth and insertion loss of 3 dB (Fig. 2). Misalignment tolerance was measured by translating the device relative to the optical input beam (Fig. 3); the full-width at half-maximum, 20 μm , is an order of magnitude larger than the entire physical width of a standard waveguide modulator.

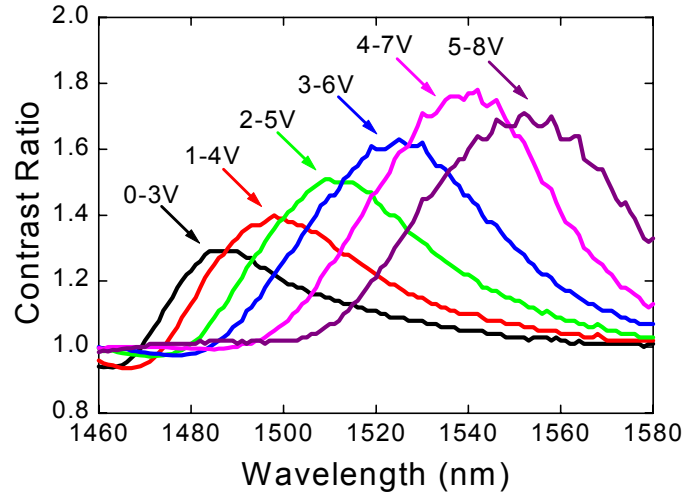


Fig. 2. Contrast ratio vs. wavelength for 3 V swing at several reverse biases demonstrating the wide optical modulation bandwidth

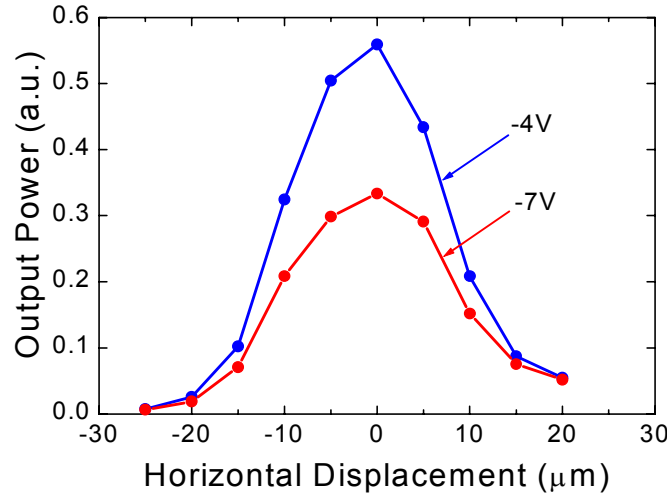


Fig. 3. Output power vs. horizontal displacement showing large tolerance to misalignment for -4 V and -7 V bias

Simulations indicate that a contrast ratio greater than 2:1 over a 20 nm range with only 1 V drive is achievable using a wafer design that includes an optical resonator structure around the quantum wells.

Providing packaging simplicity, low-voltage operation, and surface-normal optical access for a wide wavelength range in the C-band, the QWAFEM modulator architecture offers a unique combination of features for optical interconnect systems.

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