Space-grade Gallium Arsenide IQ and Modulator Arrays for VHTS Photonic SatCom Systems

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Why GaAs Electro-Optic Modulators?

Electro-optic modulators are a Critical Technology for microwave photonic payloads, with increasing interest in 50⁺GHz.

Of the possible material bases for such devices, GaAs (with AlGaAs providing refractive-index contrast) features:

- A fast *Linear Electro-Optic* (LEO) effect;
- AlGaAs lattice-matched to GaAs for all compositions providing unfettered design potential;
- High electron mobility and intrinsic resistivity;
- Conductivity engineered by epitaxial doping;

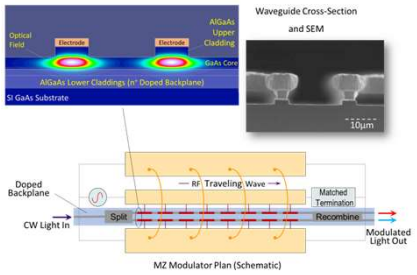
GaAs has excellent environmental credentials:

- Radiation resistant
- Bias-point stability: temperature control not required

Space-qualified foundry manufacture route

- Well proven MMIC-compatible manufacture to industry-standard design-rules
- Preferred material for solar-cells in space and for mm-wave electronics (MMICs)

GaAs/AlGaAs Mach-Zehnder Modulator



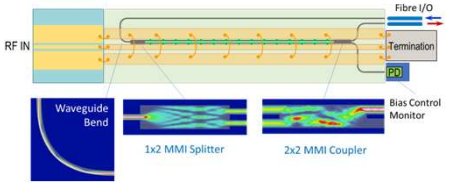
RF/Optical velocity-matching keeps the RF wave in-step with the resultant modulation, allowing a long interaction for low drive-voltage and high bandwidth.

- Velocity-matching by means of a slow-wave structure.
  - Segmented electro-optic electrodes arrayed along a CPW coplanar transmission-line.
  - RF velocity is controlled by the capacitive loading of the electrodes and is set by the geometry and filling-factor of the segmented electrode array.

RF loss/dispersion is hugely influential and must be carefully managed to achieve >50GHz bandwidths.

- CPW with arrayed ground-strap bond wires provide suitable RF properties.

Folded Modulator Topology



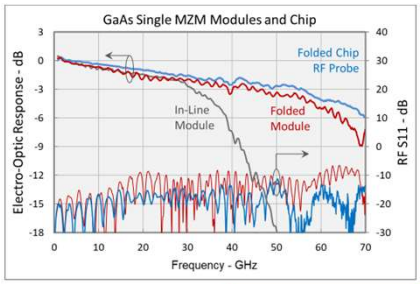
Array-compatible configuration has a simple direct RF path but a folded optical path.

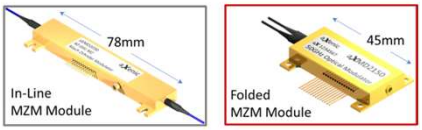
- Preserves RF feed integrity for higher bandwidth
- Perfect channel balance in arrays and IQ modulators
- Chip-length barely exceeds RF/Optical interaction
- Space-hungry fibre interfacing all at one end.

Enabling Guided-wave Optics:

- Low-loss waveguides (<0.3dB/cm). State-of-art RIE process provides smooth vertical walls.
- Low-loss (<0.05dB) corner-bends with optimised graded curvature
- Low-loss (<0.1dB) Multi-Mode Interference (MMI) Structures
  - Splitters
  - Recombiners
  - Mode-filters
  - Power-taps

Single MZ Modulators

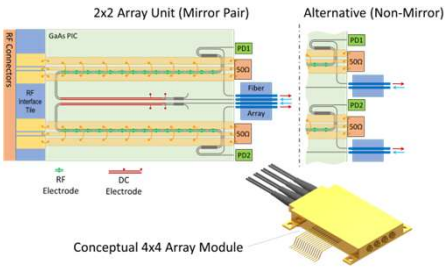




aXenic folded modulators show clear advantage in terms of performance and package footprint.

- Design objective was for an electro-optic response above −5dB at 50GHz with Vπ below 5V.
- 4.65V achieved using 18mm interaction length.

Modulator Array Topology

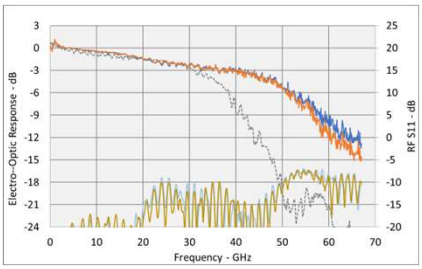


- NxN modulator array requires the folded configuration with straight-through RF
- Many different ways to configure the fibre interfaces: e.g. (as shown)
  - Mirror-pair with x2 or x4 fibre blocks
  - Repeat units with x2 fibre I/O blocks

IQ Modulators with Vπ <3V

IQ modulators are a specialised x2 modulator array

- Mirror-pair
- Single optical I/O with on-board splitter & recombiner
- Applications:
  - QPSK and QAM encoding
  - SSB generation
  - RF/photonic signal processing
- Latest IQ and single MZ modulators use a new epitaxial design and longer 22mm interaction-zone
  - Vπ below 3V
  - Low S11
  - ~40GHz bandwidth
  - Excellent channel balance



Conclusions

- Folded-optics provide a straight uncompromised RF feed to the modulator. This enables modulator arrays, shrinks both chip and module and reduces cost, footprint and weight.
- Single MZM and dual-parallel IQ versions show similar characteristics.
- Folded GaAs EO modulators have achieved Vπ of 4.6V at 1550nm and ~50GHz bandwidth.
- New design with improved GaAs/AlGaAs epitaxy has <3V drive with 40GHz bandwidth.
- New innovations further enabling GaAs modulator technology in general; for example, arrays including integrated RF terminations and on-chip optical power-taps.

New Design Features

1) Optical Power Taps

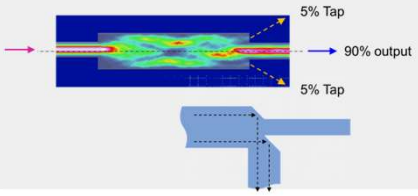
Though environmentally stable, GaAs modulators still require active bias-control. Dependence of Vπ on wavelength and temperature is inherent to the material.

Optical monitor port:

- Complementary MZ output (illustrated opposite) is a good option for pilot-tone control methods.
- Direct power-tap needed where pilot-tone control is unsuitable or where *both* complementary outputs are wanted for a differential detection system.

Integrated optical power-tap using perturbed 1x1 MMI:

- 1x1 re-imaging MMI commonly used as mode filter.
- Odd-order (antisymmetric) modes are imaged to the output 'shoulder' regions.
- Perturbed input waveguide (offset or angled) generates controlled, stable odd-mode component.
- Faceted shoulders totally-reflect the tap-light to a side-port.



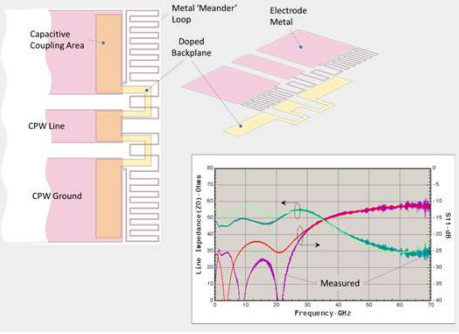
2) Integrated RF Termination

The RF termination is essential in a travelling-wave modulator, absorbing 'spent' RF energy, preventing back-reflection which would compromise system performance.

- Bulky external ceramic component
- Competes for space with fibre I/O blocks
- Bondwire connections cause RF reflections

An Integrated Termination has been demonstrated:

- Fabrication entirely within existing process
- Parallel combination of direct metallic, and AC coupled doped-semiconductor resistance elements.
- Cross-couplings to smooth the crossover band.



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