Novel Segmented Cascade Electroabsorption Modulator with Improved Bandwidth-Extinction Product

Jonathan T. Getty, Leif A. Johansson, Larry A. Coldren
ECE Department, Univ. of California, Santa Barbara, 93106
Tel: (805) 893-7163; Fax (805)893-4500; Email: beans@mrows.org

Abstract: A new configuration for electroabsorption modulators is presented and demonstrated. Compared to a conventional device of the same length, a three-stage cascaded modulator triples the RC-bandwidth while maintaining the same extinction and insertion loss.

OCIS codes: (130.0250) Optoelectronics, (230.4110) Modulators

1. Introduction

Standard lumped-element Electroabsorption Modulators (EAMs) are the workhorse of InP integrated modulation, due to their simple operation and small size. A short length of passive waveguide is appended to a laser [1] or other photonic circuit, and driven with a variable negative voltage. A voltage-dependent Franz-Keldysh absorption, similar to that shown in Fig. 1, modulates the optical input.

A large digital extinction ratio can be achieved either by swinging a large voltage, biasing at a more negative voltage, or using a longer modulator. While the first solution may be practical (up to a point!) in some applications, it can be very difficult to generate a large voltage on-chip in integrated circuits, as will be discussed below.

Setting a more negative bias causes unavoidable, and often severe, insertion loss, necessitating high-power pre-amplifiers with large power budgets and heating problems. Lengthening the modulator proportionally increases the extinction ratio (and the insertion loss, emphasizing the importance of a low bias), but increases the area and capacitance across the depletion region of the reverse-biased EAM diode. While this is an acceptable (and common) tradeoff at modest bit-rates, the diode capacitance becomes a serious consideration for 10GHz and higher bandwidths, although diode capacitance can be reduced with clever doping and epitaxial schemes [2]. This capacitance is typically driven either by a 50Ω RF driver, or an on-chip voltage created by limited photocurrent across a resistor [3]; in either case, the resultant RF circuit is a low-pass RC filter.

Finally, while traveling-wave modulator structures can be used to enhance the bandwidth of InP modulators [4], fundamental limitations, such as impedance matching and junction RF-loss limits both the maximum useful electrode length and overall available improvement in performance.

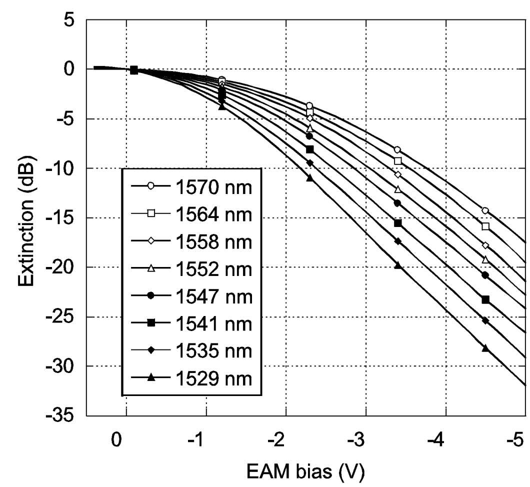

Fig.1. Voltage and wavelength dependence of a typical EAM. A larger extinction is achieved with a large voltage swing, or a more negative bias, with high insertion loss.

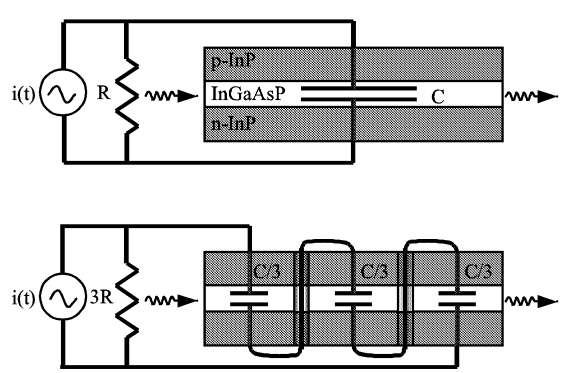

Fig. 2. RF Equivalent circuit of a conventional EAM (above), and a 3-stage segmented cascade EAM (below) of the same total length. Adjacent sections are electrically isolated by ion implantation.

2. Operating principle

This paper proposes and demonstrates that the EAM can be extended to much higher bandwidths with the configuration shown in Fig. 2. A single EAM waveguide is divided into N electrically disconnected sections, which are then wired in series. It can be seen that for a modulator of fixed length, each stage will have capacitance C_0/N (where C_0 is the capacitance of the unsegmented modulator), and the assembly will have capacitance C_0/N^2. The N-stage EAM will require N times the voltage (or N times the length) to achieve the same extinction ratio as the unsegmented modulator; if the voltage is increased by driving a proportionally larger resistor, bandwidth will still increase a factor of N. Alternatively, if N sections of constant section length each is series-connected, the modulation voltage will remain approximately the same, but with an N-fold increase in bandwidth. Table 1 summarizes the extinction and bandwidth for two different segmentation schemes, comparing them to a single-section conventional device.

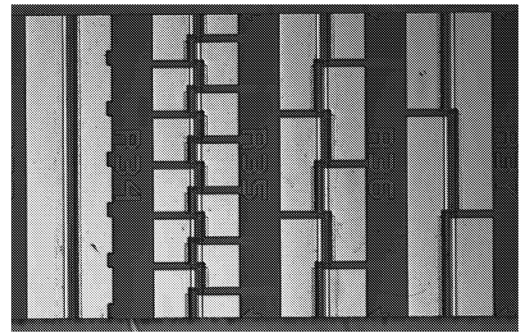

Fig. 3. Micrograph of a 600 μm-long bar of devices. From left, 1-stage control (R34), 12 -stage (R35), 6 -stage (R36), and 3 -stage (R37) cascaded devices are shown.

Number of Stages	Capacitance per Stage	Total Capacitance	Series Resistance	RC Bandwidth	Extinction Ratio
1	C	C	R	$B \equiv 2\pi/RC$	ER
N	C/N	C/N^2	R	BN^2	ER/N
N	C/N	C/N^2	NR	BN	ER

Table 1. Summary of scaling in the conventional (1 stage) and cascade EAM, with and without increased resistance

It is interesting to note that the series-connected device design requires current conservation: the photocurrent, i.e. the absorbed optical power, must be evenly distributed over each section such that the power handling of a segmented EAM is improved compared to a single section modulator, where most of the absorption is taking place close to the front end of the modulator. If uniform voltage distribution is required, instead of using a single load resistor, each modulator segment must be connected in parallel with a separate load resistor, adding up to the total required load.

3. Experimental verification

To verify the principle, segmented EAM's and single-stage control modulators were fabricated side-by-side using a mask and process borrowed from segmented laser design.[5] A passive InP ridge waveguide was fabricated atop an insulating substrate; H^+ and He^+ are implanted from the surface through to the substrate, creating insulating planes that isolate adjacent regions better than 400kΩ. Adjacent contacts are series-connected as shown in Fig. 3; the large, capacitive Au interconnects are unnecessary, but lower the bandwidths to values we can more easily measure. Finally, the material was cleaved into 600μm bars, soldered to a submount, and wire-bonded to its contacts.

Modulation bandwidth and extinction characteristics were characterized using a broadband optical source to cancel out modulator Fabry-Perot effects arising due to straight, uncoated facets. Fig. 4 shows the extinction for one and three stage modulators of 600μm total length. As expected, three times the voltage is needed to achieve, in three series-connected diodes, the same absorption as the control.

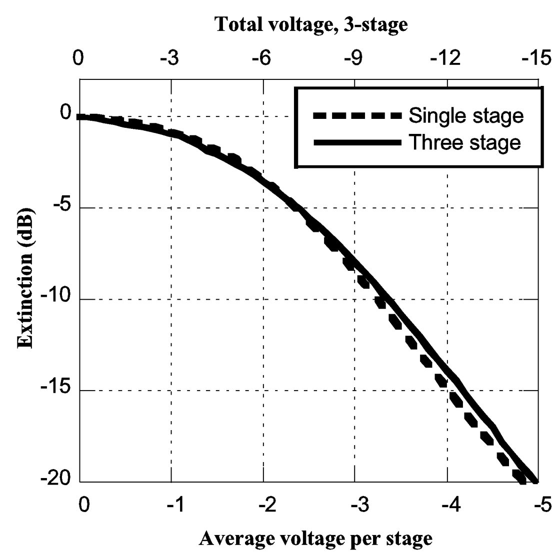

Fig. 4. DC Extinction vs. Voltage for single-stage conventional and three-stage cascaded EAM's. The voltages across the three-stage modulator balance so that each generates the same photocurrent.

However, the three-stage modulator has nine times the bandwidth of the control, as shown in Fig. 5. If the larger RF signal needed to drive the three-stage EAM is achieved by tripling the resistance, the bandwidth is still increased by a factor of three, as shown by the dashed line. Higher-bandwidth EAM's fabricated by increasing the dielectric thickness under the pads, appear to demonstrate bandwidths over 20GHz, but are limited by the probing technology. We hope to report on these, and more advanced, integrated modulators at the conference.

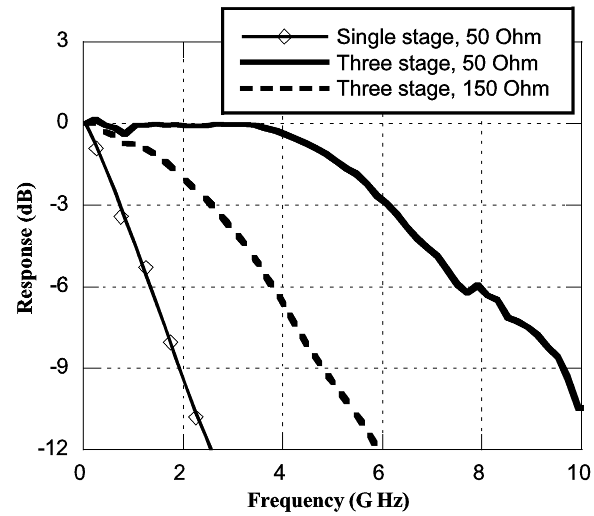

Fig. 5. Bandwidth measurements for conventional and cascaded EAM's. When the three-stage modulator is driven by a current across 150Ω, it has the same extinction characteristic as a single-section across 50Ω. Thus, the bandwidth is improved at no cost to extinction.

4. Conclusions

We have described the first demonstration of a segmented cascade EAM, allowing modulator bandwidth to be increased without sacrificing extinction or insertion loss. The division of a modulator into three segmented stages improved the bandwidth as predicted, with no apparent side effects. While we make no claim to have made a record-breakingly fast modulator, the segmented cascade can enhance nearly *any* EAM, and represents a much easier way to triple performance than epitaxial or other optimizations.

5. References

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