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High-Speed SiGe EAMs at Cryogenic Temperatures

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***Abstract*—Electro-optic modulators capable of operating at cryogenic temperatures are of interest to a host of sensing, quantum, and supercomputing applications. Silicon photonics is compelling for its low cost and CMOS compatibility, but conventional tuning mechanisms are impacted at low temperatures. Bulk electro-absorption modulators are appealing since only the wavelength of the absorption band edge varies with temperature. Cryogenic effects on a fabricated high-speed modulator are shown, with consistent extinction ratio from 5-300K. (*Abstract*)**

Keywords—Silicon Photonics, cryogenic optical links, Electro-absorption Modulator, EAM, Franz-Keldysh Effect

I. Introduction

High-bandwidth readout from cryogenic environments is desired for a wide range of applications including both classical and quantum supercomputing, infrared focal-plane arrays, and high energy physics experiments. Optical fiber preferrable to electrical cables given their superior loss, bandwidth, and low thermal conductivity. However, development of energy efficient and easily manufacturable electro-optic modulators capable of operating at cryogenics is still required. Silicon photonics are appealing for their low-cost and CMOS compatibility, but most conventional electro-optic mechanisms in Si break down at low temperatures. Even ignoring the large heat dissipation, the thermo-optic coefficient of Silicon decreases by multiple orders of magnitude at 5K from 300K rendering thermal tuning inadvisable. Junction-based devices in Si are impacted by carrier freeze-out below 40K but spoked micro rings have shown promising results so far [1].

Electro-absorption modulators (EAMs) offer a compromise between mm-scale Mach-Zehnder modulators (MZMs) and compact (~10 um) but sensitive ring resonator modulators (RRMs). Including control electronics for resonance stabilization puts RRMs on the same size scale as EAMs but it should be noted that novel link architectures could remove stabilization from the cold environment [2].

To date, there has only been one investigation of the behavior of EAMs at cryogenic temperatures [3] which showed that bulk EAMs making use of the Franz-Keldysh Effect (FKE) fared better than the more sensitive quantum well QCSE devices. However, this investigation was limited to 77K, had a low bandwidth, and required impressive but still experimental fabrication techniques. In this work a SiGe bulk EAM initially intended for datacenter operation at 1550 nm at 60°C (343K) and has demonstrated 50 Gbps modulation at room temperature [4].

II. Experimental Setup

Devices were fabricated in a Rockley Photonics multi-micron process [5] and epoxied to a printed circuit board (PCB), fiber attached with a pigtail fiber array unit (FAU), and wirebonded. Due to inaccessible bondpads, a second PCB with a cutout was brought over the PIC to shorten the wirebonds. Additional height clearance was given to the signal bond to avoid a short from thermal expansion, but the length can be reduced in future builds. The completed assembly was secured in a cryostat with coaxial cable and fiber vacuum feedthroughs to be cooled with liquid He. Insertion loss sweeps were obtained from 1240-1640nm using three EXFO T100S-HP tunable lasers (O+, ES, and CL band varieties) which were controlled by an EXFO CTP10 passive optical component tester as shown in Fig. 1(a-b). DC biases and IV sweeps were controlled by a Keithley 2401. At intervals of 5K, from 300K to 5K, a current voltage (IV) sweep was taken first, followed by insertion loss sweeps biased at 0V, -1V, -3V, and -5V. At 300K and 5K, electro-optic bandwidth measurements were acquired with an Agilent HP 8073A lightwave component analyzer.

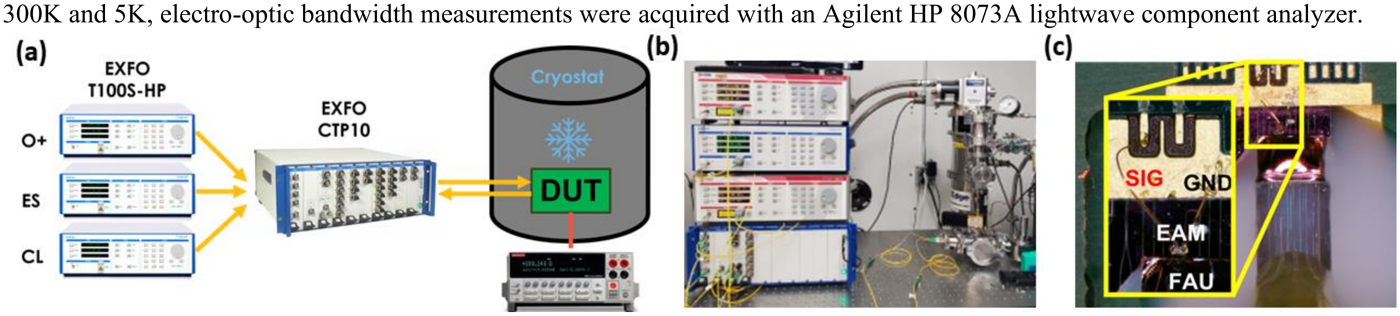

Fig. 1. Experimental setup for insertion loss sweeps from 1260-1640 nm using an EXFO CTP10 and TS-100HP lasers (a) system diagram (b) picture of setup (c) Microscope image of device assembly with fiber attach and wire bonds to PCB

III. Results and Discussion

From 300K to 5K, the absorption band edge shifted by around 120 nm, resulting in an operation point around 1400 nm as opposed to 1520 nm at room temperature. Most notably, the strength of the FKE-induced extinction was not impacted at all, just the wavelength at which it peaks. The extinction ratio shown in Fig. 2(a) is defined between 0 V and -5 V bias. The I-V curves in Fig. 2(d) denote a reduction in leakage current at low reverse biases, but DC power consumption is only one component of total power. Capacitance would also need to be measured as a function of temperature to indicate the effects on RF power consumption, which would be largely determined by the required driving electronics.

Due to damage to the fiber attach during assembly, the total coupling loss is 15 dB, although 5 dB was achieved on other assemblies. Insertion loss of the EAM itself was measured to be 7 dB by calibrating to a waveguide loopback test structure on chip. Fig. 2(e) shows the electro-optic bandwidth at -2 V bias to be about 18 GHz and unaffected by temperature. The 5K measurement was done with a wavelength of 1390 nm resulting in an 18.3 GHz bandwidth, whereas the 300K curve was at a wavelength of 1530 nm and produced an 18.7 GHz bandwidth. Test equipment, including cabling and bias tees were calibrated out, but device packaging parasitics remain. The long wire bonds for the complex assembly shown in Fig. 1(c) are limiting the speed of the device which has previously been open eye diagrams at 50 Gbps with high-speed probes [4]. Despite packaging limitations, this device has a high bandwidth compared to existing cryogenic modulators require more complex fabrication.

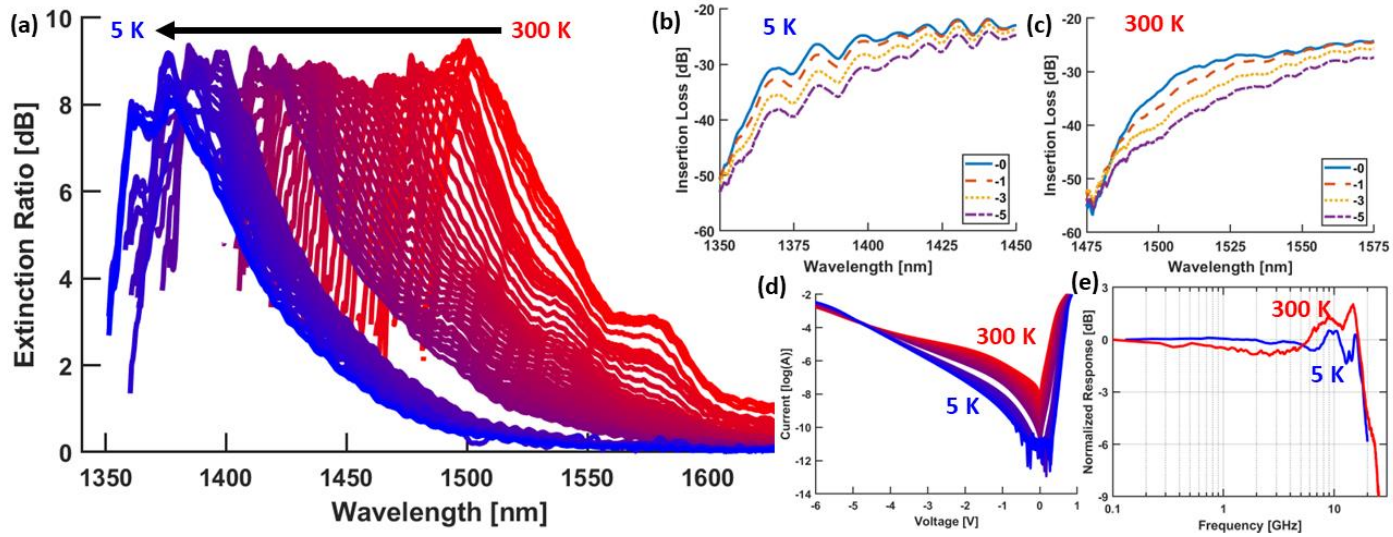

Fig. 2. Temperature dependent data (a) Extinction ratio between at 0 and -5 V bias (b) Insertion loss at cryogenic temperature (c) Insertion loss at room temperature (d) I-V characteristics from 300K-5K (e) Electro-optic bandwidth at 300K and 5K

IV. Conclusion

Bulk EAMs provide a promising mechanism for electro-optic modulation at cryogenic temperatures and shows little degradation in the extinction ratio or 18 GHz bandwidth from 300K to 5K. However, a shift in wavelength by about 120 nm is observed due to the temperature dependence of the absorption edge. More high-speed characterization is required to investigate the expected power consumption and heat dissipation and a new assembly can improve the packaged device's performance.

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