Alignment Tolerant Hybrid Photoreceivers Using Inverted MSMs

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The pervasive implementation of optical links, including fiber to the home and in-home fiber optic backbones, relies upon the cost reduction of optoelectronic interfaces. Highly alignment tolerant photoreceivers can reduce the packaging cost of optical links for applications, which include those mentioned above, by easing packaging constraints. Previously reported optical alignment tolerance measurements have been reported for speeds up to 3 kbps. To achieve a high level of optical alignment tolerance at higher speeds, a high responsivity, large area, low capacitance photodetector such as the inverted metal-semiconductor-metal (I-MSM) detector can produce excellent results. Herein, we report on the hybrid integration of a thin film large area (250 x 250 μm^2), low capacitance (0.43 pF), high responsivity (0.5 A/W, with no AR coating) InGaAs/InP I-MSM onto a Si CMOS differential receiver circuit. This integrated receiver (shown in Figure 1) demonstrated a bit-error-rate (BER) of 10^{-11} at 414 Mbps and 0.1×10^{-10} at 480 Mbps. The alignment tolerance of this receiver has been modeled and measured at 200 Mbps, and the theoretical results correspond quite well to experimental data.

Photodetector speed in an integrated receiver is limited by either the RC time constant of the device or the transit times of photogenerated carriers within the device. In order to integrate highly alignment tolerant receivers, large area photodetectors are desired; however, the input capacitance to the receiver must be minimized. PIN photodiodes are a common choice for integration onto receivers due to their high responsivities [1,2]. However, these devices have a large capacitance per unit area that ultimately limits detector size and alignment tolerance for a desired data rate. Conventional (C-) MSMs have a low capacitance per unit area, but these detectors have responsivities much lower than those of PINs due to shadowing from the interdigitated electrodes on the top of the device. By inverting the MSM – essentially flipping a C-MSM upside down so the electrodes are on the bottom of the device and removing the substrate – this tradeoff between large area and high responsivity is eliminated with only a minimal sacrifice of device transient response [3].

The I-MSM integrated onto the receiver shown in Figure 1 was fabricated from a wafer grown by molecular beam epitaxy (MBE) with the following nominally undoped layer structure: 400 A InAlAs cap layer, 500 A graded layer, 7400 A InGaAs layer, 500 A graded layer, 400 A InAlAs, 2000 A stop etch layer, and InP substrate. Ti/Au (250 A/2250 A) electrodes and contact pads were deposited via a liftoff process. The electrodes were 2 µm wide and had 5 µm spacings. The contact pads were 250 µm wide and 40 µm long. Mesas were defined by standard photolithography, and the devices were mesa etched down to the InGaAs stop etch layer. The MSMs were then embedded in a protective Apiezon W wax coating, and the substrate and stop etch layer were removed. The encapsulated devices were then bonded to a transparent Mylar® transfer diaphragm, and the wax was removed. At this point, the metal electrodes and contact pads of the MSMs were exposed as the bonding surface, and the bottoms of the devices were bonded to the diaphragm. Such an arrangement facilitated the MSM inversion process during integration.

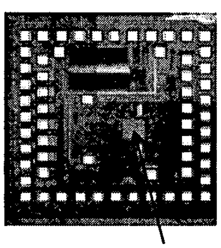

Figure 1 – InGaAs/InP I-MSM integrated onto Si CMOS differential receiver circuit.

The differential Si CMOS receiver circuit was fabricated at the MOSIS foundry. It consisted of a fully differential current mode input, current to voltage conversion, and voltage gain stages. Ti/Pt/Au (250 A/250A/2500 A) integration pads were deposited onto the circuit. The Ti acted as an adhesion layer, and Pt was used as a diffusion barrier. The exposed device contact pads were used to metal-metal bond an individual detector to the integration pads on the receiver circuit, resulting in fingers on the bottom of the MSM device. A polyimide coating was spun onto the integrated circuit and cured at 200 °C in order to promote the adhesion of the detector to the circuit. The polyimide was subsequently removed using a dry etch. The integrated circuit was then wire bonded to a printed circuit board for testing.

The performance of the integrated receiver was tested using a Fabry-Perot laser pigtailed to a single-mode optical fiber. A BER transmitter was used to drive the laser with a pseudorandom pattern. The pigtailed fiber was coupled via FC connectors to a single-mode fiber patch cord that was cleaved on the opposite end. The cleaved end of the fiber was positioned over the integrated receiver using an XYZ

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translation stage. The mode field diameter of this fiber was given by the manufacturer as 9.3 µm. A Keithley Source-Measure Unit (SMU) biased the I-MSM. Photocurrent as a function of fiber to detector misalignment was measured at 200 Mbps.

The integrated receiver was modeled and tested for two types of alignment tolerance. Longitudinal alignment tolerance refers to receiver performance as a function of the separation between the surface of the photodetector and that of the emitting source. Transverse alignment tolerance describes the receiver performance as a function of the off-axis separation between the center of the source and the center of the detector.

A Gaussian intensity distribution was assumed as a first-order approximation to the beam emitted from the cleaved fiber. In order to estimate the power coupled from the fiber to the detector, the intensity of the Gaussian beam was integrated over the area of the I-MSM to calculate the percentage of power coupled from the fiber to the detector as a function of longitudinal separation. To predict the coupling efficiency under lateral misalignments (with 1 mm longitudinal separation), the limits of integration were appropriately adjusted to effect a transverse separation between the centers of the fiber and detector. Because the device is inverted, carriers can be excited in the areas of the InGaAs absorbing region that lie directly above the metal contact pads. This has the effect of extending one dimension of the 250x250 μm^2 detecting area by 2 diffusion lengths. Electron diffusion length within the InGaAs was calculated to be ~20 µm based on the assumption of an electron mobility of ~10000 cm^2/Vs and an electron lifetime of 16.7 ns (as described in [4]).

Measured photocurrent was used to calculate power coupled from the fiber to the detector. These experimental results as well as the theoretical predictions for coupled power as a function of longitudinal and transverse separation are compared in Figures 2 and 3. The experimental data in Figure 3 was taken with 1 mm of separation between the fiber and the detector. Experimental and theoretical data in both figures have been normalized to optimal fiber-detector alignment. The discrepancy between the theoretical curve and the experimental data near the 1mm separation mark in Figure 2 may be a result of simplifying the emitted beam to a Gaussian or of the transient response of the I-MSM to excitation by a 200 Mbps pseudorandom signal. The discrepancy in Figure 2 accounts for the discrepancies in the peaks shown in Figure 3 since the latter figure was evaluated at a longitudinal separation of 1 mm.

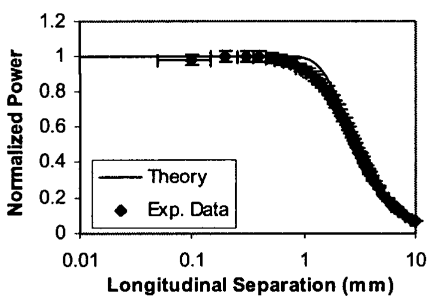

Figure 2 – Longitudinal alignment tolerance

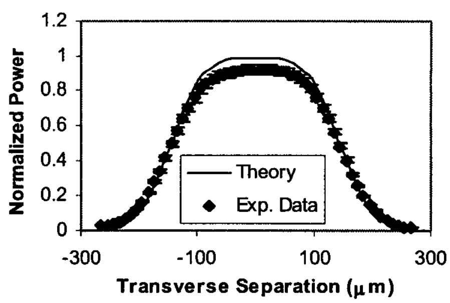

Figure 3 – Transverse alignment tolerance

Thin film large area I-MSMs have been integrated onto Si CMOS circuits. These integrated receivers have demonstrated highly alignment tolerant operation at 200 Mbps. Measured alignment tolerance of the receiver corresponded quite well to the performance predicted by theory.

Acknowledgments

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