ANALOG RF-OPTOELECTRONIC INTEGRATED CIRCUIT RECEIVERS

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ABSTRACT

Optoelectronic Integrated Circuit (OEIC) receivers have been demonstrated for analog rf-photonic links. The photodetector and preamplifier are both based on the same InGaAs/InAlAs/InP heterojunction bipolar transistor structure. On-chip AC-coupling filters accomodate links having low modulation depths. The receivers operate in 1-6 GHz and 2-18 GHz bands.

INTRODUCTION

Photonic links for analog signals are used for applications such as video distribution and remoting of radar or communications antennas. The interest in analog links has increased greatly in recent years because of improvements in the available laser power and the modulation efficiency. In such links, the need for high linearity is typically accomodated by using fairly low modulation depths. Thus, the receiver amplifiers must be AC-coupled to avoid being saturated by the high DC photocurrents. OEIC receivers demonstrated in the past were developed for digital applications and had photodetectors directly connected to the preamplifiers. We report the first AC-coupled OEIC receivers.

DESIGN

Monolithic integration of the photodetectors and preamplifiers to form an OEIC receiver offers the advantages of simplified assembly and reduced parasitics, compared to a hybrid approach. For receivers based on heterojunction bipolar transistors (HBTs), an additional advantage is that both the photodetector and the transistor can be fabricated from the same epitaxial-material layers.[1] We have developed OEIC receivers for the 1.3-1.55 micrometer wavelength range that are based on the InGaAs/InAlAs/InP HBT structure. In our design, the HBT's n-type collector layer serves as the light-absorbing layer of the photodetector. The base and subcollector layers of the HBT serve as the heavily-doped p and n layers of the photodetecting diode. The use of a common epilayer enables the OEIC to be fabricated by adding only 2 steps to our standard HBT circuit process. As a result, the fabrication yields we achieved for the OEICs are as high as the yields for conventional electronic circuits.

Use of a common epitaxial-material structure for both the HBT and the photodetector imposes some tradeoffs in their device performance. These tradeoffs involve parameters such as the thickness and doping level of the collector layer.[2]

We achieve optimal OEIC performance with collector thicknesses between 0.7 and 1.0 microns. Typical HBTs have current gains, β, above 40 for 2x5 micron devices and photodetector responsivities better than 0.5 A/W at 1.55 micron wavelength. The dark currents of the photodetectors are typically below 0.1 microamps.

The circuit diagram of the wideband (2-18 GHz) OEIC receiver is shown in Figure 1. The receiver consists of a photodetector that is AC coupled to a transimpedance amplifier stage. This

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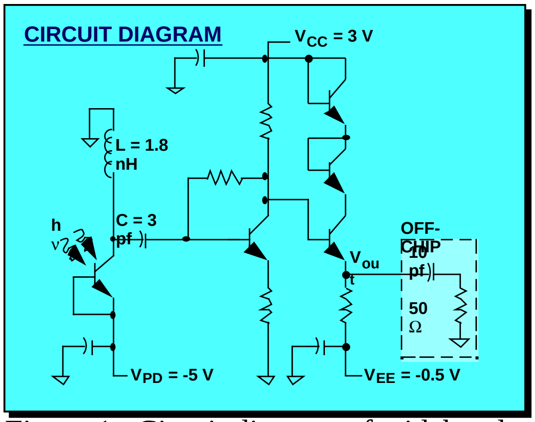

Figure 1. Circuit diagram of wideband OEIC receiver.

receiver also has an emitter-follower output stage. The mask layout of the receiver is shown in Figure 2. Note that all of the bonding pads are placed on one end of the circuit and the photodetector is placed on the opposite end. Since any bond wires or solder bumps are located away from the photodetector, the layout allows access for an in-plane mounted fiber. Such fibers can have a beveled end or be mounted in a silicon v-groove with a deflector located at the end of the groove. The resultant receiver package has a flat profile and is more compact than one that has perpendicularly incident fibers.

Inclusion of an on-chip AC coupling circuit between the photodetector and

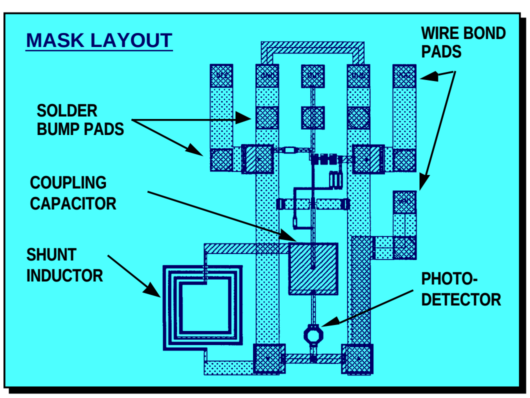

Figure 2. Mask layout of wideband OEIC receiver.

preamplifier requires the fabrication of thin-film capacitors and inductors on the OEICs. This has been accomplished without the need to change our standard fabrication process. The capacitors are metal-isulator-metal devices. The spiral inductors are formed from the normal multiple-layer metalization of the circuit. The AC-coupling circuit has a 3 pf capacitor which passes only the rf photocurrent and a 1.8 nH inductor which shunts the DC photocurrent to ground.

We have fabricated 4-channel arrays of OEIC receivers. A photograph of the wideband receiver array is shown in Figure 3. The circuits have a center-to-center spacing of 500 microns and occupy a chip size of 1 mm x 2.5 mm. Each circuit of the array is accessed by its own bonding pads for the power supply inputs. In addition, there is a duplicate set of pads for solder

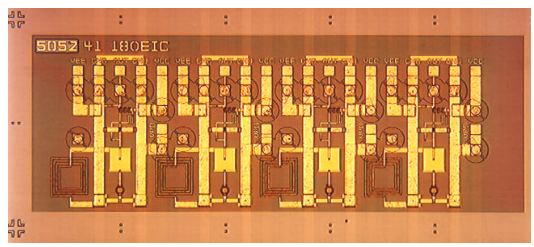

Figure 3. Photograph of 4-channel OEIC receiver array.

bumps. Thus, in addition to the traditional mounting approach with wire-bonded connections, the receiver array chip can also be flip-chip mounted on a substrate that contains mechanical features for holding the optical fibers. Flip chip mounting is expected to yield reduced electrical parasitics and improved isolation between receiver channels.

PERFORMANCE

The frequency responses of the OEICs were measured by using a Hewlett Packard 8703A Lightwave Component Analyzer. Results for on-wafer probed measurements are shown in Figure 4. The frequency response of the wideband receiver, shown in Figure 4b, has a lower 3 dB frequency of 1.2 GHz, achieved by the AC-coupling circuit, and an upper 3 dB frequency of 18 GHz. The receiver has an effective responsivity of 2 A/W for the 1.55 micron optical wavelength. Since the responsivity of the photodetector alone is approximately 0.5 A/W, this translates into a preamplifier gain of 8 dB. The frequency response for the high-gain receiver is shown in Figure 4a. This receiver contains the same photodetector and AC coupling circuit as the wideband design. However, it has a 2-stage transimpedance amplifier and an output buffer that is resistively matched to a 50 ohm load impedance. According to the measured frequency response, this receiver has an effective responsivity of 5 A/W, and a preamplifier gain of 15 dB. The circuit operates in the 1-6 GHz band.

Since these receivers are intended for analog fiber-optic links, their linearity or dynamic range is important. We have performed two-tone modulation measurements by using a transmitter configuration with two sets of wideband electro-optic modulators and distributed-feedback laser sources. The measurement configuration is illustrated in Figure 5.

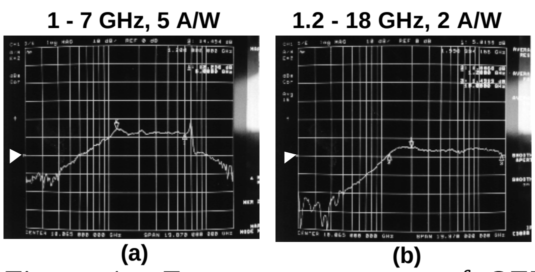

Figure 4. Frequency response of OEIC receivers: 10 dB/div scale, 20 GHz span.

Both the fundamental components and the 3rd-order intermodulation products of the receiver output were observed with a spectrum analyzer. In one set of measurements, the laser power was held constant and the rf input power to the modulators was decreased gradually until the intermodulation products reach the noise floor for the measurement. The value of the spur below the fundamental (dBc) was measured for various pairs of test frequencies between 1.5 GHz and 18 GHz. This measurement gives a worse-case estimate of the dynamic range of the receiver. In a typical fiber-optic link, the noise floor would be approximately -160 dBm. This suggests a receiver limited spur-free dynamic range of 115 dB for a 1 Hz bandwidth at 1.5 Ghz.

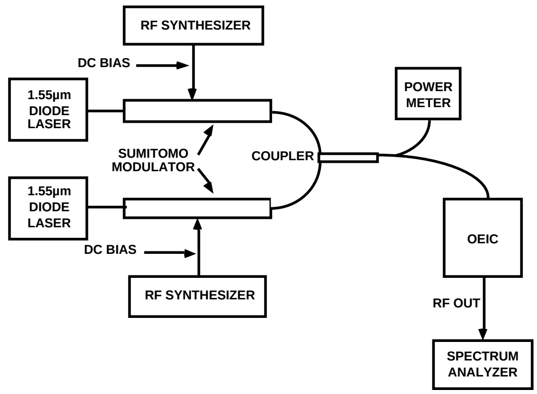

Figure 5. Illustration of two-tone modulation measurement configuration.

In analog links, it is desireable to use higher optical power levels at the receiver in order to improve the overall link gain. In Figure 6, the measured rf output power in the fundamental and the 3rd-order intermodulation product are plotted vs the incident optical power. These measurements were made with two input tones in the vicinity of 5 GHz. The modulation depth of the optical input was only 20%. These results suggest that the

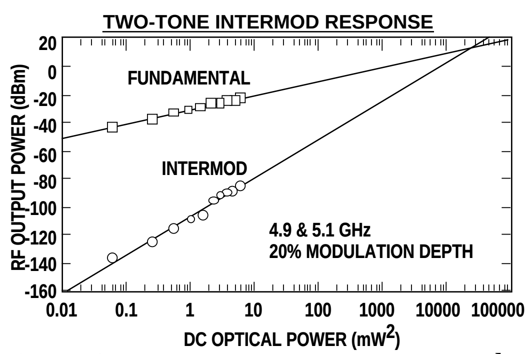

Figure 6. Two-tone measurement result for wideband OEIC receiver.

AC coupling circuit effectively protects the preamplifier from the high DC component of the photocurrent. The output IP_3 of the receiver can be estimated by extrapolating the measured curves to their crossing point. The wideband OEIC receiver is expected to have an output IP_3 of +15 dBm. The average (DC) photocurrent of the OEIC shows a linear response to input optical powers as high as 2.5 mW.

SUMMARY

In summary, we have demonstrated the first rf-OEIC receivers for analog fiber-optic links. These receivers contain an on-chip AC-coupling circuit in addition to the photodetector and preamplifier. Receivers for the 1-6 and 2-18 GHz bands have been demonstrated. Two-tone modulation measurements show the excellent dynamic range and linearity of these receivers.

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1. W.E. Stanchina, et.al., GOMAC-91 Digest of Papers, p.385 (1991).
2. D. Yap, et.al., GOMAC-96 Digest of Papers, p.404 (1996).

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