Development of Circuits in Indium Phosphide for Communication at 40Gbit/s and Above.

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ABSTRACT
Vitesse has developed an indium phosphide (InP) heterojunction bipolar transistor (HBT) process and used that process for the fabrication of 40Gbit/s communication circuits. The process is run in the Vitesse 4" wafer fab located in Camarillo, Ca which is dedicated to the production of InP circuits. Transistor performance of 150GHz for ft and fmax are achieved with a conservative mesa isolated NPN structure that leaves room for future advancements through device scaling. Single (SHBT) and double (DHBT) transistor structures have both been fabricated with success. PIN photodetectors have also been built in this process allowing the integration of optical functions. Circuits discussed here have been built in the SHBT process. The process is designed around high yield manufacturable methods which have produced circuits with excellent yield. Circuits have been designed using both distributed and lumped element architectures with success. A building block approach has been used to maximize yield, schedule, and performance success. At this time all key building blocks for the OC-768 physical layer have been demonstrated. A TIA, limiting amp, PIN diode, 4:1 MUX/DEMUX pair, and a driver with 3.5V pp swing have all been demonstrated in the lab and are now being sampled to customers.

INTRODUCTION
This paper discusses the development of a high performance InP HBT process in a manufacturing environment and the application of that process to the manufacture of circuits for 40G communication. Vitesse is a leading integrated circuit supplier to the telecommunications industry. Chips are manufactured in either GaAs or InP in internal fabs or manufactured in Si using outside foundry service. Over 15 years of experience has gone into the development and manufacture of III-V semiconductors in a high volume production environment. For 40G applications the material of choice was InP because a high performance HBT could be quickly realized in that technology and because InP is the substrate for all long wavelength optical components. As a substrate for optical components InP provides a base for increased levels of integration including the integration of optical functions and the eventual fabrication of optoelectronic integrated circuits (OEICs). The ability to operate at higher data rates, shorter development cycles, and lower system cost made possible by an internal fab were also key reasons for choosing InP.

PROCESS
The recent availability of 4" InP substrates with good flatness has made it possible to consider InP HBT fabrication in a production manufacturing environment. At Vitesse device fabrication is done in a 4" wafer fab originally used for GaAs MESFET

manufacture and now converted to InP HBT production. The first version of the Vitesse InP HBT process is based on a traditional wet etched emitter and shadow masked base contact [1]. Epilayers are grown by MBE, the emitter is InP and the base is beryllium doped allowing the use of conventional plasma deposited dielectrics. Implementation of this conservative device design allowed us to bring up a manufacturable process with adequate performance in a very short period of time. Fab yield has been excellent and runs at about 85% typically, die yield has also been excellent. Circuits with less than 100 transistors often show 100% yield. The largest circuit built to date in this process is the 4:1 mux which contains 1052 transistors and yields 40% to 60%. The high yield and reproducibility of the process allows us to focus much of our effort on modeling, circuit design, and implementation of the 40G products. Aluminum interconnect technology was adopted from the existing GaAs process, minimizing process development time. Metal thicknesses were adjusted to provide adequate electromigration resistance for an HBT process. Unique refractory ohmic contacts were developed to provide reliable devices with high temperature stability.

Transistor performance peaks at a collector current density of about 1mA/um^2, ft and fmax are both greater than 150GHz at this density. BVceo is 4.2V for the SHBT process. A DHBT device is now in development with measured BVceo > 7V. The DHBT device structure is very similar to the released SHBT process. The DHBT device is intended for use in a single ended modulator driver for an Xcut lithium niobate modulator. Thermal performance is also enhanced in the DHBT because the poor thermal performance of the InGaAs epi layer is largely eliminated by using an InP collector. Future versions of the InP HBT process will make use of dry etching rather than wet etching for better CD control and smaller dimensions. The shadow mask technology will be replaced with a spacer technology for better control and minimization of extrinsic base resistance. Ultimately copper metallization will replace aluminum for better current handling at smaller geometries. These improvements will push ft near 200GHz and fmax to 300GHz.

CIRCUITS

A block diagram of the 40G physical layer is shown in Figure 1. We believe 40G will show up first in the short reach or metro markets where deployment is more straightforward, less complex, and therefore more cost effective.

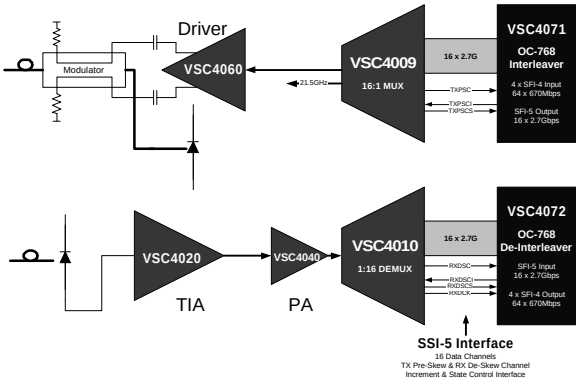

FIGURE 1: Block diagram of the 40G physical layer.

Advancements in the technology for dispersion compensation and more cost effective optical components are required before 40G will be deployed in the long haul or core applications. Our first product offering therefore consists of a TIA, limiting amp, 4:1 or 16:1

mux/demux pair, and a EAM driver, all consistent with the needs of the short reach or metro markets and all consistent with SHBT transistor performance. A brief discussion of each part follows. The few 40G TIAs that are available today typically have a gain of about 150ohms, for a –10dBm optical signal this results in a 9mV output, which is insufficient to drive the DEMUX. A plot of gain vs frequency for the Vitesse 40G TIA is shown in Figure 2. Additional gain stages in the form of a limiting

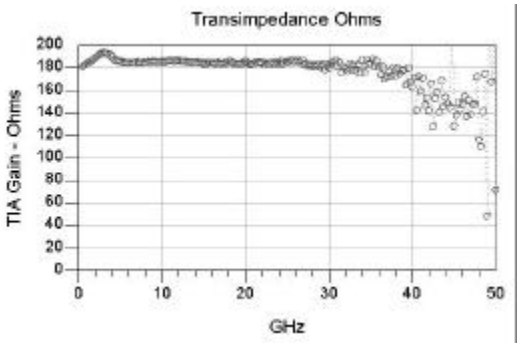

FIGURE 2: Transimpedance gain vs frequency for a lumped element TIA designed and built at Vitesse.

amp or additional gain stages integrated into either the TIA or DEMUX are required. An overall gain of 400ohms is needed at a bandwidth of about 35GHz. The Vitesse product offering addresses this need. The remaining analog component is the driver for an electroabsorption modulator. Voltage swings from 2-3V are needed for this application which can be achieved in a SHBT process. Lumped element designs have not achieved the necessary bandwidth for the driver at this time.

The Vitesse architecture uses a distributed design to achieve the required gain bandwidth product. Features are limited to gain control and common mode offset at this time. An example of an optical output from a modulator driven by our EAM driver is shown in Figure 3. The output of the MUX is shown in the upper left of the figure, the upper right is the amplified output, the lower left is the modulated optical output. The 4:1 MUX/DEMUX pair is the first digital product offering with a full 16:1 MUX/DEMUX pair

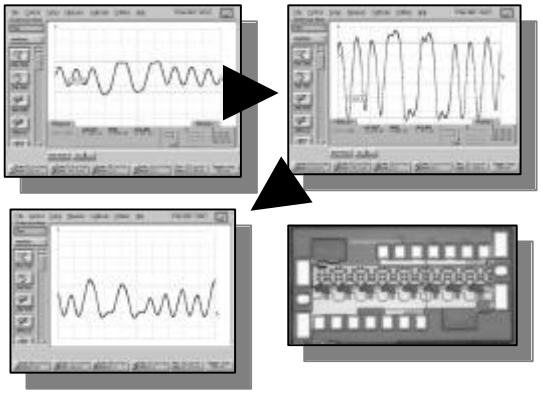

FIGURE 3: 40G output from an InP mux is amplified to 2.7V by an InP distributed amplifier. This output drives an EAM which produces the optical output waveform.

following. An on chip VCO generates an internal 43GHz clock used for full rate data retiming on the high speed output. The DEMUX includes a full CDR.

CONCLUSION

Indium phosphide has advanced to the point where high volume and high yield manufacturing in a production environment is possible. An InP based HBT has the performance today to perform all functions in the 40G physical layer. In addition InP based technology has the ability to integrate on chip optical functions with electronic functions. For these future applications Vitesse has fabricated a monolithic PIN

and TIA as a demonstration vehicle. Others have previously demonstrated similar normal incidence PINs integrated with amplifiers[2]. Demonstrations of edge illuminated photodetectors integrated with amplifiers have also appeared in the literature [3]. Future products employing waveguides and AWGs integrated with detectors and amplifiers are not far off.

REFERENCES

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ACRONYMS

SHBT:single heterojunction bipolar transistor
DHBT:double heterojunction bipolar transistor
MUX:multiplexer
DEMUX:demultiplexer
PIN:p-i-n photodiode
VCO:voltage controlled oscillator
TIA:transimpedence amplifier
MBE:molecular beam epitaxy
EAM:electroabsorption modulator
OEIC:optoelectronic integrated circuit