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Comparison of Si/CMOS and GaAs MESFET Technologies for Analog Optoelectronic Circuits

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Abstract

We investigate the feasibility of transferring analog optoelectronic circuits designed for Si/CMOS to GaAs and show results of a specific circuit, originally designed for Si/CMOS, but now fabricated in GaAs.

When building optoelectronic circuits consisting of photodetectors, electronic circuitry, and optical output devices, such as LEDs or modulators, one must choose between hybrid and monolithic integration. In a hybrid integration approach, Si/CMOS circuits are integrated with modulators through flip-chip bonding, epitaxial lift-off, or liquid crystals on Si. This allows the designer a great deal of flexibility in the circuit design because of the complementary FET technology. To monolithically integrate optical sources, one must use a direct bandgap material such as GaAs. GaAs is well suited for monolithic integration because E/D MESFET (Enhancement mode/ Depletion mode Metal Semiconductor Field Effect Transistor) technology is fairly advanced and custom designed circuits are available through MOSIS. We have recently demonstrated that LEDs can be monolithically integrated with MOSIS GaAs chips using MBE regrowth [1]. This new technique allows the system designer to build complex optoelectronic circuits with little capital investment and fast turn-around time. Because of the vast selection of analog circuit designs already available in Si CMOS [2], it would be convenient to be able to directly implement these Si CMOS circuits in GaAs. In this paper, we investigate some of the trade-offs between GaAs E/D MESFET and Si/CMOS technologies in terms of high density optoelectronic circuitry and show new results from optoelectronic circuits originally designed for Si/CMOS but now implemented in GaAs.

Both Si/CMOS and GaAs MESFET technologies were originally developed for high speed digital computations. For analog circuits. one is typically performing operations on small currents rather than the voltages found in digital circuits. While Si circuits use both n and p channel FETs to build low power circuits, GaAs circuits achieve lower power dissipation through high mobility, low voltage n-channel MESFETs. There are a number of key differences between the two technologies which makes it more difficult to implement some analog functions in GaAs. First, the absence of any gate-source leakage currents in MOSFETs allows large gate voltages swings. In a MESFET, the gate-source leakage current of the forward biased Schottky junction limits the gate-source voltage to 0.6V. The net effect is that the output voltage of E/D MESFETs circuit is typically limited to 0 to 2V as compared the 0 to 5V outputs possible in Si/CMOS. Another important difference between the two technologies is the availability of the p-channel in Si. This allows one to build current mirrors, which are commonly used to change the polarity of a current.

Despite these limitations, many optoelectronic circuits used in neural network applications can still be fabricated in GaAs. The simplest example is the optoelectronic threshold circuit, which is essentially the same in GaAs and Si. The current correlator, or "bump" function, requires five transistors in Si/CMOS and seven transistors in GaAs E/D MESFET.

On the other hand, the winner-take-all circuit is actually a bit more complicated in Si than in GaAs, because the high gain photodetectors and LED outputs in the GaAs circuit eliminate the need for the current mirrors. Figure 1 shows the circuit diagram for the winner-take-all circuit in GaAs. We have fabricated several winner-take-all circuits in GaAs, with up to 100 competing inputs. The electronic portion of the chip was fabricated by Vitesse Semiconductor Corp. through MOSIS and the LEDs were monolithically integrated by MBE regrowth. The high gain photodetectors in GaAs are enhancement-mode MESFETs with the gate left floating. The typical responsivity of such a photodetector is over 1000A/W for 10-100nW in optical input intensity. Figure 2 shows the response of two competing branches of a 3 unit winner-take-all circuit. A photograph of the winner-take-all circuits with the LEDs at the bottom of the circuit is shown in Figure 3.

In conclusion, Si/CMOS analog circuits designs can not be directly implemented in GaAs MESFET technology, largely because of the absence of the complementary FET. However, in many cases a redesigned and typically more complex GaAs circuit can duplicate the operation of the original CMOS design. In a few cases, such as the winner-take-all, a reduction in complexity is experienced.

[1] Grot, A., Psaltis, D., Shenoy, K., Fonstad, C., *Integration of LEDs and GaAs Circuits by MBE Regrowth*, to appear in IEEE Photonics Technology Letters.
[2] Mead, C. A., *VLSI Analog and Neural Systems*, Addison-Wesley, Reading Massachusetts, 1989.

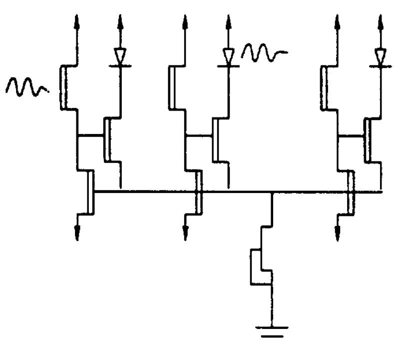

Figure 1 Circuit diagram for a GaAs winner-take-all circuit.

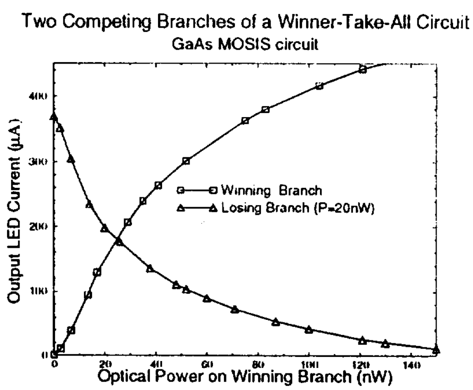

Figure 2 Response of two competing branches of a 3-unit winner-take-all circuit.

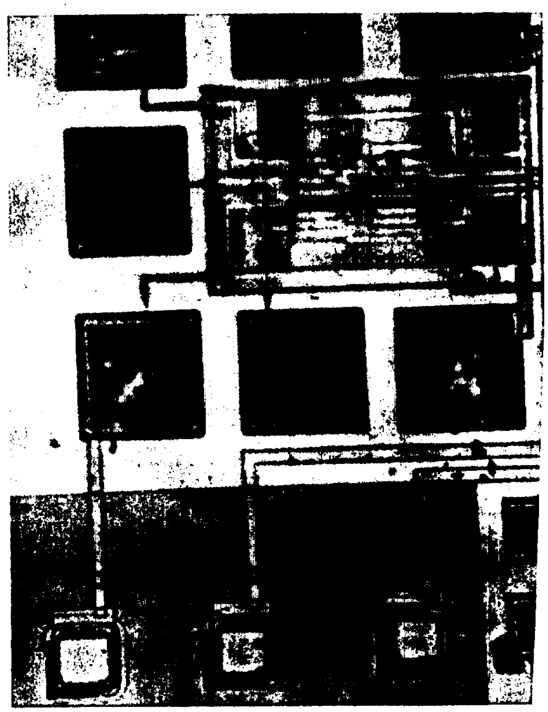

Figure 3 Photograph of a 3 unit winner-take-all circuit fabricated by MOSIS with the LEDs monolithically integrated by MBE regrowth.