Compound Semiconductors: From Oddity to Commodity

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INTRODUCTION

GaAs RF devices have been available for many years. The first applications were for two terminal devices such as Gunn diodes, impatt diodes, tuning varactors and mixers. These devices found high value applications in military and telecom-munications systems where there unique performance characteristics differentiated them from competitive offerings. The transferred electron or "Gunn" effect allowed that a two terminal device in the appropriate circumstance could directly generate RF energy from DC. Impatt Diodes could also directly convert DC to RF energy at higher efficiency and were ideal for missile seekers. With the higher electron mobility of GaAs, varactors and mixers could be fabricated with higher Q factors justifying the added cost of the GaAs components when compared with silicon. These businesses were differentiated and grew but did not support predictions of explosive growth.

GARTNER HYPE CYCLE

If the progress of GaAs RF semiconductors is mapped according to the "Gartner Hype Cycle" (see Fig. 1) the technology trigger seems to have come in the form of the field effect transistor (FET) and the semi-insulating substrate. These innovations allowed envisioning both digital and monolithic microwave integrated circuits (MMIC).

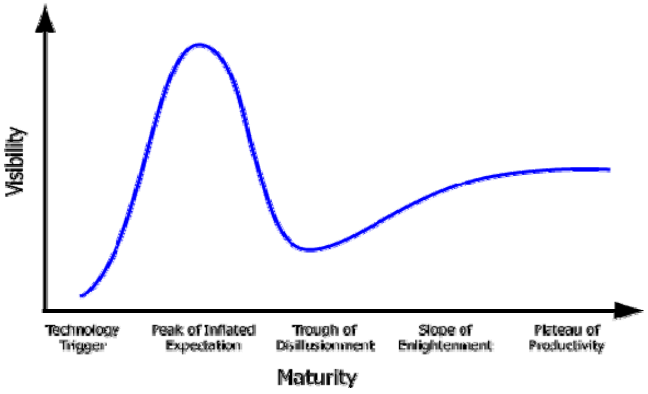

Figure 1. Gartner Hype Cycle.

These end applications were responsible for a "Peak of Inflated Expectation" that carried to predictions of significant encroachment on the silicon market for digital integrated circuits due to the inherent speed advantage of GaAs.

Substantial DoD investments were made in infrastructure and various stages of development of an industry capable of supporting both military and "dual use" applications for RFICs. These investments were crowned by the "MIMIC" program consisting of a multi-phase program with teams of contractor partnerships and lasting close to a decade.

This level of investment inevitably led to an expectation that when these programs ended, there would be a substantial underlying market that would continue the economic support of this industry. The "Trough of Disillusionment" came when it became obvious that market development for the products predicted during the height of the hype cycle had not and in some cases, would not develop.

The cell phone market had been developing for years but was limited by heavy, expensive phones and expensive service fees. Handset technology was in its infancy and most of the activity was analog and at battery voltages in excess of 5 volts. GaAs devices have traditionally carried a cost premium against their silicon counterparts and early cell phone applications were no exceptions.

However, as battery systems moved toward 3.5 volt applications, the cost differential was offset by the performance advantage GaAs devices had at these lower voltages. Discreet GaAs front end components like LNA/mixers and power amplifiers began to make inroads in the market and began the development of the market for GaAs devices for handsets. The "Plateau of Productivity" has certainly been reached with a cell phone market for GaAs exceeding $3.0 billion by 2012.

SCALE AND INTEGRATION

RFMD has been producing GaAs RFICs for over 10 years. During that time we have been on a 22% learning curve (see Fig. 2) with remarkable fidelity leading to a cost per square millimeter having been reduced greater than an order of magnitude. This data is based on production of more than 850,000 wafers of both 100mm and 150mm diameters. The words expensive and GaAs may no longer belong together when a GPRS PA can be sold profitably for less than one dollar and the semiconductor content is less than 1/3 of the total cost.

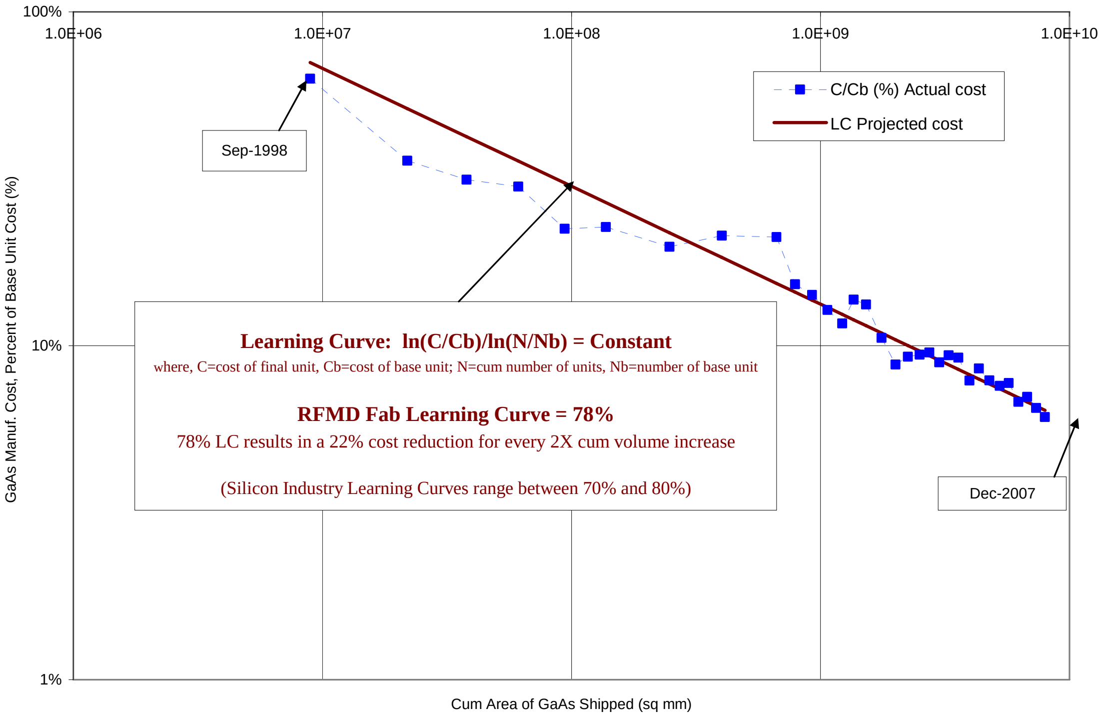

Figure 2. RFMD 10 year learning curve for GaAs.

A constant question for this and other semiconductor applications is the appropriate level of integration and the tradeoff between "system in package" (SIP) and "system on chip" (SOC). Integration is by itself not a desirable pursuit unless it offers a cost or performance premium.

There are many such tradeoffs from which we can draw parallels. In RFMD's first generation EDGE transceiver products a separate receive die was partitioned due to the need to design the LNA/downconverter using SiGe. This SiGe added too much expense to be included with the larger CMOS transceiver die so separate die were used. In the newer generation a single die is used but only because we were able to reach adequate performance for the receiver front end in native CMOS adding no additional wafer processing cost.

Figure 3 shows the logic flow diagram for making the integration decision for a particular application. A simple set of decisions is required to arrive at the appropriate partitioning and the economics of cost sensitive applications such as handsets are unforgiving if the inappropriate decision is made.

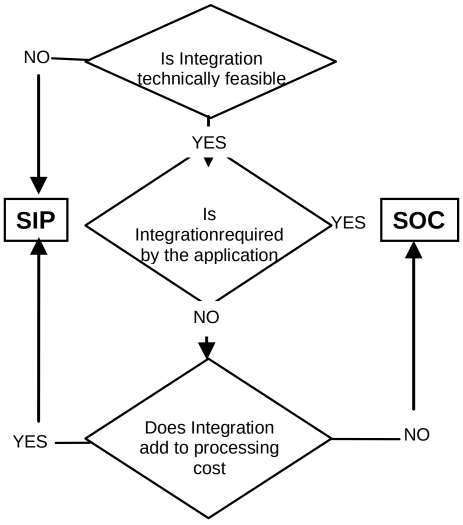

Figure 3. Logic flow diagram for integration.

SILICON VS GAAS

The inherently lower cost of silicon makes it a relentless threat to the dominance of GaAs in handset front ends. The largest threats stem from a perception that a handset modem could be fabricated in a single die using silicon. In this scenario the ability to put the baseband processor, the transceiver, the power amplifier and the antenna switch all on one die makes for a very threatening possibility indeed.

The reality of that possibility becomes increasingly remote however, as silicon moves to technology nodes that operate at lower and lower voltages due to thinner gate oxides. This movement is inconsistent with the needs of the analog components like the PA, switch and in some cases the LNA. To integrate these devices together would potentially add the cost of multiple gate oxides, SOI, requirements for high resistivity substrate and a low impedance ground connection for the PA. It may also add a requirement to isolate and shield various functions to avoid interference, oscillation or instability. Given these complications the threat from silicon is limited to detached, stand alone functions where the cost advantage is blunted by the relative percentage occupied by the semiconductor in the bill of materials for a standard handset PA or TX module.

Digital wireless modulation standards may also play a role in the technology decisions made in the future. Most comparisons of PA technologies have historically been performed using GSM (GMSK) modulation. GSM as a 2G cellular technology operating in a saturated mode, places limited requirements on PA performance. Higher level modulation standards such as 8PSK used in EDGE systems and OFDM which will appear in WiMAX and LTE systems, place very stringent requirements on error vector magnitude (EVM) and ACPs which are related to amplifier linearity.

System voltages perhaps lower than 3.5 V will also place higher demands on device performance. As has been the pattern in the past, when the performance requirements become more demanding, the higher electron mobility will help to make GaAs more entrenched.

CONCLUSION

Whether the semiconductor content is silicon, GaAs or SiGe, these products will continue to be extremely cost sensitive. There is certainly not enough performance differentiation for any of these technologies to justify a pricing premium. The market will search for value which is the optimum tradeoff of price and performance and includes material selection and integration levels. The good news for the GaAs industry is that we have arrived at a point where we can compete on both performance and cost.

ACRONYMS

2G: Second Generation
8PSK: Eight Phase Shift Keying
ACP: Adjacent Channel Power
CMOS: Complimentary Metal-Oxide Semiconductor
DC: Direct Current
DoD: Department of Defense
EDGE: Enhanced Data Rates for GSM Evolution
EVM: Error Vector Magnitude
FET: Field Effect Transistor
GaAs: Gallium Arsenide
GPRS: General Packet Radio Services
GSM: Global System for Mobile Communications
GMSK: Gaussian Medium-Shift Keying
HBT: Heterojunction Bipolar Transistor
LNA: Low Noise Amplifier
LTE: Long-Term Evolution
MMIC: Monolithic Microwave Integrated Circuit
OFDM: Orthogonal Frequency-Division Multiplexing
PA: Power Amplifier
Q factor: RF Quality Factor
RF: Radio Frequency
RFIC: Radio Frequency Integrated Circuit
SiGe: Silicon Germanium
SIP: System In a Package
SOI: Silicon On Insulator
SOC: System On a Chip
TX: Transmit
WiMAX: Worldwide Interoperability for Microwave Access