State of the Compound Semiconductor Industry
A Focus on Communications

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ABSTRACT

The year 2006 will be remembered as a transition year for the compound semiconductor industry. This was the first year in many where worldwide GaAs supply and demand came back into balance. The long awaited commercialization of third generation data handsets (3G) has solidified GaAs as a critical technology. Additionally, GaN development efforts have demonstrated success for important performance and reliability milestones in 2006.

Cellular phones, at one billion units sold per year, remain the highest unit volume consumer electronics device on the planet. Voice remains the killer application but the promise of 3G, un-tethered broadband data access, has moved into production and GaAs is the enabling RF technology. Even as 3G units are just now reaching volume, the convergence of WiFi and WiMAX, LTE and UMB is on the horizon with next generation performance – lower cost and greater data rates.

A clear trend is underway. Value is moving back into the compound semiconductor space. This industry suffered through an extended period between 2000 and 2005 where commoditization and over supply drained value and limited investment. The promise of ubiquitous wireless access remains a compelling vision and as standards and chipsets evolve, the compound semiconductor industry stands ready to reap the harvest of growing demand.

INTRODUCTION

Today, GaAs is the preferred technology for power amplifiers in cell phones and WLAN cards. Together this represents an annual market of well over one billion devices. While high volume, low cost silicon-based technologies remain the most fearful threat to the GaAs industry, this threat is losing strength. High profile launches of CMOS power amplifiers for the low cost GSM/GPRS market have not enjoyed great success. The trade-off of performance for cost in a CMOS solution has been countered by the continuing progress of GaAs down the cost learning curve.

Transmit modules have emerged as the preferred architecture in multi-mode and multi-band cell phones. A transmit module combines RF power amplification with the duplexing function in an easy to use small form factor. For CDMA2000 or WCDMA (3G), both of which employ FDD (frequency domain duplexing), a SAW or BAW based duplexer component is used to simultaneously separate transmit from receive signals. For GSM/GPRS/EDGE applications, employing TDD (time domain duplexing), a pHEMT switch is incorporated with the HBT power amplifier.

WiMAX has gained significant support as a next generation standard for wireless broadband access. Often referred to as "WiFi on steroids" WiMAX solves some of the implementation problems of WiFi hot spots. WiMAX provides greater range and a better quality of service. WiMAX will be on licensed frequency bands, with tighter controls reducing impact from interference as compared to WiFi networks. Most importantly, several major powerhouses in the industry have thrown their weight behind WiMAX including Motorola, Intel, and Sprint.

COMPOUND SEMICONDUCTOR MARKET

In the early 1950s research began to commercialize compound semiconductors. Initially, due to the high performance characteristics and relatively high manufacturing and development costs, the market was limited to mission critical governmental applications. Applications developed quickly for both optical and RF communications. With the introduction of cellular phone systems in the early 1980s, personal and portable communications were on a path to becoming the largest market for GaAs technology. The GaAs market is currently \$3.0 billion and growing at a 7% CAGR as forecasted by Strategy Analytics (Fig 1). Personal voice and data represent approximately 70% of that market.

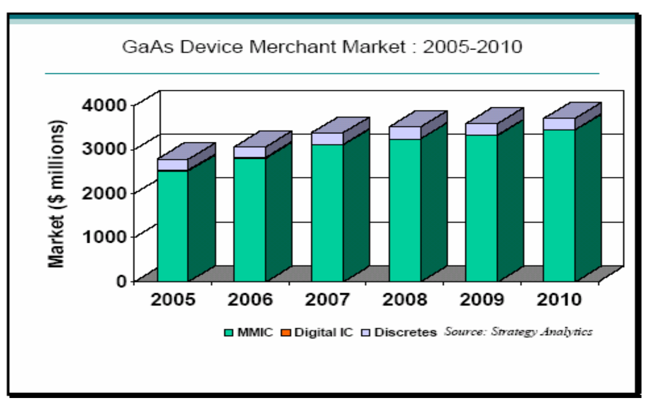
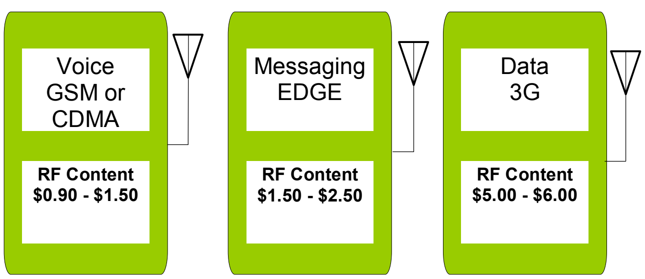


Figure 1 – GaAs Market, Strategy Analytics

KILLER APPLICATION – PERSONAL VOICE AND DATA

Since the 1990s, cellular phones have quickly evolved down the learning curve for size, weight, cost, and part count. Integration of more features, with increased performance, lower cost, and easier implementation has been the driving force for the semiconductor devices used in cellular phones. GaAs, starting with MESFET and migrating to HBT and pHEMT devices, has found a solid home in the RF section as the best technology for maximum battery life.

Phones are becoming more complex. New generations incorporate multi-mode (2.5G and 3G) and multi-band (800MHz through 2.6GHz) functionality. This increased complexity creates a demand multiplier for GaAs technologies. A simple stand alone PA represents \$0.35 - \$0.80 of content in a phone, depending upon the standard. Moving to modules, where RF suppliers design more of the front end functionality into the product, average dollar content goes up to \$0.90 - \$1.50. EDGE phones, with their higher performance demands and more complex modules raises the GaAs content to \$1.50 - \$2.50, while 3G phones incorporating both EDGE capability and one to multiple WCDMA bands more than double the content to \$5.00 - \$6.00.



These high-end smart phones will likely also include Class 1 Bluetooth for extended range and WiFi and/or WiMAX capability for data overlay – adding to the GaAs content. As the baseband and transceiver functions integrate to fewer devices, eventually reaching a single chip, the RF section is expanding in content and cost per end unit. Relative value is increasing in the RF section.

Phone manufacturers are eager for innovation to keep their products shrinking in size and part count. Multiple technologies that don't lend themselves to monolithic integration drive the need for a module solution. On the receive side of the RF section, the LNA and mixer have been integrated into the transceiver. CMOS technology performance has improved sufficiently to meet the performance requirements for these functions. Direct conversion designs have displaced the need for intermediate frequency (IF) filters previously used in super-heterodyne solutions. RF band pass filters are still typically required. These SAW filters are migrating to integrated filter bank modules or are being integrated into a receive module with the transceiver.

The transmit side of the RF section is fertile ground for compound semiconductors. Transmit modules, combining much of the front end content, are displacing discrete solutions and now represent 49% of the overall handset RF demand. A GSM/GPRS/EDGE phone incorporates an extremely fast and very low loss transmit/receive switch to perform the duplexing function. The phone is either in a transmit mode or a receive mode but never both at the same time. This Rx/Tx switch function was traditionally served by PIN (P-type Intrinsic N-type) diodes, but with the growing dominance of quad-band and multi-band phones to cover the licensed frequency spectrums around the globe, the pHEMT switch has emerged as the low loss, low current-drain solution. Integrating this switch function with the decoding intelligence required, the Tx filters and a HBT power amplifier provides a complete transmit solution. TriQuint Semiconductor is a leader in this form factor with a 6mm x 6mm highly integrated solution. See figure 2

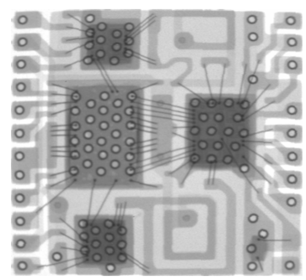


Figure 2 – TriQuint Semiconductor 6mm x 6mm Transmit Module X-ray (TQMxx4002)

For a WEDGE phone, a combination of WCDMA and EDGE, the core EDGE quad-band transmit module requires additional switch capability to include the performance requirements of the UMTS band, as shown in Figure 3.

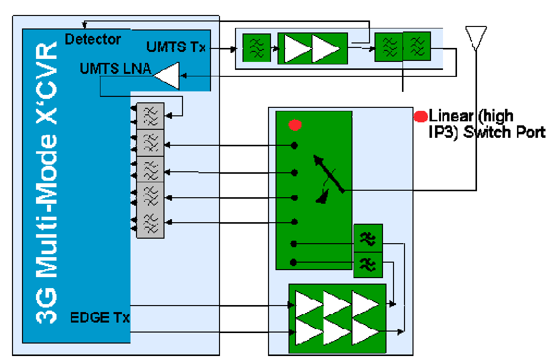


Figure 3 – WEDGE RF Design

The example in Figure 3 incorporates two highly integrated transmit modules. They are a core EDGE module with extended switch capability and a transmit module that combines the active and passive components for the UMTS band transmit chain. Additional bands may be required to ensure operation in multiple regions of the world and could easily be added by increasing the number of switch ports.

WIFI - WIMAX

WiFi has become one of the larger market opportunities for GaAs. Hot spots are available in hotels, coffee shops, and airports. Private enterprise and local municipalities have invested in public access networks. In some cases the networks are fee-based while others are either designed for free public access, supported by advertising, or are ad hoc networks sponsored by advocacy groups.

The WiFi market has developed quickly from single band to dual band solutions. As the market moved from 2.4GHz to dual band 2.4GHz/5GHz, GaAs power amplifiers began displacing silicon or silicon germanium solutions. Just as in the cellular phone industry, the inherent properties of GaAs enabled better performance in RF.

The RF section in WiFi is following the same path as cellular. Early solutions were based on discrete components while contemporary solutions are migrating to modules. WiFi also has an architectural change that will drive increased GaAs content per unit. The standard known as 802.11n or Multiple-Input-Multiple-Output (MIMO) creates the opportunity to double or triple the GaAs content per unit. The concept behind MIMO is to have two or three RF data paths in parallel, working together. The advantages include increased data transfer rates and more reliable configurations of dedicated bandwidth for sensitive applications. For example, MIMO will enable data intensive applications, such as high quality video, to be distributed throughout the home with high resistance to interference or disruption.

WiMAX extends the WiFi experience in range and creates a standard that is more appropriate for commercial use. WiMAX provides a cost effective wide area broadband network that can complement, and in some cases extend, 3G capability for data-intensive transfers. The frequency bands and power levels indicate GaAs, and possibly GaN, will be the right technology choices for WiMAX. In future applications, it is likely the two standards, WiFi and WiMAX, will be operated on the same hardware platform with the chipsets and RF sections optimized to handle both.

BEYOND PERSONAL VOICE AND DATA

Approximately 30% of the GaAs market is attributed to applications other than personal voice and data. The largest of these other markets is optical communications. In optics, compound semiconductors offer unique advantages for lasers, detectors, driver amplifiers and switches. The bandgaps of the range of available materials cover a wide spectrum from infrared to ultraviolet. Energy-efficient solid-state lighting using these compounds is expected to replace incandescent lighting in many applications. The electronics supporting optical devices for high speed fiber communications remains the domain of GaAs due to the frequencies involved.

There is also a considerable market today for point-to-point systems operating in the 6GHz – 40GHz range supporting backhaul for cellular base stations. Expanding the infrastructure for personal communications in areas where optical backhaul is not available, or problematic due to difficult terrain, has created an active market in terrestrial microwave links, an area dominated by high power pHEMT.

The defense industry has long exploited the merits of III-V compounds to meet the demanding mission critical requirements of their applications. The combination of sophisticated communications systems and powerful radar systems creates a market demand for leading edge technology. High power, high efficiency, high linearity, low noise figure, and low phase noise drive state-of-the-art requirements.

Safety and security in the automotive market are creating demand for products based on GaAs technology. Automotive radar systems are being deployed on high-end vehicles today supporting adaptive cruise control and parking assistance. Future systems will enable pre-crash detection and deployment of safely aids. Saving fractions of a second in reaction time will translate into saving lives.

SUPPLY AND DEMAND

Surprising to many in the industry, the supply and demand balance in mid-2006 swung over briefly to supply-constrained after several years of over-capacity. Each of the top-tier suppliers executed strategies to add capacity to their supply chain. The top three suppliers currently control approximately 50% of the worldwide GaAs capacity. Mid-tier suppliers control an additional 30% with the remaining 20% spread across a dozen or so companies that maintain small GaAs fabrication capability for strategic reasons.

Company	Wafer Size	% Total Industry Capacity
RFMD	6	21%
Skyworks	4	14%
TriQuint	6	14%
Freescale	6	7%
Other		44%

The anticipated consolidation of the industry is quietly happening. Since early 2003 we have seen factory shutdowns, restructuring, or combinations among the following companies: Suntek, GEC Marconi, Vitesse, Philips, Celeritek, Sanders, Mitsubishi, Sumitomo, WJ Communications, Filtronics, GCTC, and WIN. The industry is bifurcating into top tier suppliers where participation in the largest market, personal voice and data, will continue to drive growth and technology investment and small niche suppliers. The small niche suppliers serve unique strategic needs, and are typically embedded into larger vertically integrated businesses as captive units.

Mid-tier players are feeling the pressure of either not reaching critical mass or not leveraging technology differentiation. This may create an environment for foundry consolidation supporting a fabless business model. It is more likely, due to the success of standards bodies reducing the ASIC nature of RF products, that mid-tier suppliers will have to choose between consolidation or integration into a vertical business to survive.

TECHNOLOGY DIRECTIONS

The technology drivers for our industry can be separated into two camps, high volume and raw performance. For the high volume market of personal voice and data the key drivers are size, battery life and cost. An increasing number of multimedia features (music, video) are being inserted into the handset. Style and the convenience of small size and weight reduce the area and volume available for these additional features. Handset suppliers enjoyed enthusiastic demand for thin phones introduced over the last two years. The challenge for semiconductor suppliers is to supply highly integrated solutions in smaller and thinner footprints using less of the power budget to allow for the new features. Investments in integrated and/or combinational technologies that allow multiple die to be integrated into a cost effective single die solution will gain momentum. Examples are:

- E/D pHEMT
- BiHEMT
- Integrated passives

Opportunity also exists in packaging innovation. Current solutions rely on diverse technologies being integrated into a package using laminate module manufacturing. Alternate solutions that maintain desirable RF characteristics but reduce size, cost, or manufacturing steps would be welcome by the industry. Flip Chip, as an example, employs a bump interconnect eliminating manufacturing steps and reducing variation associated with wire bonds. See Figure 4.

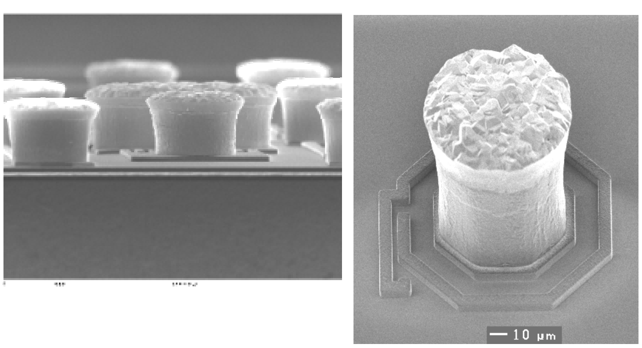


Figure 4 – TriQuint Cu Bump Technology

Additionally, technology innovations or design techniques that improve efficiency and/or lower overall current drain remain key drivers for portable consumer electronics. As phones shrink in size, total energy available in the battery becomes a scarce resource. Polar modulation, variable bias techniques and higher voltage technologies are all solutions being applied or investigated to drive lower current drain.

For markets outside of personal voice and data, the goal remains driving raw performance measured as high power, high efficiency, high linearity, low noise figure, and low phase noise. The defense industry is the traditional performance driver for our industry. There is much attention and investment currently focused on GaN for RF in the defense industry. Already successful in LED applications, GaN offers approximately 5 times more power per square millimeter than GaAs for RF power. Key advantages include:

- High breakdown electric field
- High electron mobility
- High thermal conductivity

The higher breakdown electric field allows for higher voltage operation. This provides for improved matching characteristics resulting in overall lower loss and improved efficiency. Improved thermal conductivity should reduce constraints in the design of high power, heat generating, devices.

GaN has made great strides in the last two years. Materials improvements, process improvements, and a better understanding of the application and reliability of the technology have been achieved. This technology is still very early in its cost learning curve. It will likely remain an R&D effort for the next several years with first production use coming from the defense industry.

CONCLUSIONS

The year 2006 was one of transition for our industry. Supply and demand came into better balance. Healthy consolidation of the supply chain is continuing. In the highest volume application for GaAs, personal voice and data, it appears GaAs has successfully confronted the silicon threat – at least for the foreseeable future.

As 3G and MIMO move from development into production, compound semiconductors will benefit from the demand multiplying impact of multi-mode/multi-band applications.

Continued investment in new technologies, new materials, and new design techniques will bring improved performance to our markets and customers.

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