State of the Compound Semiconductor Industry

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ABSTRACT

Compound Semiconductors are everywhere, behind many of the devices and services that we take for granted in this technology age. No longer are they only exotic devices for complex military systems. Today, they are the unsung heroes of the wireless revolution; handling the complex RF interfaces between lower-frequency silicon operating systems.

In high-volume applications, such as cellular phones, compound semiconductors like GaAs have demonstrated that they are a mature technology, capable of exceptional yields and reliability. Yet other compound semiconductors, such as InP and GaN are still at the early stages of their development, and only just beginning to reveal their potential.

These are exciting times for the compound semiconductor industry. Hundreds of millions of devices are manufactured for consumer applications each year and the range of applications continues to expand. This paper attempts to give a short overview of where we have been and where we are going; the compounds and products that are important today, and those that will be in the future. The focus is on communications and radar.

INTRODUCTION

"Un-tethered" is the new buzzword. Consumers are coming to expect that they can have access to data and communications "anywhere, anytime." As a result modern devices are expected to communicate and that communication must be mobile. A standalone computer is no longer acceptable; it must be connected to the World Wide Web, increasingly by a Wireless Local Area Network (WLAN) card. Wired phones are rapidly being overtaken by cellular phones with the total number of worldwide cellular subscribers exceeding 1 billion. These huge growth markets are enabled by compound semiconductors.

Today, GaAs is the preferred technology for power amplifiers in cell phones and WLAN cards. Together this represents an annual market of well over 500 million devices. Another nascent application for GaAs in this market is for RF switches. As the systems evolve to multi-band, multi-mode appliances - low-loss, multi-pole switches with near-zero standby current will be required. GaAs pHEMT switches are ideally suited for this application.

An important application for compound semiconductors is satellite communication. Direct Broadcast Satellite (DBS) television is making increasing inroads against cable systems and the Ku-band receivers and switches are almost exclusively GaAs.

Military, radar, point-to-point radio and other high-end commercial applications, which fostered the development of compound semiconductors, continue to be an important market. In this market, in addition to GaAs, SiC and GaN are increasingly promising.

New communications standards are creating opportunities for GaAs technology to push back the encroachment of silicon. Whereas Silicon LDMOS is the technology of choice for cellular base station RF power amplification in much of the world, WCDMA brings new operating conditions that open the door to GaAs technologies.

In optics, compound semiconductors offer unique advantages for lasers, detectors and switches. Together the band gaps of the range of available compounds cover the wide spectrum from infrared to ultraviolet. The recent breakthrough in blue/violet LEDs based on GaN is likely to be revolutionary. Within 10 years, energy-efficient solid-state lighting using these compounds is expected to replace incandescent lighting in many applications.

Looking ahead, new high-volume consumer applications for compound semiconductors, such as collision avoidance radar for automobiles are already in development. New materials such as InP with improved characteristics for both optics and high-frequency wireless applications are being commercialized. Thus compound semiconductors are important in our lives today and likely to be even more so in the future.

BRIEF HISTORY - COMPOUND SEMICONDUCTOR MARKET

Although the historic uses of Arsenic date back to early Chinese, Greek, and Egyptian civilizations it wasn't until 1875 that Paul Emile Lecoq de Boisbaudran cataloged the soft bluish white metal Gallium into the history books of elemental discovery.[1] It took until the early 1950s before research began to develop the path to commercialization of compound semiconductors. In the 1960s J.B. Gunn published what is now know as the "Gunn Effect" moving GaAs into the world of high frequency applications and the wheels of innovation were in motion as markets developed for this new technology. Initially, due to the high performance characteristics and relatively high manufacturing and development costs, the market was limited to mission critical governmental applications. Quickly applications developed for both optical and RF communications. GaAs for optical communications made obvious sense because of its combination of bandwidth and low loss characteristics. With the introduction of cellular phone systems in the early 1980s, personal and portable voice communications has become the largest single unit market in the world, generating demand for over 500 million handsets in 2003. We now have a market greater than $2 billion which is growing to over $4 billion by 2006 as forecasted by Strategy Analytics. (Fig 1)

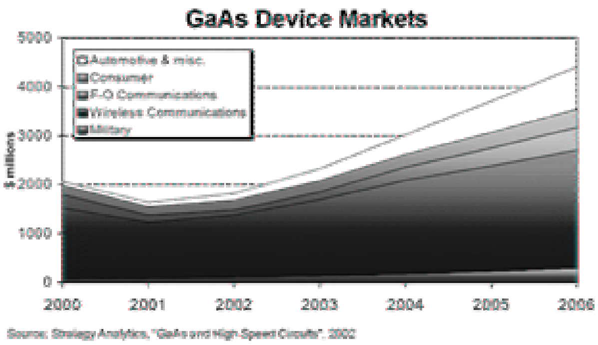

Figure 1 – GaAs Market, Strategy Analytics, 2002

APPLICATIONS - CELL PHONES AND WIRELESS LAN

Cell phones, and their various derivatives, have clearly been the "killer" application for GaAs devices. Although silicon LDMOS and silicon BiPolar technologies still find application in the power amplifier function of some cell phones, GaAs technology – specifically GaAs HBT technology – has become the solution of choice for this application. The benefit of a single power supply and overall better power added efficiency performance proved to be critical to the main drivers of the cell phone manufacturers. Fewer total components, longer battery life, longer talk times and smaller size, weight, and volume were and continue to be the marching orders for cell phone designers. These goals are superceded only by the key drivers for all high volume consumer items, lower cost and more features.

In the 1990s, as the cellular phone market was developing, it was common to see module solutions being provided to the cellular phone designer to handle much of the radio frequency function. At that time phones were referred to as "bricks" and had thousands of devices packed into a not-so-stylish design (obviously born of engineers and not of fashion trend setters). This created a unit that had the weight and feel of a "paver" and the reputation of surviving drops, tosses and fires – "brick" seemed an appropriate name. Phones quickly evolved down the learning curve for size, weight, cost, and part count. Integration played a key role in parts reduction but de-integration in the RF section, as leading manufacturers focused on finding the best technologies to improve talk time, led to component use of MESFET power amplifiers later yielding to HBT technology for the reasons mentioned earlier. As the phones became more complex, incorporating multi-mode (analog and digital functionality as standards developed and changed) and multi-band (i.e. Cellular, PCS and DCS frequencies) the pendulum has swung back to. The drive continues for smaller part count and size and volume reductions to allow for increased functionality in the phones, such as cameras and MP3 players.

Passive integration is also an opportunity for GaAs market expansion. Whereas the large majority of devices in the RF section of older generation phones were surface mount devices associated with matching and biasing, the integration of these devices onto GaAs substrates supports the phone designer's goals while maintaining the required high performance and low cost.

Multi-band GSM phones have also created a market for pHEMT switches. A GSM/GPRS phone is based on a Time Domain Multiple Access (TDMA) protocol. 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 effectively being served by PIN (P-type Intrinsic N-type) diodes but with the growing dominance of Quad-Band phones to cover both the high and low band operation in both Europe and the United States the pHEMT switch has emerged as the low loss, low current-drain solution. As phones become more complex, more feature rich, the power budget remains under pressure and pHEMT switches provide phone designers the necessary margin.

Having multiple technologies that don't lend themselves to monolithic integration is additional fuel for a module solution. Figure 2 highlights the GaAs based technologies in a Quad Band GSM/GPRS phone.

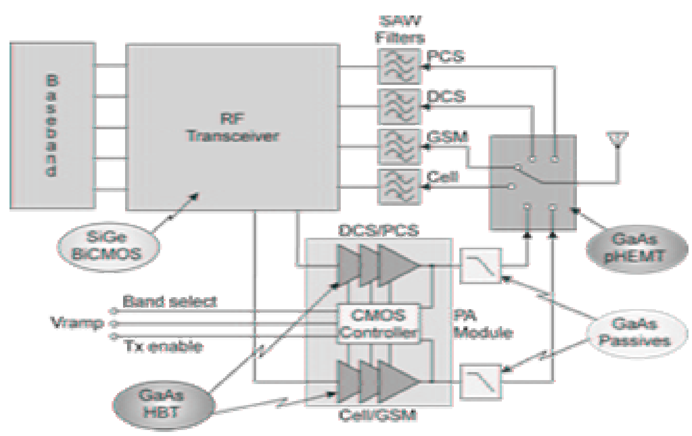

Figure 2 – GSM/GPRS Quad Band Phone

With consumer needs transitioning from voice only to voice and data as well as voice, data and multimedia the long awaited convergence of digital consumer appliances is being realized. As recently as a few years ago, the concept of a digital camera was foreign to many, let alone the idea of a digital camera integrated into a cellular telephone. It is incredible to consider that the number of camera phones sold in 2004 will likely surpass the number of digital cameras sold. This popular feature has significantly increased the multimedia content of the worldwide network. The concurrent development of more powerful handheld devices with higher density and more viewable color screens has turned up the heat on mobile bandwidth demand. Although next generation Metro Area Networks, often referred to as 2.5G and 3G cellular, offer improvements, the currently available WLAN solutions in the form of 802.11b, 802.11g, 802.11a and combinations thereof known as WiFi have been the "hot" applications of 2003 and promise significant growth in 2004 and beyond. For today's consumer, "dial-up" download speeds just don't measure up to expectations. The market wants broadband access and they want it wherever and whenever they need it. This demand for increased performance and mobility (i.e. lower power drain) is once again the impetus for increased GaAs demand. The same drivers that have made GaAs HBT the technology of choice for cellular RF power amps are working in WiFi applications. Although silicon had an early presence in this market, the increased data density of the "g" standard and the increased frequency of the "a" standard push the value equation for WiFi power clearly into the GaAs marketplace.

APPLICATIONS – POINT TO POINT RADIO

LMDS and MMDS were once considered the up and coming wireless systems. Local Multipoint Distribution Service (LMDS) is located in the 28 GHz and 31 GHz bands and is a broadband radio-service designed to provide two-way transmission of voice, high-speed data and video. Multipoint Microwave Distribution System (MMDS) is a similar system at lower frequency with greater range. These systems were originally conceived to solve the "last mile" issue of broadband access to the home. DSL and cable have proven to be more popular at this time. However, with the advent of Wi-Max 802.16, a new standard that may be appropriate for the last mile, interest may rise again. This is especially true for developing countries where cable and telephone infrastructure is limited. There is also considerable market today for point to point systems that operate in the 14GHz – 30GHz range, largely to support backhaul communications for cellular base stations.

APPLICATIONS – SATELLITE

Space based systems have long been the domain of GaAs technologies. GaAs has a higher tolerance against interference and failure from the radiation found in space (it is "radiation hard"). For this reason many of the satellite on board functions are designed with GaAs MMIC devices. Phased array communications antennas that can be electronically steered or focused are a technology enabled by GaAs MMICs. Satellites are often powered through the use of solar cells. GaAs solar cells achieve 25% conversion efficiency. It is estimated that between 50-70% of all commercial satellites now under construction will use III-V solar cells. There is wide application demand for space based systems. Global position systems, imaging, weather monitoring, resource mapping, telecommunications, direct broadcast television, direct broadcast radio, navigation and internet in the sky are some of the commercial applications. Although the excitement for commercial space-based systems peaked in the 1990s and the ambitious plans of that time have experienced the same "bubble bursting" that reset the internet economy, this market is not lost in space. Direct broadcast television continues to grow. Two way space based systems, which allow internet access anywhere you can see the sky, are in use today with improved versions built and ready to launch. Satellite broadcast radio has now made its debut. As the systems become more sophisticated, as data density increases and as applications become two-way, the market demand for compound semiconductor solutions in space based systems increases.

APPLICATIONS – MILITARY

The defense industry has long exploited the merits of III-V compounds to meet the demanding mission critical requirements their applications are built on. 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. The preferred technology in the military industry for power is pHEMT due to concerns over HBT reliability. These are concerns that may be unfounded with today's HBT technology implementations. There are two growing trends in the defense industry that will have a direct impact on the world of GaAs suppliers. First, the implementation of phased array radar on virtually all ships, planes, and vehicles in the US service. Radar is widely deployed today on virtually all ships and planes but there is a sea change underway. Sophisticated US fighter aircraft would not be nearly as lethal without the agility, speed, power and multi-target capability of advanced phased array radar systems. Phased array systems, because of the value and benefits provided, will expand to fill all radar applications in the military. In addition, future systems will be deployed for implementation on small ground force vehicles providing detection of incoming threats and the ability to intercept and destroy those threats. Real-time communications, while on the move via airborne or space based infrastructure, has been lacking in military operations. Systems are being developed to make this connection. These are future markets that will be dominated by compound semiconductors.

APPLICATIONS – AUTOMOTIVE

Safety and security in the automotive market will also create demand for products based on GaAs technology. Automotive radar systems are being tested and installed on high-end vehicles today in the following application areas:

- Urban collision avoidance
- Collision warning
- Pre-crash detection
- Parking aid
- Pedestrian avoidance
- Advanced cruise control

Existing 24 GHz systems provide limited resolution and angular range. New 77 GHz systems are being developed and implemented based on GaAs technologies. The ability to provide a "constant distance" cruise control system or to develop an air bag system that deploys based on more sophisticated decision trees resulting is a safer deployment are the opportunities created by implementing automotive radar systems. The automotive electronics industry has long been driven by governmental regulation around environmental, safety, and security issues. Automotive radar systems will be one of the next big markets for compound semiconductors.

WHY NOT SILICON – WHY TOLERATE GAAS PAINS

To work in the compound semiconductor industry is to work in the shadow of the much larger silicon industry – always looking over your shoulder wondering what areas are safe from the ever encroaching freight train of smaller geometries yielding increasing performance. This certainly happened in the early 1990s as evidenced by Cray computer in their failed attempt to create a GaAs based super computer. It also happened in the high performance area of optical communications PHY layer devices.

Some clear factors in favor of Compound Semiconductors are: direct bandgap, higher electron mobility and electron velocity, and low noise. These are the traditional advantages of compound semiconductors that make them the technology of choice for light emitting and communications applications. Two other features more recently apparent are:

- Volume
- Can't shrink power

Volume – The compound semiconductor industry is young. Nonetheless, thanks to the cellular phone application, there is now sufficient volume to realize economies of scale. No longer is GaAs manufacturing an engineering adventure. The tools, techniques and practices of high volume manufacturing have been applied by those suppliers that have survived and grown to critical mass. Significant yield and manufacturing improvements have been made over the last 4 years. The continuous reduction of critical dimensions in silicon has become increasingly complex and costly. GaAs improvements and greater silicon complexity, working in opposite directions, have help to close the "cost per function" gap considerably.

Can't shrink power – as geometries shrink in silicon, breakdown voltages decrease. In the world of RF systems, there are critical requirements for ruggedness in a mismatched environment. This can drive breakdown voltage requirements in excess of 20 volts. Silicon has its place in high transistor density low voltage digital applications that require less than 100 GHz performance and low power and low data density short range communications. On the other hand, for communications where you need greater than 20 dBm power out or operation at greater than 100 GHz or if radiation hardness and low noise figure are critical – you need GaAs.

RUNNING OUT OF GAAS – EVER?

The last cycle in semiconductors, driven by unbelievable expectations for communications products, has left the world with more than twice the amount of compound semiconductor supply than demand. This has not been a healthy artifact. Fighting for share, suppliers have lowered prices to prevent losing their customers to one of many competitors. There has been consolidation in the market place and this consolidation will continue. Growth is coming back to our industry but without a diversity of products and markets as well as critical mass the ability to survive is questionable. As we look to the future, critical mass does matter and it is the innovators that will prosper.

CONCLUSIONS

The year 2003 was a recovery year for many of our markets. Demand for wireless handsets is up and the outlook for continued demand, driven by camera phones, color screens and growing demand in India, China and Eastern Europe is strong. Capital spending for infrastructure is once again on the rise. Demand for optical communications products, the poster child for the post internet bubble crash, has begun to stabilize. The silicon world and the compound semiconductor world have come to understand their respective places and the demand for new applications is driving growth for both technologies.

To communicate over large distances, to help sense danger whether in a family car or a high performance aircraft, to bring rich multimedia into our homes or wherever we travel, to help power the world, to bring new light to dark places – these are the opportunities we face. Our challenge remains straightforward – Make it so.

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REFERENCE:

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