Business Opportunities for GaN Devices

Fred A. Blum
Nitres, Inc.
5655 Lindero Canyon Rd., Suite 404
Westlake Village, CA 91362

INTRODUCTION

GaAs-based electronic and optical devices came forward with great technology fanfare and promise between 1975 and 1985. However, because of the immaturity of the technology and limited market applications, profitable growing commercial business took another 10 to 15 years to develop for many of the GaAs device types. The past five years have brought an explosion in technology development for GaN and its ternary alloys InGaN and AlGaN for electronic and optoelectronic devices. To date, the drive to market has been led by LED and laser products, but other devices such as HEMTs, UV photodetectors, and HBTs are coming up in performance. Also, LEDs and lasers have just begun to tap the large potential markets for these products. Will the story be the same? Will it take another 10 to 15 years to develop true profitable GaN-based business? The answer is "It depends". It depends on which devices and markets you wish to consider. While all the compound semiconductor markets are larger and more mature, one must consider each device type separately.

GaN-based HEMTs, HBTs, and MMICs face the daunting task of outperforming their GaAs and InP/GaAs-based cousins, not to mention SiC-based devices. The story is different for GaN-based optoelectronic devices such as LEDs and lasers. Operating in the UV to green portion of the optical spectrum with astonishing performance, they are creating new applications and improving old ones. There are no viable alternatives for solid state light at these wavelengths.

We will review the various applications for GaN-based electronic and optoelectronic devices, and highlight the most likely winners. The technological and manufacturing challenges which face the GaN community will be discussed. The links between technical performance, manufacturing cost and market sizes will be covered. The most promising business opportunities for electronic and optoelectronic devices will be identified. Drivers for manufacturing scale up for volume and low cost will be discussed.

MICROWAVE POWER DEVICES

With the development of wireless communications, the need for high-power solid-state amplifiers is rapidly increasing. Wide bandgap semiconductors promise the potential of ultra-high power, high efficiency, and high linearity. The GaN based family of semiconductors is attractive due to the technological advantages over competing wide-gap semiconductors (e.g. SiC and diamond). GaN possesses attractive electronic material properties such as high breakdown field, modulation doped AlGaN/GaN structures with high electron mobility, and extremely high electron velocities. Of the possible device structures, AlGaN/GaN high-mobility-transistors (HEMTs) are attractive as the 2-dimentional-electron-gas provides both high mobility and high carrier density. Early devices developed at Nitres using sapphire substrates have high power densities of 3 to 5 W/mm at 6-18 GHz. Recently, the use of semi-insulating SiC substrates has facilitated heat dissipation of the

GaN-channel devices and increased the power performance of Nitres' devices to near 10 W/mm .

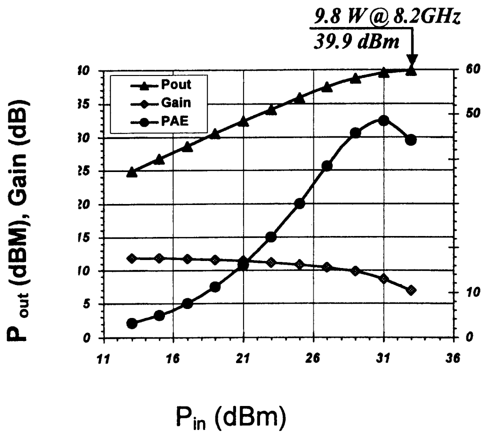

Figure 1. Power performance of Nitres 2-mm-wide AlGaN/GaN HEMTs

This phenomenal power density is over 10 times that of GaAs-based HEMTs, but is achieved to

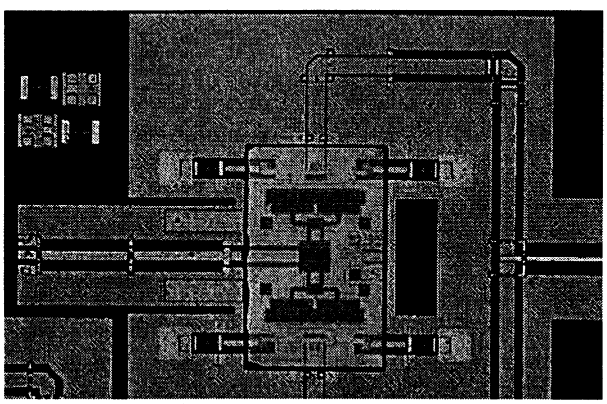

Figure 2. Nitres 14 W GaN HEMT 6 – 10 GHz Amplifier

date only in small devices. When biased at class-AB and tuned for efficiency, an excellent PAE and power density combination of 60% and 6.5 W/mm was also achieved. This outstanding performance confirms the promise of AlGaN/GaN HEMTs as superior microwave power devices.

Larger devices with output powers of 10–14 W are shown in **Figures 1 and 2.** The 14 W output power level is the highest for GaN-based amplifier to date, and is a factor of 4 – 7 higher than the GaAs-HEMT-based amplifiers using the same size of output devices. Although both the gain and efficiency need to be improved, this encouraging initial result shows great promise of the GaN HEMTs for power amplification at microwave frequencies.

GaN based Pnp Heterojunction Bipolar Transistors (HBTs) transistor technology for highly linear and efficient broadband microwave power amplifier applications. HBT technology offers single supply operation (normally off), improved 1/f noise performance and high linearity. Transferred substrate HBTs would combine the advantages of a low parasitic-high performance HBT technology with the high power operation realizable from GaN based materials. With improved ohmic contacts and scaled technology, simulations predict that Pnp HBTs with cutoff frequencies f_τ and f_{max} in excess of 40 GHz and 250 GHz can be achieved. This would make it possible to develop high power, broadband, linear and efficient amplifier modules.

Many challenges remain to make this a production worthy and cost effective microwave power technology. Possible market applications include cellular base stations, satcom gateways, communication satellites and V-Sat terminals. The technological and market challenges will be discussed in the conference presentation.

LIGHT EMITTING DIODES

High brightness GaN-based LEDs are not "just another LED technology". For sure, the very bright blue and green LEDs are and will be used in a wide variety of traditional LED applications like indicators and signs. But the magic of this technology lies in its short wavelength and high efficiency. In the UV and blue wavelengths, GaN-based light emitters can be used to excite phosphors and polymers to downconvert to the visible. Then through color mixing white light is produced. This is the time honored technical feat of the common fluorescent lamp! Thus opens the new field of *solid state illumination and lighting.*

Heterostructure light emitters using InGaN are capable of very efficient light emission through much of the visible spectrum and into the ultraviolet. Output powers range from 1 – 12 mW at 20 mA drive current over the 400 - 600 nm band. Lifetimes are 50,000 – 100,000 hours. Multicolor InGaN light emitters are illustrated in **Figure 3** showing emission at blue, aqua, and green wavelengths. White lamps are made by color mixing with fluorescent down-converted light. Applications for these products range from green traffic signal lamp replacement with 85% to 90% electricity cost savings to automotive and aircraft interior lighting with long lived white lamps.

Wavelength	Color	Example Application
470 nm	Blue	Color outdoor displays
505 nm	Blue-Green	Traffic signals
525 nm	Green	Color outdoor displays
N/A	White	Automotive & aircraft lighting

Lighting and LED companies are teaming to develop solid state lamps. Nitres has an R&D joint venture with **GE Lighting** funded in part by the U.S. Commerce Department's NIST organization to develop high efficiency white solid state lamps.

The solid state lighting and illumination market is particularly exciting. The total market for all light emitter sources (traditional light bulbs plus semiconductors) is about $17 billion/yr. This is about double the market totals for *all compound semiconductor devices* (electronic and optoelectronic). GaN-based emitters promise to bring fluorescent-like efficiencies, with semiconductor-like weight and size reductions *and continuous operating left up to 10 years!* This could be the biggest compound semiconductor market yet, with worldwide energy and cost savings.

Figure 3. Nitres GaN-based light emitters

The case for high brightness GaN-based light emitter business growth will be discussed at the conference. Multi-billion dollar markets are possible with large scale manufacturing of low cost chips. Nitres' vision for solid state lighting will be discussed in the conference presentation.

LASERS

Blue GaN-based laser diodes are attractive for use in optical storage in order to increase the storage capacity. The minimum diffraction limited spot size that light can be focused to is directly proportional to its wavelength. The storage capacity is quadratically proportional to the spot size. Therefore, a reduction in wavelength from 760 nm to 400 nm yields approximately a four-fold increase in storage capacity. Currently, by using lateral epitaxial overgrowth, blue lasers have reached 10,000 hours of reliable CW operation. Typical current densities in the 2kA/cm2 range and threshold voltages as low as 4.5 V have been demonstrated by **Nichia** in Japan. These lasers are now being tested in new higher density DVD drives which can store up to 12.4 GB per disc. In addition to optical storage, several other exciting opportunities are emerging for blue lasers in laser-based projection displays, lighting, laser printers, and fluorescence for biochemical reagents sensing. CW GaN-based lasers are very difficult to make and many challenges remain. However, as the laser powers increase and costs decrease these new markets and applications will begin to emerge. Markets in the billion dollar range are also possible for GaN-based lasers.

ULTRAVIOLET PHOTODETECTORS

Potential applications of GaN-based UV detectors include chemical and environmental optical sensors, long-range differential absorption UV-LIDAR systems, UV sensing for early warning and flash detection in military armor protection systems, and UV-focal plane arrays. Advantages are given below.

- Flexible spectral response between ~235 and 365 nm
- ***True solar-blind operation*** (sensitivity below 300 nm with strong rejection of visible light)
- Lighter, more compact, robust, and cost effective compared to photomultiplier tubes
- Direct bandgap for high quantum efficiency and fast detector response

Nitres developed a novel AlGaN photodiode technology which has resulted in the successful fabrication of *true solar-blind* (<300nm) AlGaN-based photodiodes. The spectral responsivity of the solar blind photodiode structure (see figure) displays peak responsivity at < 300 nm, 37 % quantum efficiency and a ~10,000X cut-off by 350 nm. Nitres has also fabricated wavelength selective detectors having a sharply peaked spectral responsivity centered at 357 nm, with a narrow (14 nm) spectral response with visible cut-offs of 1000X by 400 nm and 10,000X by 450 nm.

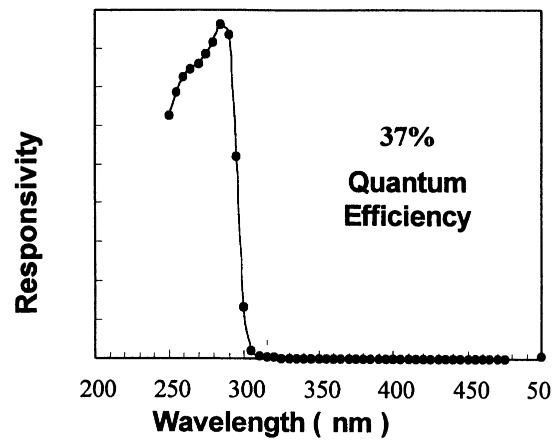

Figure 4. Responsivity of a Nitres solar blind UV photodetector

CONCLUSION

The promise of GaN-based technology is substantial with total markets in the billions. The conference presentation will outline the markets and the challenges. The Nitres technical results cited above were sponsored in part by BMDO, DARPA, NIST, and ONR.