3A. ABSTRACT OF RESEARCH PROPOSAL

We propose to develop integrated circuits fabricated in wide-bandgap semiconductor technology for unconventional fields, including monolithic switchmode power conversion and precision diathermy. This project is very timely.[1]–[3] Foundry access to Field-Effect Transistors (FETs) made in the Gallium-Nitride (GaN) system in Monolithic Microwave Integrated Circuits (MMICs) will first become commercially available circa 2008, and is already available to contributing researchers. Only discrete FETs have been available previously.

Large R&D concerns (University of California, Rockwell Science, Triquint, etc.) concentrate on applications of GaN in mobile communications and radar, to the exclusion of niche markets, and to the exclusion of markets with no existing semiconductor penetration.[4, 5] In other words, every wide-bandgap company sees wide-bandgap as an upward step in applications currently lucratively served by an existing Silicon or III-V technology.[6, 7] In contrast, we see wide-bandgap as a technology that can take transistors where they have never been before—namely miniaturised high-voltage applications (e.g., monolithic switchmode power conversion), harsh RF environments (e.g., localised microwave diathermy in tissue), and extremely wide dynamic range circuits (e.g., ultralinear amplification, low phase-noise oscillators, vacuum-tube replacement). Entry into such novel fields will demand ab initio circuit design. We will prove or disprove the feasibility and identify benefits of bringing GaN devices to these fields. We believe this is being overlooked world-wide, because it is too risky and too novel to attract commercial funding.

Both investigators have 30+ years of experience in electronic design and both have recent MMIC and GaN involvement. We have the skills and capability to design MMICs and guide postgraduate students and emerging researchers to expand GaN's sphere of application.

Wide-bandgap semiconductor active devices in the Gallium-Nitride material system have three acknowledged advantages over Silicon and III-V technologies: (1) They have 10 times higher power-bandwidth than even Indium-Phosphide; (2) they have intrinsic high-voltage capability; and (3) they can operate at higher temperatures and in harsh environments.

Our vision for GaN-based switchmode systems is to integrate the entire converter in an IC using GaN to implement resonant converters at GHz frequencies.[16, 17] The last 20 years has seen SwitchMode Power Supplies (SMPS) shrink in cost and size as operating frequency increased. However, there has never been a demonstration of *wholly monolithic SMPS*, since silicon and GaAs MMICs are not up to the task. MicroGaN, a foundry spinoff at the University of Ulm in Germany, have a process with $F_t > 30$GHz and a breakdown voltage of 70V, sufficient for converters operating between 42V and 12V. This range, for example, will be in great demand once domestic automobiles convert to the new standard of 42V.

The vision for GaN-based diathermy tools is to replace the current "microwave antenna on a length of thin coax" [19, 20] with a monolothic dc-microwave oscillator based on a GaN MMIC. The power will be supplied to the probe tip at dc, giving low loss, low cost, and fine mechanical form. Freed from the need to deliver power through coax, the RF energy can be delivered at tens of GHz, giving highly localised heat.

The vision for linear amplifiers and low phase-noise oscillators rests on the expectation that the high-voltage capability of GaN will give it a wider dynamic range than any previous solid-state technology.[10, 13, 8] We will prove or disprove our expectation by design and comparison of circuits for *low-power* application, including vacuum-tube replacement, [12] and low phase-noise oscillators employing high-voltage dielectric resonators [21].

Our plan is the traditional "fabless design" model, namely to fit CAD models to transistors and passives from potential foundries, design circuits, have them fabricated, test and analyse the returned chips, and publish our results. We will be able to test all of our novel ideas in parallel, since multiple independent circuits may be fabricated in each run, using a "pizza" mask.

References

[1] *Compound Semiconductor*, vol. 12, no. 6, July 2006.
[Special issue on GaN Electronics and the wide-bandgap sector.]

[2] Report on Australian Startup "BluGlass", *Compound Semiconductor*, vol. 12, no. 10, November 2006, pp12–13.

[3] "UK Defence Chiefs Feel the Need for GaN", *Compound Semiconductor*, vol. 12, no. 10, November 2006, p5.

[4] R. J. Trew, "Wide bandgap transistor amplifiers for improved performance microwave power and radar applications", *15th International Conference on Microwaves, Radar and Wireless Communications*, MIKON-2004, Volume 1, 17–19 May 2004, pp18–23.

[5] T. Kikkawa, "Recent progress and future prospects of GaN HEMTs for base-station applications", *IEEE Compound Semiconductor Integrated Circuit Symposium*, 24–27 October 2004, pp17–20.

[6] R.T. Kemerley, H.B. Wallace and M.N. Yoder, "Impact of wide bandgap microwave devices on DoD systems", *Proceedings of the IEEE* Volume 90, no. 6, June 2002 pp1059–1064.

[7] U. K. Mishra, P. Parikh, and Yi-Feng Wu, "AlGaN/GaN HEMTs-an overview of device operation and applications", *Proceedings of the IEEE* Volume 90, no. 6, June 2002 pp1022–1031. [This issue concentrated on wide-bandgap technology.]

[8] U. K. Mishra, "Gallium nitride electronics: Watt is the limit? [summary of GaN semiconductor devices]", *Digest of the* 62^{nd} *Device Research Conference*, 21–23 June, 2004, Vol 1, pp3–5.

[9] G. Crupi, D. Xiao, D.M.M.-P. Schreurs, E. Limiti, A. Caddemi, W. De Raedt, and M. Germain, "Accurate Multibias Equivalent-Circuit Extraction for GaN HEMTs", *IEEE Transactions on Microwave Theory and Techniques*, Volume 54, no. 10, Oct 2006, pp3616–3622.

[10] Sungjae Lee, K. J. Webb, V. Tilak, and L. F. Eastman, "Intrinsic noise equivalent-circuit parameters for AlGaN/GaN HEMTs", *IEEE Transactions on Microwave Theory and Techniques*, Volume 51, no. 5, May 2003, pp1567–1577.

[11] Sungjae Lee and K. J. Webb, "The influence of transistor nonlinearities on noise properties", *IEEE Transactions on Microwave Theory and Techniques*, Volume 53, no. 4, April 2005, pp1314–1321.

[12] Sony C800GPAC Studio Tube Condenser Microphone Product information, `http://bssc.sel.sony.com/BroadcastandBusiness/DisplayModel?id=24120`

[13] C. Fazi and P. G. Neudeck, "Wide dynamic range RF mixers using wide-bandgap semiconductors", *IEEE MTT-S International Microwave Symposium Digest*, Colorado, 8–13 June 1997, vol. 1, pp49–51.

[14] R. J. Trew, "SiC and GaN transistors - is there one winner for microwave power applications?", *Proceedings of the IEEE* Volume 90, no. 6, June 2002, pp1032–1047.

[15] S.C. Binari, P.B. Klein, and T.E. Kazior, "Trapping effects in wide-bandgap microwave FETs", *2002 IEEE MTT-S International Microwave Symposium Digest*, Vol. 3, 2–7 June 2002, pp1823–1826.

[16] M.K. Kazimierczuk, and J. Jozwik, "DC/DC converter with class E zero-voltage-switching inverter andclass E zero-current-switching rectifier", *IEEE Transactions on Circuits and Systems*, Volume 36, no. 11, Nov 1989, pp1485–1488.

[17] Hiroyuki Hase, Hiroo Sekiya, Jianming Lu, and Takashi Yahagi, "Resonant DC–DC Converter with Class-E Oscillator", *IEEE Transactions on Circuits and Systems—I: Regular Papers*, vol. 53, no. 9, September 2006, pp2025–2035.

[18] R.D. Nevels, G.D. Arndt, G.W. Raffoul, J.R. Carl, and A. Pacifico, "Microwave catheter design", *IEEE Transactions on Biomedical Engineering*, Volume 45, no. 7, July 1998, pp885–890.

[19] I. Longo, G.B. Gentili, M. Cerretelli, and N. Tosoratti, "A coaxial antenna with miniaturized choke for minimally invasive interstitial heating", *IEEE Transactions on Biomedical Engineering*, Volume 50, no. 1, Jan 2003, pp82–88.

[20] Heng-Mao Chiu, A.S. Mohan, A.R. Weily, D.J.R. Guy, and D.L. Ross, "Analysis of a novel expanded tip wire (ETW) antenna for microwave ablation of cardiac arrhythmias", *IEEE Transactions on Biomedical Engineering*, Volume 50, no. 7, July 2003, pp890–899.

[21] Wang Li-li, Ke Xi-zheng, and Xi Xiao-li, "Technique allows simple design of microwave DROs", *IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications*, Volume 2, 8–12 Aug 2005, pp944–948.