TRANSISTOR-BASED MINIATURE MICROWAVE HEATER

Eli Schwartz, Abby Anaton, Dan Huppert, and Eli Jerby

Faculty of Engineering, Tel Aviv University, Ramat Aviv 69978, Israel

This paper describes a solid-state amplifier implementation in a small-scale microwave heating. The miniature heater employs an LDMOS-transistor amplifier in an oscillator scheme, in which the heating applicator is incorporated in the positive feedback loop. The paper presents the conceptual design and the experimental results of a 20-W transistor-based microwave heater for biological tests at 2.14 GHz. The applicator contains a test tube of <1-cm^3 *volume filled with proteins heated to temperatures up to 40°C (controlled by the transistor's DC bias). This heater is used in a study of the effect of microwave radiation on the time resolved luminescence of green fluorescence protein (GFP). The paper discusses also the availability of high-power microwave transistors and their applicability for future transistor-based microwave heaters.*

INTRODUCTION

Most of the microwave heating systems, widely used in industrial, domestic, and research applications, employ conventional magnetrons as their microwave source. The low-cost magnetrons are known for their high efficiency and reliability, but their high-voltage operation and poor spectral properties might be considered as drawbacks in some delicate heating applications. Furthermore, these applications may require much less power than provided by the domestic microwave oven, as for instance the controlled heating of small biological samples needed in this study. The use of solid-state (rather than vacuum) electronics for microwave heating was proposed already in the early 70's by McAvoy (1971), and studied by Mackay et al. (1979), Voss (1986), and others. The main obstacles had been the relatively higher cost and lower efficiency of solid-state generators as compared to magnetrons. Lately, new high-power transistors have been developed for cellular communication applications [e.g. Bindra et al. (2006), Schwierz and Liou (2003), Trew (2002), Weitzel (2002)]. In particular, the low-cost base-station transmitters employ >10-W solid-state amplifiers with laterally-diffused MOS (LDMOS) transistors. Currently, commercial solid-state microwave generators are offered by several companies, for low-power heating applications.

Further advancements in the development of wide band-gap devices, like gallium-nitride (GaN) and silicon-carbide (SiC) transistors [Trew (2002)] increase the feasibility of solid-state microwave generators of >100-W effective power for heating purposes in the near future.

The wider band-gap allows a higher operating voltage due to the higher breakdown threshold. These devices have larger area for given impedance, hence allowing larger RF currents and higher power. According to Weitzel (2002), the Silicon LDMOS technology achieved an output power of 180W with 46 % power-added efficiency (PAE), the GaAs FET's produced almost 300W with 50% PAE, SiC MESFET's yielded output power of 80W with 38% PAE at 3.1GHz, and GaN HFET's demonstrated 108 W at 2GHz. These technologies are aimed toward a 300-W base-station transmitter in the frequency range of 1,700-2,200 MHz, and a 1$/Watt cost. Yet, solid-state generators will remain more sensitive to impedance mismatch and less efficient than magnetrons.

Our interest in solid-state generators integrated in compact microwave applicators stems from two types of applications. One is for controlled heating of a single test-tube for biological and chemical tests as presented here, and the other is the integrated microwave-drill for delicate operations [Jerby et al. (2002)]. Both schemes require a miniature solid-state generator embedded in the microwave applicator, either in a cavity or in an open-end applicator [Jerby et al. (2002), Copty et al. (2004)]. In this paper we present an integrated solid-state microwave applicator based on an LDMOS transistor, and its implementation for biological tests.

METHODS

Microwave amplifiers can be used to feed heating applicators in two basic schemes shown in Fig. 1. In the first scheme, a low-power oscillator is amplified to provide the microwave output power. The other scheme incorporates the applicator in a feedback loop hence the amplifier oscillates when the positive-feedback conditions are satisfied. The latter scheme is simpler and

---

Key words: miniature microwave heater, LDMOS transistor amplifier, microwave drill

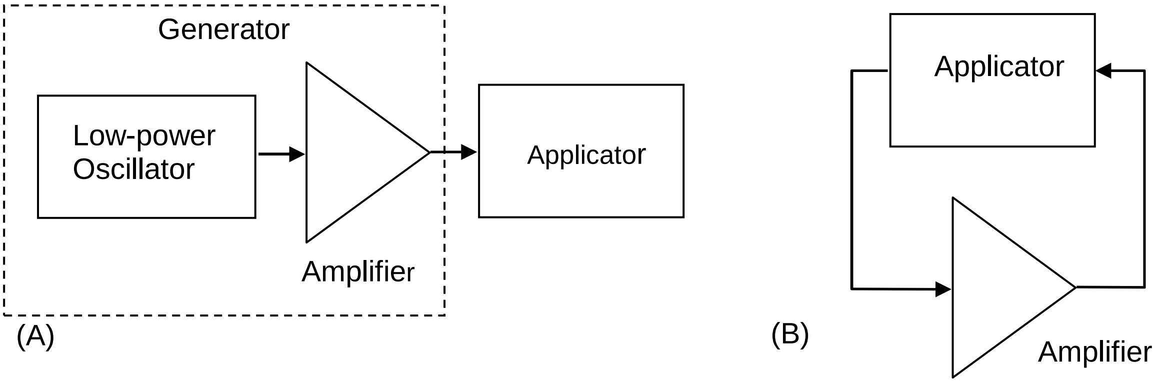

Figure 1: *Two optional schemes of microwave applicators fed by amplifiers; (A) an external oscillator scheme, and (B) an integrated positive-feedback oscillator scheme.*

more appropriate for a compact design of an integrated solid-state microwave applicator. Varying the feedback conditions or the transistor's DC bias provides means to control the frequency and power, and even for an adaptive impedance matching. The two-port applicator in thisscheme could be either a closed cavity, like a miniature furnace, or an open-end applicator, like the microwave drill or any other near-field applicator [Copty et al. (2004)] (with an additional sampling port for the feedback).

The experimental microwave-heater scheme developed for a test tube is shown schematically in Fig. 2. It consists of an amplifier based on an LDMOS transistor (Freescale MRF21125) and a tunable resonator. The latter was designed to resonate at 2.14 GHz and to provide a positive feedback to the amplifier at this frequency. The adjustable mirrors enable the fine tuning of the resonance conditions. The resonator contains a sapphire test-tube filled with a fluidal solution enriched with green fluorescence protein (GFP) in order to detect the effect the effect of microwave radiation on its time-resolved emission.

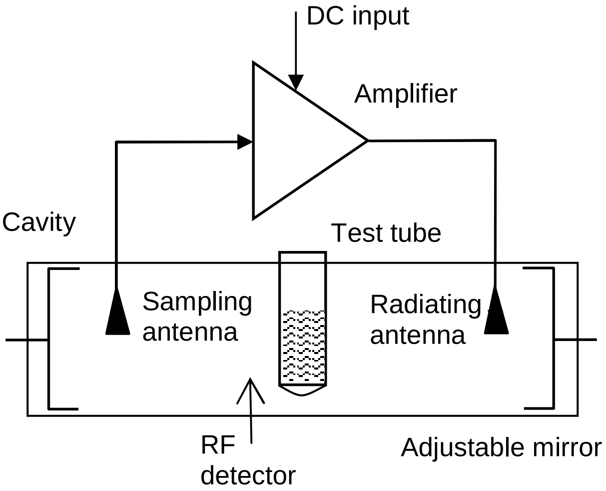

Figure 2: *The experimental test-tube microwave heater.*

The temperature required for the biological tests was controlled below 40°C inside the sample. Holes in the cavity enabled a line of sight for the laser excitation of the proteins' fluorescent emission and its optical measurements.

The frequency tuning (in a 70-MHz range) and temperature control are achieved by varying the amplifier DC bias and the feedback-loop conditions (by adjusting the mirror positions). The temperature is measured by a shielded thermocouple or by a pyroelectric sensor. An RF detector provides a reading of the power inside the cavity, and a spectrum analyzer (Rohde&Schwarz FSH6) is used to measure its spectral content.

Following Copty et al. [2005], the effect of the microwave radiation on the green fluorescence protein (GFP) was detected by a time resolved emission technique, using the time-correlated single-photon counting (TCSPC) of the fluorescence decay. For excitation, we used a cavity dumped Ti:sapphire femtosecond laser (Mira, Coherent) which provides short pulses of 80 fs at the second harmonic frequency, over the spectral range of 380–400 nm with the relatively low repetition rate of 500 kHz. The TCSPC detection system is based on a Hamamatsu 3809U, photomultiplier and Edinburgh Instruments TCC 900 computer module for TCSPC. The overall instrumental response was about 35 ps (FWHM). Measurements were taken at 10 nm spectral width. The excitation pulse energy was reduced by neutral density filters to about 10 pJ. Measurements were taken at 10 nm spectral width. We have also used in this study several mutants of GFP which enable us to amplify the effect of microwave radiation on the time resolved emission.

EXPERIMENTAL RESULTS

The measured power spectrum of the solid-state microwave heater is shown in Fig. 3. The center frequency is stable in a 0.3-MHz line width, and is tunable in the

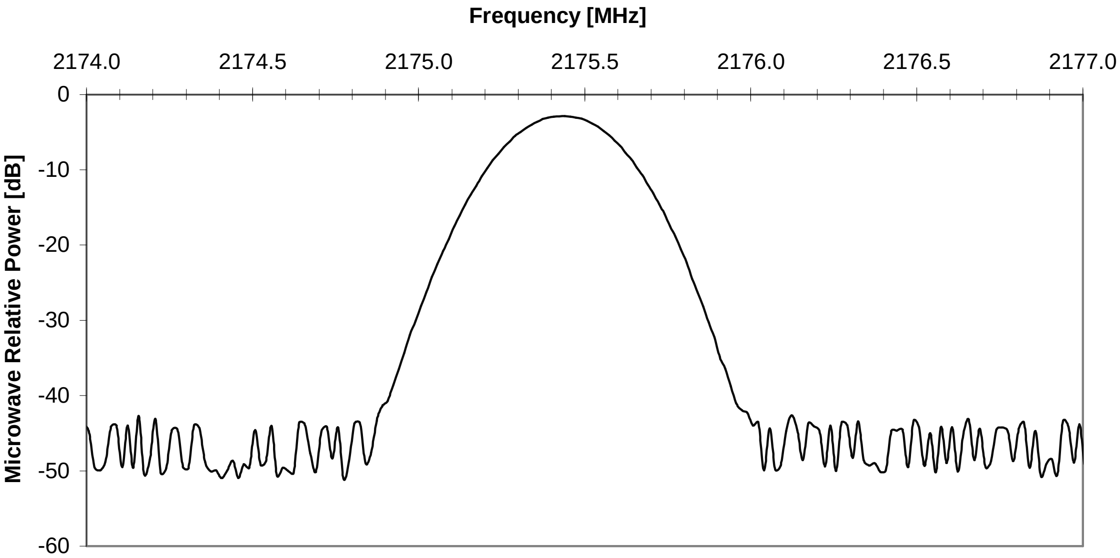

Figure 3: *Radiated power from the microwave applicator*

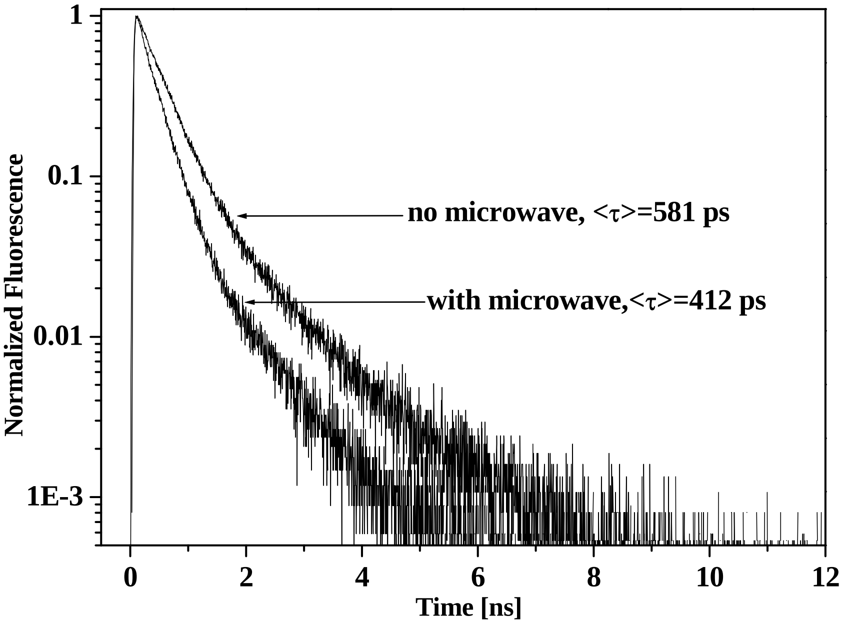

Figure 4. Time resolved emission of a GFP mutant, excited at 400 nm and measured at 450 nm, with and without microwave heating.

range 2,110–2,180 MHz. The thermocouple temperature measurements (immediately after the microwave power turn off) indicated a maximum heating over 70°C. The device is calibrated to a 40°C limit, to avoid the proteins damage. The amplifier operates at a 7.3V DC bias level, and exceeds a 20% total efficiency at 2,175 MHz in this configuration.

The microwave radiation is absorbed both by the liquid bulk water and by the few water molecules within the protein barrel structure. The water molecules next to the chromophore positioned at the barrel center might heat the chromophore more effectively than the bulk water. Both the proton transfer and radiationless processes depends on the temperature of the chromophore. Figure 4 shows the time resolved emission measured at 455 nm of GFP mutant [Heim et al (1995)] with microwave radiation and without. As seen in the figure the rate with microwave radiation is much faster than in the absence of the microwave radiation. The temperature of the sample at the beginning of the experiment was 22°C and at the end of the measurement it was about 30°C (the measurements take between 5-10 minutes).

DISCUSSION

In view of the advancements in cellular technologies, miniature solid-state microwave heaters seem feasible in the near future in power levels well above 100 W. In addition to stand-alone generators (as in Fig. 1A), compact heaters could be designed in integrated schemes embedded within the applicator as shown in Fig. 1B. Furthermore, such units could be integrated as modules in large arrays to form distributed high-power microwave heating systems.

The advantages of the solid-state heaters are their compact size and simplicity (alleviating the high-voltage power supply), their spectral coherence and tunability, and their power controllability (as for instance, by varying the transistor's DC bias one can compensate for the load impedance variation due to its temperature change). The solid-state heaters are simpler to integrate with other electronic and mechanical systems. On the other hand, they are more sensitive to impedance mismatch, and their efficiency is inferior with respect to magnetrons.

The miniature solid-state microwave heater presented here was integrated successfully in a large experimental optical-biological system, aimed to explore the effect of microwave radiation on the green fluorescence protein emission. In such applications, the advantages of the solid-state devices are much more significant than their drawbacks mentioned above.

The foreseen improvements in high-power transistors and amplifiers, and the expected reduction in their costs, will lead to their further implementation in miniature heaters, and their integration in larger systems, and will open new possibilities for advanced microwave-heating technologies.

ACKNOWLEDGEMENTS

This research was supported by The Israel Science Foundation (Grant No. 1270/04).

REFERENCES

Bindra A., M. Valentine, and K. Vick (2006). " Next-Generation Wireless Propels GaN Power Transistors, CMOS RFICs and Passives," *RF Design*, Jan. '06, pp. 16-21.

Copty A., F. Sakran, M. Golosovsky, and D. Davidov (2004). "Low-Power Near-Field Microwave Applicator for Localized Heating of Soft Matter," *Appl. Phys. Lett.*, 24(5), pp. 5109-5111.

Copty A., F. Sakran, O. Popov, R. Zibalt, T. Danieli, M. Golosovsky, and D. Davidov (2005), "Probing of the microwave radiation effect on the green fluorescence protein luminescence in solution," Synthetic Metals, 155, pp. 422-425.

Heim, R., A. B. Cubitt, and R. Y. Tsien (1995). "Improved green fluorescence," *Nature*, 373, pp. 663-664.

Jerby E., V. Dikhtyar, O. Aktushev, and U. Groslick (2003). "The Microwave Drill.", *Science*, 298, pp. 587-589.

Mackay A., B., W. R. Tinga, and W. A. G Voss (1979). "Frequency Agile Sources for Microwave Ovens." *J. Microwave Power*, 14(1), pp 63-76.

McAvoy, B. R. (1971). "Solid State Microwave Oven," US Patent 3557333.

Schwierz, F. and J. J. Liou (2003). *Modern Microwave Transistors*, John Wiley & Sons.

Trew, R. J. (2002). "SiC and GaN transistors - is there one winner for microwave power applications?," *IEEE Proceedings*, 90, pp. 1032-1040.

Voss W.A.G. (1986). "Solis State Microwave Oven Development.", *J. Microwave Power*, 21, pp 188-189.

Weitzel C. E. (2002). "RF power devices for wireless communications," *IEEE MTT-S Int'l Microwave Symp.*, pp. 285-288.