Can a Semiconductor Generator Be Used at Microwave Heating or Energy Applications?

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1. Introduction

Recently, RF power semiconductor devices have been attracting attention for use in microwave heating and energy applications, as alternative sources for the magnetron generator, and basic research on their usage has also been actively carried out. Various new ideas have already been reported in the fields of automobiles, plasma, medical care, environmental conservation, energy, chemicals, materials and biotechnology, hence this field is currently gaining increasing attention.

This paper presents applications of solid-state generators for intelligent microwave ovens and microwave plant cultivation, which I have studied with my colleague. In 2005, when I began using semiconductor devices for microwave heating and energy applications, the semiconductor source was said to be "expensive, and have low output as well as low power conversion efficiency, so it will not be a substitute for the magnetron" in domestic applications. However, these problems have been improved over the past few years, and fewer people express such comments. At present, a 1.2 kW output microwave semiconductor generator (including power supply and water cooler as well) is sold for less than $5000, and it can be purchased at a lower price than some industrial magnetron sources. Prototypes exceeding a conversion efficiency to microwave of over 70% have also been released by using GaN. Surprisingly, in Japanese, there is the word "*Ten years can bring a lot of changes*", but technological innovation is progressing as if the word "*One year can bring a lot of changes*" matches better. Also, chemical reactions that can only be made by semiconductor generators[1], biological related substance reactions[2], etc., have also been reported, which is a field where further attention will be paid in the future.

2. Microwave oven

2.1. Significance of intelligent microwave development

The first Japanese domestic microwave oven launched in Japan for business use in 1962 was introduced as a new high-speed cooking appliance which can be heated without using fire. Initially, it was equipped in restaurants and Shinkansen train dining cars, became popular, and led to the sale of household microwave ovens (~1965). After popularization, sales volume fell temporarily, but in 1977 oven ranges with oven functions added to the microwave ovens were released, and the unit sales increased again. In 1978, a hot air circulation type oven range was released, and it was possible to assist the surface heating of food, which is a disadvantage of the microwave method, by using it in combination with hot air. In recent years the evolution of microwave ovens continues, and automatic cooking is progressing. The heat source is a microwave oven equipped with hot air and high temperature steam. In order to introduce a new innovation into the microwave oven, I have proposed an intelligent microwave oven in collaboration with some companies.

Various foods and food culture are spreading with individualization being advanced. However, individualization with regard to heating has not advanced. Food cannot easily be heated because various measures are necessary to bring out personality due to the food dependence on the heat conductions. Also, since the temperature of food directly affects the human sense, it is an important factor, as well as taste. Heating with such individuality cannot be achieved with magnetron sources that have been used for many years in microwave ovens. In order to do this, it is necessary to control the microwave with high precision, and it is meaningful to use semiconductor sources.

Although there were attempts to utilize semiconductor sources for microwave ovens long time ago, these were not available in terms of equipment size and price, and the idea could not be put into practical use. However, in recent years, many companies have tried to calculate that ultra-miniaturization and price reduction have advanced and it has now become practical to be fully used in microwave ovens. Table 1 compares the function and performance of the semiconductor generator and the magnetron generator.

Table 1: Comparison of function and performance of semiconductor and magnetron sources[3]

	Magnetron	Semiconductor
Applied power	30W～100kW	～600W
Weight of the power supply	6 kg (@ 1 kW)	0.5 kg (@ 1 kW)
Applied voltage	4 kV (@ 1 kW)	0.05 kV (@ 1 kW)
electric power efficiency	70-80 %	50-70 %
Frequency control	No	Yes
Life time	500－1000 hours	20 years
Price	Cheap	Expensive
Environment	Weak in vibration	Weak at high temp.

The microwave frequency generated from the magnetron generator built in the existing microwave oven is distributed at 2.45±0.02 GHz, but the frequency of the microwave generated from the semiconductor generator could be exactly 2.45000 GHz (Figure 1). Whereas the magnetron generator generates irregularly broad microwave, the semiconductor generator has a remarkably narrow frequency range and no fluctuation thereof, so that the microwave may oscillate continuously with constant intensity. By utilizing this feature, it is possible to precisely control the phase of the microwave, so that it is possible to perform phase synthesis in the space inside the microwave oven and selectively heat the food. I propose new functions of microwave ovens by applying this phenomenon to microwave food heating.

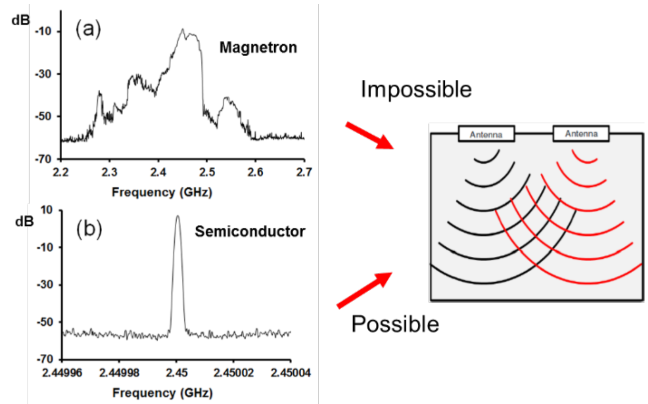

Figure 1. Spectrum comparison and phase control image of (a) magnetron generator and (b) semiconductor generator[4]

2.2. Intelligent microwave-oven prototype and selective heating of food

The latest prototype of the current intelligent microwave oven is Unit 4, shown in Figure 2. With a sashimi lunch-box inside, this model can selectively heat rice. Since the advantage of the semiconductor generator unit is that it can remarkably be made smaller than the magnetron generator unit, four GaN semiconductor generators are installed in this microwave oven. In addition, a tablet type computer was embedded in the door of the microwave oven and devised to visually control the heating temperature and heating area. Further-more, inside the microwave oven, several cameras are installed for observing the shape, color and temperature distribution, and these controls can be observed with the door tablet. In the next prototype, since the microwave oven can be operated and monitored remotely, it can be linked with various services.

2.3. Delicate heating of food

Since the semiconductor generator can oscillate weak microwaves of about several watts, it is suitable for thawing frozen foods. As an example, ice cream was heated at an appropriate temperature. The ice cream just out of the freezer does not pass through the spoon at about -8°C. However, by heating it for about 15 seconds in an intelligent microwave oven, it can be thawed to about -2°C eclipse[3-4]. I do not think anyone will do it, but when thawing the ice cream with the existing microwave oven, weak power control cannot be done, so it will become liquid by heating for several seconds. Using an intelligent microwave oven allows delicately heating of ice cream with a weak microwave signal, to realize "Good condition for eating".

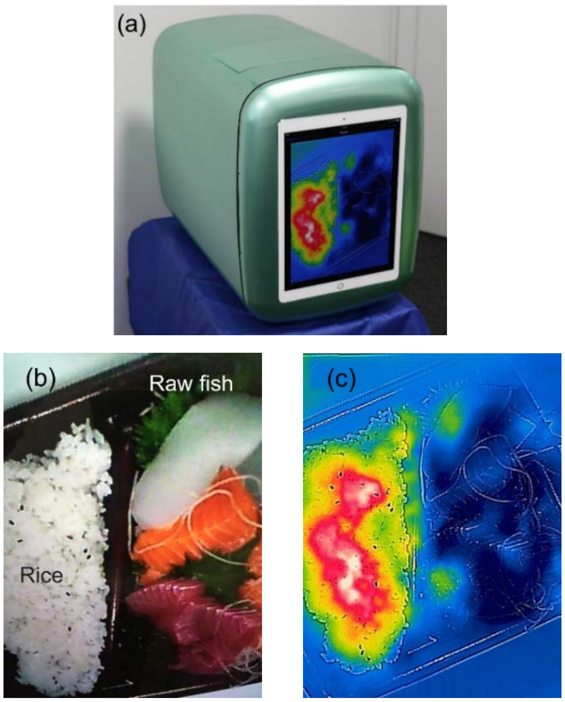

Figure 2: (a) Exterior view of the intelligent microwave oven (Unit 4), (b) Sushi (raw fish) lunch box, (c) Diagram of thermography where only rice is warming[5]

2.4. Delicate and selective heating demonstration

When ordering a seafood rice bowl at a sushi shop, one can see that the temperature of the rice is over 10ºC and that of the seafood ingredients are at around 3ºC. Different ingredients such as Sushi bowl are served in one place, and further heating must be done delicately, selective heating must be done delicately. In fact, when making a simulated Sushi bowl and chilling it in a refrigerator for one hour, the whole is cooled to about 1ºC (Figure 3). So one can use an intelligent microwave oven to get precisely 10ºC for rice and 3ºC for seafood ingredients. It was demonstrated that rice can be adjusted to the proper temperature without heating the raw seafood ingredients, by selective and delicate microwave heating.

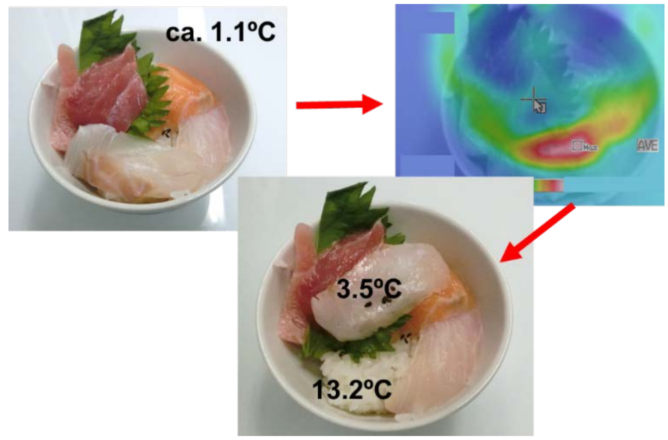

Figure 3: Heating of delicate and partial sushi bowl with intelligent microwave oven[3].

3. Application of plants to effective breeding

One may ask "Why did you irradiate the microwave energy to the plant?". Even though vegetables (plants) are cooked in a microwave oven (microwave), there is no example used for cultivation. I started the experiment with the following hypothesis. Microwaves are the same kind of energy (electromagnetic waves) as light necessary for photosynthesis, hence plants may also accept microwaves. However, since the wavelength differs from that of light, at the molecular level in the plant body there is a different energy effect from light. I expected the plant feels it as a good stimulus (effective stimulation). Also, since microwaves do not exist in nature but have to be artificially created, they should have never been exposed to microwaves in the process of evolution of plants up to the present, and this is also a reasonable effective stimulus. On the other hand, we have been studying the use of non-thermal microwaves in chemical reactions for many years. Electromagnetic waves (microwaves) are the highest quality energy, and it is useless to convert to the lowest thermal energy quality. I imagined giving it as an effective stimulus to plants while maintaining high quality.

In the experiment, Arabidopsis thaliana (Columbia) was used as a model plant. To emphasize reproducibility in the experiment, we proceeded to growth while adjusting the temperature, humidity and light in the growth chamber. Arabidopsis thaliana was irradiated with weak microwaves for about 1 hour, then immediately returned to the growth chamber and continued to grow there. A photograph of the plant body after 38 days is shown in Figure 4. The height of the inflorescence stems of the same plant grew to about 16 cm by microwave effective stimulation. This was about 2 times growth promotion compared with no stimulation. Irradiating microwaves for one hour in Arabidopsis thaliana growing can be an effective stimulus and sustained influence on later breeding and promoted growth. There is no need to worry about gene recombination or chemical substances remaining in plants.

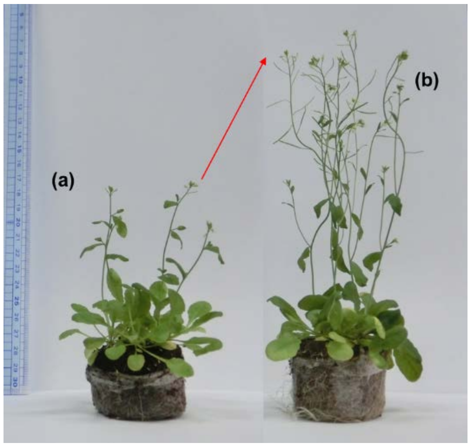

Figure 4: Comparison of growth of Arabidopsis thaliana by (a) no stimulation and (b) microwave effective stimulation method[6].

The advantage of this technology is that plants irradiate buds or seeds at the early stage of their development with weak microwaves only once for a short time, so that the plants feel it as a stimulus and are continuously and favorably affected. Therefore, it is not necessary to provide microwave effective stimulation over the lifetime of plant development, and there is no need to install a microwave source in the field or plant. For example, it is possible to construct a production process at the seedling stage by giving effective stimulation to a large amount of plants, using a continuous microwave effective stimulation device combining the buds or seeds at the initial stage of growth with a belt conveyor and a microwave irradiation device. At this time, since stable microwave output and frequency are required, the semiconductor source becomes an important technical factor. On the other hand, microwave effective stimulation can be continuously applied to plants already seeded, while irradiating microwaves with moving bodies such as drone (Figure 5). By preliminarily setting various data into a database, using a drone loaded with cameras, it would be possible to apply effective microwave stimulation to each plant with optimum conditions, by drone made automatic by GPS or center. At this time, the magnetron cannot load onto the drone due to weight and vibration problems. However, semiconductor generators can do this. Currently, attempts to convert agriculture to the Internet of things (IoT) are actively carried out. This method can also provide effective stimulation with the power of electricity, it is easy to incorporate into IoT agriculture. And, in combination with other technologies, further synergistic effects can be expected.

Figure 5: Experiment showing the continuous effective stimulation of microwave to plants by drone connected with GaN semiconductor generator[7].

4. Conclusions

Microwave heating has been effectively used into the home and industrial fields over the last half century. Currently microwave is considered as a mature technology, and the number of engineering researchers and engineers is decreasing year on year. However, by controlling microwave or capturing it as electromagnetic wave energy, it is still a future technology with a promising potential. Semiconductor sources are indispensable devices as the utmost tool to extract this. Depending on the idea, it may also be used for applications that are unexpected. I hope this paper will become a "hint" leading to them.

For Further Reading:

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About the Author

Satoshi Horikoshi is an Associate professor at Sophia University, Department of Materials and Life Sciences, and a Director of the Microwave Science Research Center MSRC there. Satoshi Horikoshi received his PhD degree in 1999, and was subsequently a postdoctoral researcher at the Frontier Research Center for the Global Environment Science (Ministry of Education, Culture, Sports, Science and Technology) until 2006. He joined Tokyo University of Science as Associate Professor in 2008, after which he returned to Sophia University as Associate Professor in 2011. Currently he is Director of the Japan Society of Electromagnetic Wave Energy Applications (JEMEA), and is on the Editorial Advisory Board of the 4 international Journals. His research interests involve new functional material or nanomaterial synthesis, molecular biology, formation of sustainable energy, environmental protection using microwave- and/or photo-energy. He has co-authored over 190 scientific publications, and has contributed as editor or author to 23 books.