



The Spectrum

November 2006

Volume 1, Number 3

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Website Links

MW Working Group

AMPERE

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Upcoming Conferences

Microwave/RF Workshop and Technology Fair
Held in conjunction with the:
31st International Cocoa Beach Conference & Exposition on Advanced Ceramics and Composites
January 21-26, 2007

IEEE MTT-S

International MW Symposium

June 3-8, 2007

Honolulu, Hawaii

www.ims.org



Asia-Pacific MW Conference

December 11-14, 2007

Bangkok, Thailand

www.apmc2007.org

www.apmc07.com



Immediate Energy Savings via Microwave Usage in Major Materials Technologies

The National Academy of Engineering
Northeastern Regional Meeting
Pennsylvania State University

By: Dinesh Agrawal

Many leading US and International researchers participated in the meeting. The focus of the meeting was the technology of microwave usage in major materials processing technologies and the enormous savings (80–90%) of energy usage in many **high temperature** materials industries. Many experts from the leading laboratories in US, Japan, China, India and Europe described the enormous opportunity available to governments and corporations eager to cut energy usage with major costs and environmental benefits by using microwave for materials processing. Many representatives from US government agencies and industries were also present and were urged by the researchers to catch-up to the benefits of microwave energy. Among the invited speakers were some of leading researchers in the field such as M. Sato (National Institute for Fusion Science, Japan), Jon Binner (Loughborough University, UK), R. Varma (Environmental Protection Agency, USA), R. Roy (PSU), Robert Schiffmann, D. Agrawal (PSU), M. Willert-Porada (University of Bayreuth, Germany), Bernard Krieger (Cober Electronics), Diane Folz (Virginia Tech), Stuart Nelson (USDA), Hu Peng (Longtech Corp. China), Eli Jerby (Tel Aviv University, Israel).

Few consumers need to be sold on the benefits of the microwave oven in their kitchen. Microwaves are clean, safe, and efficient, creating remarkable savings in both time and energy. But when it comes to industrial uses, the US manufacturing sector has been slow to accept the benefits of microwave technology.

At the meeting, Dr. Robert Schiffman, an energy consultant for government and industry, cited two reasons for the slow acceptance of microwaves in the US: first, he said, is reluctance to abandon existing equipment and processes with which the company is already familiar; second is a lack of knowledge of the true energy costs of manufacture. In his experience consulting with industry, he said, he finds that executives may have a sense of their annual oil or electric bill, but rarely do they try to determine the energy cost of producing each unit.

Penn State is a world leader in high temperature microwave research, according to Dr. Dinesh Agrawal, Professor of Materials and Director of Penn State's Microwave Processing and Engineering Center. In 1999, Penn State microwave scientists were the first to report the use of microwaves for metal sintering and melting (Nature 399, 668–670, 1999), creating worldwide interest among scientists and industry.

Conference keynote speaker, Dr. Motoyasu Sato, from the National Institute of Fusion Science, Japan, was one of those who paid attention. Dr. Sato convinced the Japanese government to fund research into industrial uses

Links to other future MW Events

www.usri.org/calendar

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for microwaves, forming a consortium that proved microwaves could be successful in converting iron ore to pig iron. Japan has since built large commercial microwave systems for ceramics and metals. Dr. Sato made two key points that he believes were critical to the successful commercialization of high temperature microwave technology in Japan: an energy savings of 80% in the production of ceramics and pig iron due to the speed of microwave heating; and a 50% reduction in CO₂ emissions compared to processing iron in a conventional furnace.

Dr. Rajender Varma, senior scientist at the US Environmental Protection Agency, noted that US industry spends \$200B a year to comply with environmental regulations. Much of that expense could be saved, he said, because microwave is a "greener" technology, allowing for solvent-free chemical synthesis through microwave irradiation. The process is solvent-free because the reaction takes place in a solid state with no liquid phase. In addition, the process takes only seconds or minutes, cuts waste, and saves energy.

The future for microwave is bright, Dr. Agrawal believes. In China, Japan, and India, companies are building less expensive microwave systems that will lower the cost of capital investment. In addition, microwave processing is expanding into new areas including: metallic materials, recycling of tires, pretreatment of coal to reduce emissions, and possible reclamation of fossil fuel from oil shale and oil sands that otherwise might not be economically or environmentally feasible.

In order to understand how microwaves create their unusual effect on metals and ceramics, Penn State researchers in 2001, learned to split the electromagnetic field of microwaves into separate electric (E) and magnetic (H) fields 3 centimeters apart. Since that time, researchers in the Penn State Microwave Processing and Engineering Center have explored irradiating various materials in nearly pure E-field and H-field, with some dramatic results.

Until this discovery, no conclusive evidence was available about how microwaves actually interact with matter, according to Agrawal and Penn State colleagues Rustum Roy, and Evan Pugh, Emeritus Professor of the Solid State. "Since then we have found important clues as to the science of microwave/material interactions and have learned how to make microwave processes more efficient and faster in metals," said Agrawal.

One of "the most important findings was the magnetic field effects – which are shown to be profound – and the ability of such 2.45 GHz AC magnetic fields to cause matter to de-crystallize," Dr. Roy told the conference attendees. He also urged governmental agencies and US industry to catch-up with other countries in the commercialization of microwave energy.

SCIENCE

Microwave Spectroscopy

By: Iftikhar Ahmad

Spectroscopy is defined as "the study of interaction between radiation and matter, investigating the radiation or particles emitted, absorbed or scattered by matter." Although spectroscopy has been used often in physical and analytic chemistry, new applications utilize not only light, but almost every type of radiation giving rise to x-ray spectroscopy crystallography, Fourier Transform infrared (FTIR), nuclear magnetic resonance (NMR) spectroscopy, interstellar microwave spectroscopy and numerous others found in the literature.

However, the one of interest for this discussion is **Rotational or Microwave Spectroscopy**. This method studies the interaction of microwave energy with molecules where the rotational motion can be quantized. This requires that molecules have a dipole moment equivalent to the separation of two unlike charges or even difference in the center of charge (electrons) from the center of mass (protons). The dipole moment thus formed allows microwaves to torque the molecule causing it to rotate. The higher the temperature of matter, the more the average distance, and the higher the dissipation of microwave energy. Rotational spectroscopy is only practical in the gas phase, because in liquids and solids the free rotation would be restricted by the collisions of all the molecules trying to rotate.

Although, the movement of molecules is restricted in liquids making microwave spectroscopy somewhat difficult, the friction of the neighboring molecules trying to rotate generates heat in the polar water molecules and hence all food. Beyond heating food, chemical synthesis is where microwaves can have the most impact, sometimes providing significant enhancements in reaction rates. Liquids having molecules with high dipole moments should have more interaction with microwave energy and should exhibit more enhancements. However, other factors like atomic mass, geometric structure and collision frequency can also be contributing factors in reaction rate. The size of the microwave chamber or the power density can influence the interaction with the polar molecules as well. Another factor researchers are exploring is the frequency of microwaves used. From the spectroscopy perspective, the microwave frequency used could influence reaction rate, perhaps proportional to the degree of rotation caused in the molecules. But as the movement becomes restricted, resolution could be lost and absorption peaks broader. The effect of frequency may appear to be insignificant in a small frequency ranges (1-2 GHz). However, over a much larger variation in frequency (10-20 GHz), there could be a clearly distinguishable region of higher absorption versus a region of poor absorption.

When using variable frequency microwave equipment, people expect to see the effect of frequency in the bandwidth (1 GHz) offered. Since mostly liquids and solids are processed and the only observable parameter is the temperature rise with a fixed power for a fixed time, the effect of frequency may not be pronounced enough, if it exists at all. If the adjacent frequencies provide no resolution in interacting differently with the molecule, their identical heating will provide identical results in the product. However, if the frequency range is larger and hence the difference between two frequencies is large, one could expect differences in the yield as well as the microstructure and morphology of the product.

Not only is microwave spectroscopy useful in the understanding of microwave heating and synthesis, it can be effectively used in process analysis. Unlike microwave generators, which are expensive and available only at a few frequencies, microwave spectroscopic work can be performed using low power microwave sweep generators having a wide range (up to 25 GHz). Commercial microwave spectrometers were available a few decades ago but have disappeared lately. However, an experimental set up with a waveguide having a transmitter and a receiver port can be used to monitor and analyze, preferably a gas, in an industrial process.

With a much larger frequency range, an experimental set up employing a transmitter and a receiver for analysis, the technique can be used as a non-invasive, non-destructive approach to analyze suspensions, liquids and solids. For liquids and solids, the quantized rotational spectra may not be available, but the microwave spectra based on the different dielectric constant of different materials, can act as a quality control for the product. Although the configurations can differ there are various microwave moisture-detection techniques, including hand held meters, being used in numerous applications.

For more information and databases for diatomic, triatomic, and hydrocarbon molecules refer to the NIST site shown below.

<http://physics.nist.gov/PhysRefData/MolSpec/index.html>

TECHNOLOGY

Fiber Optic Temperature Sensors Enter Mainstream

By: Keith Lam

Fiber optic or Fluoroptic[®] temperature sensors used to be thought of as very “high tech” and used only by scientists in government laboratories. The fiber optic probes also were thought to be very brittle, due to the glass silica fiber inside, and could not be used in rugged industrial environments. How things have changed! Now, fiber optic temperature sensors are widespread, rugged, and used daily in industrial microwaves, magnetic resonance imaging (MRI) equipment, semiconductor equipment, and power transformers. The types of fiber optic temperature sensors have also expanded from small medical MRI probes to rugged power transformer probes built to last more than 30 years.

Why use fiber optic temperature sensors? They are immune to electromagnetic interference (EMI), including microwaves, magnetic flux, and radio frequency interference, and do not require any electrical shielding. The sensors are also immune to high voltage and do not spark or transmit current, hence, they are safer in electrical temperature sensing than metal thermocouples, thermistors or resistant temperature detectors (RTDs).

In 2006, there are more than six companies that provide fiber optic temperature sensors and instruments for industrial, medical and energy applications. These companies use one of three types of temperature sensing technologies. A description and the pros and cons of each technology are described below:

- Phosphor decay
- Semiconductor band gap
- Fabry-Perot (interferometry)

Phosphor Decay

Phosphor decay technology is based on the phosphorescence decay time of a special thermo-sensitive phosphorescent (phosphor) sensor, located at the end of a fiber optic cable (see Figure 1). Light generated by an LED excites the phosphor sensor located at the probe tip. Older Fluoroptic[®] temperature systems used Xenon flash lamps that need to be replaced over time, but current systems use LEDs that never need to be replaced.

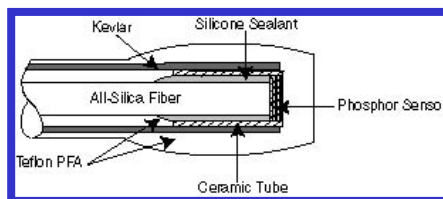


Figure 1 – Phosphor decay probe (source: LumaSense Technologies).

When stimulated with light from the LED, the phosphor sensor emits

light over a broad spectrum in the near infrared region (Figure 2). The time required for the phosphorescence to decay is dependent upon the sensor's temperature (Figure 3). After the LED is turned off, the decaying fluorescent signal continues to transmit through the fiber to the instrument, where it is focused onto a detector. The signal from the detector is amplified and sampled after the LED is turned off.

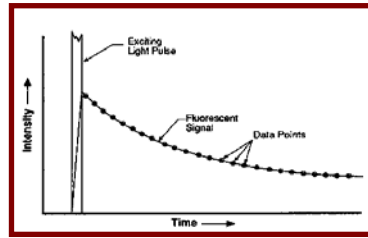


Figure 2 – Excitation and decay of phosphor (source: LumaSense Technologies).

The measured decay time is then converted to temperature by the instrument's software using a calibrated conversion table. The faster the decay time, the hotter the temperature, so the decay time of the emitted light from the phosphor sensor would be slower for 100°C than 200°C.

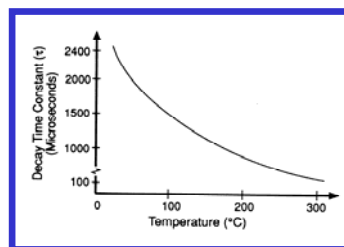


Figure 3 – Decay time vs temperature (source: LumaSense Technologies).

Semiconductor Band Gap

Semiconductor band gap technology uses the band-gap shift principle to deduce temperature from a semiconductor crystal attached to the end of the fiber optic probe (Figure 4). A broad-spectrum band light source sends light to illuminate the semiconductor crystal sensor, normally a gallium arsenide sensor. When this broad spectrum light interacts with the crystal, there is a wavelength at which the light propagation changes from being transmitted through the material to being absorbed by the material. As the temperature of the crystal increases, the wavelength where this transition occurs "shifts" to longer wavelengths as shown in Figure 5. This shift occurs due to a corresponding shift in the sensor's energy "band gap" with temperature.

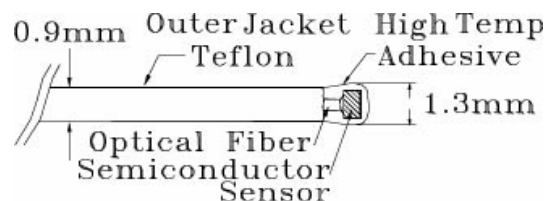


Figure 4 – Semiconductor Band Gap Probe (source: FISO Technologies).

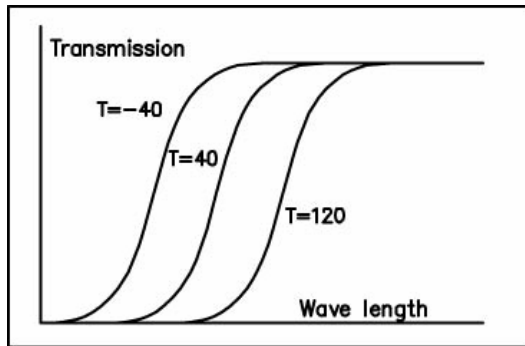


Figure 5 – Semiconductor Band Gap Shift (source: Fiso Technologies).

Fabry-Perot or Interferometry

Fabry-Perot or interferometry technology uses light interferometry to measure temperature. A white light source sends light down the fiber optic cable through a Fabry Perot cavity (a crystal or glass rod with mirrors at the entrance and end of the cavity) (Figure 6). As the light bounces back and forth within the cavity, there will be constructive and destructive interference of the light that will create fringes (Figure 7) in the light coming back down the fiber optic cable. The light fringes coming back from the cavity are measured using a photodetector and translated into temperature, pressure, or strain. The cavity is thermally sensitive and will expand or contract with temperature; hence the fringes will change depending on temperature.



Figure 6 – Fabry Perot cavity.



Figure 7 – Fabry-Perot Fringes (source: Davidson College, Dept of Physics).

In summary, fiber optic or Fluoroptic[®] temperature sensing is not a “new” technology but a technology that has been in use for more than 20 years in harsh EMI environments. Today, fiber optic temperature probes are more rugged and are designed for a myriad of applications from MRI patient monitoring to power transformer hot spot sensing.

Fiber Optic Temperature Sensor Comparison Table.

| Type | System Accuracy | Temp Range | Remote Sensing | Sensing Tip Strength | Size of Tips | Other |
|------------------------|-----------------|-----------------|----------------|----------------------|--------------|--------------------------------|
| Phosphor decay | +/- 0.5°C | -200°C to 330°C | Yes | Robust | 0.5mm | None |
| Semiconductor band gap | +/- 1.5°C | -40°C to 350°C | No | More fragile | 1.1mm | None |
| Fabry-Perot | +/- 1°C | -40°C to 350°C | No | More fragile | 1.8mm | Pressure, strain, displacement |

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APPLICATIONS

Do you have an application you would like featured in the newsletter? If so please submit your write-up to the editor. We would love to hear from you!

MICROWAVE WORKSHOP/TECHNOLOGY FAIR

This intensive two-day program of technical papers, short courses, and a technology fair is now part of the 31st International Cocoa Beach Conference! Microwave & RF Workshop 2007 is designed as an intensive, hands-on program for scientists, technologists and vendor companies in this field. The registration fee for this workshop is \$305 per person if registering prior to December 29, 2006. Attendees of the 31st International Cocoa Beach Conference and Exposition on Advanced Ceramics and Composites may attend the Microwave and RF Workshop at no extra charge. Please follow the link for more information about the [Cocoa Beach Conference](#), or contact Joe Cresko or Bernie Krieger for more information.

Microwave Workshop

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Microwave Technology Fair

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**Sponsored by the Microwave Working Group
and
The American Ceramic Society**

ASK THE EXPERTS

Since we did not have any questions or articles for this column in this issue, I decided to put in a little fun – it 's not Sudoku but see how many microwave terms you can find (hint: there are 54)

C O U P L I N G A M S A L P M C O A X I A L
A P E E U Q A P O Z T R E H A G E M C G G U
E N E L E C T R I C O T F N G P A A E M E R
I H T P E D N O I T A R T E N E P S L R N N
A O E E P C T P C O E A N T E R K G C O E D
N M N V N A T E T D R V F E T M P O I T R P
O V O T S N L R T U D E I O I I M S H A A E
R F E D R F A T O M E L I O C T S O Y C T E
T L A V E A N I E M D I S T R I B U T I O N
S Y O R O L N E I Y A N D I M V E T I L R O
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R Z H E I R R N N T R E T E M I L L I M U Q
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